<u>Design of Performance data through Wearable Technology for ankle movement upon football shots</u>

Gobinath Aroganam

Brunel University London

Design

Collateral ideas are the final piece to any design

Gobi

Abstract

The motivation for this work came from observing amateur footballers making video recordings of themselves kicking footballs, to send to scouts. An opportunity was seen to apply wearable technology to capture additional kicking data and to provide feedback to the players to improve their kicking performance. The penalty kick was chosen as the setting for this research study. Initially inertial measuring unit sensors were used with participants to track ankle movements prior to the shots being taken. In this experiment, a simple kick study with Brunel University Women's football team regarding their technique upon Ball Contact is analysed. The aim was to understand each player's technique regarding their position profile and gameplay approach. A Decision matrix was created to rank each kicker against tracked features linking to selected biomechanics. After reviewing video and sensor data, 2 players showed differences compared to initial observed rank, with greater understanding of 1 player's technique. Additional experiment involving force sensitive resistor sensors were placed around low/midsole and vamp regions of a football boot on a test rig. The test rig consisted of a swinging barbell which emulated a kicking motion, and video capture monitored the ball projection and velocity. This produced further performance data relating to the accuracy of ball projection in relation to the contact region of the boot. The midsole contact region showed greater accuracy of ball projection, and low vamp region showed greater ball velocity. A test of repeatability was done, to provide an estimation of variance, which further justified that midsole aids accuracy for inside foot shots. Mid to low vamp produced more consistent accuracy for laces shots. A new form of accuracy metric was considered which aided the sensor data to filter out error shots, by having greater outer sole tracking coverage to identify when the correct kicks were executed. User research outlined how the sensor data from experiments around the wearable technology used, formed a decision matrix which ranked attributes including kick to ball velocity, dependant on the user's choice. A data framework was then designed which shows how ankle motion data transforms into meaningful shooting performance data. The key contribution of this work is to show that ankle motion prior to ball contact is an important parameter in football kicking biomechanics.

Acknowledgments

Without my family I would not be able to enter University. My mum and dad have made countless sacrifices to flee extreme difficult situations, and to build a life passed the financial struggles, so that me and my sister can have education for a better lifestyle than they did. Their work ethic can never be stated enough, and I am eternally grateful for my parents who I owe a lot to, and hope to repay some of it back. The resilience shown by them is something I can't ever live up to, and this is me hoping, I can deliver in other aspects of life, to make them proud and happy. My sister is the one who keeps me humble and grounded, and without her protection I wouldn't be in the position I am today. My Nieces and Nephew have shown me what great courage and strength are, ones that have never been able to match. They are also the reason why I go through difficult phases in life easier, because the character they show is remarkable for their young age. I have friends who I consider family, these are the only personnel outside of Brunel and my immediate family who know I do PhD research. They have backed me in whatever decision I made throughout my life, and their acceptance has allowed me to be myself. I know want to prove to my loved ones that the belief they had in me, I can justify. I am forever grateful for these people.

Dr.Nadarajah Manivannan first offered me to take on PhD during my Maters year, and I never considered it before. His belief in me took me to this stage, and I have learnt so much from him even outside of academia. Prof. Rob Holdway was my supervisor on this project during postgraduate year, made me believe in my abilities to achieve beyond expectations. Professor David Harrison's continuous support as a Research development advisor, kept me in line with this PhD thesis. Dr.Vanja Garaj granting me opportunity to work on simultaneous research projects, that increased my software skills which transferred to this project helped me become more competent. Dr.Federico Colecchia, who I have had the utmost pleasure working with as a Graduate Teaching assistant, provided me continuous support and guidance throughout the testing phase and mitigate the experiments after the Covid-19 Pandemic. Without Marilyn Powell and Camilo Sanabria Aragon, have made my PhD life much easier, and their continuous help regarding booking the right spaces, ordering the right equipment and being very responsive will always be remembered. Another notable acknowledgment to Dr.Timothy Minton, who provided me with advice on how to correct the thesis in both a technical and design perspective.

I would like to thank the Funding Committee by the Engineering and Physical Sciences Research Council (EPSRC), as without it I would not be able to afford to conduct this research. Julie Bradshaw's consideration after my back injury and Covid impact, won't ever be forgotten, she gave me the flexibility to submit my thesis when I could, supporting my funding extension.

This work is supported by Brunel University, Design school College of Engineering, Design and Physical sciences. I am forever in debt to Brunel University for making me the researcher I am, and it was always meant to be, that I was to study here.

Brunel,

Thank you for everything, Thank you for the most important years of my life.

Gobi

Limitations that affected research

In the middle of the 2nd year of this research, The Covid 19 Global pandemic, halted the world. The Pandemic was an unprecedented impact, which hit me harder than I ever imagined. Testing had to be stopped and mitigated research, which meant there was more emphasis on software and Ethics would not allow any more User tests, after 2020. This meant that final testing with the overall sensors all integrated could not be done. The research did however integrate sufficient Design and Technology elements to answer the research question.

Publication from this Research

Review on Wearable Technology Sensors Used in Consumer Sport Applications: https://doi.org/10.3390/s19091983

Building Subjective Opinions on Amateur Football Player 1 Step Kicks by Analysing Ankle Biomechanics: https://www.jscimedcentral.com/SportsMedicine/sportsmedicine-8-1174.pdf

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Nomenclature

TERM	ABBREVIATION MEANING
AC	Actual lift
AR	Angle range on contact
AVR	Angular velocity range
BC	Ball contact
BCC	Ball contact consistency
BLV	Ball launch velocity
BS	Backswing
COR	Coefficient of restitution
D	Drag
DC	Drag coefficient
DS	Decision matrix score
EFF	Efficiency of Backswing/Follow through
FSR	Force sensitive resistor
FT	Follow through
GPE	Gravitational potential energy
H	Height of drop
IMU	Inertial measuring unit
In.	Inside foot shot
IR	Initial ranking based on observation
KB	Kick to ball velocity range
KE	Kinetic energy
La.	Laces shot
LC	Lift coefficient
MB	Mass of the ball
Mp	Mass of kicking barbell
Pl	Player
R	Radius of ball
S	Spin
Þ	Density
TL	Theoretical lift
UB	Initial ball velocity
UF	Initial foot velocity
UI	User interface
Up	Initial pendulum velocity
UX	User experience
VB	Ball velocity after kick
VF	Velocity of foot
VPA	Vernier physics application
WT	Wearable Technology

1.Wearable sensors research

1.1 Introduction of Wearable Technology research in amateur level football

1.1.1 Project outline

This PhD research studies how wearable sensors for sport monitoring, can be integrated to produce meaningful performance related data to help amateur footballers learn about their kicking ability. Studying the technology that makes wearables a smart device and the biomechanics involved in football kicking, led to critical tests being conducted with sensors to broaden the understanding of how they can work for kick analysis. This technical ability was chosen as the sector for wearable technology (WT) to track in football, delving deeper into how design of the obtaining key data can be applied to other attributes within the sport, and how it impacts future analysis by relying on this study.

Football being a team sport, means there are numerous aspects that require analysing, with multiple views and scenarios than can define performance. To delve deeper into the technology's capability and how it can impact the sport at amateur level, there needs to be some control measures. Players from different positions, all must know how to deliver powerful penalty kicks. This set piece, give constraints regarding distance and target (goal size). This setting was chosen as the base of this study, to analyse the technology available, and how to increase its ergonomic value regarding acquisition of data, for amateur footballers. Ankle motion was chosen as the biomechanics scope to investigate how it influences two most popular shot types in Laces and Inside. The methods to extract the data out of the technology, needs to be applied in monitoring other elements of football. This is the intended influence from this research. Double Diamond design methodology enabled more construction in conducting the research process.

User research identified which End-Users consisted in the focus group study. These were amateur level footballers that helped identify more needs, in relation to what data they want to know about themselves regarding kicking. Design influences the way data is perceived by the intended consumer, and how attribute ranking can impact wearable value in amateur level sport. Consulting experts in the field, allowed advancements in researching WT's reliance on sensors and its importance regarding user experience of this data. Software analysis informed how anatomy and materials are important parameters when analysing the effects of monitoring a kicking motion. Inertial measuring unit sensor test with participants, and Pendulum rig consisting of Force Sensitive resistors allowed collection of data, giving a reference to what kind of readings they produce. An Attribute ranking Decision Matrix bases technical penalty kicking stats derived from sensors and mechanical quantities, illustrates the importance on Ankle biomechanics that may not have previously been focussed by amateur level footballers. A framework model displays how WT transform physical monitored data into meaningful football shooting performance data.

1.1.2 Motivation for the project

Studying Integrated Product Design at Brunel University enabled me to undergo many projects with a variety of modules exploring multiple design problems. Having studied engineering at undergraduate level, I wanted to express my creativity having already garnered technical knowledge, and this course and place was the perfect platform for me to become a well-rounded technical designer. Together this helped build a rapport of the key fundamentals necessary for this project. Having a keen interest in sport, representing schools and borough, I wanted to link my passion for this and product design. This was the foundation as there was existing knowledge of the sport and technical elements built academically, proving a good combination to mix. Choosing football as the sport of focus, added a sentimental value, having been playing and following for so long, giving more core insights to apply for this research.

Supervising football social activities every weekend, I got the chance to meet young aspiring amateur footballers. Setting up games for them every week, whilst studying, allowed me to understand how many young players want to achieve their ultimate career as a professional footballer. This is when I got to see how they work, and what they look for when they go to trials for Semi-Pro/Professional clubs. Seeing individuals train on their own and record them taking shots towards the goal, inspired ideas of how technology can be used based on sensor monitoring.

Interest started to grow, the more I spoke with aspiring footballers. Hearing stories of how their progress gets disrupted, not being able to attend recruitment trials, not having the right personnel and facilities to do gameplay recordings, all hinder their exposure towards a scout. This gave me an emotional trigger to try make a difference, as an occurrence of hearing these sensitive stories of amateur players who may not have access to the technology other players may do, grant them less opportunities to showcase their ability.

Consistent weekly activities helped me identify greater motivation of wanting to incorporate some sort of human centred design solutions through WT that can allow greater opportunity for amateur footballers to stand out in possible trials. There can be a quantified dataset, (something professional players have of themselves), showing different “ratings” of these amateur players, using a similar model. Initial ideas wanted a potential WT system to produce performance related data of these players, so they can show recruits specific attribute traits of themselves. Examples such as their max sprint velocity, number of successful long passes, ability of shooting, distance covering etc, all could give potential semi pro clubs more information about these players. This can eliminate the need to have scouts having to be there, and rely more on some sort of technology, which produces data to be sent to them, granting greater opportunity for exposure.

As this research progressed during master’s dissertation, key findings and gaps were slowly starting to emerge. The opportunity from Brunel university to take the research further at PhD level, and EPSRC funding via a studentship allowed this project to be more focal. The technology integrates with design through how the sensors obtain data from biomechanical movement. The Design displays the steps taken to show how biomechanical data becomes meaningful in relation to football shot types.

1.1.3 Wearable Technology (WT)

Wearables in the fitness sector are vastly growing. Smart gadgets are used to track athletes and relate the data to performance. Increasing need for self-improvement, has given the opportunity for Wearables to change the perception of self-analysis. Video tracking capability has limiting factors, even though it allows greater observational points that can be visualised, with the Wearables Sensor aiding the data to be understood better.

Professional sport has access to multiple technologies to track and observe. The data does not need to be understood by athletes, as they have coaches, doctors, physios, psychologists, and data scientists, to educate them in how to improve their performance, nutrition, mental health etc. Surrounded by experts who can interpret the tracking data, linking to relevant sport science, gives professional athletes the best education possible about themselves relevant to the sport. Most of the time, the player’s only role is to then follow what the expert’s advice is. Consumer wearables that track performance is an increasing trend, especially for the fitness sector, providing real time monitoring, (increasing its ergonomic value). Amateur and semi pro level players can self-learn using this technology if implemented correctly in their sport specific environment [Beecham, 2018].

Research advancement in sensors has allowed greater design solutions for the wearable industry. The need to quantify achievements are increasing, and wearables allow consumers to use them daily. Social media influence is fundamental to making wearables a disruptive tech. Wearables that possess sensors to monitor how the body is manoeuvring, gives the user greater insights of themselves [Hatton, 2014] [Creasey, 2015]. Increasing the capability to monitor "specific physical attributes", allows greater "elements" to be quantified. These could be things that the user may not have regarded as important to understand, which only makes wearables that much more influential in educating the consumer. The user can understand these "new data" and "grade" themselves, providing a sense of achievement. This broadens their awareness in importance of tracking, and how it affects them. The user can easily "judge" themselves with this data and visualise benchmarks of progression. Learning more about themselves with freedom to make any changes to their lifestyle, reassures them that they are in full control of their growth in physical capabilities, benefitting their mental wellbeing, reducing any potential anxiety of the "unknown".

The function of specific wearables differs, to match the needs of intended users. Some users need it, such as health monitoring reasons (e.g., blood sugar levels for diabetics). Some users desire it, if an opportunity to improve their lifestyle is accessible (e.g., calories burned for weight reduction). The trend in wearables is making it normal to need it more, than want it. Therefore, it is considered disruptive, as the applications are becoming more user-oriented and improving oneself is easily accessible due to it being part of their daily lives.

The adaptation processes a user must undertake is based on the perceived usefulness of the wearable, against the actual ergonomics [Kalantari, 2017]. Presently, in this "self-obsessed era" where success is being graded on quantity data, human centred design solutions are making accessibility easier, by improving user's ergonomic controls (e.g. voice commands) [Papi et al., 2017] [Beecham, 2018]. This improvement in lifestyle, causes an increase in people's interest to be involved with this application, where the next improvement must be a greater ergonomic refinement to be considered successful. Therefore, as progression is made in ergonomics of the wearables, more design research is needed to make sure that the adaptation process is as smooth as the previous benchmark, if not better.

1.1.4 Amateur Football

Applying sensors to equipment is a potential advancement consumer WT could need, but it must produce meaningful data, with no reduction in ergonomics [Hinch, 2017]. Using equipment is where, sport specific attributes can be given the opportunity to be monitored. Football as a sport does not only depend on physical statistics, because analysis is also based on observations, where subjective opinions influence how progression is made. This means WT solely cannot be a standalone solution in self teaching players about their improvements and benchmarks. It aids the overall analysis, helping more attributes to be tracked.

The importance of WT in football should not be discounted. Its impact is valued greatly, due to it being used as a tool to monitor precise player improvement and quantifying them. This impact varies for different levels. Professionals have access to greater technology, with the right personnel analysing thoroughly as every training and game performance is recorded, to give observational feedback. Amateur level players will not have the best version of these facilities. Some games may be recorded, but not to the standard of TV broadcasts and high-tech cameras that professionals can rely upon. Therefore, WT can make a greater impact for amateur level players.

Figures 1.1.1 – 1.1.4 explore the differences that a professional athlete has compared to an amateur for self-improvement. Due to professionals having historical researched data around them, as well as the members they play with, improvements can be made in different scales, allowing greater elements to be tracked, for overall team improvement. Because of the extensive attention for professionals, every element regarding an attribute being tracked, will have an expert consultation. This maximises efficiency in improvement. The limitations that amateurs potentially have, can be regarded as the parameters that can be worked around for this project.

Figure 1.1.1: Examples of the Access a Professional footballer has access to

Figure 1.1.2: Example of the Access an Amateur footballer has without WT

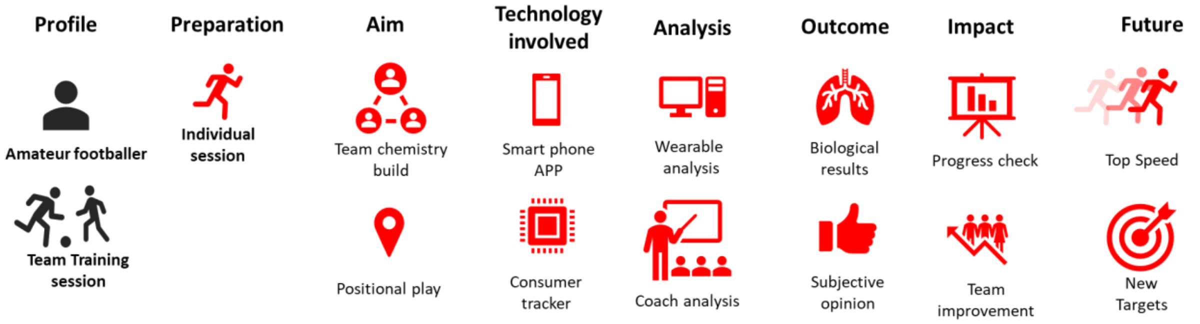


Figure 1.1.3: Access with WT for an Amateur footballer has for self-improvement with a club

Figure 1.1.4: Access with WT for an Amateur footballer has for self-improvement alone

The impact of WT can be seen, where there is a greater opportunity for an Amateur player to self-learn about their performance to increase an attribute they desire. This accessibility will in turn, help improve them as a player and the quantification of their physical capabilities, can give them a clearer structure, to how well they are improving. This project will dive into the depths of how effective the Technology involved can be, and how Design will influence its effectiveness.

1.2 Overview of ankle movement study within penalty kicking environment for amateur level footballers

1.2.1 Prequel Study

Preliminary study relied on an online survey to conduct User research on Amateur footballers. Results showed that users were willing to invest in WT and spend most on football boots. This opened the idea of having technology being integrated into that equipment. Most participants stated a budget range of £20-50 for investing in equipment, whilst having the desired feedback option to track both injury (overuse) and performance. An indication of the consumer age group (16 - 26 years) was identified during this process. Results also showed there is a need for WT in amateur football as players who have used them before were willing to invest further, hinting potential gap which requires fulfilling.

Conducting this study showed that there is a need, a futuristic one, for data monitoring in amateur football sector. Consulting with experts in key areas revolving around WT, gave vital insights into sensors, performance data, User experience/User Interfaces and the sport itself. Discussing the importance of monitored data, reliance on subjective opinion, how user experience translates in performance data, makes WT a crucial "educator" in this integrated system. The technology monitors key biomechanics with the use of sensors, where any advancement in sensor application will need a thorough ergonomic analysis.

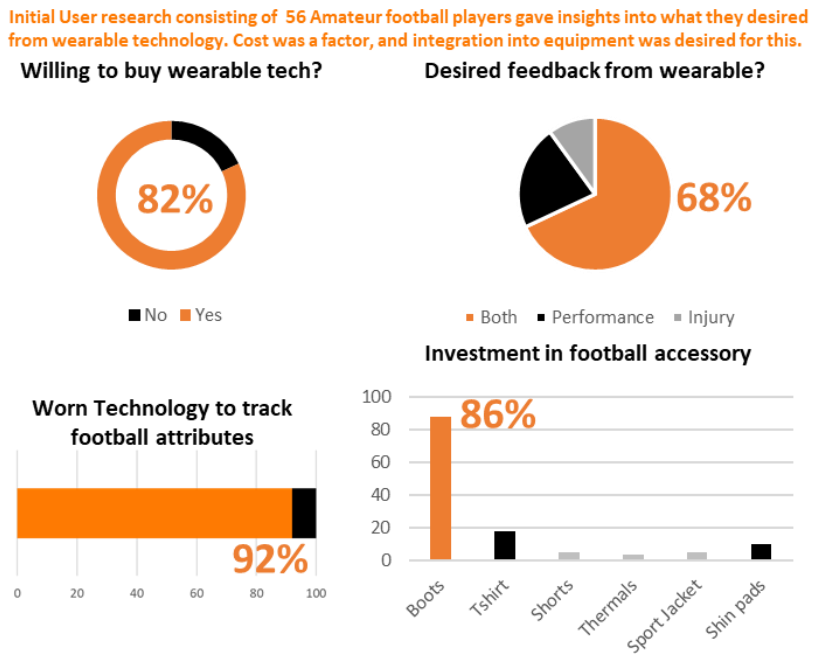


Figure 1.2.1: Initial User research feedback on WT integration in Football

It is impossible in WT's current state to track all elements and be as effective as having the key stakeholders around, to improve the athletes in different ways. For this PhD thesis, it is important to refine a scope, increase the depths of technicality and design, showing the impact WT can have for amateur level athletes.

1.2.2 Scope

What does this PhD thesis research into?

Sensors are the most fundamental component to WT. Inertial measuring unit (IMU), compromised of Accelerometer, Gyroscope and Magnetometer, found in most wearable devices will be used, and compared with a form of pressure sensor in Force Sensitive Resistor (FSR). This is not used as much, hence a comparison between the 2 can indicate, how each can provide relevant enough raw data to be converted into performance data.

The research setting is **Penalty kicks**. The technical attribute for monitoring is **Shooting**. These decisions are made due to the constraints already applied for this "set piece", hence control variables are assigned. Having the environment conditions controlled increases the depth of this research in terms of what sensors can track. Important factors such as ball and boot properties provide the data that's monitored to be refined, including all the necessary elements as a weighing factor in improving WT application. The results from this simpler setup identify where crucial biomechanics can produce relevant performance data.

Preliminary study showed greater investment in boots, and the focal point of the chosen attribute has a great dependency on boot to ball contact, hence the region of **Ankle Motion** biomechanics is researched greatly. The method of extracting and "making sense" of data in terms of football kicking needs to be analysed, where relating key ankle motion deliverables of shooting attributes, aims to answer this study's research question.

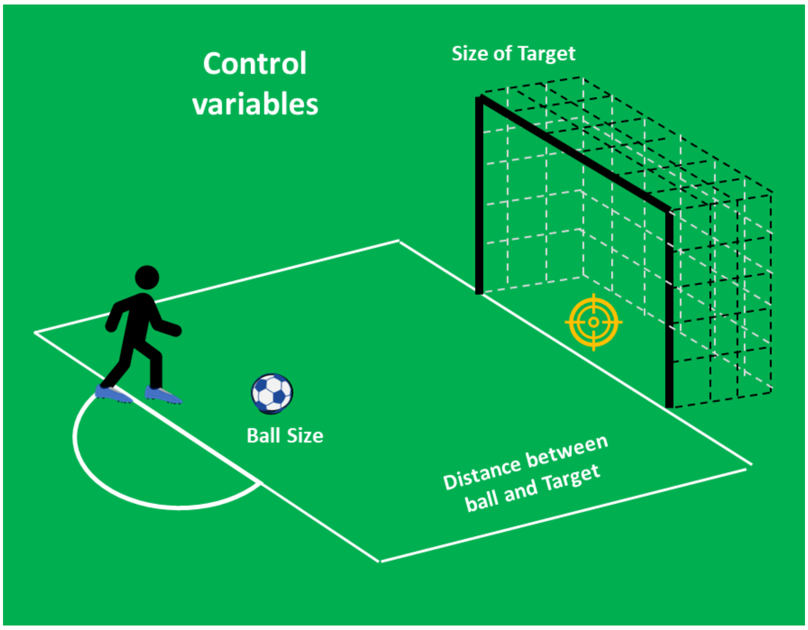


Figure 1.2.2: Control Variables for this Project

How will this research be conducted?

A setup of penalty conditions is planned to test IMU and FSR sensors around the ankle region. These are used to analyse how ankle biomechanics are important in executing a successful football shot. Two shot types are analysed in Laces and Inside foot (predominant shooting techniques in football). Football relevant data will be designed from sensor outputs, involving key mechanical quantities, aiding the design of the Data model framework. This results in how the senor used for tracking, creates additional biomechanics analysis relevant to football shooting attributes. The method of creating this data model from these control measures, can be applied for WT application to rely on, regarding monitoring other football attributes. This will show how great of an impact, sensor integration has in creating more data for analysing, helping amateur level players learn even more about themselves.

Figure 1.2.3: Monitoring variables

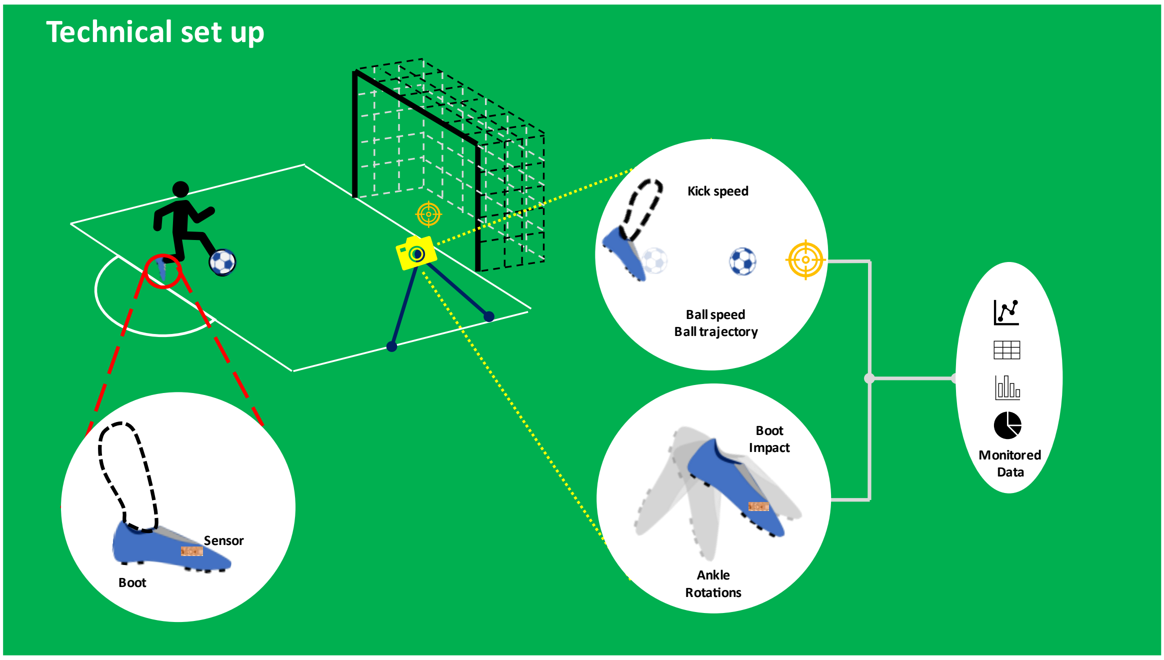


Figure 1.2.4: Technical setup of monitoring Ankle biomechanics

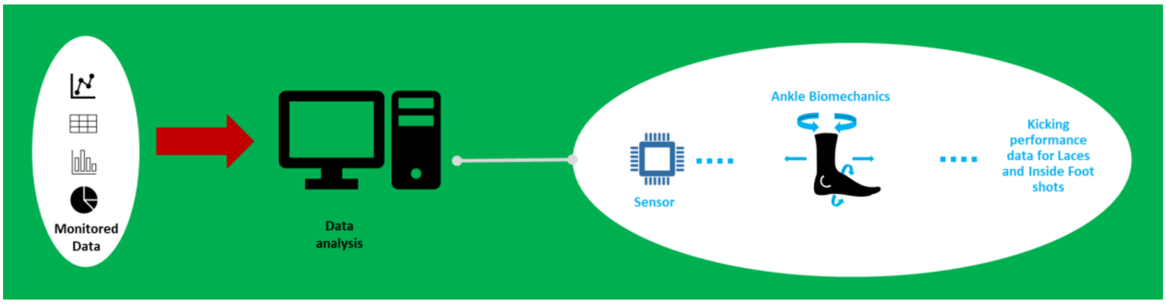


Figure 1.2.5: Data Journey of computing kicking performance parameters

Impact?

Biomechanics of kicking is fundamental for football. Understanding this, identifies the opportunities of how to improve one’s ability. Data from analysing penalty kick shots and looking at ankle variations, due to the result being definitive (goal being scored in an area and speed), enables precise monitoring. The steps taken to convert physical monitored data into performance, gives the opportunity to test the capability of sensors for sport specific tracking. This method can then be applied to other important elements in football such as, Freekicks, corners, Crosses from open play etc. This will help grade the success of WT application for Amateur level footballers, referring to this study into penalty kicks, as guidance to compute further research.

Physical Data

Physical data are statistics that can be read via WT whilst directly measuring from the body itself. In football terms, examples consist of Distance overed, High intensity distance, Sprint distance, number of sprints, number of kicks, jump height, running speed and strength. Some of these can be used to judge performance in football. Even penalty kicks can benefit from knowing running speed towards the spot and kick speed. In this project, the Physical Statistic Kick speed and ankle motion velocity (linear and rotational) is strictly monitored during the Ball contact phase, to fully scrutinise the sensor’s capability and its influence in WT.

External factors

Ball Trajectory and Speed affect the accuracy of the kick and is used to judge how well the player's technique is. With real conditions, numerous factors such as environment, material of boot, air resistance, ball air pressure, all can affect ball trajectory. The experiments are conducted indoors and outdoors, to try and nullify as much external resistances, (e.g., drag and lift forces on ball being directly linked to the kick, rather than external environment affects). The ball stitching (panels) and boot design (outer soles) can also cause the coefficient of restitution between them, to affect the trajectory of the ball's aerodynamics. Software analysis will identify if material dissipation affects potential WT data framework.

Performance Data

Performance Data statistics are more desired, as they define how well a certain attribute has been executed. Performance stats for penalties depend on Accuracy and speed hitting target. Accuracy defines how well the precision of the kick has allowed the ball trajectory to hit intended target. "Target" defines how well the kick is executed, and regarding penalty, it is if a goal is scored against a Goalkeeper protecting it. Speed of ball will be critical to define shot type success and "grade". Shot on target can determine precision, however, for a penalty kick to be successful, sometimes speed does not need priority. This is because in a situation with a Goalkeeper guarding the Goal, if the player executes a shot, in the direction in which the goalkeeper did not dive towards, the shot will be successful. For this project, to increase the "accuracy of kicking shots", speed will be calculated as a performance data equivalent, to help build new "meaningful data", with regards to ankle motion velocity and ankle stance upon ball contact.

1.2.3 Aims and Objectives

Aim

Create a **framework** that displays how Physical **Ankle movement** data converts into **Meaningful Performance Data** using **wearable sensors**, illustrating the importance of **ankle biomechanics** upon **Penalty kick ball striking,** for amateur level footballers

Objectives

1. Conduct Biomechanical research analysis during a football kicking phase
2. Locate where wearable sensors can be relevant to provide Laces and Inside foot shot monitoring
3. Identify the role of IMU and FSR sensors that provides ankle movement data to form performance data
4. Define how User conditions the Decision Matrix Attribute Ranking that alters the perception of Quantified Performance Data depending on their priority
5. Design a Framework, that's shows the method of capturing raw biomechanical physical data and the steps needed to convert it into performance data

Key Tasks

1. Complete a **Literature review** that identifies the key elements revolving around Technology, Football, Human factors, Data and Design
2. Observe **Amateur Footballers** and conduct Expert Interviews to list out potential needs in terms of improving kicking techniques
3. Analyse **Ankle motions** and Kicking **Biomechanical** movement for Laces and Inside shots within Penalty kicking
4. Theoretical development on **External factors** that could affect football shots
5. Identify **Sensor** working **parameters**
6. Conduct **Test** with **User** to monitor **ankle motions** prior to **ball contact**
7. **Build Test rig** to emulate a kicking motion, to understand the **Outer Sole Contact regions**
8. Create End User survey to calculate which **fundamental kicking attributes** will form the weighing for **Decision matrix**
9. Form a **strategic Framework model** which uses relevant **Physical Data** to compute meaningful **Performance Data**
10. Conclude where **Contribution of Knowledge** has been made and what the future is regards to WT for Amateur level sport

1.2.4 Research Gap

Gaps in research

There is a scarcity in WT that produce meaningful data from sensors for amateur level footballers to improve their kicking ability. Researching this can advance methods through this technology, making better use out of sensors to improve kicking ability. The importance of Ankle motion has also not been identified in relation how important it is to execute right technique of the shot.

Research question?

How sensors on a foot create an extra biomechanical football shooting feature in Ankle motion prior to ball contact, to help design a performance data framework to quantify subjective opinion of laces and inside foot penalty kicks?

Why are there gaps?

- Poor quality in meaningful sensor readings when dealing with sport activities
- Poor existing consumer sport wearable devices
- Insufficient feedback data for amateur level players to improve on
- Lack of self-learning user experience to improve technical attributes

Contribution to knowledge - Gap in research and intended solution

1. There are 6 key biomechanics involved in football kicking (Section 2.4.1), can this study add another fundamental biomechanical feature; **Ankle motions prior to ball contact;** through the use of Wearable sensors

2. To illustrate the steps taken in how **raw biomechanical sensor data** produces **sport specific performance data**

Impact

- Ankle stance on Ball contact is fundamental to how well the type of kick has been shot
- Ankle motion prior to it, is equally important
- Players can learn new skills using results as guidance to how their ankle moved, honing their attributes and technique in the process
- Framework used as guidance of transforming raw sensor data into performance data to help increase future sport application relying on WT

Summary

- Design PhD specifies ankle motion as focal point of analysis in terms of Penalty kick shooting
- Sensors are the most fundamental component to WT
- IMU and FSR Sensors used around Ankle and Boot region to produce data
- Decision matrix displays how weighing of certain attributes can be applied to other elements of football kicking dependant on End User desires
- Designing framework to display method of extracting physical data of ankle biomechanics and how they become meaningful shows contribution to knowledge
- Impact translates to how well the Framework design can help other sport biomechanics to be analysed, understanding greater influence of motoring through WT

2. Literature review

2.1 Wearable Technology industry and its current application in sport

2.1.1 Market

The market displays the present state of wearables. Due to the sudden rise of disruptive tech such as smart phones, which then later allowed smart watches to become consumer lifestyle product, the current climate of wearables shows positive forecast. With exponential growth already, and even bigger growth predicted, wearables are thriving in this "self-obsessed era". The military and space industries are heavy influencers in advances of technology in wearables [Hatton, 2014]. This heavily impacts consumer level smart devices because a decrease in cost of electronic parts, allow more accessibility of expensive technology, that may not have existed previously in handheld devices. Due to this sudden shift, consumer wearable market has become as big as defence [ID Tech, 2018].

"Waves" are used to describe the growth states of wearables [ID Tech, 2018]. The 1st stage is established wearable sensors such as Hearing Aids, Headsets, Global Positioning Systems (GPS), Cameras, Thermistors, etc. These are wearables that have long been used in different industries. These electronic parts have been able to evolve in many ways, and as such, allows consumer products by default to have the latest version of them in it. The 2nd phase is made wearables, which are compromised of micro-electro-mechanical sensors (MEMS) that have been developed specifically for WT. Influenced by the impact of smart phones as a daily essential, sensors involved like GPS and IMU, give fitness tracking wearables a dependency to rely on them. Research into these sensor technologies, allows wearables to exist the way they are in the present climate. The 3rd phase is the future phase; these are made for wearables, which use advances in research to make better use out of sensors, thus continuously develop and improve (e.g. flexibility, motion, and smart fabrics) [ID Tech, 2018] [Ferraro, 2015]. Future investments focus on this, hence they are not commercial yet, where testing and user reviews will impact its success.

The market research of industrial wearable devices has 4 key themes: Product, Trend, Driver, and Forecast. With Product, wrist worn devices possess the biggest share in the market, but goggles are increasingly becoming more in demand. This could be due to certain industries requiring them for their work force. The Trend is patenting the technology that is used for innovations during progressive findings in wearable systems. When small improvements are made, relative to existing products or technology, it is crucial that designers and engineers patent their ideas, so that copyrights can be protected. This is a delicate section, as patents require constant investment to keep them, and when it expires, the idea can no longer be under protection. The Driver comes in the form of growth in Internet of things (IoT) products, with the help of immersive content such as Augmented reality, reaching the industry to new sectors. Immersing the content through different methods, requires extensive testing, but such measures are taken to improve the experiences felt by the user. The more they feel immersed with the new product, the greater its impact would be on their daily lives. The Forecast shows the growth increase in the future. This is not just based on past success rates but researching the potential future developments by big and small firms in this industry, so there can be some sort of accurate protocols to judge how different sectors behave [Business wire, 2018]. These protocols can be viewed as benchmarks that the different industries involved can look up to, and it helps them understand their potential competition or partners. These 4 "pillars" make the roots for market research in WT. Each are important for the present and future, whilst the adaptation process required for their intended user group can affect these, it can still be validated that these 4 will remain very important, as long as WT remains disruptive.

When new technology is marketable, the best suited industry will want it first. An example of this is Smart body worn trackers, which the military benefited from first before they became useful for different purposes [Hatton, 2014]. Smart goggles are an example which is used in multiple industries, so the sensors that are involved, produce data that can be processed for different uses. WT is "essentially a computer that's worn", and is part of the user, being fully controllable and working on minimal effort [Kamisalic, 2018]. This form can somewhat be seen in present day wearables, as they are considered "Smart" due to operating certain tasks themselves with minimal human input in controls. It provides the user the freedom to act from the data that are presented from the wearables [Gobinath ,2019].

Fitness and lifestyle products will grow the most for WT sector, but advancements in multiple industries should not be neglected, as research can be used as crossovers [Beecham, 2018]. Gaming is becoming a reputable industry for WT. The emergence of Virtual and Augmented reality, which is heavily involved in this sector, is playing a part in increasing how a user can immerse themselves with the product and experience. WT allows senses (haptics) to be felt, giving a more authentic feel to the experience [Sherman et al., 2003]. These types of innovations are constantly refined from the hardware, to applying wearable sensors on the user themselves. The product's lifecycle may not involve continuous long hours of usage like those in the medical or fitness sector but is altered using existing technology (same sensors), to give a different type of user their desired feedback. Game designers will have to identify which senses are authentic for their games, and then choose sensors accordingly.

A simple example of this format is the Nintendo Switch Labo. Using their Joy cons, consisting of default sensors (accelerometer, gyroscope) found in consumer wearables, and cardboard to build own "artificial wearables", and apply it to a gaming function [Nintendo, 2018]. This is Nintendo's way of breaking barriers for future generation, who are more involved with technology at younger ages, to have an immersive experience with simplified "custom WT". Some parents may view this as an ethical solution, as they prefer their children to play with these, rather than Virtual reality headsets (popular gaming immersive experience). They will also think about social considerations, depending on how they can use technology to safely interact with their children [Godfrey et al., 2018]. The form of adaptation starts from a wearable that is useful/desired for an "individual", which then moves to "wearables for social impact". Gamers experience immersion with their family and friends, where the impact on their communication with them using a different medium, leads the perception of the Labo edition, being a "wearable for public interest", as the end users are both diverse and inclusive. The process is the concept of sustainable wearables known to "enhance the quality of human life" and this structure can be used for any wearable manufacturers that want their designs to become marketable [Lee et al., 2016]. In ergonomic and anthropometric terms, positioning of the wearables is crucial to success. It is fundamental for consumer, before purchasing that they know their mobility limitations whilst wearing the device [Kalantari, 2017]. This will also influence their adaptation for future WT.

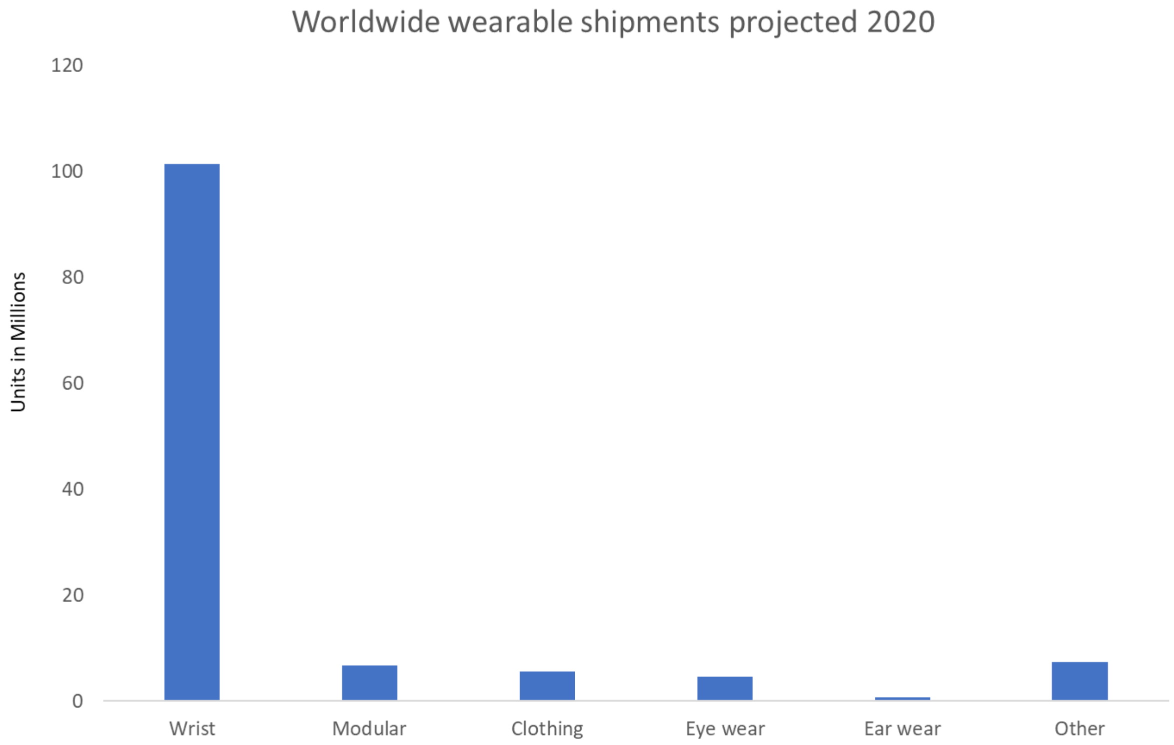


Figure 2.1.1: Worldwide Wearable Shipments projected 2020; Data adapted from Statista plot [Hinch, 2017].

Figure 2.1.1 shows how Wrist wear will remain a popular wearable. This could be due to it replacing traditional watches, which consumers have worn for years. If this forecast continues its trend, then more manufacturers will look to improve on this element alone, but depending on positive consumer feedback, researchers may find another body part that can be used for future device placements, if they're more feasible. This is very dependent on the use of the wearable, e.g., in sport terms, more focus could be looking into how the key biomechanical movements affect game play individually and in a team. Greater research development on integration of sensors into equipment, can be possible upgrades.

Sensors are the core of WT, as without it there is no use for them. Consumers are desiring monitoring systems that produce specific data. These data come from sensors and get processed for the intended user. Figure 2.1.2 displays the importance of accelerometers and gyroscopes in their share of the market size for WT sensors, which is forecasted to be $2.86Bn by 2025 [Grand view research, 2018]. IDTech complimented this research claim, in that the type of sensory components that will lead in revenue for WT (forecasted 2022), showed the importance of IMU and Optical [IDTech, 2018]. This gives an idea of which "future phase" sensors may undergo more research. MEMS are very suitable for WT as these sensor sizes make them a good choice, where designers prioritize being minimal, in weight and power consumption (reducing costs, whilst increasing ergonomics). Table 2.1.A shows the sensors that are present in WT, for different types of industries. This compliments with data from Figure 2.1.2 where accelerometers are heavily present in multiple wearables.

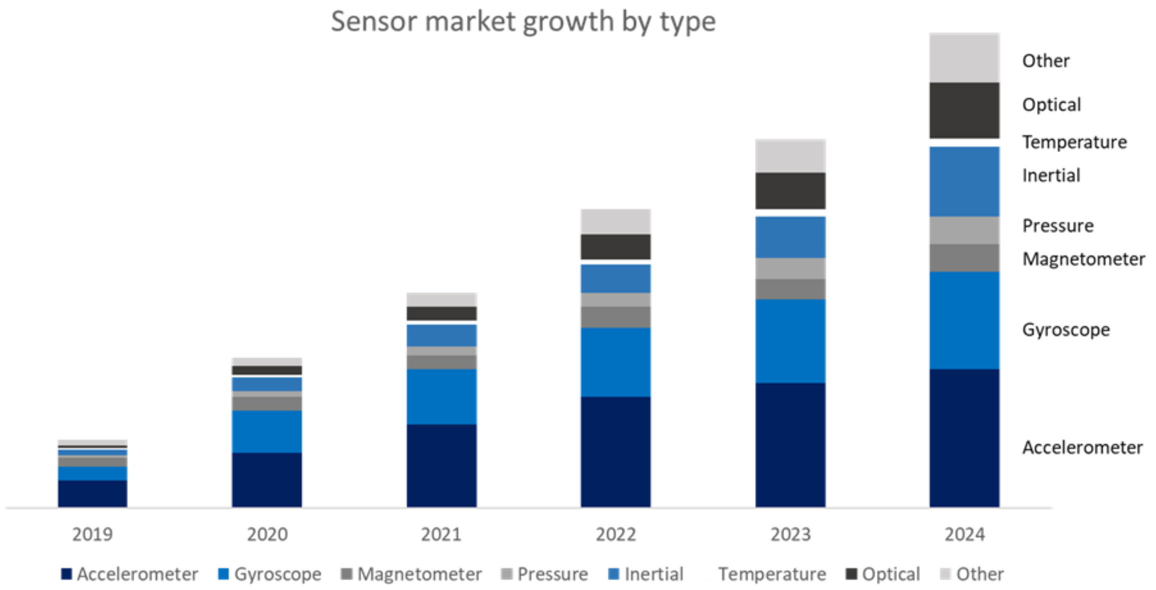


Figure 2.1.2: Sensors found in wearables and its projection until 2024 [Grand View research, 2018]

Wearable	Accelerometer	Gyroscope	Heart rate monitor	GPS	Smart category	Application	Body place	Other sensors
Apple watch 2	X		X	X	Watch	Lifestyle	Wrist	Speaker
Fitbit	X		X	X	Watch	Fitness	Wrist	Photodiode
Nintendo Joy con	X	X			Controller (modular)	Gaming	Hand*	IR sensor, NFC
PlayStation VR	X	X			Eye wear	Gaming	Head	Microphone, speaker
OM Bra	X		X	X	Clothing	Medical	Upper body	Pedometer
RealWear HMT	X	X		X	Ear wear	Industrial	Head	Microphone, Speaker, camera
HexoSkin	X		X		Clothing	Fitness	Upper body	Pedometer, ECG sensor, Thermometer
Vuzix AR3000	X	X		X	Headwear	Medical	Head	Camera, Magnetometer, microphone
Google Glass	X	X		X	Eye wear	Industrial	Head	Magnetometer, microphone, speaker, light sensors, IR sensor, Camera
Samsung Gear S3	X	X	X	X	Watch	Lifestyle	Wrist	Barometer, Light sensor

Table 2.1.A: Sensors for WT in different industries; [Gobinath, 2018]

All WT listed on Table 2.1.A have Bluetooth. Nintendo Joy con differs on body place, as the Labo edition allows the joy cons to be placed on any slot depending on the game [Nintendo, 2018]. Data from Vandrico showed what each industry possess in WT and its hardware. Alongside microcontrollers there are some essentials for WT to work. These are how its communicated (wireless data transfer), storage and battery [Vandrico,2018].

Wearables in Fitness, Healthcare, IT and Defence all forecast to increase in market value exponentially. Such progression shows the impact WT has on multiple industries [Grands View Research, 2018]. The research found in one industry can easily be used for others, and this process has allowed the overall wearable sector to thrive [Inclusive Design toolkit, 2019]. The impact of having a technology that's disruptive, is gauged on how much audience it can garner and how the selected demographic feel they can experience multiple uses within 1 device (subsequently increasing its market value).

Figure 2.1.3 below shows an example of a single person who has more than 1 wearable for different uses. This segment doesn't just come under "lifestyle wearables", but it can easily come under "work" and "entertainment", depending on what and how the end user uses it for. Figure 2.1.4 shows how 1 user has multiple wearables, each for its own designated use. This also supports that the uses will link to different industry sectors.

Figure 2.1.3: Diagram showing how 1 wearable can have multiple uses

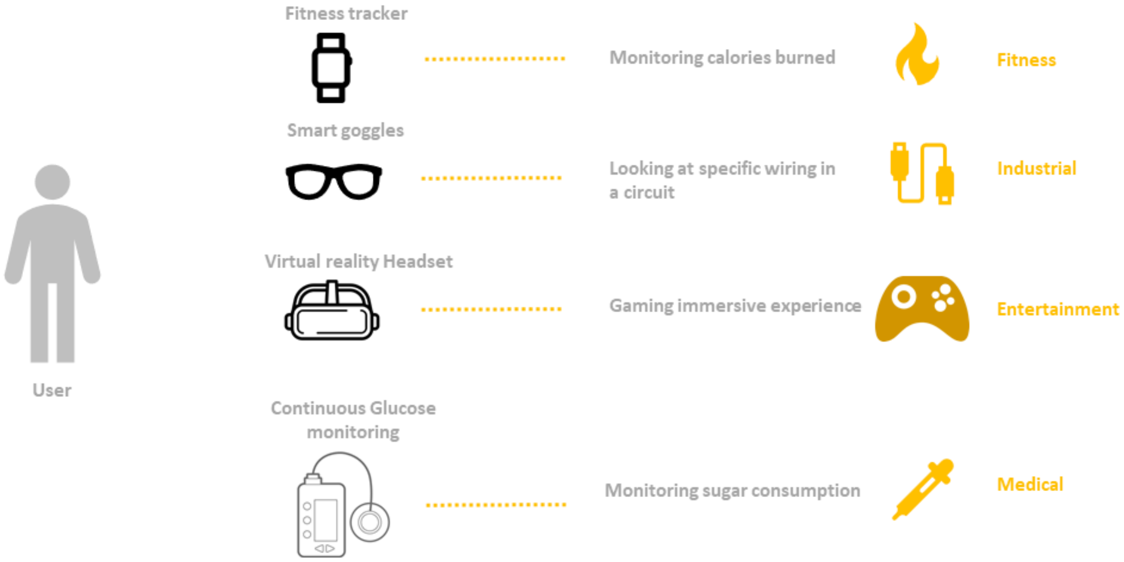


Figure 2.1.4: Diagram showing how multiple wearables have specific uses

Fitness and lifestyle sectors are dominant in the wearable industry due to people wanting to be at peak fitness levels for health, sport, and lifestyle reasons [Karim, 2014] [Beecham, 2018] [Grands View Research, 2018] [Hatton, 2014]. [Gobinath, 2019]. Fitbit is the most popular wrist worn device for the fitness sector, that allows monitoring of the body during exercises [Fitbit, 2018]. This wearable can be viewed as a lifestyle device if a user's priority may perceive them to view fitness as a lifestyle rather than as an activity. Figure 2.1.5 displays the hardware that Fitbit has and its uses. Fitbit state that their wearables monitor multiple elements such as heart rate, sleep, and food consumption (via user input). This adjustment made by single sensor processing, makes it efficient. However, the accuracy of the processed data depends on how well the monitored data is inputted into their microcontroller. This will then affect the algorithms that are present in the processing of the data, which is what the user would read as outputs. It is important that these programmed algorithms must not be affected, as this can corrupt the monitored data during processing phase making the output data meaningless [Gobinath,2019].

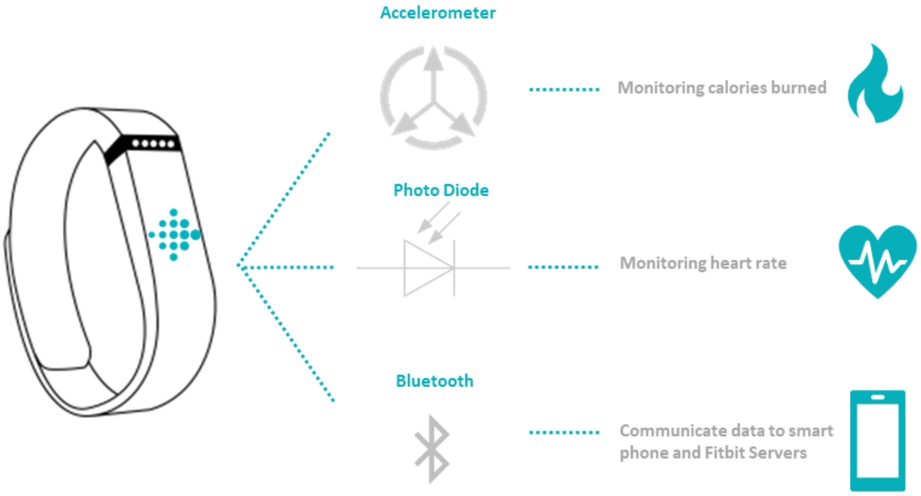


Figure 2.1.5: Hardware involved with Fitbit and its function

Figure 2.1.6 shows the example block diagram in how fitness WT can be used for lifestyle applications (Weight, calories burned, heart rate, speed etc.). The user will have their activity monitored via sensors, input some of the data themselves (food eaten), which is then communicated to a smart phone, or the providers "cloud" service. The data then gets processed, so it becomes useful for the user to understand and is fed back into either the paired smart phone [via APP], or the wearable, depending on type of display.

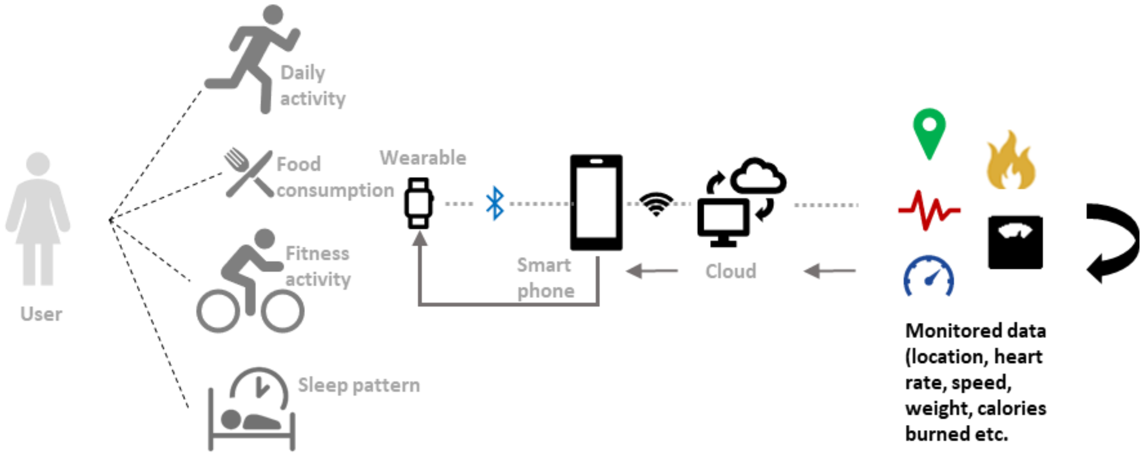


Figure 2.1.6: Block Diagram example of a Fitness Wearable's process.

With increasingly human centred designs in the use of WT, industries can work more efficiently, so funds can be invested effectively. A greater impact from the technology can benefit the elderly and disabled, where extensive human factors research, could provide a solution for end users who may be novice to new tech or have accessibility issues. If the user research is done effectively, it can help ease a way of living [Mao et al, 2017]. Remote monitoring can be a solution, as advancements in biosensors has led to this contribution being impactful [Majumder et al., 2017]. In the medical field, instead of having a patient, booking an appointment in advance for a hospital, sensors that allow a recording of the patient's ECG, [e.g. printed PCB on t-shirt], can allow the doctor to be notified if there are any abnormal activities [Patel et al., 2012] [Iqbal et al., 2016]. Figure 2.1.7 shows an example block diagram of how WT can be used to monitor health for the elderly and disabled, through wireless body area network [Jovanov et al., 2005]. This benefits the user and the doctor, saving time, giving a more transparent form of communication and analysis.

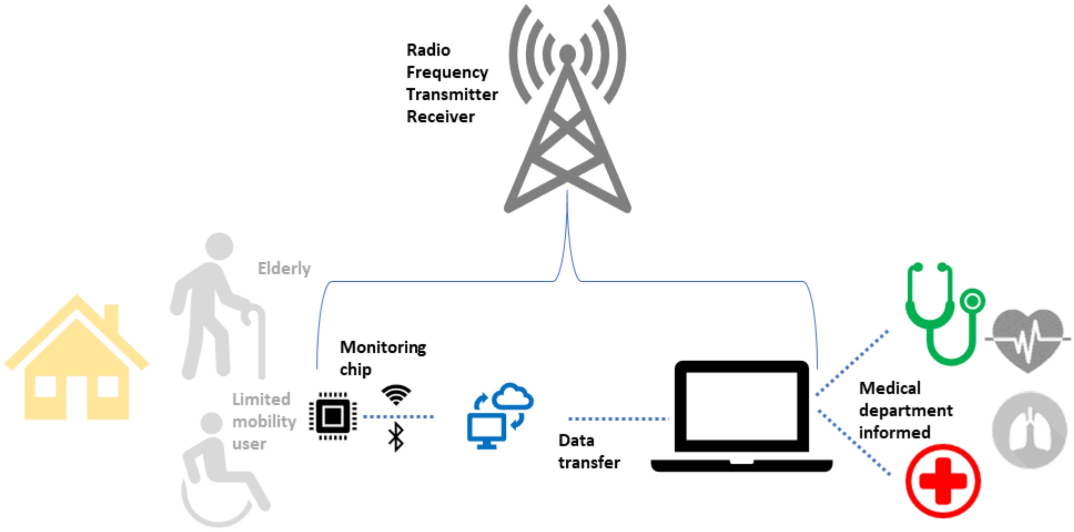


Figure 2.1.7:Block Diagram example of a Medical Wearable's process [Gobinath, 2018]

The environment is a crucial factor in how smart wearables in the medical sector plays a role. In rural areas, the chance of seeing a physician is less than one in an urban area. To have good access to health care, one must travel further, hence a monitoring system that can simplify elements relating to a user's health condition, can benefit them psychologically, as well as physically. There is a greater transparency between the condition, the user, and the doctor. The user may not prefer this way, as they may not be accustomed to such maintenance of technology and would prefer regular reassurance from an actual doctor present [Mardonova et al., 2018].

2.1.2 Sport Wearables

Application of WT in sport come in different forms. The popular ones being body worn devices (wrist), but there are other types such as sensor embedded equipment and smart textiles (printed PCB or conductive threads) [Kamisalic et al., 2018]. The goal of these different approaches to WT for sport, is to enable the user to have the best possible way of monitoring their performance without hindering any movement. This is also dependent on where the sensor is placed within the equipment, regardless of, if it's an accessory or not [Ebling, 2016] [Ferraro, 2015]. In some sport, the equipment having sensors embedded into them would be a better solution than having a wrist worn sensor, such as American football or Ice hockey, where sensors placed on the pads (knee/shoulder) or helmet, can feedback more meaningful data (hands free). Location of sensor placement will always be a factor in design as the intended function has greater priority [Iqbal et al., 2016]. There are instances where external factors such as the sport's ball, affect biomechanical factors, based on player behaviour approach with it. Football boots having sensors on the outer sole, have been known to produce data that shows ball maneuvering characteristics, which can work well with the sensors placed inside, in how the feet reacts to it and relate to precise biomechanical refinement, giving the user maximum understanding of their movement, hence to how to improve [Zhou et al., 2016][Gobinath, 2021].

Fitness wearables being considered as a lifestyle application is due to its versatility because the hardware involved can be altered to match other needs. This is where the sport wearables become more exclusive by using the same sensors but matching it for sport specific needs, as each has its own performance and physical attributes. Each user would want to improve on different aspects under their control. Hence sport wearables are made precisely for its intended use. The table below shows researched examples of sensors in consumer WT for sport. This shows how different sports wearables rely heavily on accelerometers and gyroscopes for similar purposes, even if they are used differently, their positioning increases its relevancy [Vandrico, 2019]. Table 2.1.B below shows researched examples of such sensors in consumer WT for sport [Vandrico, 2018].

Sports wearable	Accelerometer	Gyroscope	Magnetometer	Heart rate monitor	GPS	Position
Fitbit	X		X	X	X	Wrist
Zepp Play	X	X			X	Equipment*
Lumo Run	X	X			X	Lower back
Optimeye	X	X	X			Back (Vest)
PlayerTEK	X		X		X	Back (Vest)
Viper POD	X	X		X		Back (Vest)
Adidas MiCoach	X	X				Ball

Table 2.1.B: Examples of sensors in consumer WT for sport; Data taken from [Vandrico, 2018]

* Zepp Play uses their sensors for four different sports. They link the sensory findings to technical attributes for specific sports. GPS = Global Positioning System.

Zepp Play	Accelerometer type	Gyroscope type	Position	Sport specific attributes tracking
Football	3 axis accelerometer	3 axis gyroscope	Calf	Sprints, Distance, Kicks, Top speed, Loads
Baseball	Dual accelerometer	Dual 3 axis Gyroscope	Handle of Bat	Bat speed, Accuracy, projectile, hand speed, attack angle, vertical angle, time to impact
Golf	Dual Accelerometer	3 axis gyroscope	Top of glove	Club speed, Hand plane, Downswing, Backswing, hip rotation, Tempo ratio
Tennis	Dual accelerometer	Dual 3 axis gyroscope	Handle of racket	Ball speed, ball spin, serve, forehand/backhand, topspin, drive, active time, calories, slice

Table 2.1.C: Types of Accelerometer and Gyroscope in Zepp WT for different sport Applications; Data taken from [Zepp, 2018]

Zepp play is a WT company that uses their sensors for different sports. They link the sensory findings, to technical attributes for specific sports [Gobinath, 2018]. Table 2.1.C highlights how they use different combination and types of accelerometer/gyroscope for these different applications, with measuring the specific skills that the user could desire. Zepp Play uses Bluetooth Low Energy to communicate data for all sensors [Zepp, 2018]. What’s interesting is how they position their sensors so the readings can give intended or allocated data. Biomechanics involved in Baseball and Golf swing are similar, yet Zepp Play have positioned their sensors on the handle of the bat for baseball and on top of the glove for golf. This could indicate how readings may differ on positions, for intended data (sport specific purpose) and what data is truly wanted by different players. Evidently biomechanical research has been thoroughly conducted to assign the placement of sensor on equipment.

The same sensors are programmed to produce data for different attributes. 3 Axis gyroscopes are used in Zepp Play Football and golf. Two very different sports, yet they measure “orientation”, and are used for different skill sets [Zepp, 2018]. It could be argued that gyroscopes are more influential in Golf, even though they are known to filter out errors alongside accelerometer readings [Niel, 2010]. Yet for similar sports (Baseball and Golf) in terms of biomechanics of the upper body, there are different types of gyroscopes used. This indicates that the versions of sensors influence data monitoring.

Table 2.1.D shows examples of existing sensors found in football wearables, and which specific position its placed in. This gives a better understanding of where these sensors are being utilized the most for its purpose. These sensors are available for attackers and defenders of football. However an amateur Football defender may prioritize other attributes that typical defenders may not need or want to improve on, so having a user centred design process, helps build trust amongst sport WT consumers. This will make the wearable more personal, and it allows the user the freedom to monitor, to improve attributes they want, rather than what is assigned. It may benefit or hinder ideas of how to improve as a team, due to tactics or where an individual can be most effective because biases affect decisions of how a player wants to grow.

Sports wearable	Accelerometer	Gyroscope	Magnetometer	Heart rate monitor	GPS	Position
Zepp Football	X	X			X	Calf
Optimeye	X	X	X			Back (Vest)
PlayerTEK	X		X		X	Back (Vest)
Viper POD	X	X		X		Back (Vest)
Adidas MiCoach	X	X				Ball

Table 2.1.D: Examples of sensors in consumer WT for Football; Data taken from [Gobinath,2018][Vandrico 2018]

Zepp releases multiple wearables for different type of sport. Their research and development build them to towards becoming an "expert" in data handling of the sensors, as they are relating the monitored data, into performance terms for specific sports. Therefore, the data that is monitored via these sensors, can be transformed into selected sport specific performance attribute with different algorithms. Figure 2.1.8 and 2.1.9 are examples of Zepp Baseball and Soccer, where they use combinations of the same sensors to produce intended outputs. Zepp Baseball use two of each sensor, hence the programming of each may monitor different biomechanical properties of a Baseball swing. The data collected by all sensors can then link those properties into performance attributes. Zepp Football has a different device which measures that sport's specific attributes. Being placed on the calf, reiterates how well Zepp have studied the human factor analysis to give the best possible feedback for football users.

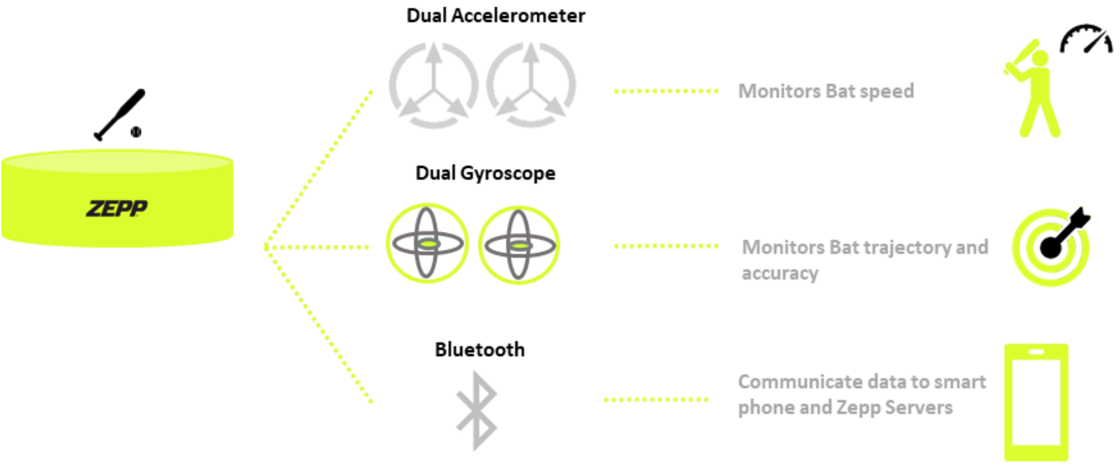


Figure 2.1.8: Hardware involved with Zepp Play Baseball

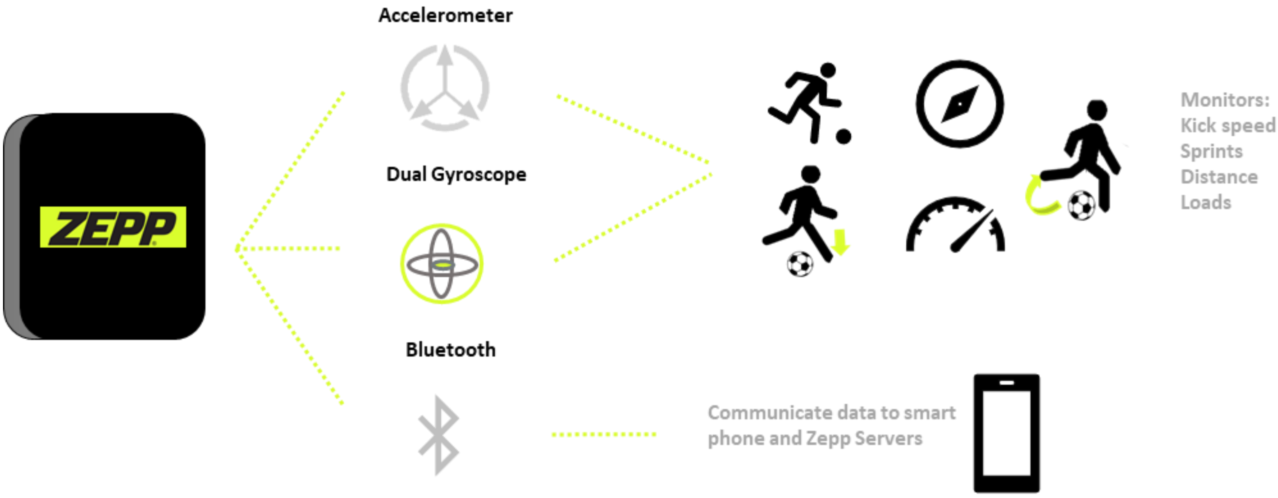


Figure 2.1.9: Hardware involved with Zepp Football

2.2 Technology involved in monitoring and capturing physical data through existing wearables sensors

2.2.1 Hardware and Software Sensors

WT in sport is also implemented to allow coaching staff to analyse performance of athletes more accurately. In football this can be complex as there are multiple scenarios where one “data” could be preferred to another, depending on type of positions or attributes a player desires. There are also ethical concerns where too much data is harming sports, and tactics are becoming more complex. Some wearable manufacturers send data to their provider’s “cloud”. This is also another ethics concern, in particularly for consumer sport wearables, as the providers try to study the data and make “best use” out of it, even though it only should belong to the user [Gobinath, 2019]. The user must give consent of allowing the data to be held as part of GDPR regulations [Forrest & Syrenis, 2022]. Players can indicate a hindrance in their ability with extra “accessories”, so having a wearable device attached, such as a smart vest, may not be the best choice for some. More research into football equipment is important, to understand the potential of having integrated sensors within them to allow WT to produce greater human centred design solutions within ergonomics. A user’s desire to “quantify their ability" in an area they want to know more about and improve, allowed smart wearables to penetrate the market and advances in sensors increased depths of measuring capability.

Microcontroller

The key component in allowing WT to function is a microcontroller. This is typically viewed as a system on a chip (SoC). It enables the Internet of Things (IoT) to be present in these applications [Ebling, 2016] [Verle, 2009] [Gobinath, 2019]. Importantly, it reduces multiple electronic components that are tasked with performing various functions on a single chip [Reviseomatic, 2018]. This is important for football wearables, as it reduces the size of the device, as hindering movements with large accessories will not be comfortable. Its simplicity to program, reprogram, cost, size, compatibility with other sensors, and the ability to control complex outputs, such as graphical displays, make it fundamental for consumer sport wearables [Gobinath, 2019] [Pires, 2017]. The versatility allows designers to optimize the microcontroller to meet their user needs.

Online influence

Social media's rise, as a strong medium for consumer's daily use, started a perception change to make it a need to be at the best physical shape for aesthetic/health reasons. This rise allowed fitness wearables to be an important lifestyle product. This opportunity gave Micro electro-mechanical systems (MEMS), i.e. sensors, such as accelerometers, gyroscopes, and magnetometers to increase in value. These are now more important in consumer products than before. The data obtained by these sensory readings are linked to fitness attributes a user can understand and learn from, to improve themselves. With nutrition becoming more important in how human body aesthetics are affected, monitoring the consumptions of contents a user takes are equally important. The more data involved, the more complex the processing. However, making them easier to understand in terms that the user wants to know, i.e. ergonomic value and simplicity, will make it more successful. A data/sport scientist will know what the sensor reads in terms of biomechanical movement such as "how fast a user changes direction" and link it to an attribute such as agility (important skill for any position in football). But for the user, they need to first understand what agility is, and how to define it in terms of improving themselves as a player. In sport terms this can be more straight forward, as a football player can link it to how well they can "mis direct or react" in situations. This can increase their awareness of the subsequent body parts that influence agility.

Figure 2.1.2 showed how important accelerometers and gyroscopes are. Sport trackers monitor movement of user via with these sensors. The ability to measure a user's motion in any "angle or direction", is very important for football wearables. There needs to be emphasis on the accuracy of monitored and processed data. Monitored data accuracy can be how well the sensor is able to capture minuscule changes. Processed data is how well the programming of the monitored data is giving out meaningful user centred data. This is very difficult for football, as there are numerous performance data that a user could desired. Even the same positional players may not want the same specific attributes. This is where the freedom to give the user how they want to improve as a player, influences the impact WT can have. At consumer level, this is more complicated, and if sensors are to be embedded into equipment, then more testing is needed to know to what extent can the user control their improvements. Accessibility and real time feedback all relate to how well these sensors perform. Sensors that are important to wearables are described below. These are fundamental electronic parts which are pivotal for football monitoring.

Accelerometers

Accelerometers are a common sensor found in wearables. Their sensing capabilities range from different types of accelerations (linear and gravity) [Anuva, 2018] [Live Science, 2018]. Having measuring capabilities to allow monitored data to be programmed for different uses, gives it multifunctionality, such as monitoring running and sleep patterns. One can be linked to the fitness industry and the other medical [Hilderman, 2018]. These two examples show that a football smart tracker can benefit from an accelerometer-based wearable due to its capability in producing a diverse range of meaningful data, and link it to performance or injury [Gobinath,2019].

Accelerometers can be defined by their limitations; this is normally their maximum capacity of measuring acceleration, where it turns kinetic movement into digital measurement [Anuva, 2018]. It does this by measuring the accelerative forces. A piezoelectric effect enables this, through microscopic crystal structures. These are stressed due to forces, and display a difference in voltage. [Dimension Engineering, 2018] [TE Connectivity, 2018]. The other method is via a capacitance difference (capacitive for DC) between two microstructures. This is the same for both classes of accelerometers (analogue and digital outputs). More sensing type variations exist in strain gauges, servo, and vibrating elements [Shodhganga, 2018] [Gobinath, 2019]. The amount of potential sport attributes that can be sensed via these methods allows the device to know how the user moves, both in accelerations and orientation. The location of the sensors allows flexibility in position, confirming the accelerometer as a very multi-functional sensor [Salazar, 2010].

Gyroscopes

Gyroscopes are a common sensor found in smart sport wearables (trackers). It is one part of an Inertial measuring unit (IMU), alongside accelerometer and magnetometer [Anuva, 2014] [Grand View Research, 2018]. Gyroscopes measures angular accelerations exclusively and this can help understand the different biomechanical factors regarding ankle movements in football scenarios [Gobinath, 2019] [Gobinath,2021]. Gyroscope measures angular velocity on a "disk". Vibration gyroscope sensors does this via "Coriolis force" (natural forces due to earth's rotation) which acts on a vibrating arm. The "sensing arm" feels the vibration when the forces act on them. This "motion produces a potential difference", which is the reading that gets outputted via an electrical signal [Epson device, 2019]. The output data from the sensing can be used to measure angular velocity. This is useful for football, due to how agility affects the player and how "techniques" are linked to quick feet movement. The data from gyroscope can be beneficial for stats that involve angles and positioning [Sciencing, 2017] [Passaro et al., 2017].

Applications have used both gyroscope and accelerometer to determine rotational acceleration to increase the accuracy of the monitored data. If sensors are given priorities to sense certain sports attributes, the programming of the algorithms won't be as complicated, giving less of a chance for inaccurate readings [Husted, 2017]. The alternative can work too, where combining both data sets of accelerometer and gyroscope can give even more information out of the sensors. However, it's important to understand the characteristics of the output data from gyroscopes alone, to differentiate performance and injury related stats, with or without accelerometer. This allows understanding of sensor efficiency regarding data monitoring.

Magnetometers

Magnetometers are typically combined with accelerometers and gyroscopes to form the inertial measuring unit (IMU). Each of these sensors can possess three axes each, depending on the type. It is very similar to what a compass does, and it helps with coordination [Gobinath, 2019]. Whilst it is normally used with the other two sensors, it complements them by filtering the orientation of the movements [Brunner, 2015]. This can be a factor in football wearables, as some don't have magnetometers, but allocating an attribute to be monitored from them, can help integrate the full IMU into the wearable, aiding the accuracy and potentially outputting more monitored results.

Magnetometers measure magnetic forces in relation to Earth's magnetic field. It does this via the principles of the Hall effect, where, if a current carrying conductor is placed in a magnetic field, then a voltage is generated across the conductor perpendicular to the current and the magnetic field [Anuva, 2018]. The electrodes inside the conductor get disrupted (change in density) by the interception of the magnetic field, which results in the voltage reading. If the forces applied changes, then the voltage reading changes proportionately, giving the value and the direction of the magnetic field. This is then given out as an electrical quantity, which gives the orientation, due to the vector calculations [Gobinath, 2019]. Detecting different movements of the same body part gives an extra scale to consider as part of the IMU [Kamisalic, 2017].

Pressure Sensors / Force Sensitive Resistors

Pressure sensors work from strain gauges. When forces are applied on sensors, it produces a resistance change in the circuit. Mechanical quantities such as force are experienced in multiple ways for sport, and these are converted into an electronic measurement dependent on resistance. This form of measuring strain is done by a Wheatstone Bridge formation, which can detect resistance changes in static or dynamic form [Omega, 2018]. The sensing element can occupy one, two or four of the arms in the Wheatstone bridge formation. This number is dependent on the application of the sensor (how many in compression and tension). The mechanism in sensing allows them to be embedded around equipment to monitor external factors, such as ball contact [Zhou et al., 2016]. It can be used for performance or safety gait monitoring applications because the way force is measured on each part of the foot, can determine the distribution, which can be applied to football, in terms of "loads" [Hedge, 2016]. Data can be given on how a player can improve their physical attribute or if they are exerting too much force on one foot or the other, which can link to injury prediction [Gobinath, 2019].

Pressure sensors can evolve in multiple ways. One form comes from graphene based flexible sensors, which measures how graphene conductive network changes, depending on resistance. Another form is Force sensitive resistor sensors, composed of semi conductive ink that work upon physical detection of pressure or weight working under piezoelectric conditions, where the application allows a force to be applied on the sensing region to send an electric signal [Adafruit, 2021]. Having flexible sensors is important for football WT, as it allows them to be embedded into equipment such as boots, socks, or shin pads [Gobinath, 2019] [Patel el al., 2012] [Lou et al., 2017]. This can help the adaptation process a user would go through when they invest in the equipment itself, which integrates circuits inside. This eliminates the need to invest in a separate wearable, however, it also takes away the freedom for the user to choose their own wearable device and equipment. Maintenance of this sort of equipment will be harder than normal equipment, as electricals could come with hazardous concerns.

Global positioning Systems

GPS is a very common sensor found in multiple smart appliances. It is used for navigation, as it informs users about their location. Data are sent to a satellite where the precise location and time are measured. This works as a transmitter and a receiver, where the information is fed back into the sensor to inform the location [Anuva, 2018]. It is used in wearables to measure key data, such as distance, (football importance). However sometimes due to the game's nature, most distance run just shows how well a player performs physically rather than technically, for example, a player might have run 50m more than another, but made costly errors like misplaced passes and lost possession. This makes the data misleading, if it thinks the player who ran 50m more, was the better performer. GPS is useful for team data, as it eliminates issues that arise with time motion analysis, and coaches can navigate positional team play [Castaneda, 2018]. This is very important for coaches who prioritize multiple things and may not always provide feedback individually [Gobinath, 2019].

2.2.2 Electronic Applications

Wireless Communication

Wireless communication is an essential part of wearables. It is regarded as the wireless sensor network composed of different topologies (e.g., mesh, star, etc.) [Gobinath, 2019] [Jovanov, 2005]. These work with sensor nodes, which have low maintenance, and monitor the environmental conditions to determine how data transfer would occur [Gobinath, 2019] [De Arriba-Pérez et al., 2016]. This component is fundamental for football wearable data communication in relation to ergonomics and product lifecycle. When a player is training or in game, it is important that the data can be stored, and then sent to a medium that instantly shows how well the user has performed. This real time feedback mechanism is what makes WT useful, as the ease of obtaining instant results on performances, are the best way for a user to understand what they did. Data storage can be designed regarding where the communication should transmit and receive. Radio frequency is commonly used for all essential communication methods. Table 2.2.A shows the different wireless technologies for wearables. Actual quantitative specifications vary for different versions of the same wireless tech [Gobinath, 2019].

Wireless technology for wearables	Cost ($)	Power consumption	Range (m)	Bandwidth	Bit Rate (Mbit/s)	Physical size	Wearable Industry
Bluetooth LE	5 – 35	Low	~100	Low	0.12 – 2	Small	Sport
Near Field communication (NFC)	25 – 100	Low (higher with passive tag)	~0.2	Low	0.4	Small	Medical Lifestyle
Bluetooth classic	5 – 35	Moderate	~100	High	1 – 3	Small	Lifestyle
ANT	15 – 40	Low	~30	Low	0.12 – 0.6	Small	Sport
ZigBee	4 – 20	Low	10 – 100	Low	0.25	Small	Industrial
Wi-Fi	50 – 120	Very high	10 – 70	High	2 – 54	Small	Industrial Lifestyle

Table 2.2.A: Different wireless communication methods for wearables [Gobinath, 2019]

Battery

The source of power comes from batteries. Evolving battery technologies, such as sensors being self-powered can be very important if the sensors are embedded into equipment [Gobinath, 2019] [An et al., 2017]. If the wearable device is a modular design, then it is important to know the steps of assembling the parts to make sure the user does not damage anything, to easily replace them [Ovrebekk, 2019]. The importance in the size of wearables is distinguished by what the designer wants. There is a trade-off between operating time and data quality, which hinders the power source as well as the sensors used. This means that the size of the battery will affect the size of the sensor used. The battery consumption usage can be split into three. The first is the idle state, which can range from 0 to 25% of consumption. Sensing state also consumes within a similar range. Communication can use up to 50%, however some wearables may send the data whilst sensing, which would make the total (combined) consumption larger [Gobinath, 2019] [Maxim Integrated, 2018]. For football wearables, the user group can also define, how this works, as the time intervals needed for the wearable to sync with a potential smart phone can determine the battery life per charge. This means that if the data can be transferred in bulk, periodically, the properties of the battery can be different to that which needs constant communication (e.g. lifestyle or industry wearables). Common types of wearable batteries are alkaline, Nickel metal hybrids, and lithium ion (polymer versions as well), with the latter being the more popular option. With flexible thin film, energy harvesting is possible due to its high energy density, which can be perceived as another important benefit of Li-polymer batteries (pouch cell) for consumer wearable devices [Gobinath, 2019] [Kuruganti, 2014].

Table 2.2.B illustrates an example of how two different WT in Fitbit and Viper pods, differ in use. Viper PODS are used just for a certain period, whereas Fitbit is used throughout the day. This means that the power for both these wearables differ due to the electronics needed, and the run time of the device itself. It is important that the designer tests how much power, the device's battery consumes at various states. These two wearable sensors aren't giving the opportunity for the user to be more flexible in their approach. Fitbit monitoring too much can be a hinderance, and Viper Pod only working during certain hours, may limit its capacity to judge certain parameters. When designing WT for the sports industry, it is important to know what the training regime can be for different types of users. This can identify which components are needed. Table 2.2.B shows an example of a "day in the life off…", a term used to detail the system's stages throughout the day. Figure 2.2.1 displays a chart form of Table 2.2.B, in how the battery consumption rates change during the day for both wearables. The projections are based on theoretical consumption rates, without specific values, to show an example of the difference between Fitbit (lifestyle wearable) and Viper Pod (Football sport specific wearable), where they experience different percentage of consumption during their 3 states. This is to show how the function of the wearable defines parameter, i.e., battery used. This is important in this study, as it forecasts a potential football WT lifecycle difference compared to a popular fitness WT.

Time	Wearable	06:00	09:00	12:00	15:00	18:00	21:00	24:00	06:00
Activity	FitBit	Wake up	Eaten, travelled to work	Eating lunch, outside of work	Been at desk for 2 hours (idle)	After Work finished, Workout at Gym	Dinner eaten, resting at home	Already in Sleep	Wake up
	Viper Pod			Analysing previous performance	Charging, setting up for today	Training starts	Training finished, analysis feedback		

Table 2.2.B: Example of comparing different stages of Fitbit and Viper POD throughout a day.

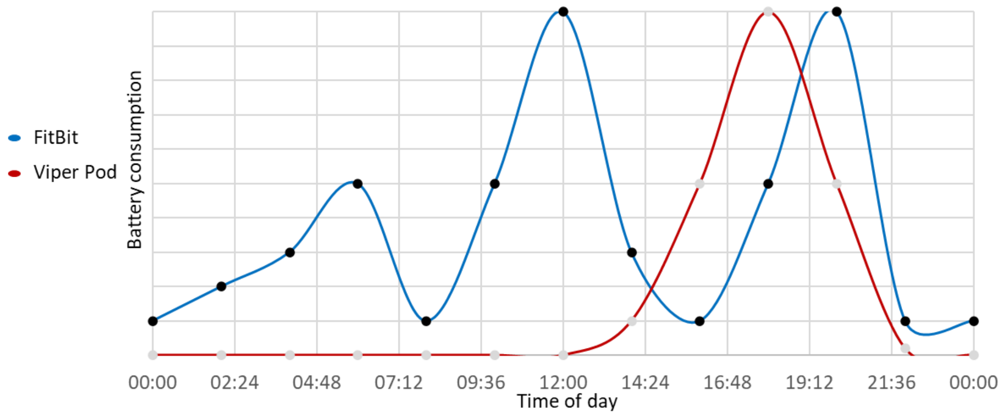


Figure 2.2.1: Example of potential Battery consumption rate changes, during the day for both wearables

There has been research into Battery-less wearables [Kuruganti, 2014]. This is due to weight reduction, as batteries tend to be heavy, and for better energy conservation (sustainable). The form of harvesting energy, such as using potentially lost energy, like piezo electric effect, or Solar, which use photovoltaic cells (converts photons into energy), are potential advances in this sector [Bing et al., 2014]. Kinetic energy (body movement) to charge a wearable can be very desirable and useful, if not obvious due to the nature of WT application. These are still hindered on material advancements and how it can be integrated into WT, due to its size. University of Southampton have used piezoelectric energy harvesting methods placed on the insole of shoes for charging using kinetic movements. The sustainability of the piezo elements is what may be a hinderance, due to ease of damage. The use of solar and kinetic energies can be used for health purposes too, such as sunburn time and more accurate readings from footsteps. With the advancement of wireless charging, this can also be used for design consideration, when the components are embedded into the equipment (easier maintenance).

Having sensors only send and receive data periodically (or in bulk), can help power consumption. This will mean it has to be “stored” somewhere [Godfrey et al., 2018]. WT being integrated with smart phones, have an advantage in that they can use the phone’s storage capability. Data that needs to be kept somewhere safe with continuous readings, like for lifestyle applications, may require to use “every data”, something a consumer may want [Cavaleiro 2017]. With firms using cloud services, to store consumer data, which has live encryption monitoring, storage priority may not be a concern [Ovrebekk, 2016]. However, when ethical issues arise, in data privacy, this may make consumers uncomfortable.

Figure 2.2.2 example shows how the wearable has a chip with potential IMU sensors, track data and is communicated via wireless technology, before getting processed. The option to have it on servers or phone can be dependent on the user, and the feedback is fed into where the designer planned for. This block diagram is designed to show how key components around the WT system processes the data, almost like it’s lifecycle. This is important to outline as it shows the elements that exist within data transformation and how it relays back, for end user can benefit.

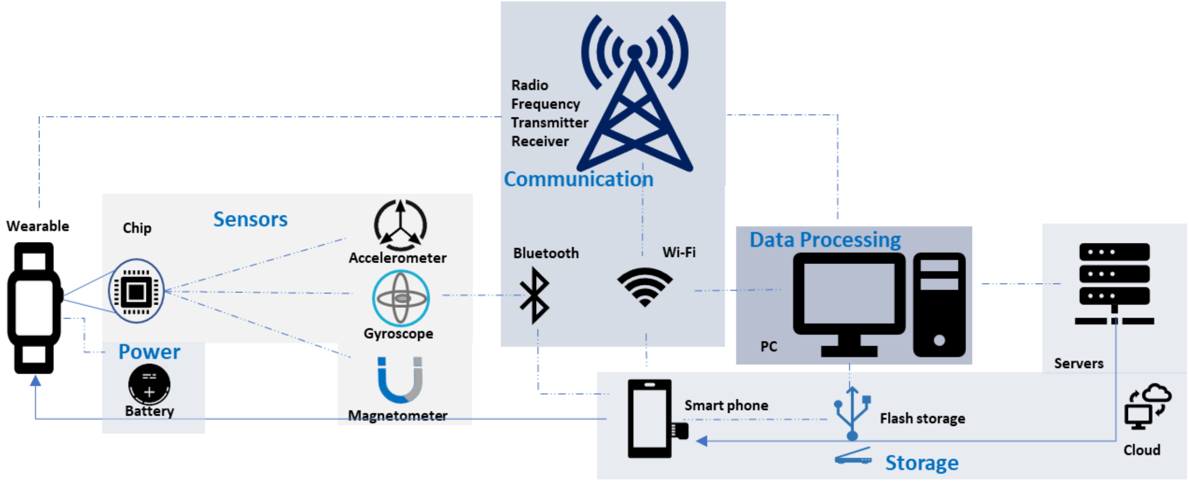


Figure 2.2.2: Block Diagram example of WT Framework [Gobinath, 2018]

Storage in wearables is dependent on its operating system. The nature of feedback mediums such as smart watches, phones, tablets, or PC, depends on its application. With the use of Cloud storage, wearable firms, can send the data from user’s wearable onto their servers, for it to be processed (ethical concern) [Godfrey et al., 2018]. With consumer wearables, most applications give feedback on handhelds, meaning there can be a possibility of having the data stored on the phone itself (internal/micro SD). The time taken to sync the data can vary, meaning there needs to be a "base" where the storage is kept at. This is what can differ between storing on the device itself e.g. flash, or onto servers. WT manufacturers benefit from using a smart phone, as it possesses electronic components that are useful for wearables (Wi-Fi/BLE) [De Arriba-Perez et al., 2016].

To summarise, there are fundamental hardware components involved in WT. These revolve around a microcontroller which processes the input signals from relevant sensors and is programmed to output via wireless communication. A display, either on the wearable itself or through a smart phone, communicates the processed data. Typically, a rechargeable battery is used to power the wearable.

2.3 Human Factors analysis of biomechanics in football shots

2.3.1 Anatomy, Muscles and Bones

Understanding the Biological elements of the leg and ankle is a crucial research segment as further testing, will iterate how the leg/ankle, behaves upon ball contact motion, and where there would be greater scrutiny. This part of research also influences sensor placement, and what readings may alter depending on it. Kicking a football will use muscles to control the joints and bones of the lower body. Muscles are the key "actuators" that transfer the energy of the player and create a force onto the ball to kick. The bones are there to give that rigid frame [Live Strong, 2020] [Sports Rec., 2020]. Key parts include hip, as it allows the flexion of the leg. Feet bones are contact point between ball and player. Figure 2.3.1 shows the bones of the hip, lower leg, and ankle, with the later shown in greater detail on Figure 2.3.2. Figure 2.3.3 shows the front and back view of the lower leg muscles (right leg example). Figure 2.3.4 magnifies into the muscles around the foot and ankle.

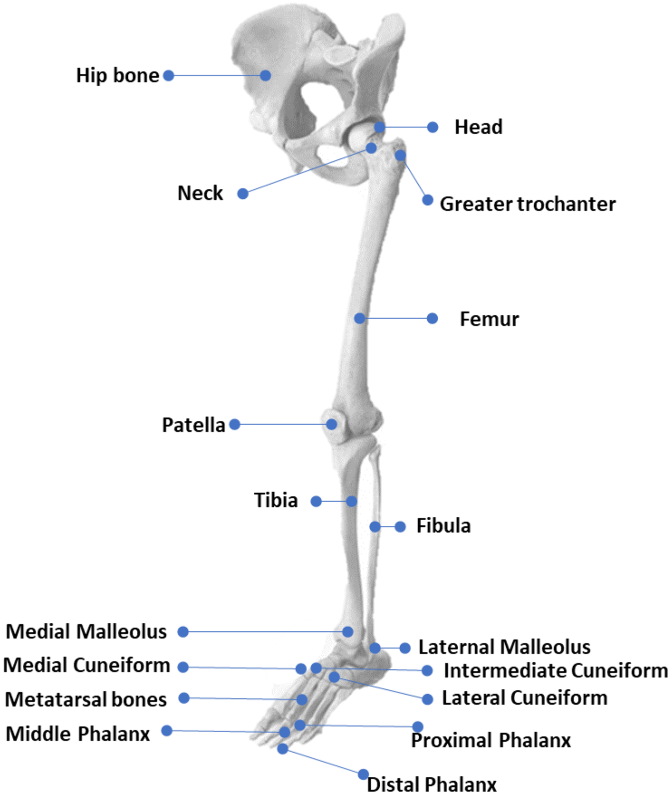


Figure 2.3.1: Bones of the lower leg and ankle; Picture adapted from [Pixel Squid, 2020]

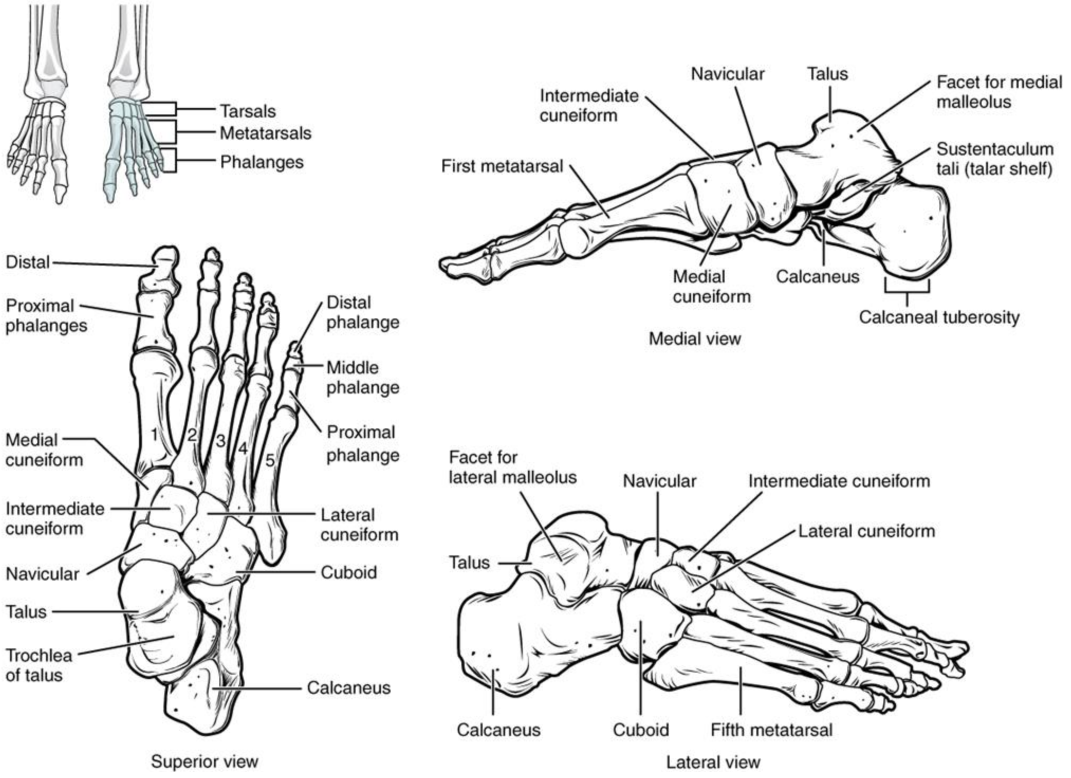


Figure 2.3.2: Ankle bones; Picture courtesy of [Lumen, 2020]

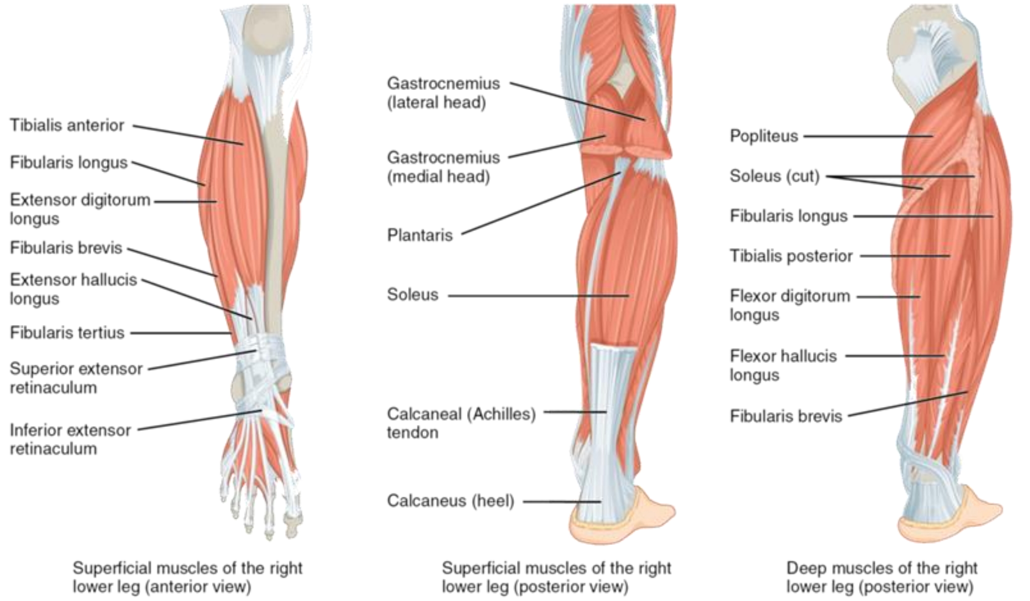
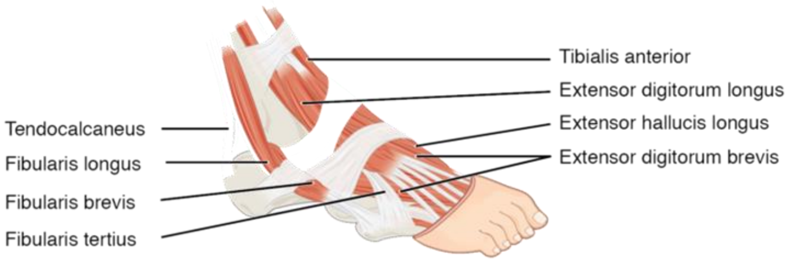
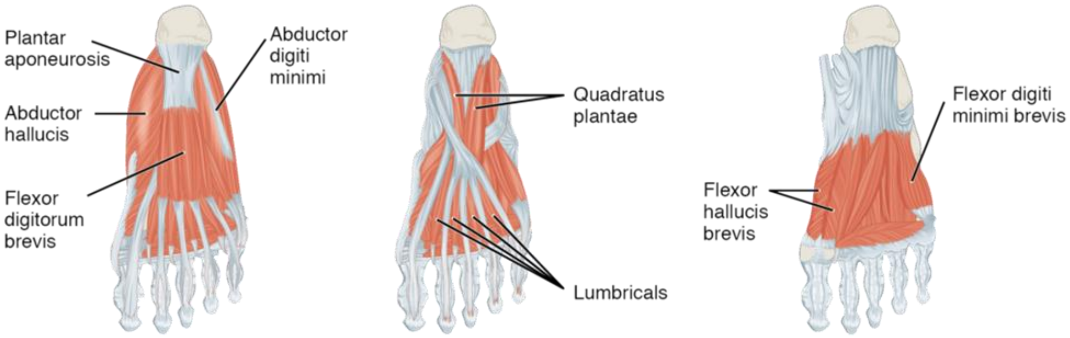


Figure 2.3.3: Leg muscles; Picture courtesy of [Lumen, 2020]



(a) Dorsal superficial muscles of the right foot (lateral view)



(b) Superficial muscles of the left sole (plantar view)

(c) Intermediate muscles of the left sole (plantar view)

(d) Deep muscles of the left sole (plantar view)

Figure 2.3.4: Ankle muscles; Picture courtesy of [Lumen, 2020]

From Figure 2.3.2, the tarsals are shown as the higher region of the foot (navicular, cuboid), which will elevate depending on the plantarflexion of the player, as they strike the ball. The fibularis and Longus muscles on the feet (Figure 2.3.4 (a)), determine how much plantar and dorsi flexion is. This is important because when executing laces shots, the angle of decline (bottom – plantarflexion), needs to be adequate to allow maximum possible chance of contact of the feet bones. Not enough or too much can cause injury to the toes and possibly the ankle depending if the kicking force is too great upon Collison (e.g. against the ground) [Wiewiorski et al., 2016]. This is also controlled by the quadrus plantae (Figure 2.3.4 (c)) muscle which provides the angle of feet (determines laces shot direction of intended ball movement and rotation of the ankle joint).

The metatarsal bones are the key area of contact to the ball. This is where possible sensors could be placed to monitor the force felt, dependant on the acceleration of the leg/ankle whilst in kicking motion. The flexor digitorum brevis muscles are also required to be flexed along with Laternal Malleolus when executing shots, to give that extra rigidity to the foot positioning upon ball striking, reducing the chance of losing shot power [Live Strong, 2020].

The phalanges can affect the trajectory of the ball, but also an injury prone area, when executing poor form [Wiewiorski et al., 2016]. These bones, just between the metatarsal joint and the toe ends, have key responsibility, in keeping a rigid position upon ball contact for laces and inside foot shots. If they are not in a safe position, the angle of this joint, could cause injury (e.g. unintended Toe kick). For chip shots also, players could choose to rotate these bones upon ball contact for elevation. However some players, try to chip the ball whilst maintaining a consistent stance of these bones in order to use the force from the feet to cause a chip motion of the ball (Figure 2.3.12). Inversion and eversion ankle movements both work around the Subtalar joint, but with different muscles. Tibialis with flexor hallucis brevis for inversion and Peroneus with flexor digiti minimi brevis for eversion [Anatomy Zone, 2012] [VCU ,2019].

Regarding biomechanics, during the backswing into the ball contact phase, there is hip flexion. The knee joint, consisting of the connection between Tibia, fibula, femur, and patella, extends as the kick goes from backswing to follow through, contracting the hips. Fundamental muscles that give the strength of the kick, comes from the Quadriceps working in conjunction with hamstrings as it rotates around the leg at knee and hip [Writer, 2022]. Muscles around the calves' help generate lift for the kicking foot, as well as providing balance support for the shot to be executed [Reyes, 2016]. Achilles tendon links the calf muscle to heel bone, contributing to the elastic energy of kicking leg [Cleveland clinic, 2021]. A series of ligaments provides hinge between the lower leg bones and ankle [Ankle anatomy, 2022]. The ankle muscles hold whatever shape the player wants to, i.e. "isometric contraction where the joints are rigid but still being under load from these muscles" [Live Strong, 2020]. These muscles allow the energy from kicking power, to be transferred towards the ball (Kinetic energy + gravitational potential energy which gives the elastic energy of leg during backswing) [Wiewiorski et al., 2016]. Quadriceps muscles allow knee extension, the subsequent motion to further influence the energy transfer from the backswing. The follow through will have the hip flexing, where the top leg bone, i.e., femur, moves upwards towards the player. Hip flexors and quadriceps are both responsible for the power in the shank of the leg [Sports Rec., 2020]. This must be done whilst the "hamstring muscles are relaxed". Hamstrings experiencing too much strain could be very serious injury concern. Applying sensors here could potentially show strains as the player undergoes the kick from backswing, but is again dependant on the speed and form at which they execute the kick. Even then there is still greater influence from the angle of ankle, regarding shooting. There is however, potential to monitor possible injury occurring motions throughout the leg.

The lower body does the "bulk of the work" for kicking due to the respective body parts being used. However, it is important that the related body segments with kinetic links generate and transfer the power efficiently without any risk of injury. This means that there needs to be some "stabilizers" to allow the hips to flex, whilst the calves and quadriceps execute the kick [Live Strong, 2020]. The stability could come in the form of the landing feet, which contracts the key lower body muscles, but more importantly the "core abdominal, back and glute muscles", which provide the structure to kicking. When the player approaches the ball to strike, these big muscles control the "kicking part", but the shoulder muscles (trapezius and deltoids) and the upper trunk above the core, all have stabilized for the hips to flex properly without injury [Sports Rec., 2020]. These big muscles all work together, and sensors being placed there could benefit the player knowing how the bulk of the body works when executing good kicks. This again can be hindered by the ankle position, where the hard work of allowing efficient transfer of energy, having minimal strain of the big muscle groups, could be undone if the ball contact execution is poor. This further justifies why ball contact is a fundamental focus with ankle position dependencies. Table 2.3.A displays which muscles are involved for subsequent ankle movements, and it's influence in the type of shot a player can perform.

Ankle/ feet- movement/ rotation	Muscle involved	Part of leg	Shot influence
Dorsi flexion Inversion Dorsi flexion (Reaching) Extension of toes	Tibialis Anterior	Front	laces
	Extensor Digitorum Longus		
	Extensor Hallucis Longus		
Plantarflexion Flex lower leg	Gastrocnemius	Back	Laces inside
	Plantaris		
	Soleus		
Inverts and plantarflexion the foot, maintains arch of the foot	Tibialis Posterior		
Eversion /Plantarflexion	Fibularis Longus	(Lateral) Side	Inside
Eversion	Fibularis Brevis		

Table 2.3.A: Muscles involved in the shot types

2.3.2 Biomechanics

Kicking is the main skill in football, where the motion of the leg, foot, and ankle, along with hips and the upper body, combine to compose the biomechanics of kicking. Different technical kicking can be dependent on ankle movements. Figure 2.3.5 displays how there are variables that affect biomechanics of kicking. These variables can exist in any form of football kicking (e.g. passing, crossing, shooting). A lot depends on the manner of approach of either the ball or the player [Bousfield, 2015]. It will require different functions of the body, such as reaction time, agility, power, speed, and flexibility. The posture of the body will greatly depend on how the kick is made. Different type of shots will require different motions of the body.

Figure 2.3.5: Biomechanics involved in kicking a football

The backswing generates potential energy to be converted into kinetic energy during kick motion. The kicking leg's knee will have the greatest flexion. The landing/planted leg (non-kicking) would have the greatest loads experienced on the quadriceps. The swing motion utilises the lower body, and the hip rotation allows the extension of the leg to exert the necessary force [Bousfield, 2015] [Elisa Vaselli 2015]. The hands will accommodate the swinging leg, which can help with balance, throughout the kicking phase. "Elastic energy" is stored during the backswing, and then gets released as the kick goes through the ball.

The extension of the hip and knee allows greater forces to be produced before backswing. The landing leg (non-kicking) is crucial to transferring the momentum, as the loads which are applied on those muscles allow the body's balance to stabilize [I. Anderson, D. and Sidaway, 2013] [Elisa Vaselli 2015]. The extension of the knee and the sound of the ball contact is evidence of the energy being transferred. The force and speed of the kick can be determined by the amount of "hip rotational torque, hip flexor strength, calves and quadriceps strength" (physical attributes) [Elisa Vaselli 2015]. If there is good balance of hip rotation and relaxation during kicking phase, then less effort can be required for enough distance of ball travel [I. Anderson, D. and Sidaway, 2013] [Kellis and Katis, 2007].

Ball contact is the point of energy transfer. The position of the foot can vary, and the posture is linked to the power and accuracy of the kick [Bousfield, 2015]. The condition of the ball, such as the air inside can affect the projection. Environmental conditions (wet weather/air resistance) all play a factor [Kellis and Katis, 2007]. Incorrect sudden movements can impact how the feet contacts the ball, which may cause injury. The knee can be fully extended just at this point, depending on how far the ball is to the player. The ankle of the landing feet is "flexed" by force. The kicking force transfers between the player's boot to the ball. Further energy dissipation from the player's force comes via follow through.

The location of the landing foot is important to direct the ball. This is where the projection of the ankle contact can be most influential as it allows such technical contacts to occur. The space the player "creates" for themselves between the landing foot and the ball, can determine how good their posture can be [Kellis and Katis, 2007]. This will give them the best chance to perform their intended kick. At this point the composure of a player's performance attribute can be identified, depending on the rate of change in their reaction time to settle, before kicking. Consistency with precise coordination, improves the form [I. Anderson, D. and Sidaway, 2013]. The centre of mass influences the safety of the landing foot, which can generate good projection of the required reaction force.

Follow through is what happens after the contact of the ball, where the elastic energy that was present from the backswing, gets released [Elisa Vaselli 2015]. The momentum would allow the forces to be exerted [Bousfield, 2015]. The deceleration of the kicking leg must be done efficiently to avoid injuries. The kinetic energy generated must be the same to be efficient, and if there is a sudden change of motion during this, such as kicking the ground first, or encountering another player, forces get experienced on the body, potentially causing injury. Poor form of kicking will also incur problems. The trunk stabilises the hip rotation during follow through.

Figure 2.3.6 explores the different motions and technical terms in ankle movement. These are split into three, due to their motion direction, something which could be important when linking it to 3 axes on potential IMU sensors. The "views" are projected to give the best visualization of describing ankle movement. Dorsi flexion is when the feet move up vertically only, with no horizontal movement. The angle between the lower leg and the feet's toe, decreases. Plantar flexion increases this angle, where the foot moves in downward direction, vertically [VCU ,2019] [Lakna, 2017]. Abduction is when the feet move horizontally outwards, without any vertical movement. Adduction is when it moves inwards [VCU ,2019]. Inversion is when the foot rotates facing inwards, and eversion is when its outwards. They both work around the Subtalar joint, but with different muscles, i.e. "Tibialis for inversion and Peroneus for eversion" [Anatomy Zone, 2012] [VCU ,2019].

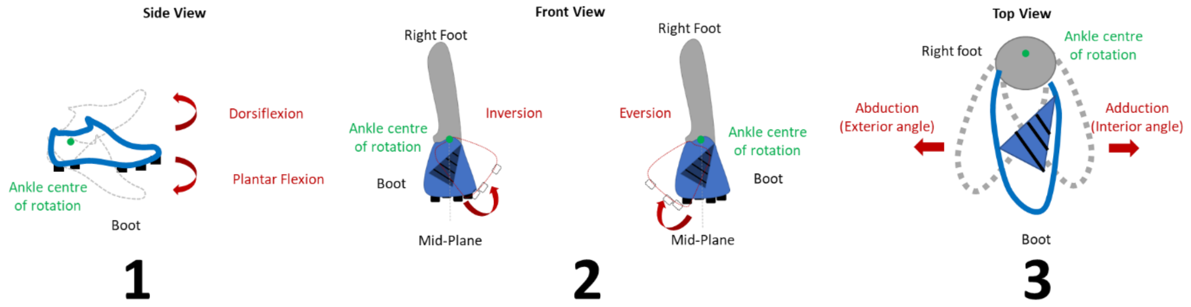


Figure 2.3.6: Different motions of the feet movement

Figure 2.3.7 explores examples how when a player approaches the ball, the different types of kicks they intend to do, for different projections of the ball. This is directly linked to the ankle tilts against the ball. The tilts are the point of contact, directing where the ball wants to be placed. Defining these helps understand how to program potential output of the sensor readings to be more meaningful, educating the player at different stages of their gameplay improvements. Biomechanics of ankle contact against the ball define the technicality attributes of football. As the player approaches towards the ball, their speed is linked to kick power (momentum). Kicking from a diagonal approach gives the body more "chance of pelvic rotation". This means that the player has a greater range of motion to process the kicks with adequate contact of the ball, allowing enough follow through. Three examples on Figure 2.3.7 give different ankle contact scenarios.

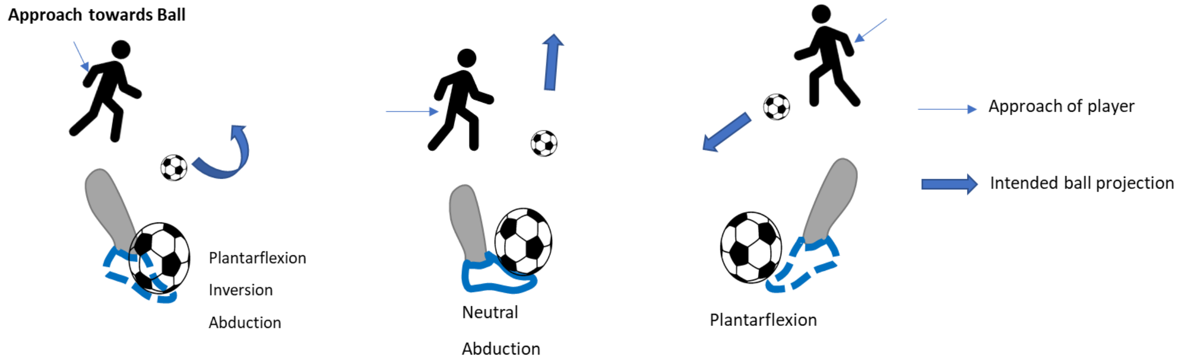


Figure 2.3.7: Technical attributes when a player approaches the football and the different contacts

The technical terms in ankle movements can be directly linked to biomechanics of kicking. Figure 2.3.8 shows the Internal and External Axial Rotations that the leg can experience around the ankle. The "internal rotation occurs during dorsiflexion and external for plantarflexion" [Brockett and Chapman, 2016]. Table 2.3.B completes the resultant motions relating to the 6 degrees of freedom it possess. The full range of motions revolving around the ankle are present on Figure 2.3.9, to display the different axial rotations with respect to their biomechanical movement, providing an overview of key terms that will be analysed when linking to sensor data [VCU ,2019] [Brockett and Chapman, 2016].

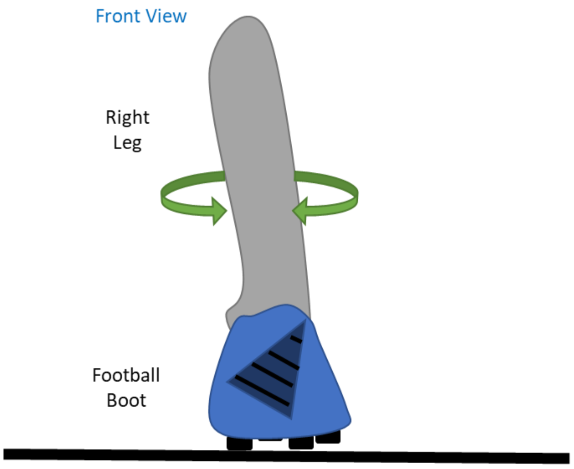


Figure 2.3.8: Internal and External Axial Rotations around the ankle

X	Y	XY	6 DOF Movement	3 Dimensional Resultant Motion
Plantar	Inversion	Adduction	All interior + down motion	**Supination**
Dorsiflexion	Eversion	Abduction	All exterior + up motion	**Pronation**

Table 2.3.B: Resultant ankle movements for Supination and Pronation

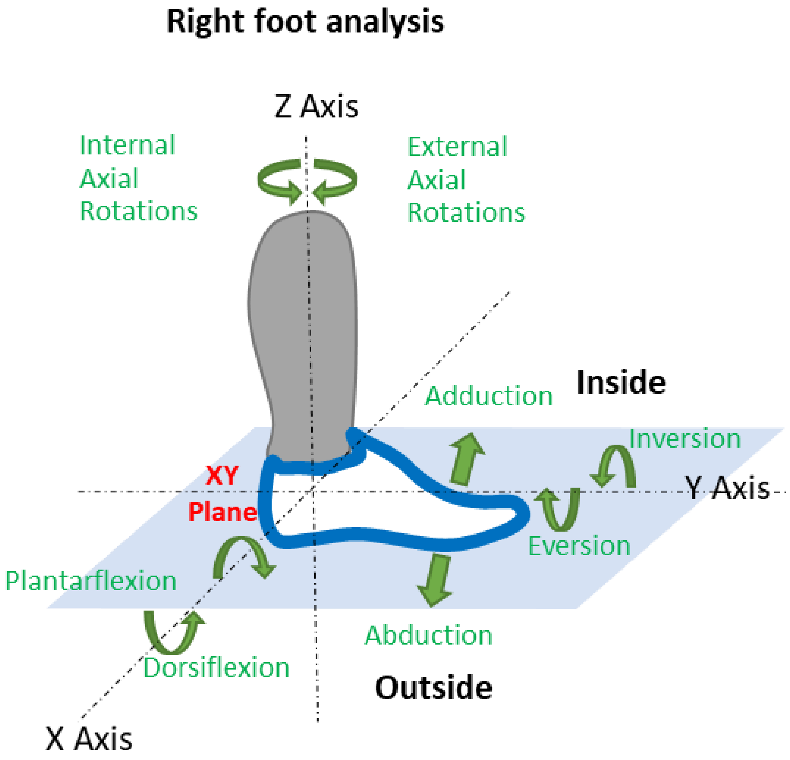


Figure 2.3.9: Full Analysis in range of motion

2.3.3 Football shot types

2.3.3 Football shot types

There are different types of shots in football, which are defined by the region of foot the player strikes the ball. The two that are focussed on this research are **Laces/Instep** and **Inside** as they have the greatest distinguished features, as well as being the most predominantly used. The other kicks can be categorised as highly technical kicks. Type of shots can be monitored due to their sequence of ankle movement. It is important to understand the sequence of movement needed for these shots, to understand whether a sensor can help identify how well the player has struck. The following images describe how different circumstances in shot variations will allow the athlete to use various ankle stances in dorsiflexion, plantar flexion, inversion, eversion abduction and adduction.

Inside

A traditional kicking technique using the inside of the foot to contact the ball. Frequently used in short passing methods, where there are small distances between players exchanging the pass with ball being at ground level throughout. This kick prioritises accuracy and the pace of the ball can easily be influenced by the backswing of the player. It is also determined by the landing foot, which is supposed to be perpendicular, to allow efficient biomechanical energy distribution. The contact of the ball is said to be aimed at the "centre line" of the ball, depending on its position. To improve, the kick can be performed at a slow pace, with a stationary target, to refine the technique, before exerting more power. This is to allow accuracies to be honed, before being able to determine how far the ball should go and at what speeds, so the player determines how much they should exert for bigger passes such as crosses to be accurate. This helps them understand if they can allow more power for shots, transferring the skills obtained honing a kicking technique to another kicking type. The ankle biomechanics are only eversion to inversion if the player intends to kick the ball along the ground. If they want projection, there could be a slight plantarflexion to get underneath the ball, to allow the ball to go higher. There will always be slight abduction and adduction due to the nature of angle of ankle movement. An illustration of the inside foot shot motion is shown on Figure 2.3.10.

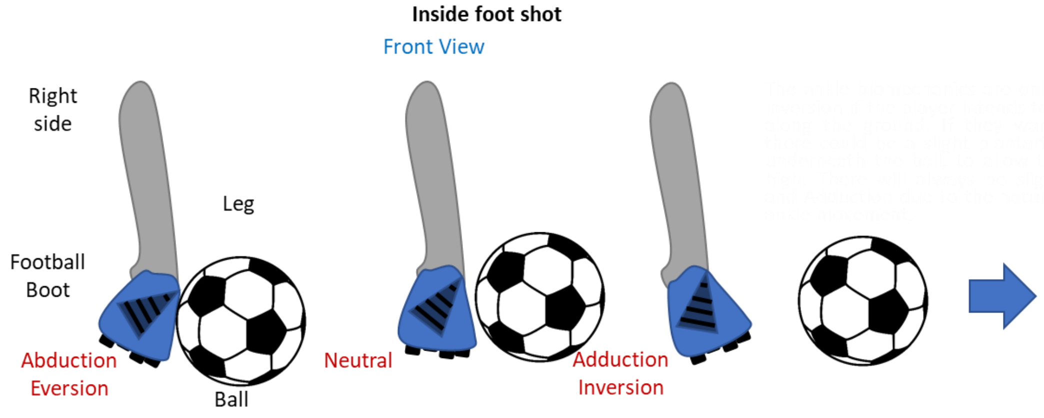


Figure 2.3.10: Inside foot shot kick

Laces / Instep Kick

Another predominant form of kicking where, the contact of the ball consists mainly of boot's laces (metatarsals of foot region). This means that the player must allow their foot to get underneath the ball to project it to where they want to. The approach that the player takes can vary, as they could be coming in straight to the ball or from different angles, depending on which their preferred foot is, and where they want the ball to go. This contact can also happen if the ball is not on the ground, as the laces part of the boot can be angled to contact the ball at an intended point [SportsRec., 2019]. A highly skilled version, considered as the “knuckle ball shot”, is also from the laces kick family. For laces shot, the intended direction of the ball may cause more eversion or inversion. But for executing it, plantarflexion is dominant biomechanical ankle stance upon ball contact.

Plantarflexion is only experienced if the approach of the player is straight towards the ball as their ankle can be directly vertical around the ankle joint, allowing a straight hitting projection. If the player was to come from the side, they experience more ankle rotation. Because this motion gives a degree of freedom to follow through efficiently, there is less chances of dorsiflexion straight away. This allows better energy transfer to the ball, and decreases the stresses on the foot.

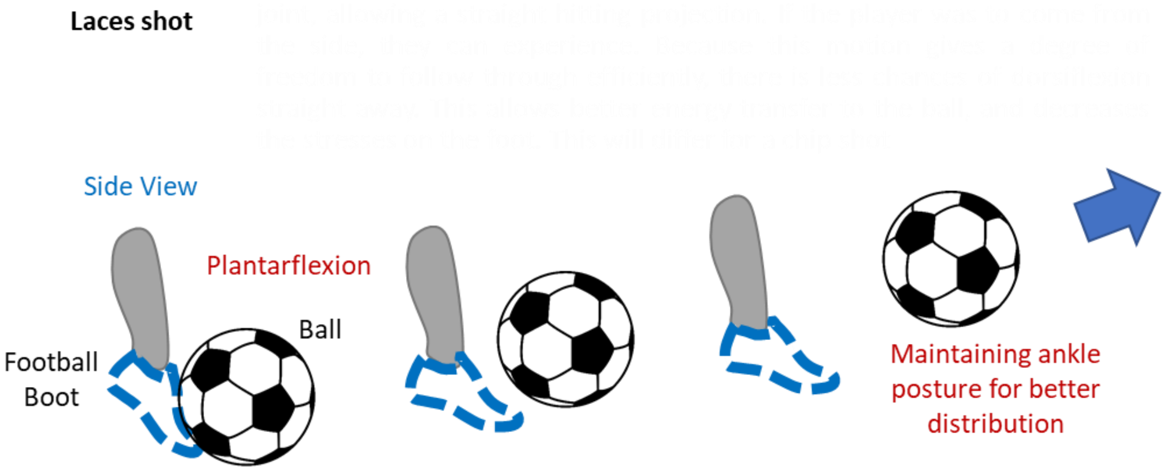


Figure 2.3.11: Laces / In-Step shot

Outside Kick:

The outside of the foot kick technique is used for several reasons. The player may feel their body position at a particular time, that they are better suited to use the outside of the foot to get the ball where they want. It may also be the most natural motion for them, to reduce risks, (e.g. less body movements needed to shoot the ball). Regarded as a form of producing curl on the ball, if the player can produce more using this method, compared to the inside of the foot. Curling shots from the outside of the boot is considered a highly technical attribute, as it is difficult to perfect, with a higher chance of misdirecting the kick (can be used for crosses). Like the laces shot, the best way to perform this kick is to maintain the ankle stance, to allow the best energy distribution throughout the ball. This will also depend on how high the player wants to kick the ball with their outside foot. If its on the ground, then there wouldn’t be much Adduction.

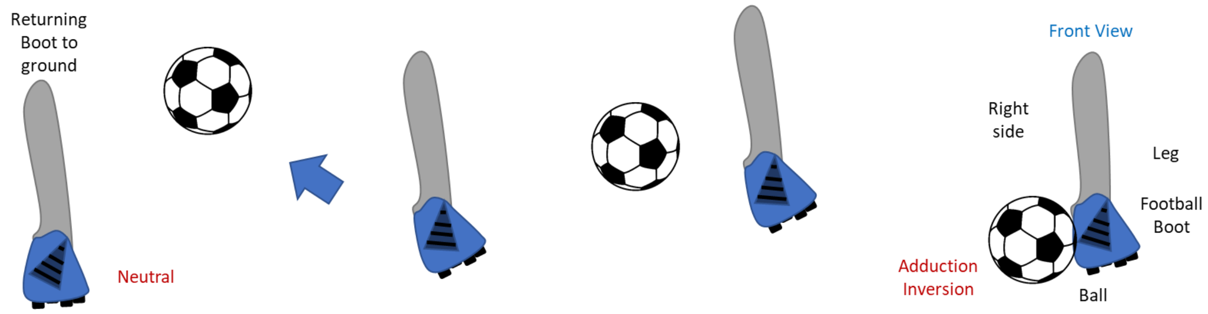


Figure 2.3.12: Outside foot shot

Backheel:

The back of the foot technique is a very skilful kick, one which can happen instinctively in any given situation, or a player just wants to show their "flair", with a nice piece of trickery. This will be very difficult to cross with but passes along the ground can happen.

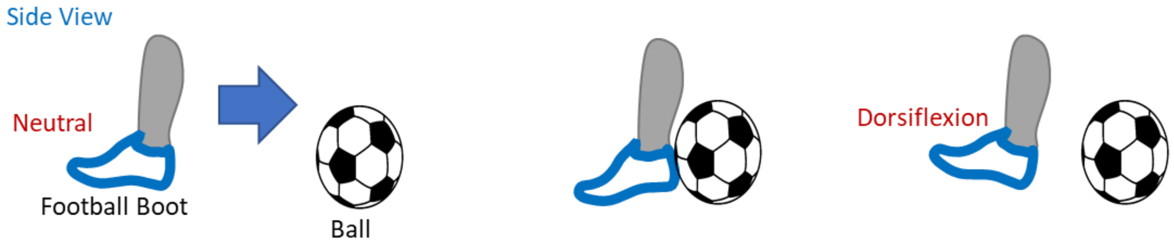


Figure 2.3.13: Backheel shot

Toe Kick:

The toe kick is an early technique used by amateurs for greater accuracy in kicking a football. When done correctly, it can be effective due to how simple the technique is and how good the result can be with minimal effort. If executed in a powerful, yet wrong, way, there is a risk of injury towards the toe and metatarsal bones. It is used during gameplay, if there is no need to exert too much force, as a "toe poke" is a simple kicking technique that uses the front of the boot only to push the ball where the player directs it. It does not have to be a shot, it could be used to pass, or even just dribble to obtain more space. The motion of the leg follows through in a straight direction. For this kick, the ankle doesn't need to move as much, and neutral stance is the common biomechanical ankle movement, however the toe could move to direct the ball to different directions.

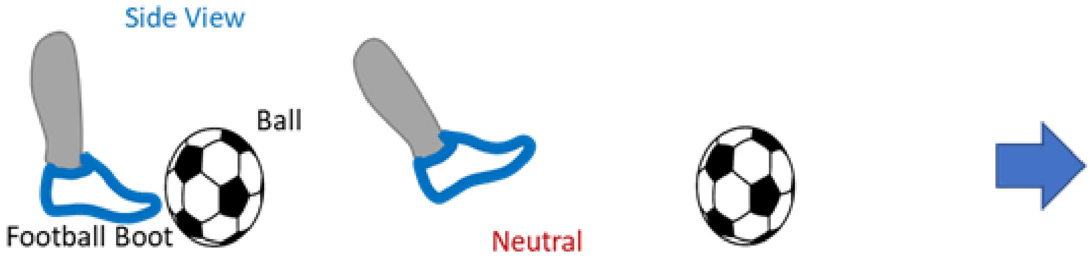


Figure 2.3.14: Toe kick shot

Chip Kick:

This technical kick gives ankle harder manoeuvrability experience. The player must enforce their toe under the ball and lift it up with adequate power to get the required distance and projection (can be a pass or a shot). This is sometimes confused with a "Lob shot", but the key difference is that in a chip shot, the ball is on the ground and greater ankle movement with minimal kicking leg lift. There are two techniques that could execute a chip. These can be analysed separately to distinguish which method may be best suitable. However, it is also very dependent on the player themselves as they will have their own experience and comfort influencing this shot type.

For the first type, the motion of the ankle experiences greatest changes throughout this kicking phase. It is important that the player doesn't exert too much force whilst returning to ground, due to injury risks. The quicker this is done, the higher chance of injury due to sudden change from plantar to dorsi flexion. The other factor is that this kick can be done, both on the inside and outside of the foot. This means that more biomechanical factors will be involved, making it appear as a flick.

A second form of chip shot is when the foot maintains minimal plantarflexion and contacts the ball at the small surface area between the lowest point of the ball and the ground. This force being executed at an angle towards the ground and ball, can cause the ball to elevate upwards. These types of techniques used depend on the player's ability or their interest in preference, depending on successes.

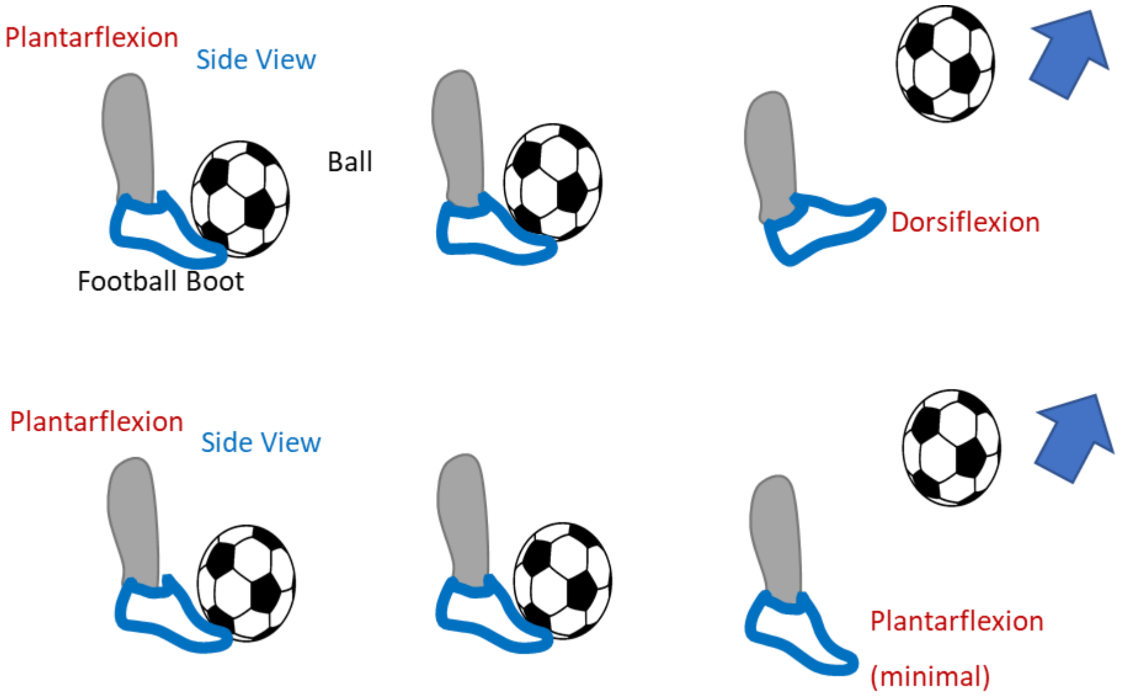


Figure 2.3.12: Chip shot kick with 2 different techniques

Figure 2.3.C shows the different types of technical attributes regarding shot types and how it revolves around ankle movement. The toe kick is a basic kick type, one that is not viewed as an attribute of kicking. With back heel kicking being very technical and difficult, this is something that is not essential for instant improvement analysis but WT can investigate tracking these.

The table is used as guidance for this research to monitor at what level can a single sensor truly characterise the type of shot that was taken, and how well it can be graded so WT can judge the user's kicking ability.

Type of shot	Biomechanical movement sequence
Laces shot	Plantarflexion
Inside foot shot	Abduction, Eversion, Adduction, Inversion
Outside foot shot	Adduction, Inversion
Chip	Plantarflexion, Dorsiflexion
Toe kick	Neutral
Back heel	Dorsiflexion, Neutral

Table 2.3.C: Projected Ankle biomechanics for all shots (Red highlights the 3 shots being studied)

2.3.4 Injury

Wearable technology in sport is multifunctional, where solely tracking performance, isn't it's only capability. Health monitoring systems that are applied in the medical industry, use the same sensors that can be used in sport, allowing WT research to be very compatible [Kamisalic et al., 2018]. The same sensors can give both the player and their physio a greater interaction using this technology, to monitor live time health status. This also educates the player on where they are making it easier to become injury prone. Harbin university's research into how a multifunctional single sensor is used for bioengineering applications such as gait monitoring and gestures, can be useful in sport, by reducing complexity of architecture [Quan et al., 2013].

American football is known to have sensors embedded into their helmets, to monitor the state of head injuries, such as concussion [Awolusi et al., 2018] [Karim, 2014]. Due to the sports nature (frequent head-to-head tackles), there is a need to monitor how the forces are being dissipated and dispersed throughout the helmet [Ryall ,2017]. This measurement can give an idea of "how much energy" is being felt on the inside of the dampening material (inner foam pads mostly made of polyurethane). For a Football boot example, insole modifications can have potential biomechanical effects such as, how much shock absorption it allows, pressure distribution and where the centre of pressure points are [Ferraro, 2015]. This is where smart clothes influence in this sector, can be an argument that the protection or monitoring unit may not be aesthetically pleasing or comfortable, hindering the user from wearing it [New atlas, 2017] [Makhni et al., 2018] [Nagano & Begg 2018]. For an amateur footballer, the boot is a vital investment, so what they prioritise when looking to purchase one, could be influenced by how much technology integration affects overall comfort and function.

Wearable technology in the form of smart clothing has researched and developed improving a Baseball pitcher's biomechanics, through compression shirts to detect "arm movement and technique" [Awolusi et al., 2018]. This method can be used to track diverse pitching styles. Sensors are placed in the lower back and arms, with conductive threads to give power. Producing data of how pitching consistencies are performed and how injuries can be prevented helps condition the techniques [Makhni et al., 2018]. This exhibits another example where integrating sensor technology into the equipment, allow greater refinement in analysing potential injuries (stresses). Zepp play Golf and Baseball editions, allow monitoring of the player's swing (biomechanical features), to improve their stance, not just for optimum attributes related to performance (timing, strength, speed etc), but also to educate how their movements should be done to minimize chance of injury, emphasizing their multifunctional capabilities.

North American Baseball also have a “Health and Injury Tracking System (HITS)” displaying injury surveillance without WT, exclusively with observations [Pollack, 2016]. Trends are easily noticed this way by collating data on “injuries, sessions, body part, position, history, lost time, recovery time, medical clearance and diagnosis”. This generates reports for the team physios and doctors, to consult and support players/coaching staff in training routines. This data can be available for WT to rely upon, giving it more information about the user, increasing its “smart value”. If in some way, a user’s medical history can somewhat be split into the body parts of injury occurrence, then the sensor data could be programmed to “react” differently when stresses on that particular area are occurring (e.g. precautionary analysis).

Injuries in sport are classified in 2 forms, Accidental or Overuse [O'Reilly, 2019]. Accidental injuries are sudden, where players won’t predict it occurring. However, there are some observational judgements that can predict an accident could occur during a game. When a player makes a mistake, they are more prone to “rash” decisions to compensate, meaning they can cause these accidental injuries. Another way could be using trackers that monitor sleep patterns, and if they are irregular then it can be linked to making bad decisions based on mental fatigue [De Arriba-Pérez, 2016]. These are examples of predicting accidents due to human errors by a player [Edger, 2012]. When an injury occurs the treatment process can be compiled with medicine, physiotherapy, and adequate rest, which professionals will have greater guidance due to experts surrounding them at every rehabilitation step. This will give an idea of when to undertake gradual training before returning to fitness and what loads should they experience to slowly increase their exercises intensities by [Govus et al., 2017] [Esmaeili et al., 2018].

Overuse injuries can be a result of “repetitive actions”, with or without “correct form”. It can be dependent on the strains and loads which are applied to certain parts of the body [Williams et al., 2017]. Minor overuse injuries can heal on its own or with minimum treatment. Major overuse injuries will need extensive care. The intensity at which a player performs at can determine how severe it can be. A minor injury also has the possibility to become a major injury if the player has not treated it properly. Overuse injuries can affect the “bones, muscles, joints, tendons or ligaments” [NHS, 2017].

Overuse injuries can be prevented, with correct form of movement whilst training, which enables the body to familiarize these motions [Drew & Purdam 2016]. Warming up, is renowned as a traditional form of exercise before intense training begins [Williams et al., 2017]. This allows the muscles to be “flexible, strong, and healthy”, giving greater blood supply. In terms of cardiovascular strength, low intense cardio allows the heart rate to gradually increase, which sets up the body to be in a good position to react to drastic changes (accelerations). These range of motions can be done with adequate loads on the tendons and ligaments. “Loosening” of the muscles is needed to give user enough “degree of freedom” in their movement, passing the strength to resist potential movements that causes “joint pain or muscle damage” [Health Harvard, 2017].

A study conducted where a warm up programme was tested in multiple ways to reduce injury showed signs where the risks of overuse injuries were reduced, when there is more structure to the warm up [Soligard et al., 2008]. Another study looking into United States high school football injuries stated that injury patterns are dependant on the gender and the type, which lead to “developing evidence based targeted injury prevention”, [Yard et al., 2008]. University of Birmingham and Southampton FC researched how workload relates to injury in youth level football players [Bowen et al., 2016]. The research revolved around acute chronic ratio (acute workload ratio divided by the chronic work load ratio). This calculation is mostly used to decide when the player can return to their last best-known fitness level and predicts the recovery time of the player to avoid risks.

Acute work load is the sum of forces experienced by the player in the most recent week of training. Chronic work load is the average forces experienced by the player during "4 week time period" prior to the present week (rolling averages). This method is used for different sports, with the characteristics being forwarded to different situations. Gradual increases in loads and intensities must be taken with precaution, to reduce the chance of overuse injury [Health Harvard, 2017]. Mechanical loads can be defined by sensors, as "cumulative index of effort based on acceleration" [Taylor et al., 2017]. This format is trying to build a resistance to the loadings at an adaptable pace. If the acute loadings "spike" abnormally, then it's likely to cause injuries. It is important to gather data of a player before they train, to know their different states [Govus et al., 2017].

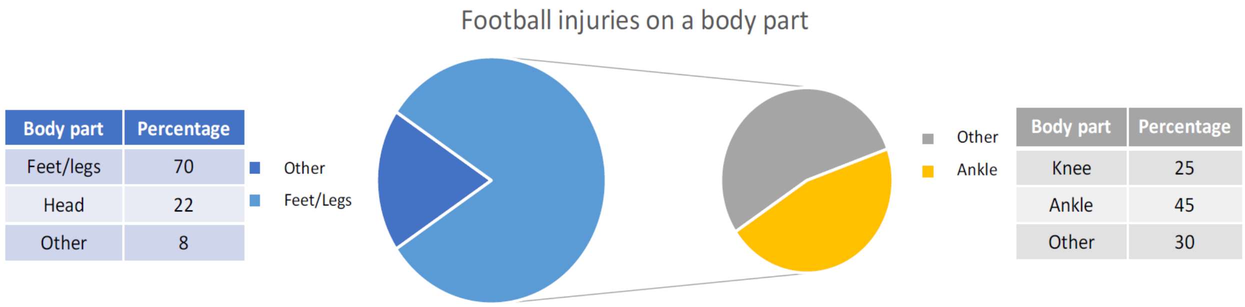
If a wearable device has been preprogramed to measure these loads, then certain conditions need to also be applied. This is where human input is very important. E.g. If a player has not been putting as much effort during the first two weeks, for psychological reasons, then manages to increase their efforts, the tracking device could show that there is a chance of injury because there was very minimal readings considering "rolling averages". This hinders the accuracy of the wearable in feedback, even when the sensors are working perfectly. The player could have been accelerating at a normal rate, during times where the device may have not been worn. The choices that a player makes, can make WT's judgment less reliable. This requires precise and sensitive monitoring throughout the day to fully define chronic load injuries. Essentially the acute to chronic ratio helps player conditioning and prevents injury whilst allowing player to perform efficiently to an extent minimising risks [Health Harvard, 2017].

The acute to chronic workload ratio, is regarded as a better predictor of injury than just either acute or chronic alone. Hulin et al. conducted a study into rugby league players, finding that a higher chronic workload, players are more resistive to injury in moderate ratio conditions [Hulin et al., 2016]. They are more prone to injury when the acute to chronic ratio is very high. These can be causes of those "sudden spikes" in abnormal motions during training. It can be noted that sensors have shown enough characteristics to predict elements that can identify high risk movements [Health Harvard, 2017]. Bath university worked on Rugby Union players and how they have less "thresholds", i.e. "the maximum load that a player can exert before injury", decreases during a season due to "fatigue" [Cross et al., 2016]. Therefore, conditioning during preseason is necessary as players can increase their "threshold limits". Combining multiple key elements will help physios know how a player can recover. The important question designers will face, is how this information can be relayed back to an amateur athlete who solely relies on WT feedback [Taylor et al., 2017].

Most injuries in sport that occur are graded as "soft tissue injury", meaning that it affects body components that are viewed as "soft", e.g. muscles, ligament and tendons [Physio works, 2017] [NHS UK, 2017]. Lower body can be considered as more prone than upper body, for certain injuries, however this is dependant which sports has greater upper body involvement. Ankle injuries are the most common types in sport [Gómez-Espinosa et al., 2018]. The seriousness of ankle injury depends on many factors.

Sprains in sport could be a sudden occurrence of incorrect motion, or another player inflicting a bad tackle. Example of self-inflicted injuries are, continuous excessive loads on one side of the feet, which could slowly over time tear the ligaments of the ankle [NSMI, 2017] [NHS UK, 2017]. This is considered overuse, however a sudden excess load on one side of the feet can easily cause the same injury, however it would be classified as accidental. Scenarios such as a sudden high intense sprint, or a repetitive movement of incorrect form are both examples of short term and long-term occurrences that leads to ankle injuries, hence it will not solely fall onto one classification type. First signs are how the player reacts, as their motions would change depending on their pain threshold they're withstanding [NHS UK, 2017]. It is harder to judge a sprain if there are no visibly physical symptoms, as the player may not feel anything, thus not knowing the severity yet. Precise and consistent physiotherapy will improve the conditions around the injured bone or muscle. The possible monitoring of the loads during this phase, educates the user on injured motion through WT [Gómez-Espinosa et al., 2018] [Physio works, 2017].

Due to the sport's nature, lower body injuries are more prominent in football. However, there are head, shoulder, arm and neck injuries, with the sport becoming more physical, as the game evolves. Figure 2.3.13 shows the composition of injuries involved in football. Sprained ankles are the most frequent feet injury, in football [Web MD, 2019] [Gómez-Espinosa et al., 2018]. The definition in the exact occurrence of an ankle sprain can be when the "ligaments are overstretched". The seriousness of sprains depends on many factors. Twisted ankles are considered a common type, with low severity. When there is a rupture of the ankle ligament, this is a higher-grade injury, and broken bones are even more severe [Web MD, 2019]. There are different grades that are used to identify the extent of ankle injuries [Chu et al., 2010]. Table 2.3.D shows the grades of ankle sprain injury with symptoms.



Body part	Percentage
Feet/legs	70
Head	22
Other	8

Body part	Percentage
Knee	25
Ankle	45
Other	30

Figure 2.3.13: Body parts of football injuries, Image courtesy of [Gobinath, 2017] data courtesy of [Physio Works,2017]

Grade of sprain injury	Description	Possible Symptoms
1	Overstretched ligament (NO Tear)	Pain, Slight inflammation
2	Fractional Tear in Ligament	Bruising, Swelling
3	Full Tear of Ankle Ligament	Swelling, Feet numbness, Stiffness

Table 2.3.D: Grades of sprain injury and potential symptoms

Acute to chronic workload ratio can be used in football, with the characteristics being forwarded to sort with positional players. The process is the same for professional level, hence consistency in this method allows WT to be easily transferable, should more sensors need to rely on it. Consistency is key to how gradual work load increases safely. This method of defining injury, via quantifying workloads, means that if a player is accelerating at a higher level continuously for over 2 weeks, it is regarded as having a greater chance of injury. This "higher level" can only be determined by how the wearable defines the user's "average acceleration". This reading must be crucial, if the wearable can measure the user's change in "average levels". This could then distinguish if the player is slowly improving their work load but without risking themselves to injury. Presently, it is considered that if the ratio is large [greater than 1], it means that the acute workload is greater in the current training week [Health

Harvard, 2017]. If a player experiences an overuse injury, would there be an option to implement this data in WT, to allow it to become smarter.

There are numerous factors to determine how frequent overuse injuries occur for a player [Williams et al., 2017]. Sensors can monitor total distance covered but observations can show external factors when WT is not worn. The longer the player runs, the sorer their muscles will be, due to endurance, the higher chances of injury based on observation. This would link to how injury prone the observed player could be. Multiple factors must be combined to determine over use injury, such as length of high intense loads and momentum (linked to the mass and speed of the player). These can be used to forecast a player running at high intense speeds as the more frequent loads per step they experience, gives a better understanding of where the injuries could occur. This shouldn't be mistaken for gradual improvements, hence sensor calibration and load values need to be defined depending on individual. GPS trackers on WT are known to monitor "load values" with "average peak impact of each step on both feet". This shows where the user may be more injury prone (left or right side) [Health Harvard, 2017] [Stats Sports, 2017]. It helps user maintain correct form and improve efficiency, therefore, the programming of WT (microcontroller data processing), is vital.

Table 2.3.E signifies how important IMU sensors can be. They are heavily used in sports wearables for performance, but this table shows how some data can potentially show signs of injury monitoring via the same sensors. This is where data processing is a complex feature, as it needs to be able to derive these parameters and distinguish the difference between what measurement is performance, and what is injury. Even when analysing kicking, there is a need to understand thorough biomechanical features to determine how to increase performance or reduce injury. This is where the advancement of both accelerometers and gyroscopes together are useful [Mischke et al., 2017]. E.g. Using gyroscopes to determine the angular rotation of the hip, accelerometer to determine kick speed can immediately show if either are too excessive. The data from these sensors can calculate and program values to be used in acute: chronic ratio, based on monitoring "rolling averages", subsequently leading to potential injury predictions for the future. Figure 2.3.14 shows how inversion and eversion motions can be technical yet injury prone. This is where the uses of multiple sensors working together can be beneficial, as more data being processed can distinguish the small differences, which can result in technical or injury movement.

Biomechanical factors leading to Injury (potential incorrect manoeuvres included)	Football positions	Motion and possible injury example	Sensors
Falls	ALL	Dangerous drop of body weight or collision	IMU
Excessive loads on leg (feet, knees)	ALL	Dangerous running methods Excessive jumping (vertical) Incorrect agile sprints Unbalanced loads on one feet Dangerous skating elevations	IMU, pressure
Excessive load on arm (forearm, biceps, hands)	Goalkeeper, ALL	Consecutive bad throw ins Incorrect passing balance can lead to loads on joints	IMU, pressure
Stress	ALL	Irregular heart/respiratory rate, blood pressure	Heart rate monitor, IR
Arm speed	Goalkeeper	Incorrect rapid dangerous incident angle swings Sudden irregular reactions	Gyroscope, Accelerometer
Kick speed	ALL	Improper technique can lead to cramps	Gyroscope, Accelerometer
Angular Collision	ALL	Due to tackling nature can harm any part of the body including head	Gyroscope, Accelerometer
Excessive rotation arm	Goalkeeper	rapid motion (passing with hand) Too fast in combinations of saves can exert force incorrectly	Gyroscope, Accelerometer
Excessive rotation leg	ALL	Incorrect balance whilst pedalling Vigorous kick elevation can cause muscle strains	Gyroscope, Accelerometer

Table 2.3.E: Example of what sensors can monitor Biomechanical injury movements for different positions

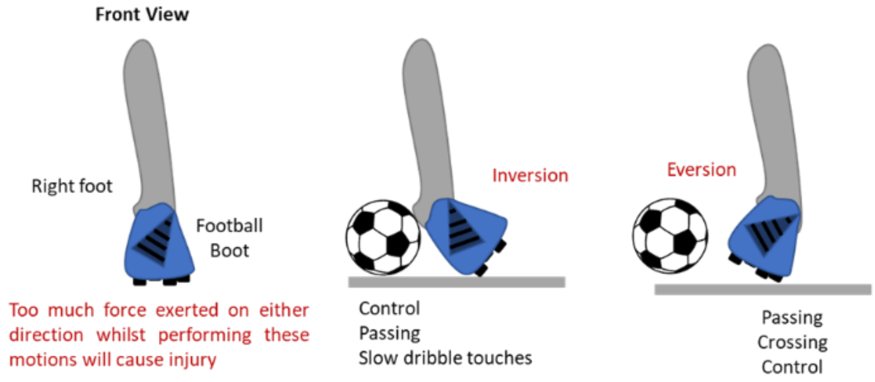


Figure 2.3.14: Inversion and eversion technical motions that may also incur injury

Summary

Conducting a literature review outlines key components involved the technology that creates Wearables. This chapter highlighted major findings relating to relations between existing biomechanics in how the Phalanges and Quadrae Plantae movement define Inside and laces shots. IMU and FSR sensors have great potential to increase the impact of WT in amateur level footballers where their placement is paramount to computing relevant meaningful data. Enough literature supports that there is a great deal of how data could be desired, and there is a need in confirming how ankle motions implemented into WT becomes a fundamental biomechanical analysis involved in football kicking. The block diagram of WT framework helped understand the overall factors that exist, inspiring how to design and communicate further findings that will resolve the gaps in this research.

3. Design Methodology procedure and tools to tackle the aims and objectives of the study to answer research questions

3.1 Project tools outlining the key variables that needs to be addressed to answer the research question.

3.1.1 Design Process

Methodology is needed to give a structure to how Design research can be conducted thoroughly. This constructs the tasks in a format to achieve the aims and objectives, combining the findings to fulfil the research gaps. With a vast selection of methodologies that can align with this project type, key elements require secondary and primary research, with approaches that can be taken to allow deeper learning, it was important to prioritise which was suitable from a researcher perspective.

This procedure is important for the researcher to follow, so they are responsible for choosing one that can encourage disciplined research process. It is very easy to take parts of multiple methodologies, adapt them to expand research development and understanding in line with WT field. As this consists of design and technology, many options were fit for purpose, however it was important to eliminate any complex evaluation of the steps taken to conduct this research.

Studying ankle rotations upon penalty kicks specifically to allow greater refinement of what sensor readings produce requires extensive Technology research. What output data processes are needed to make it meaningful, will also require the methodology to accommodate human factor element for Design research. This is how the intended contribution to knowledge can be achieved, where the best use of sensors can be identified, followed by steps taken to make data more user oriented, regarding how it relays its importance to the players. Refining data extracted for ankle biomechanics just for shooting, can lead to how other human factors involved with football, could follow this Design Research process in quantifying subjective opinions of performance data. Quantifying is the best way to validate progress, but there must be a weighing factor, to accommodate the sport's needs. This is what this study should show, where the technology and design converge to make more useful outputs from existing sensors. This should result in a greater significance of ankle motions upon to become part of the kicking biomechanics family.

The methodology should allow the key tasks to be made, and subsequently follow in a systematic format. Figure 3.1.1 illustrates a rough linear representation of project process that give research some shape. As the research takes place, other exploratory findings that will influence the outcomes of the main research question.

Figure 3.1.2 shows what elements of this research process would entail. Each column heading highlights the functions that the researcher involves in. The red headings are what technology (sensor/data) and design (observing/process) elements are involved in obtaining required results (grey) for user. This is how the project is envisioned to analyse amateur level footballer needs and how the outcomes will lead to objectives.

Figure 3.1.3 displays tasks that needs to be done sequentially. The yellow boxes highlight key research method, with blue boxes representing the research area. The specific components within the selected research area, is shown in the grey boxes. The sum of this research phase should answer the research question and contribute to knowledge via the intended outcome shown in green box. These are important to clarify, in order to know what needs to be done, so a methodology can be chosen which can suit this planned process.

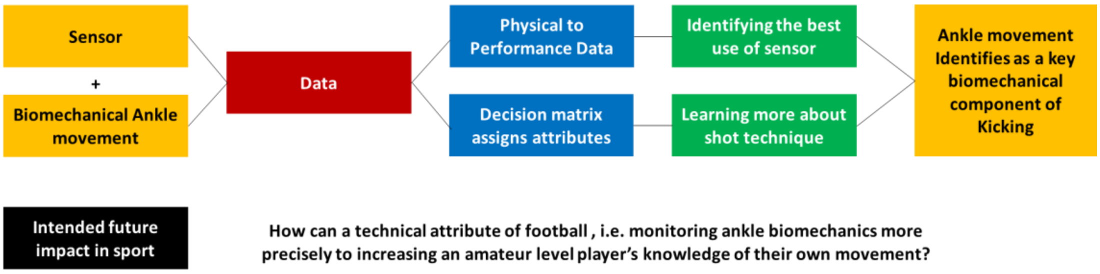


Figure 3.1.1: Intention of Project Process

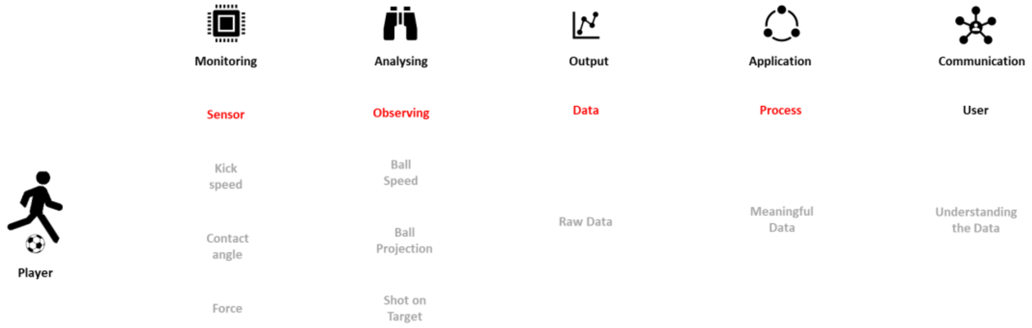


Figure 3.1.2: Functions of technology and design involvement in this research

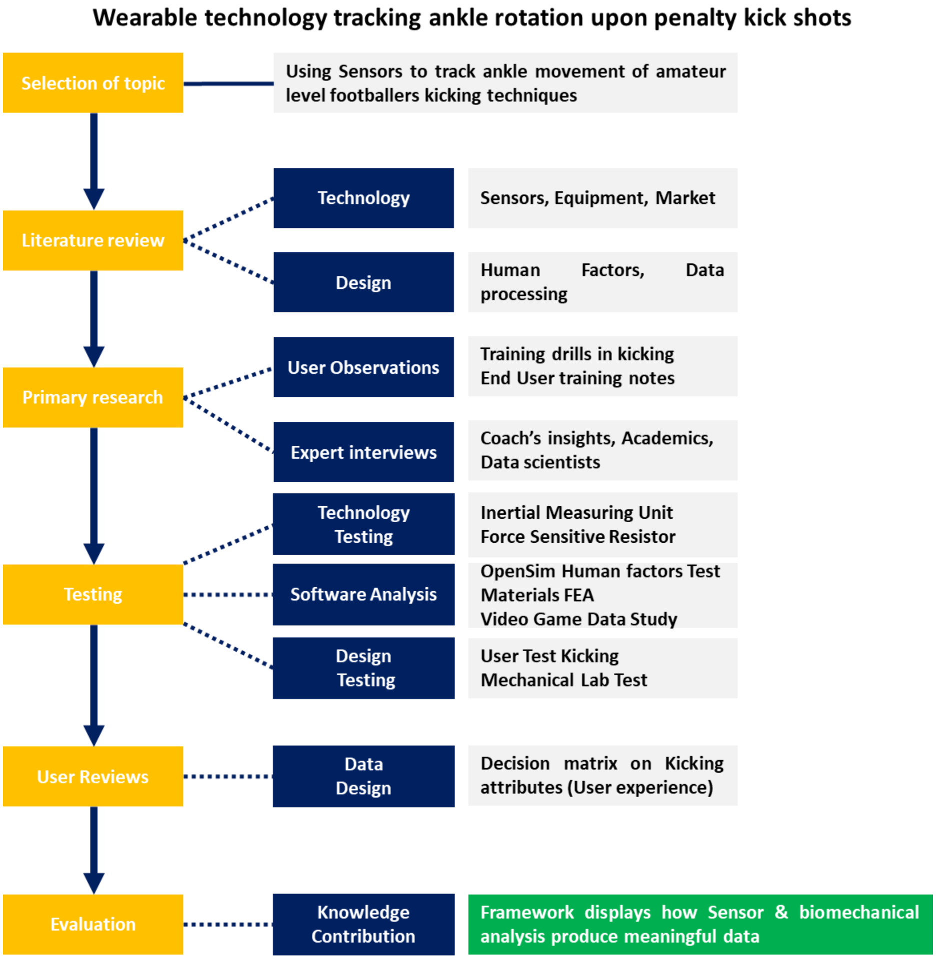


Figure 3.1.3: Process of Design Research

3.1.2 Design Research

The Research process in design is a generalised model outlining the key fundamentals for a project. It is important to follow precise methods whilst the project progresses, where sticking to a core structure can always discipline the researcher to maintain a sense of control in obtaining findings that answer the intended research question [NTU, 2019]. To meet Research objectives the study should not drift too far from its intended origins, as its crucial in justifying valid research.

Understanding different approaches in types of research available, helps how tasks are undertaken throughout this project. Technical elements of this research can be linked to Engineering, but heavy reliance on user input, means Design is equally important. Primary and Secondary research can be split to show where positivist and interpretative appropriateness is made during different phases of study. These 2 research types overlap at different phases of the research where a reliance in data of one can feed into another [Thompson et al., 2019] [Villers et al., 2013]. There could be greater influence from primary research in sense of design, where user focus groups can outline what kicking attributes are important to them. Secondary research maybe perceived to have greater impact with technical elements, but examples like expert interviews (Primary), could advance technical side of the project and User experience can contribute to the ergonomic factor of framework design. This is where both primary and secondary types of research influence both the technology and design elements of this project.

User-centred research identifies the needs of amateur footballers through observations and focus groups. Primary research influence from all stakeholders around WT, dictate how to conduct this study. User centred Design approach practises, identify and elaborate on specifics that leads to a solution of the problem, all articulated by the Usability Testing [CDG, 2019].

When conducting user research, unity can be viewed how the designer works with a range of end users, understanding their styles of kicking and their approach to penalty shots. Empathy is important, as it is required for designers to understand and empathise with the end user's feeling and thoughts, whilst they kick laces and inside foot shots. This is done with practicality and rationality, to reduce biases, whilst solving the user problem. These can be considered key pillars in conducting detailed user research.

Working with IMU and FSR sensors can be considered as A/B testing. This test method allows both sensors to be analysed, to see where they are best fit within wearable technology for amateur footballers. Comparing both aspects of the sensing capabilities and methods of ankle motions per shot, increases evaluation of the biomechanical features between backswing and ball contact. They both aim to analyse different parameters within this study, however because of the nature of their sensing methods, it can be classified under the A/B testing type.

Observations are important for insight building around end user, and the first phase of usability study. This is essential research conducted in their environment (football training / Match pitches). The researcher builds a better understanding of where other key stakeholders, such as coaches have a greater involvement. In this case, there would be greater in-depth conversations about technical kicking, regarding Laces and inside shots. This is also where sentimental values can be formed, giving a greater understanding of various situations that each stakeholder has their "subjective opinion" on.

A survey is where all amateur footballers get asked the same question, to synthesize what their approach to penalty kicks are, and how they prioritise certain shooting attributes. This is a powerful tool to monitor which kicking attributes will provide most effective decision matrix ranking. Gathering results and insights from this will be done with close ended questions to provide quantitative data. The type of language used, also must be mindful because “confirmation bias” can exist. It is important to educate end users, hence they were purposely chosen to compare on survey answers between chosen football kicking attributes. This can be linked to A/B test type as it delves into what they think between them. The end of the survey did provide an open ranking system, so that they aren’t forced to answer within a constrained confirmation bias. This allowed the survey to have greater control in understanding how end users approach a penalty and their priorities regarding biomechanics. This prompted further discussion post survey, to gather further insights about WT framework.

Intercepts research method allows on-site feedback, and this is useful when interacting with Amateur footballers after they complete a survey to allow greater engagement relating to kick analysis. This research method allows great levels of feedback, discussing with the End User, and analysing their ankle motions for the laces and inside kicks, validate how well sensors and camera recording build greater data around them. It is important, that the researcher spent time with specific end user to discuss post survey, to make sure there are no independent thinking biases. Discussing with multiple end users at the same time, can cause a group’s influence on user issues. This can make any user feedback analysis altered based on what the majority thinks. This also allows less implicit and social desirability bias to be based, when collecting data and conducting post analysis discussions. The same biases can be prevented when conducting 1 to 1 expert interviews.

Projecting the stakeholder scenarios give an idea of who the “extremes” in that sector are. Designing for Extremes is a protocol used by product designers, to develop designs to be unique. This can be a study that is conducted as a part of Design research, if it allows the research questions to provide viable solution to the gaps. Gathering of all these factors allow the synthesis of stakeholder insights. The structure of interviews varies from person to person and being open ended reduces confirmation bias. There are many forms of conversations that can take place during focus group and expert interviews. The study revolves around principles of developing something design dependant, with maintaining ambitions to fill gaps of knowledge that is Technology dependant [Edvocate, 2019]. How the researcher teaches themselves throughout the project shows development. Praxeology is the theory of human action, which is a big segment in this study, due to reliance of biomechanical studies and specifying user needs.

3.2 Design research procedures to tackle the aims and objectives of research

3.2.1 Double Diamond

Aim of methodology

The aim of the methodology is to show a structure and process for this project to be done strategically, so that other researchers can follow it. Figure 3.2.1 shows what the research aims to do. These are the core sectors of this project with the reasoning behind each listed. For specific design elements that are required within this study, the methods are used to give guidance to how technology experiments affect study progression. It is important that the technical elements of this project, is controlled and carried out fairly, to make sure the studies are validated, and results are reliable. Ideally, the research should take place at a consistent pace, to feed the design experiment process stage efficiently (affected by Study limitations). The methodology should allow best possible data collection and smart application throughout different research stages. When dealing with IMU and FSR sensor tests on user and test rig, scientific data can be worked on before the design process commences. This means that the methodology must give the opportunity for this to occur before user experience flowcharts are created. The user influences what priorities are made to increase user experience effectiveness within decision matrix to rank the key kicking attributes, which should enable greater learning around ankle rotations upon ball contact. Reiterative usability test comes in the form of doing a survey with end users and discussing their knowledge on ankle motions upon laces/inside foot shots. This should then allow more clarity on how FSR and IMU sensors placed on ankle generate relevant data and how this sensing can be transferred to other elements of football kicking attributes.

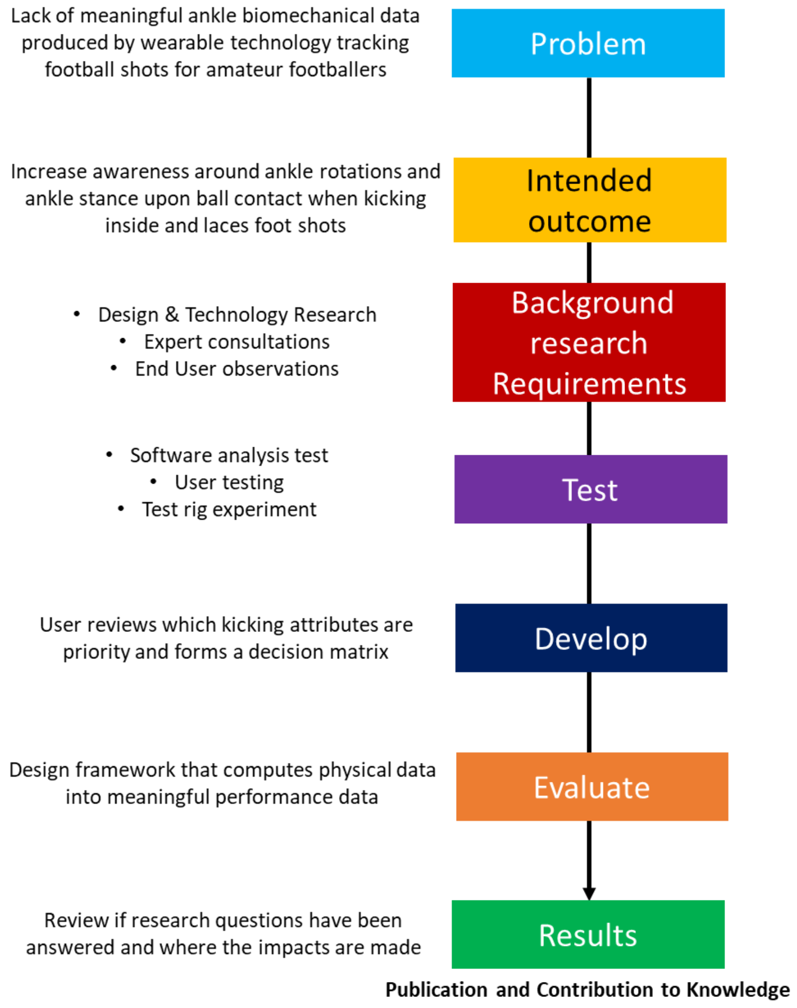


Figure 3.2.1: Core sectors in this project which Methodology aims to dissect

Double Diamond

The Double Diamond methodology is chosen as a key management tool for this research, adapted from the design council [Design council, 2018]. This is because it gives a clear outline of how this project aims to deliver both in technology and design. In terms of the technicality, FSR and IMU sensors and the data that is produced by them are prioritised accordingly. This will allow easier comparisons to be made to identify the best application for them. User experience methods to validate which are the best kicking attributes, and the transformation of physical to performance data, develop design synthesis for this research. This methodology is best for this study to work in both elements. Obtaining influence from the intended user is very important to how this project develops, that is another reason why following the Double Diamond method is important, as their input will guide both the testing (data capture) and creative (data application) phases. These can be viewed as technology and design, respectively. The phases of the Double Diamond methodology, involving the Discover, Define, Develop and Delivery for this research study is shown on Figure 3.2.2. These outline what their purposes are within this thesis, and how it integrates the technology and design elements of the study.

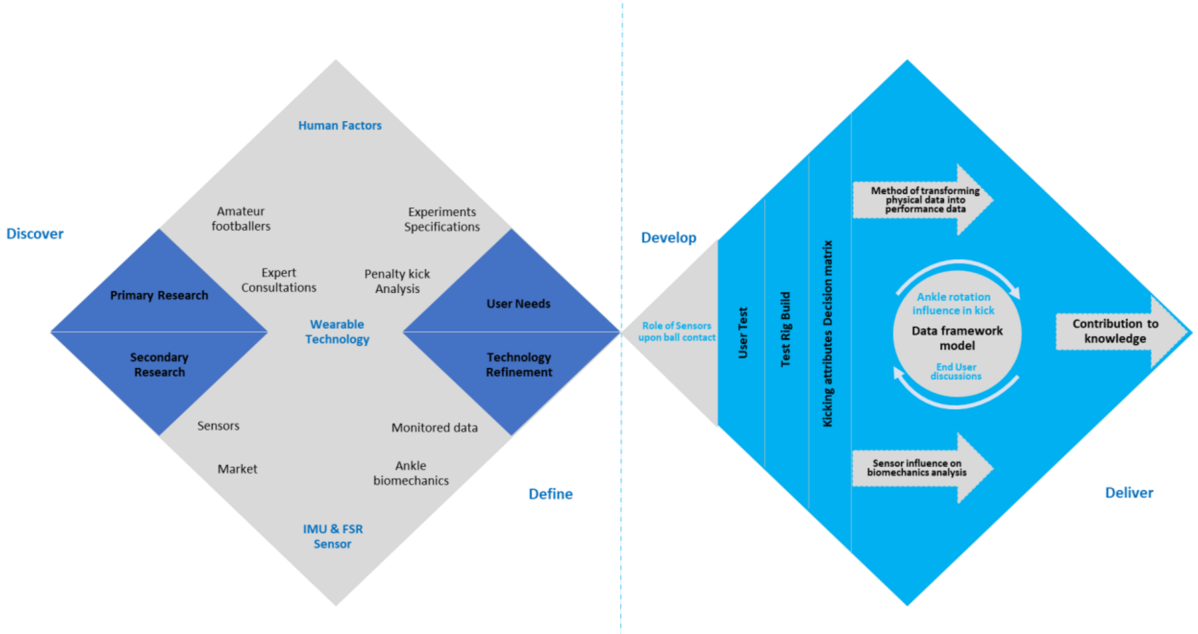


Figure 3.2.2: Double Diamond Methodology for Research project

Double Diamond phases

Commencing the project, the collection of key information should be in line with the schematic of the Double diamond (Discover), this consists of collaborating with end users and coaches, to generate the working parameters. This is to build up to a working system involving IMU and FSR sensors that can test ankle motions and ball contact biomechanics involved in football shooting (Define). The technology used becomes more resourceful and relevant to the aim of this research, so it follows the converging for the next stage in the design research process. The execution of this project comes in making the best use out of the sensors, where after usability testing is required to form a decision matrix ranking key attributes, which helps understand what to do with data processing. This follows the Double Diamonds schematic in diverging (Develop), before it explores the end user's experience priorities for their kicking data, leading it to be more meaningful. The study is refined as converging part of the Double diamond schematic (Deliver) concludes how vital this research is in relation to ankle rotations becoming a key biometric in football kicking, and how the method of obtaining this data is transferred to other football attributes through WT (converting physical to performance data).

Define and Discover phase:

1. **Design & Technology** literature conducted
2. Expert interviews; **Coaches, Data scientists, Sport scientists**
3. End User observations; **Amateur level footballers**
4. Theoretical development of **Penalty kick analysis**
5. Software analysis for **Ankle motion** and **boot materials** within Football shooting

Develop and Deliver Phase:

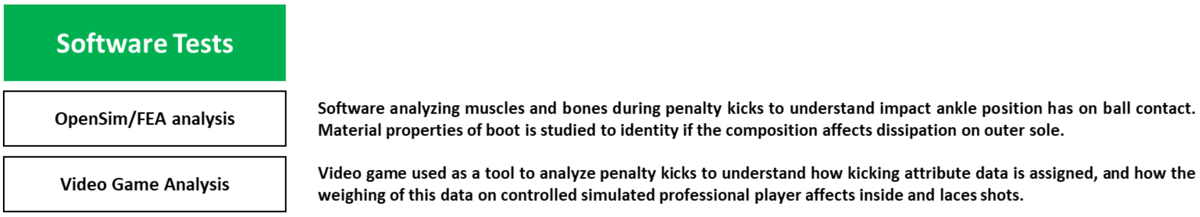
1. **IMU** User test on **Biomechanics** of Kicking a football accurately
2. **FSR sensor** test on **Test rig**

3. **Survey and control study** reviewed with End Users to formulate Decision Matrix
4. **Framework creation** displaying how sensor data transforms into **meaningful data**
5. Identify where **future implementations** can be made for other Football Kicking elements

3.2.2 Development plan

Software analysis, Experiments and Focus groups

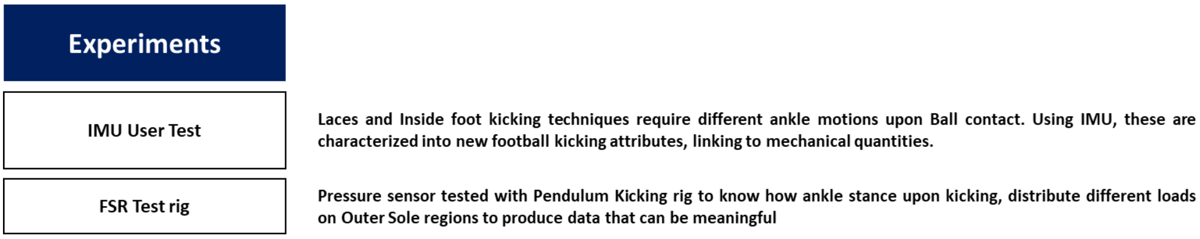
Software analysis is used as part of developing the external factors that surround this research. This involves key mechanical formulas that affect the study, human factor analysis of bones and muscles, boot material FEA study and video game application of professional footballer data, all within penalty kick environment. All this is done before figuring out how weighing of attributes is affected by User. Figure 3.2.3 shows the software tests involved and what their function is relative to research task.



Software Tests	
OpenSim/FEA analysis	Software analyzing muscles and bones during penalty kicks to understand impact ankle position has on ball contact. Material properties of boot is studied to identity if the composition affects dissipation on outer sole.
Video Game Analysis	Video game used as a tool to analyze penalty kicks to understand how kicking attribute data is assigned, and how the weighing of this data on controlled simulated professional player affects inside and laces shots.

Figure 3.2.3: Software Tests to refine Penalty kicking factors

Experiments are planned to understand how the sensors work, and what needs there are for it to be tracked. The 2 experiments and their role are shown in Figure 3.2.4. A User test studies IMU tracking of ankle motions upon Laces and Inside foot kicks. This is followed by the FSR test rig to simulate the kicking motion, enhancing sensor readings to understand their output data, with greater control of the kicking velocity. Both these tests help compute how to produce meaningful ankle biomechanics data within the Ball contact phase of shooting.



Experiments	
IMU User Test	Laces and Inside foot kicking techniques require different ankle motions upon Ball contact. Using IMU, these are characterized into new football kicking attributes, linking to mechanical quantities.
FSR Test rig	Pressure sensor tested with Pendulum Kicking rig to know how ankle stance upon kicking, distribute different loads on Outer Sole regions to produce data that can be meaningful

Figure 3.2.4: Technology experiments refining what sensors produce

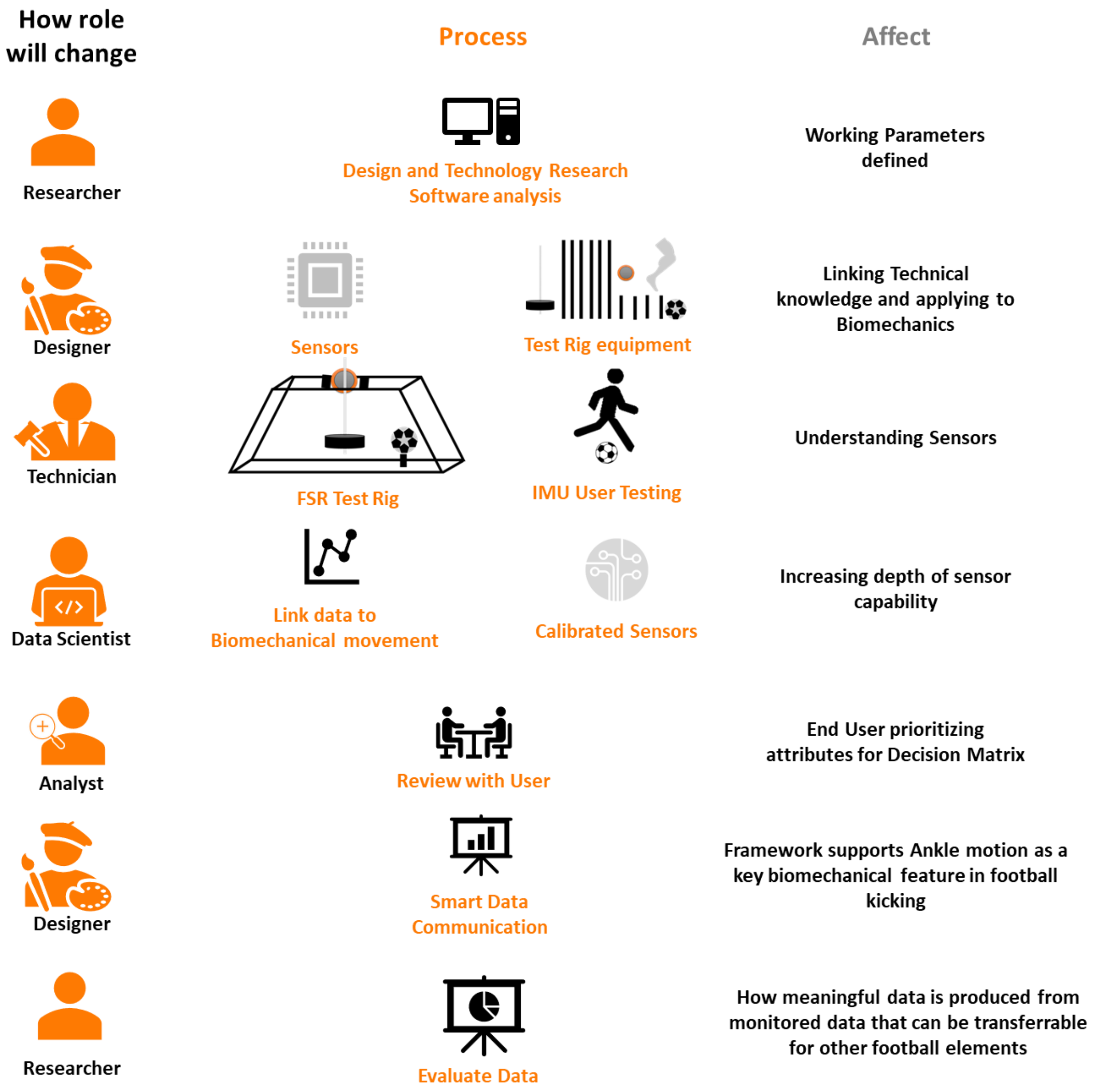
With end user input, a survey is followed to understand how their thought process varies in relation to key attributes. This data feeds into the end user focus groups to form attributes decision matrix. This progressed from the previous methods and calculations taken to make best use out of the sensors. This is where the data that was monitored is analysed and processed to make it meaningful. Combining all factors validates how WT can produce meaningful ankle motion data relating to improving kicking techniques of a football, at amateur level, to be applied in other scenarios. The key end user focus group research components and task is shown on Figure 3.2.5.

End User Focus group	
Decision Matrix	Survey and Discussion to understand how amateur players approach penalty kicks and what kicking attributes are ranked highly forming a Decision Matrix
Framework Design	Communicating how monitored ankle biomechanical data transforms into meaningful performance data
Evaluation	Method of capturing and processing data being applied to different football Biomechanics and Set pieces

Figure 3.2.5: User discussion finalising the process of producing meaningful shooting attributes Data

Roles

As project progresses, the specific role of the Researcher will change. This is to accommodate for the needs of how the tasks are set out. Figure 3.2.8 shows how the roles adapt for necessary task.



How role will change	Process	Affect
Researcher	Design and Technology Research Software analysis	Working Parameters defined
Designer	Sensors Test Rig equipment	Linking Technical knowledge and applying to Biomechanics
Technician	FSR Test Rig IMU User Testing	Understanding Sensors
Data Scientist	Link data to Biomechanical movement Calibrated Sensors	Increasing depth of sensor capability
Analyst	Review with User	End User prioritizing attributes for Decision Matrix
Designer	Smart Data Communication	Framework supports Ankle motion as a key biomechanical feature in football kicking
Researcher	Evaluate Data	How meaningful data is produced from monitored data that can be transferrable for other football elements

Figure 3.2.8: Role of Researcher as Project progresses

Summary

The Double Diamond framework gives guidance on how the tasks are conducted in a disciplined manner. This framework aligns with Design Thinking methodology, where its important to understand and make observations on end users. Defining the problem within the wearable technology sector for amateur footballers and ideating how sensors placed on the ankle region can be an opportunity for prototyping performance data through monitoring physical data [Design Methodologies, 2012]. From initial research to developing via software and testing of the sensors, then user input of ranking key attributes shows the key driving themes for this project. The phases involved in the Double Diamond identifies how the gaps in research and objectives are tackled. This gives more focus encouraging the depth of the study to deepen. Key research practices occur throughout the process, where reiterative user consultations shape framework design. Overall, the chosen methodology tackles this project with technical and design importance, fulfilling its purpose.

4. Primary Research

4.1 Consultations from experts on key topics surrounding wearable technology within sport monitoring

4.1.1 Expert interviews

Expert interviews are conducted to give primary research validity on the collected data being relevant and enabling more reliability on key research topics. These discussions were conducted 1-to-1, basis, lasting approximately 1 hour. It is important to be considerate and understand that when conducting expert interviews, slight biases can form. This is due to every expert having their own experience towards the intended topic of discussion. However, their consultations have been valued greatly, where the influence to refine key research areas, are elaborated in relevant context. Each expert is regarded as an important stakeholder within the different elements of this research. This tackles both the technical and design elements of WT space, and each consultation is part of key research process.

DR David Broadbent:

Brunel University Professor in Sport Psychology and Research Methods; Recruitment and Scouting Department Everton FC (3 Years); 1st Team Performance Analyst

Data:

- *So much technology for professional teams, Pro Zone used to analyse all there key data*
- *Pro zone gives access to information such as high distance, total distance ran, high sprints, frequency, and for all players, including opponents*
- *Players need to see and then understand data*
- *Looking at player videos and creating some statistical forms of Data that can be filtered*
- *Data should be analysed and collated into a package*
- *Discuss with coach per player*
- *Analyse strengths/weakness*
- *Technology to track performance exists in most professional leagues, (non-league also)*

Subjective Data Coding:

- *Players are individually coded. The hours of coding that produces data will then form trends*
- *Simple method of a skill being completed as successful/unsuccessful (Skills range from passing, dribbling, decision making)*

- *E.g., Mental toughness: looking at a player who made an error, with the next ten things they did. Some players try to do something more extreme, to compensate, some people hide and some people carry on normally. Players that carry on normally are defined as mentally stronger than those that do extreme.*
- *E.g., Midfielder's long passing: Select if successful/unsuccessful. Data range accumulated, presented to coach, to help improve player's game.*
- *Physical stats are crucial to recommend a recovery time scale*
- *Physical stats are also used to link to overuse injuries*
- *More information about overuse injuries in training than in matches*

Prof. Joseph Giacomn:

Brunel University Professor in Human Factors Design

Human Factors:

- *People don't know what to do with the data*
- *The human body is too complicated, sizing them to the data signals will be complex*
- *WT cannot give precise amount of tissue data*
- *There are different levels of muscle and fat mass per area of a body*
- *Muscles work in various ways, hence the data measurements are all approximations*
- *The loads on feet are a good way to show how incorrect positioning of the feet can help tutor the user work on their form*
- *Energy dissipated through a leg, even with a same G force rating, will not be the same effect for a skinny and muscular person*

Performance Data:

- *Performance is exciting when numbers link, but the progress must be shown in a relative measure*
- *Technology don't work as reliably as they claim*
- *Designers are more of an expert, the user is not*
- *Relating signals to actual human movement will be hard and not fully accurate*
- *There are limits of physics that will inhibit the accurate measurement of performance*
- *The performance of football players comes from a variety parts of the body*
- *Non experts won't know the researched data, unless it allows to be taught*
- *The design of data should target educating the user*
- *Data filtering considerations must be programmed relative to how the sensor works*
- *Need to make meaningful information for the user with the data*

Dr Oliver Gibson:

Senior Lecturer in Exercise Physiology; Amateur football coach

Player psychology:

- *Decision for a player to play comes from themselves*
- *If player really wants to play, they will hide their pain*
- *Tests are run before games to see how fit the players are (100m dash speed)*
- *Players that stand out are ones performing better at certain things or doing mistakes*
- *Coaches are always prioritising certain elements over others, such as tackle or set pieces*

- *Some things are easier to visualise than others*

Data from Technology:

- *Putting a chip in ball shows if it has crossed a particular line, this technology can exist on equipment's*
- *Match statistics benefits are limited, so best make best use of them*
- *No one knows what to do with the numbers*
- *Defining technical stats, is hard as pass importance could define the game rather than performance*
- *You can tell some physical stats just by looking*
- *Decision making could be predicted*
- *Consistent performances can be difficult to spot as there should be a need to look, such as short passes*
- *Judging progress needs to be better, such as defining conditions which those physical stats are being done*
- *Consistency and accuracy of what the player is doing means progress*

Professor David Harrison:

Professor - Design Research

Integrating sensors:

- *Power would be high in demand*
- *Microcontroller is the essential component of this whole circuit to connect everything*
- *Identifying precise end user before assigning the electronics*
- *Simplify and link to one element to increase the depth of study*
- *Specify anatomy to be tracked*
- *Placement of sensor needs to be known*
- *Computer vision analysis could be used as an observation technique, hence camera recordings are essential for research*
- *Know the scopes of what the sensors can and can't do*

Defining Data:

- *Make the research simple with chosen resources*
- *Raw data needs to be characterised*
- *Make sense of the data that is chosen*
- *Knowing the player position and linking could be useful*
- *Define the type of physical stats that should be used via chosen sensors*
- *Should allow comparing with others, for progression purposes*
- *Identify which core data will be researched around the body movement of football kicking*

4.1.2 Industry Experts influence on Study

Wearable Tech Show 2019 gave insights to what aspiring firms have been working on in this sector. Discussing their opinions on different elements in WT, built insights to how the end users of this research may benefit from these applications. This is done to increase the potential future impact this study can be developed upon. There were numerous companies specialising in multiple wearable industries, with the majority around medical sectors. Industry discussed in this section, are ones that could contribute to amateur footballers in how this project is conducted revolving around technology and design.

"Performance is monitored to a good degree, but injury is where research needs to be focal" – Kymira Sport [KYMIRA, 2019]. Companies are tackling more reasons to research injury monitoring regarding "prediction". Both the sport and medical industries strive to advance in forecasting potential problems that can lead to injury. Having an injury prevention mechanism in place, helps both sectors in many ways. It is important to identify early which injuries need to be "tracked" most for football. Ankle injuries are most common, but there are few relevancies to football shooting, as most are accidental.

In terms of wearable designs, ergonomic features are dependent on human factors. WITgip, are working on smart wearables that emphasize on ergonomic features revolving around wrist wear. This is dependent on where the "Display" is placed along the wrist. To position the screen on the side, of the inner wrist, is an ergonomic design solution [Witgrip, 2019]. This is because naturally the wrist does not need to rotate for the user to see the screen. The limitation is that it only applies to wearables that have screens embedded on them. Wearables that have a smart phone to display data, will not benefit from this idea. A very important anthropometric design phase will really determine how well it can perform in terms of inclusive design. This is important as users who wear smart devices, don't have to adjust their wrist to see the screen. There aren't any clear benefits for footballers.

Another important accessory wearable on show which had sensors embedded in them is "My Smart Bottle". This bottle has a patented sensor on its lid that monitors how much liquid intake the user consumes [My Smart Bottle, 2019]. This can distinguish water and other liquids. Because nutrition has garnered more reputation regarding its influence in fitness, this "accessory", is an example of product design, that utilizes its equipment to complete the experience. This component is important to many sectors such as lifestyle, medical and sport. The water bottle can easily be something amateur footballers can purchase, and any possible additional data in collation of the other wearable data, can give a better learning experience linking nutrition to performance. This example can inspire immersing the technology with everything around the user, increasing information about themselves.

With battery technology evolving, due to numerous advancements in sustainable development, Zinergy highlighted how wearables are taking multiple approaches regarding power. Lithium is a material used in rechargeable battery production and are frequently present in wearables. However disposable batteries which are thin and flexible like Zinergy's, also allows designers to modify certain design considerations around their tech [Zinergy, 2019]. Instead of resorting to default battery packs, Zinergy's Zinc Carbon batteries, can change the whole design lifecycle use of their intended wearable. An example would be when a footballer (training periodically) wants to track how well they take free kicks; the battery will only need to work for a small amount on time. After this, the battery can be disposed, whilst the data is logged. There is no need for recharging, as the next time its needed, new battery can be inputted due to quantities available per purchase. This is not only because of its very thin and small size, or the mechanism it operates, this is an opportunity to decrease weight, with adjustment only in maintenance. This sort of application can be beneficial, as users may not want to maintain the technology regularly, so they only must use it when they want. This method may benefit sport scientists, coaches, and doctors, who want to immediately analyse a user, and gather data on them efficiently, without looking after too much electronic involved, i.e., battery status. Although Zinergy claim that their "roll to roll printing techniques, reduce the cost of printed power suitable for mass adoption", there is no indication on how much it affects the environment when they must be disposed.

Conductive Transfers showcased their circuitry design where heat application methods embed sensors to transform fabrics into smart fabrics. Embedding the circuits onto fabrics is just one part of a complex procedure. If amateur footballers were to use this, perhaps on the boot or sock, Conductive Transfers thin materials will accommodate them as they are very flexible with circuit print and washability, making it durable. It can help amateur footballers, who will not want to take the electronics out of the equipment to clean them, this compatibility can help "break the barriers of investing in smart clothing" [Conductive-Transfers, 2019].

Protective WT on around the head has great focus, however with football's frequency of injuries coming from the lower limbs, it was very hard to distinguish whether the technology can be applied to future football wearables. HP1 Technologies © replaced previously IMU sensor-based helmets with graphene-based sensor (pressure). This was purely because graphene sensors produced the intended data results, that they required for helmet protection [HP1T, 2019]. Having flexible pressure sensors printed on the inside of the helmet shells, provides data on the quantified energy transferred through the helmet structure, can either be directed away or to the head. This worked better by linking it to software that is accessible by the observers (coaches, doctors etc). For amateur football and in particular this research, potential pressure sensors in the form of FSR will need extensive research to back its placement. HP1 replaced IMU, whereas this study is using both to understand how to make more meaningful data from them to relate ankle motion and contact of the ball from boot. This would mean the ankle region of the foot will have focus on testing, to guarantee that the data which is produced, has viability for all end users. It is a step towards researching impact monitoring methods via smart equipment and could be a powerful input for this project. If programmed correctly, data from both type of sensors can work well to give meaningful results.

4.2 End user observation and interview based personas to understand core needs with wearable sensor integration for amateur level football

4.2.1 Footy Addicts User Observations

Footy addicts are a weekly organised football session consisting of 8-a-side games every week. The players who play consistently range from general enthusiasts to aspiring semi pro players. As a supervisor and host of these matches, observing intended end users on a regular basis, allowed further insights to be formed from viewing, and gathering feedback allowed ideas to commence. Synthesizing the information regarding how important the kicking attributes are, led to specification of which attribute priorities are greater. It is very important to observe the end users regularly to understand their needs and learn their user journey's in identifying what WT data priorities can be. This has a very important influence on the design aspect of this research and where the technology could feed into it. These observations increased the empathy of end users, and allowed participant recruitment for the focus group discussions, which aims to aid the design of data transformation framework.

Over 6 months of observations (Figure 4.2.1 showcasing some of the field photos taken) , most amateur players emphasize "technical" attributes to success as a footballer. Every week the elements that a user remembers when they played well, are if the team won by playing efficiently (collectively), scoring multiple goals, passing of high quality or important tackles/interceptions. These elements are all linked to the performance attributes of football. The physical attributes interestingly were length of running, the shot power they executed, their longest pass range and overall maximum running speed. These were the findings that players remembered, post-game week.

Players coming and asking to take videos of them playing also shows their interest to see from an observational point of view, where they want to send them to scouts and coaches. This could make WT complicated, but Zepp Play Wearables encourage smart phone camera usage as part of their overall experience. This is a sign, that observational elements are always desired, even with WT integration.

Players bringing tripods and placing a smart phone on them to see their techniques during practise shots were one of the key early indicators of where this study could focus on. This was done to hone their technique and analyse what they can do consistently to keep kicking their intended targets. The method of learning the techniques from video recordings isn't new, however, as they self-improve, they aren't "recognised" as much of what they can do in game. This requires recordings of players from someone watching the game itself.

For this research it was crucial to identify user needs within the training sector alone. This is important as certain elements can be rectified in just training, i.e., shooting technique. Therefore, there needs to be a process in deciding which shooting attributes are prioritised for training to be applied in game. Table 4.2.A summarises, a POINT (problems, opportunity, insights, needs and themes) table is created below, highlighting the observed problems, what opportunities they entail, the insights from the end user, what their needs are and common themes.

Figure 4.2.1: Sample photos of Amateur level games (intended consumer user group)

P Problem	O Opportunity	I Insights	N Needs	T Themes
Recording Target practise	Focus on shooting techniques via recording	Players spend good amount of time recording their shots and watching straightaway	Observational analysis of their kicking leg movement	Observational analysis Recordings
Hard to identify which technical aspects are consistent	Players want to understand what they are doing best and what they can work on	With general kicking practise players were frustrated when they couldn't execute their kick properly	A need for the player to understand how to replicate their technical movement	Consistency Technical attributes
Players didn't know their feet positions at times upon ball contact	Display where they have connected on ball and what their ankle position was	Players can identify immediately they have not connected the ball properly	Understanding the ball contact angle upon kick	Kick angle Ankle position on ball contact
Players don't know the exact technique they executed for a good goal	Elaborate how form can be improved in order for technique to be honed	Hard to replicate the precise technical movement	Understand the movement player made in order to execute their intended kick	Learning their best kicking technique
Players are inconsistent in good passing	A way to educate players so they can be consistent	Even with simpler tasks, players can not consistently perform inside foot passes	Teaching methods in order to quantify good and bad kicks	Teaching Quantifying kick attributes
Players trying to stick to what they do best	Give players opportunity to try something different in practise	Players are too scared to try something different as they are not confident in certain kick executions	Players need to be in shooting situations they may not encounter regardless of position	Player Position Personalised practise sessions
Players are constantly practising penalty kicks	Player can be trialling different penalty shot techniques	Players of all position feel the need to be able to execute a penalty kick	Penalty kick analysis and shooting technique can be applied in game	Penalty kick Shot types

Table 4.2.A: POINT Table analysis of End User

4.2.2 End User Personas

Personas are a user centred design tool to develop end user traits. This is to identify how the potential consumers feel, what they say, what their thought processes are and what they do. Their goals and characteristics represent the needs of a larger group of users; hence it is crucial that for amateur footballers, these are created to display their core needs. This is a vital part of the design process because it reflects the core user needs.

Figures 4.2.2 – 4.2.9 are personas of amateur footballers who play weekly. They are created to have a broad representation of the precise group of users this research aims to help. These personas are designed under football considerations, using their profile as a footballer to rank their overall attributes, then kicking attributes to illustrate how behaviours alter depending on different positions. These are designed based on feedback from players themselves on their profiles, and weekly observation. There are some biases that can affect the weighing of the attributes, but with an overall agreement on the assigned range without quantification, resulted in these personas. The insights are referred to WT in amateur level football, and the needs relate to specific monitoring techniques.

Figure 4.2.2 shows a goalkeeper persona, and how they rank themselves in terms of physical and kicking attributes. These attributes are quantified with against a rating of 10 (being greatest). A short bio is written to give context of the player, building a rapport of their experiences. The kicking attributes on the persona designs, are consistent throughout all the positional players, which gives a clear representation of the performance data parameters that could exist in WT in football.

Name : Santos

Age : 29

Position : Goalkeeper

Level : University football

Bio

Having played football from a young age in Germany, continued training at twice a week with playing matches at least once a week at university level.

Insights

Stamina defines most of performance

Ball control is where judgement is made on how well performed

Number of shots saved define, but 1 mistake could mean failed game

Goalkeepers need a different programmed wearable technology regarding physical stats

Needs

Needing to improve control of ball

Long range passing is priority as a goal keeper technically

Prefer personal training for kicks via potential feedback

Attributes

Kicking Attributes

Shot power	●●●●●●●●○○
Kick precision	●●●●●○○○○○
Short passing	●●●●●○○○○○
Long passing	●●●●●●●●○○
Short shots	●●●●●○○○○○
Long shots	●●●●●●○○○○
Penalties	●●●●●●●○○○

"You are required to only give short burst of movements when the ball is nearing you and then you get to rest again after"

Figure 4.2.2: Goalkeeper Persona

Figure 4.2.3 persona of a defensive midfielder highlights how their needs are wanting to track their shot power, where Figure 4.2.4 shows a forward player, whose very data driven. These are important player personalities that will influence the user research of monitored data from wearable technology. Although they are different positions with different kicking attributes, the way they want to evolve their game is very personal. This is something that WT is implementing as its core function, by giving the end user full control of how they choose to grow.

Name : Naz

Age : 29

Position : Defensive Midfielder

Level : Footy Addicts FC

Bio

Represented football clubs in borough, schools and university level. Trained regularly and played matches both in tournaments, and for fun.

Insights

Playing in different midfield positions has different needs and this affects judgment

Overall gameplay is much more than stats and better achieved by watching others

Dead ball situations may benefit more from observant related feedback

Opponents and team leaders advice are taken into whose playing

Needs

Needing to reduce unnecessary injuries

Shot power and Long range passing would be preferred to improve

Improve weaknesses rather than refining strengths, but more balanced

Kicking Attributes

Shot power	●●●○○○○○○○
Kick precision	●●●●●●●●○○
Short passing	●●●●●●●●●○
Long passing	●●●○○○○○○○
Short shots	●●●●●●○○○○
Long shots	●●○○○○○○○○
Penalties	●●●●●○○○○○

“ I support the idea of sensors tracking my shots”

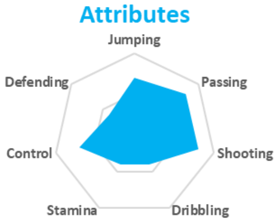
Figure 4.2.3: Defensive Midfielder Persona

Name : Raul

Age : 28

Position : Second Striker / Forward

Level : Footy Addicts FC



Bio

Represented football clubs in schools and university. Regular Sunday League player

Insights

Game days are different to training days in terms of intensity

Positioning changes all the time, so tracking this may allow

Don’t wear guards as it affects speed

Adapting to sensors may be the hardest part

Needs

Need something better for footcare

Processing stats is important

Targets have to be technical and personal

Kicking Attributes

Shot power	●●●●○○○○○○
Kick precision	●●●●●●●●○○
Short passing	●●●●●●●●●○
Long passing	●●●○○○○○○○
Short shots	●●●●●●●●●○
Long shots	●●●●●○○○○○
Penalties	●●●●●●●●○○

“as an analytic mind, stats are important”

Figure 4.2.4: Second Striker Persona

Central defender from Figure 4.2.5 has impressive kicking attributes throughout, however, their emphasis on football being a subjective where physical traits doesn't define how good a football player is, shows why this research needs to differentiate how performance data is extracted. Implementing these subjective opinions and quantifying them bring greater meaning to WT, as players can use some metric as benchmarks for self-improvement.

The transformation of physical to performance data must be meaningful for the end user, and this means that their desired improvements must factor in a weighing that considers the subjective review on the attributes, in how it will influence their overall game. If a player chooses to increase their shot power, and undergo training regime for this purpose, their must be a personal achievement benchmark they want to implement within their game play, e.g. shooting from long range more accurately.

Name : Kevin

Age : 28

Position : Central Defender

Level : Sunday League Regular

Bio

Represented semi-pro and academy clubs in France.
High school Football Coach in China.
Regular Sunday League player

Insights

Harder to coach without actual observation and just stats

Having a good or bad game depends on results

Influence and impact are what makes a good game

Performance differs depending on situation and how much you can help a particular team

Needs

Need to identify problems easily

Needs to show how much I am doing and how much I should do

Must have a score option, and personal input in how well they've done

Kicking Attributes

Shot power	●●●●●●●●●●
Kick precision	●●●●●●●●○○
Short passing	●●●●●●●●●○
Long passing	●●●●●●●●○○
Short shots	●●●●●●○○○○
Long shots	●●●●●●●●○○
Penalties	●●●●●○○○○○

"physical but also technical, football is played with your brain, being physical doesn't mean you're a better football player"

Figure 4.2.5: Central Defender Persona

Central midfielders from Figure 4.2.6 - 4.2.7 signified how there are goals that need to be achieved in the next game, with monitoring of decisions being made, which suggests how gamification could be relevant for any future user experience of wearable technology data. These two personas show how the same position players, use what they can achieve in the next game as progression indicators. Their gameplay is significantly different, due to their kicking and physical attributes making them play in their intended way.

Name : Najah

Age : 27

Position : Central Attacking Midfielder

Level : University Level footballer

Bio

Represents University Football and Futsal. Regular Power league player

Insights

Mistakes define a bad game

The bigger the occasion (league cup finals), the greater the motivation, hence higher intense performances

Boots best choice to have wearable technology implanted

Team mate opinions are valued

Needs

Need Human feedback input in feedback type

Feedback must be meaningful for improvement and accurate

Needing to improve based on kicking technique tutorials

Attributes

Kicking Attributes

Shot power	●●●○○○○○○○
Kick precision	●●●●●●●○○○
Short passing	●●●●●●○○○○
Long passing	●●●●○○○○○○
Short shots	●●●●○○○○○○
Long shots	●○○○○○○○○○
Penalties	●●●○○○○○○○

“set me goals to try achieve in the next game”

Figure 4.2.6: Central attacking midfielder Persona

Name : Jonathon

Age : 26

Position : Central Midfielder

Level : Sunday League Regular

Bio

Represented football clubs from High schools and districts in Germany up to university level. Train regularly and play matches in tournaments for Sunday league games

Insights

Size and stamina of players define a better footballer

Only relevant stuff should be needed for amateurs

Stamina changes depending on type of game

Price of Technology must be affordable and worth the investment

Needs

Decision making tips can be good

Needs to help in weaknesses that cant be found with self observations

Average stats for each attribute would help

Attributes

Kicking Attributes

Shot power	●●●●●●●○○○
Kick precision	●●●●●●●●●●
Short passing	●●●●●●●●●●
Long passing	●●●●●●●●●○
Short shots	●●●●●●○○○○
Long shots	●●●●●○○○○○
Penalties	●●●●●●○○○○

“As a central midfielder you have to be the engine of the team, this can be tough because you have to make the right decisions”

Figure 4.2.7: Central midfielder Persona

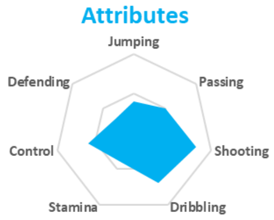
WT needs to accommodate the differences between positional players, for it to be impactful. There needs to be some input into the system to inform WT the current state of the player and what they want to achieve, and how they’ll be graded on it. This is further encouraged by the persona of forward player in Figure 4.2.8 where importance of competitiveness can arise from the monitoring of key statistics. Quantification of these performance metrics are indicators of how much they’ve improved on a particular attribute.

Name : Reuben

Age : 28

Position : Forward / Winger

Level : Power League regular



Bio

Represented private football clubs in Malaysia. Trained once a week and played matches in tournaments for Sunday league games

Insights

Size and stamina of players define a better footballer

Fatigue and stress causes more injuries

Believes wearable technology will be norm in the future

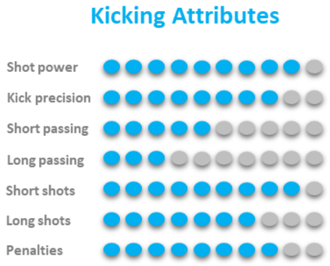
Preferred to be on the boot, so weight doesn't affect as much

Needs

Simple learning experience

Has to motivate to train harder

Need to be in control of what ability user wants to improve on



> "It may not even serve its purpose but the idea of a device being worn which assesses your statistics will definitely encourage competitiveness"

Figure 4.2.8: Forward Persona

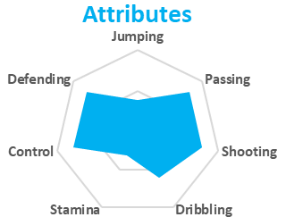
Being able to apply this into gameplay situations allows more education for the amateur footballer on their performance, as highlighted by wing back player on Figure 4.2.9. These personas have shown similarities in what is desired within wearable technology space for amateur footballers. Forming insights and creating actionable tasks will form the next phase of research where analysis is needed to be done with sensors that would exist in football WT.

Name : Junis

Age : 27

Position : Wing back (Left + Right)

Level : Power league player



Bio

Represented university football team, plays once a week power league sessions. Works as a steward for multiple Professional level league and Tournament matches

Insights

Confidence with possession and contribution defines good footballer

Physical depends on how their presence influence the game

Mistakes and decision making are important in how good a player has improved

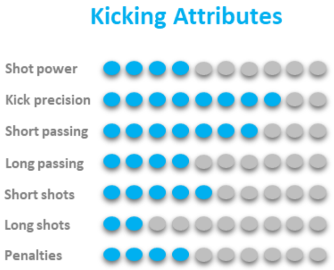
Data obtained may be preferred with technical

Needs

Make Stats important to apply for Gameplay

Need to know what unnecessary steps I'm doing

Progressive feedback should be shown smartly to allow motivation

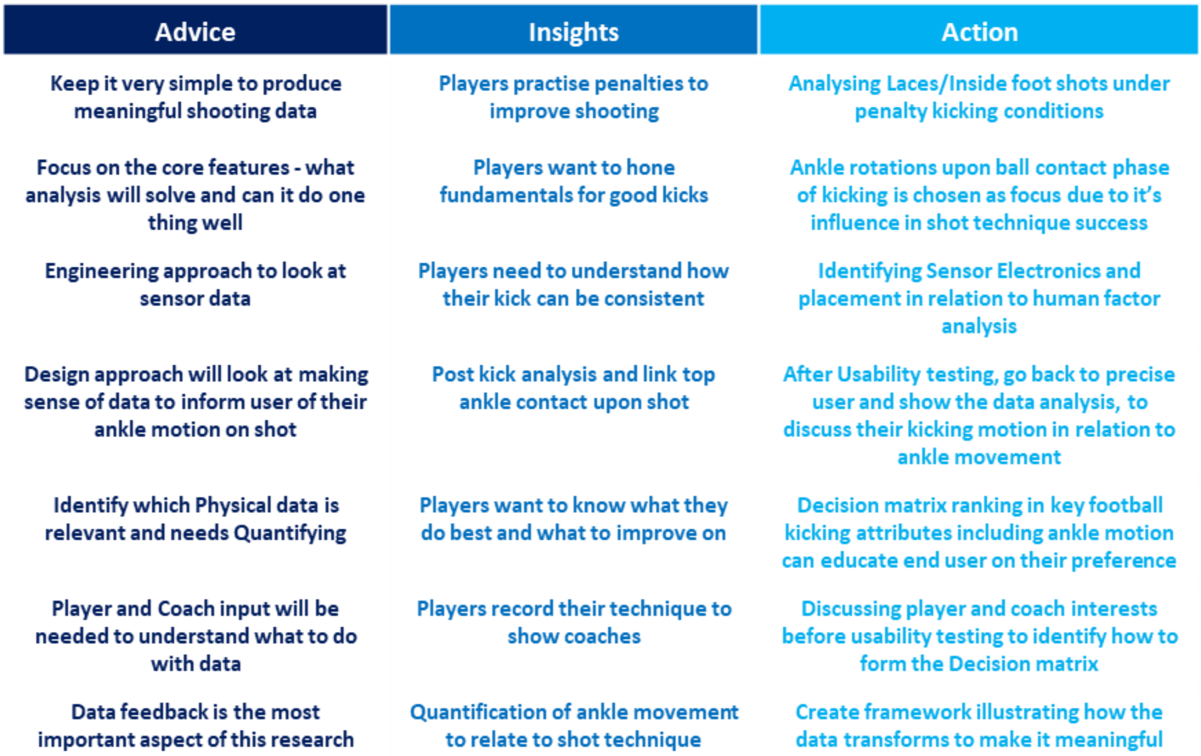


> " Sensors that can track and feedback my weakness to tell me what to do next, would be very interesting"

Figure 4.2.9: Wing Back Persona

Summary

Table 4.2.B illustrates how the expert consultation and user observation examined the different elements of consulted research topics. This table combines the primary researched data to identify what key actions are necessary to complete study, in a focussed and thorough way. Advice column are the input from expert interviews, and the Insights are from the End user observations.



Advice	Insights	Action
Keep it very simple to produce meaningful shooting data	Players practise penalties to improve shooting	Analysing Laces/Inside foot shots under penalty kicking conditions
Focus on the core features - what analysis will solve and can it do one thing well	Players want to hone fundamentals for good kicks	Ankle rotations upon ball contact phase of kicking is chosen as focus due to it's influence in shot technique success
Engineering approach to look at sensor data	Players need to understand how their kick can be consistent	Identifying Sensor Electronics and placement in relation to human factor analysis
Design approach will look at making sense of data to inform user of their ankle motion on shot	Post kick analysis and link top ankle contact upon shot	After Usability testing, go back to precise user and show the data analysis, to discuss their kicking motion in relation to ankle movement
Identify which Physical data is relevant and needs Quantifying	Players want to know what they do best and what to improve on	Decision matrix ranking in key football kicking attributes including ankle motion can educate end user on their preference
Player and Coach input will be needed to understand what to do with data	Players record their technique to show coaches	Discussing player and coach interests before usability testing to identify how to form the Decision matrix
Data feedback is the most important aspect of this research	Quantification of ankle movement to relate to shot technique	Create framework illustrating how the data transforms to make it meaningful

Table 4.2.B: Resultant insights from Expert interviews and the intended action planned

5.Theoretical Development with software analysis

5.1 Key formulas that are fundamental in football kicking biomechanics and how it influences sensors calculations

To probe into the research's specification, there is a need to determine all elements involved between the ankle rotation, kicking leg and ball contact within penalty kick environment. For this, key theories are developed, and software analysis is done, to study greater about the finer details within this space. These derivatives will aid WT in increasing the accuracy of data calculations, by applying greater context to the sport's situation.

5.1.1 Coefficient of Restitution (COR)

Coefficient of Restitution (COR), derived from the Newton impact law, can be defined as a variable between 0 – 1, without any units [Physics-Tutor., 2016]. The true definition for a Football kick example is how the speed of separation between the ball and foot upon impact, is related to the initial kick speed approach of the player. This formula links key kicking biomechanical features in backswing, follow through and ball contact.

To understand COR for a football, the elastic properties will need to be listed. A football which falls to the ground experiences kinetic energy as there will be slight deformation on impact. This is because of its material and the air pressure inside, dissipating the energy transfer causing the change in shape. Labelling this as elastic potential energy is crucial in understanding the conservation process because, unless punctured, the ball regains its original shape. This causes the ball to bounce from the surface it collided with. It cannot be "perfectly elastic", as it doesn't retain the kinetic energy before the impact, which depends on the material of the football and its elasticity property [Physics-HKU., 2016].

The composition of a football has the surface (cover), stitching, internal lining, and bladder. The surface of a football is made from a combination of polyvinyl chloride and polyurethane, which composes synthetic leather. The stitching will then allow the different "panels" of the cover to be sewn together via polyester threads [Made How., 2021]. The lining affects the thickness between the cover and the bladder. Multiple linings can increase the strength of the ball, made from polyester or cotton. This supports the ball to "bounce". The bladder's job is to maintain the "spherical shape" when air is pumped [Soccer ball world., 2019]. This can be composed of latex or butyl, to sustain the air pressure consistently as the ball gets kicked around (multiple impacts).

From Figure 5.1.1, when collisions offer a COR value of 0, this is the most inefficient conservation of energy. When the player kicks the ball, if the ball sticks to the boot and travels the same velocity as each other, during Follow through, this could be considered as "plastic" collision. The COR is 1, when it is at its highest efficiency, which means that the collision "is elastic" and total kinetic energy is completely conserved [Aris et al., 2013]. If the initial boot velocity was 15ms-1, upon ball contact, and the velocity after contact (follow through) reached 10ms-1, with the ball experiencing 25ms-1 when it reaches the intended target distance (e.g., goal line), this would give an absolute COR value of 1. Regardless of the player's leg mass, these quantities regarding biomechanical movement, can show how efficient a player has been striking the ball. This can be used to design possible future kicking attribute. COR is always worked out by the absolute values, hence negatives are negated. COR is 1 when highest efficiency is achieved and has an elastic collision where total kinetic energy is conserved.

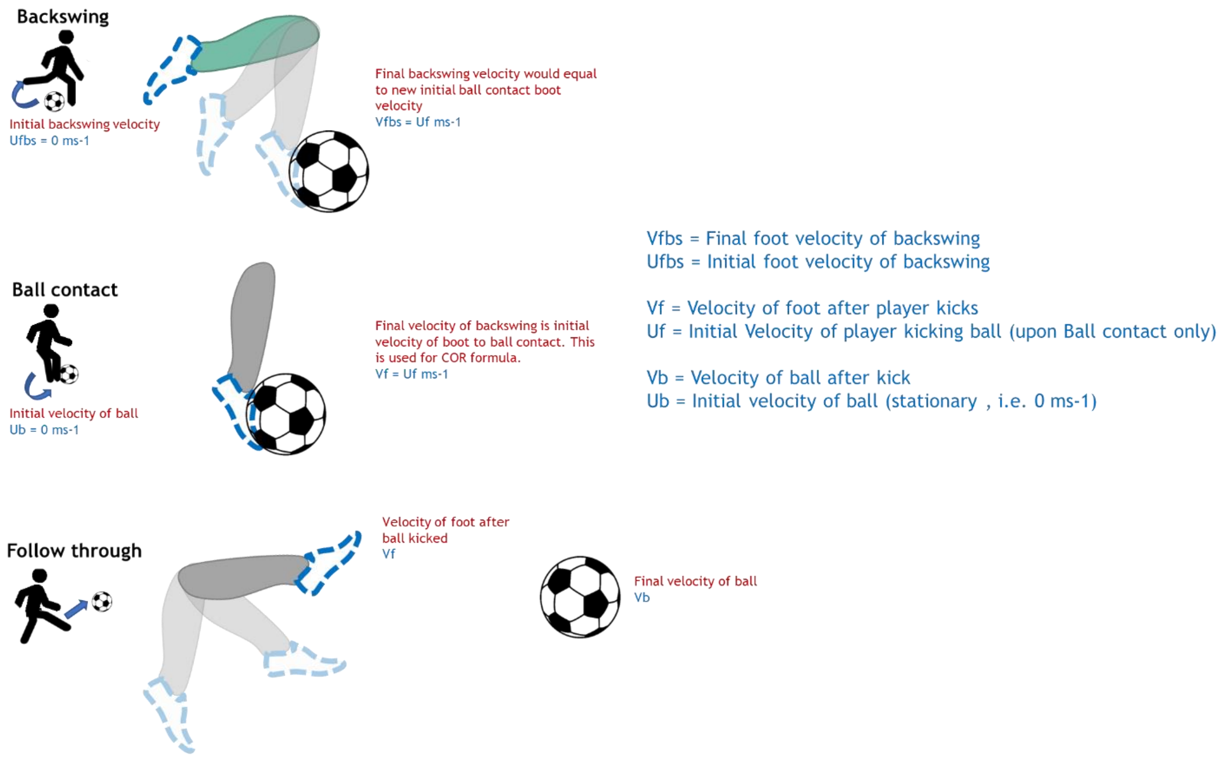


Figure 5.1.1: COR involved in Football Kicking

COR Equation terms:

$$\boldsymbol{COR = \frac{Speed\ of\ separation}{Speed\ of\ approach}} \qquad \text{(Equation 5.1)}$$

$$\boldsymbol{COR = \frac{Vb - Vf}{Uf - Ub}} \qquad \text{(Equation 5.2)}$$

$$\boldsymbol{COR = \frac{Vb - Vf}{Uf}} \qquad \text{(Equation 5.3)}$$

5.1.2 Momentum

To calculate COR, it is important to keep the kick velocity that the foot plants onto the ball, constant. The initial velocity must be constant upon ball impact so that the velocity after impact, can then be calculated. This in turn will help lead to COR, where the stationary ball having initial velocity of 0m/s, and working out the velocity after the kick, completes the variables existing in the COR formula.

For the COR formula, the weight of the leg is not used. However, with biomechanics and how well a kick is executed in terms of efficiency of muscles used to obtain a good level of power, the mass of the leg would be a beneficial factor. This is hard to monitor even though the mass of a player's leg can be determined by their bodyweight. Computing percentages of total body weight, gives an approximation of 5% (+-0.35) of body mass being leg mass for male and female [Human Body, 2020]. The precise distribution of muscle and fat mass composition will make it somewhat inaccurate but can be calculated relatively.

In a kicking motion, momentum plays a crucial role in identifying the velocity, relative to the masses of the ball and the player's leg. This is visualised as a collision that considered the "relative effective" mass of the leg. The "relative effective" mass considers a point on the foot, where "no external forces" are applied. This is because when considering the foot, it's mass, will have forces acting (e.g. gravitational, reaction, shear etc) which all influence the calculation of the precise velocity of kicks taken. Therefore the "relative effective mass" is considered, so that it can be analysed with just the knowledge of the "leg's mass". Neglecting the external forces that are already applied to the leg, as the backswing and ball contact motions are undergone, allows "dynamic" calculations to be computed, which is used in the momentum equation.

The actual mass is less than the relative effective mass. If the precise "real mass of the leg" is considered, then all the forces acting on it will also have to be considered, which increases the complexity of calculation. Neglecting the real mass of the leg, allows the conservation of momentum equation and the COR to combine. With momentum being conserved due to the Law of Collison physics.

Mass of the ball (*Mb*)

Initial ball velocity (Vb_1), becomes (*Ub*) and as it is stationary, the value is 0 m/s

Ball velocity after kick (*Vb*)

Effective mass for the foot (*Mf*)

Velocity of foot (Vf_1) becomes initial velocity (Uf) at ball contact

$$Mf(Vf_1) + Mb(Vb_1) \ = \ Mf(Vf_2) + Mb(Vb_2) \tag{Equation 5.4}$$

$$Mf(Uf) + Mb(Ub) \ = \ Mf(V\mathrm{f}) + Mb(V\mathrm{b}) \tag{Equation 5.5}$$

Combining Equation 5.3 and 5.5 gives:

$$\mathrm{Vb} \ = \ Vf(Mf\left(\frac{1+COR}{Mf+Mb}\right)) \tag{Equation 5.6}$$

5.1.3 Magnus effect and Drag/Lift Coefficient

When a football is kicked, the ball flows through air. This can be regarded as the medium between the goal and the boot. The air fluid, assuming it is incompressible flow type, will flow around the ball depending on how the player has kicked it. This can be considered as friction due to the viscosity present in the air, which manipulates the "spin" on the ball. This results it in impacting the projection and speed whilst travelling, where the direction of how the ball travels mid-air, is known as the Magnus effect [Physics Of Soccer, 2020]. This is prominent when "knuckle" ball shots are kicked, a form of an angled laces shot, which require high technical movement of the foot, to purposely make the ball's fluctuate horizontally, whilst travelling mid-air, confusing opposition players who try to stop it [Baptiste et al., 2016].

When a football player kicks the ball, they have intensions of projecting it high or low, (e.g. cross or shot). Airflow will be acting on a particular direction, and if the tangential velocity, (velocity that is acting on the edge of the ball in a direction), acts in the same direction of the airflow, this is the direction the ball would spin. For example, if a right footed player kicks the bottom right of the football, intended projection would be to the left at a high trajectory. If the air flow is also directing towards the left, where the tangential velocity is also in that direction, there would be bottom spin. If the player kicks it on the left side bottom region of the ball, the tangential velocity would be towards the right, and because airflow is towards the left, the ball will experience top spin [Science ABC, 2021].

Foot contacting the ball affects the spin on it and the air conditions surrounding it, determines where greater velocity is experienced. The magnus force acts towards the direction of the where the kicker intended to kick, which in turn will allow the ball to curve in that direction. When the ball is intended to be a high trajectory, the bottom section of the ball will experience more rotational velocity, than the top. The speed of the ball being greater at the bottom, allows the air at the top of the ball to be lower, and there is greater pressure wherever there is less velocity (Bernoulli’s principle). As the ball goes through the air, in the intended direction of the kick, whilst wanting to project it high, the contact of the foot to the ball being greater at the lower end, causes the ball to experience more velocity and acceleration there. This is where the skill of the footballer being able to connect well on the ball, regarding how they have transferred their energy via backswing of the leg, and the angle of the ankle upon ball contact, can affect the success of the kick in relation to ball speed and direction.

The football which travels through air after a kick, will have the accelerative force generated by the player’s backswing that's transferred upon ball contact, and a reactive force due to the air resistance. The air around the ball is disrupted from the kick, hence creating a lift. In situations when kicking with the knee over the ball, to guide it towards the ground, there is no lift. Whilst the ball is in air, i.e., the flight, there will be a lift force (determines how high the ball projects) and drag force (resistance). These are defined by their Drag and lift coefficients which determine how the ball will behave in conditions. Researchers examined that when the velocity of the ball is low, the drag is high, where when reaching the critical Reynolds number, the drag coefficient decreases drastically, before increasing as the ball moves further [Lees et al., 2010] [Asai et al., 2018] [Carre et al., 2005]. When a ball is kicked, there will be drag force increasing until it reaches the critical speed. When it surpasses this point, the drag force decreases, whilst the velocity of the ball is still increasing [Physics HKU, 2020].

The stiches around the ball also affect the aerodynamics which alter the lift and drag whilst the ball is in flight. Equation 5.7, is an estimate of what a lift on a football will be, assuming that the ball is smooth and rotating constantly, with SoccerNASA simulator approximating the value of Coefficient of lift to be 0.25. This is also the case regarding drag, as the theorical drag formula, is assuming a smooth spherical football, where the stitches will affect the air’s viscosity in flight [NASA, 2012][Tuplin et al., 2012]. Naito et al., 2017, studied the effects of the surface characteristics in footballs on Critical Reynolds number, and experimented with the aerodynamics of recently used professional footballs with different designs [Naito et al., 2017]. The wind tunnel study concluded that the Panel design and seam increases as the drag coefficient increases, all being tested at 30 m/s. The stitching “depth” will increase the roughness of the ball; hence the drag coefficient will be affected.

Hong & Asai conducted a test comparing 5 different footballs, with different number of panels and stitching methods used in professional games. This was another Aerodynamic test which used wind tunnel to understand the drag forces around the ball, with a kicking machine. The drag coefficient were lower for some of the popular balls which were known to have a very erratic flight characteristics (e.g. 2010 World cup Jabulani), which caused a lot of attention for its affects. These types of footballs also showed higher critical Reynolds number. Varied behaviour of the ball is shown as when the ball velocity was increased there was a greater change in irregular fluctuations of the Side and Lift forces. This study showed how the drag coefficient being lower, gave that ball the opportunity for more forces to act on it, as it goes through flight, concluding that the ball design does affect in how it travels in flight. Using particle image velocimetry, it was further rectified that the shape of panels, also affect the aerodynamics of the ball, with forces acting during flight, and that the critical Reynolds number increases as the panel width decreased. It also showed that with the panel length increasing, the critical Reynolds number decreases [Hong et al., 2015]. Their study concluded that the depth of the panel, which are influenced by stitching, affects the roughness, hence the lift and drag coefficients will differ.

A magnus effect on the football can be viewed by observing its trajectory, where the ball spins in the opposite direction to the ball travelling through the air. For a penalty kick as the distance is shorter as opposed to other set pieces, a kick velocity applied at an angle on ball must be higher to view such a drastic change, within this distance. For this PhD research, having focus on penalty kick set piece, the distance between ball and target is insufficient for trajectory to analyse full swerve experienced on the ball, as this would normally require greater distance. This can be present in other set pieces such as corners and direct/indirect free kicks. A visualisation of magnus effects is shown on Figure 5.1.2, with drag and lift coefficients.

LC : Lift coefficient, AC : Actual lift , TL : Theoretical lift, P : Density, Vb : velocity of ball, r : radius of ball , S : Spin, D : Drag, A : Area, V : Velocity, DC : Drag coefficient

$$TL = \frac{4}{3}(4(\pi^2)pVb(r^3)S \qquad \text{(Equation 5.7)}$$

$$LC = \frac{AL}{TL} \qquad \text{(Equation 5.8)}$$

$$DC = \frac{2D}{P(Vb^2)A} \qquad \text{(Equation 5.9)}$$

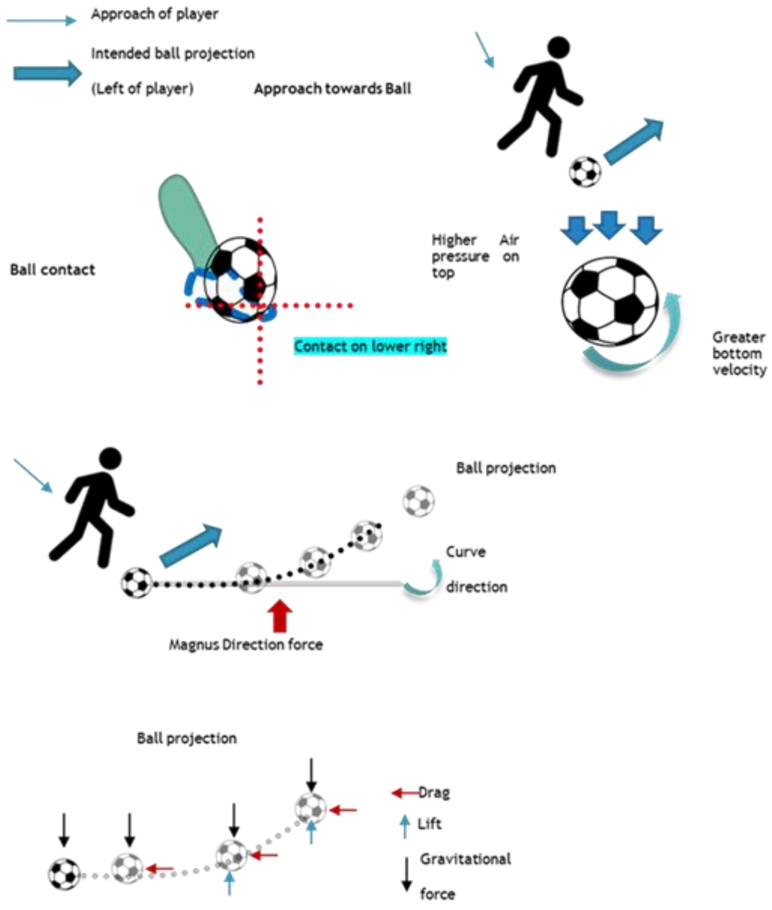


Figure 5.1.2: Magnus Effect and Lift/Drag of Football upon kicking

5.1.4 Reynolds Number

When the ball is kicked powerfully, the velocity of the ball will be fast, (Power = Force x Velocity). If it is faster than the surrounding air around it, this will cause the airflow around the ball to be turbulent. This means that the pressure of the air around the ball will not be dispersed evenly. This is where air pressure and drag, affects the balls flight, and causes it to slow as it travels further. The more powerful the shot, the more disruption of airflow, hence it delays that resistance further.

Reynolds number shows the ratio of inertial forces acting on an object due to the viscous forces of the surrounding fluid flow. In football terms, the ball is the object, and the air is the fluid as it travels through it. Because inertial “forces” depend on the area and mass of an object, as it’s the object’s reactive force, this would vary for different size footballs. The density of the fluid, i.e., air, would also affect the Reynolds ratio. The influence of Reynolds number on the trajectory of the ball is that when the ratio is high, the “air swirls” around the ball. When the ratio is low, there is “laminar flow”, where the air of the environment is moving in the same direction and speed. When it transitions from laminar to turbulent, this point is known as Critical Reynolds number. This varies for the type of football used, as the designs would have different surface panel shapes that affects the roughness, and the stiches differentiates the dimples of the ball [Hong & Asai, 2017]. Reynolds number is higher, for higher ball velocities, as the air resistance around the ball, is disrupted at a quicker rate, in transforming the flow to be turbulent.

Environment test impacting Reynolds number and Drag force on ball

To compute Reynolds number ratio, there are certain variables that need to be defined. The viscosity and density of air, the speed of the air as it flows passed the football and the size of football used. The density of air is dependent on the altitude, hence if the ball’s testing was done outdoors, the geographical environment will affect the Reynolds number. The viscosity of the air is dependant on the temperature.

$$Reynolds\ Number = \frac{Density\ of\ air\ x\ football\ length\ (ball\ diameter)\ x\ flow\ speed\ (velocity)}{viscosity\ of\ air\ (temp)} \qquad \text{(Equation 5.10)}$$

Studies have shown that the design of the football affects the aerodynamics as it flows, hence the Reynolds number is not the same for every football. This means that when analysing, and increasing the accuracy of WT, these parameters may influence in how reliable the data is, to the player’s actual physical attributes. In terms of analysing ball deformation, Reynolds number has been present, when considering the factors associated with ball design [W Johnson et al., 1973].

Using equations 5.9 and 5.10, more theoretical data on how WT output can change due to environment is formed. To show what differences there could be for these metrics, different geographical locations were chosen as potential study sites, and key deliverables of drag force and Reynolds number were inputted. Different footballs will have varied panel designs that would affect the drag coefficient. Drag coefficients (DC) for footballs are determined experimentally using wind tunnel [NASA, 2012]. For this theoretical analysis, drag coefficient is given predetermined values between 0.1-0.5 for different number of panels. A ball with no panels, assumes that it is perfect smooth sphere without any stiches is given a DC of 0.5, and a ball with 25 panels, owing to greater stiches, would have DC of 0.1.

Five cities are chosen in Lima, Cape Town, Toulouse, Tokyo, and Helsinki. Their average summer and winter data in air pressure, air temp, humidity and dew point are inputted into an air density online calculator [Omni,2022]. This gives the different air density values of the geographical locations which deter depending on how their temperature is at sea level. Reynolds number is also dependent on this, hence two different seasons are calculated because viscosity of air defers with temperature, and this is set between peak winter and summer geographical averages.

Certain variables are kept constant to analyse the drag force, dependant on different ball designs, assuming they have different DC.

Control variables:

- Speed of ball (20 m/s)
- Cross sectional area of size 5 ball (0.038m^2)
- Ball diameter (0.22m)
- Assumption same player kicks the football

Measured variables:

- Drag force (N)
- Air viscosity (dependant on temperature chart differing for winter and summer)
- Air density (based on geographical city data for peak winter and summer)
- Reynolds number

Figure 5.1.3 and 5.1.4 shows graph plots of the different drag forces that occur on different ball designs based on temperature averages of summer and winter season from the chosen geographical locations. From these images it can be deduced that if a player kicks with the ball and it reaches a velocity travelling through air at 20 m/s, there would be greater drag experienced on the ball that have greater stiches on their panel designs. This would mean that a player would have to kick with more effort onto the ball that has greater stiches, to get the required ball velocity. In terms of WT monitoring physical data of a player, this is an important metric to allow the technology to judge the player's ability fairly. Greater input data into the WT system, the smarter the WT can calculate with considerations of ball. Different football will also have to be inputted, as it informs WT the behaviour it could experience based on the different geographical locations and weather conditions. This makes WT to judge the outcome of kicks more fairly and can be considerate of the end user's environment.

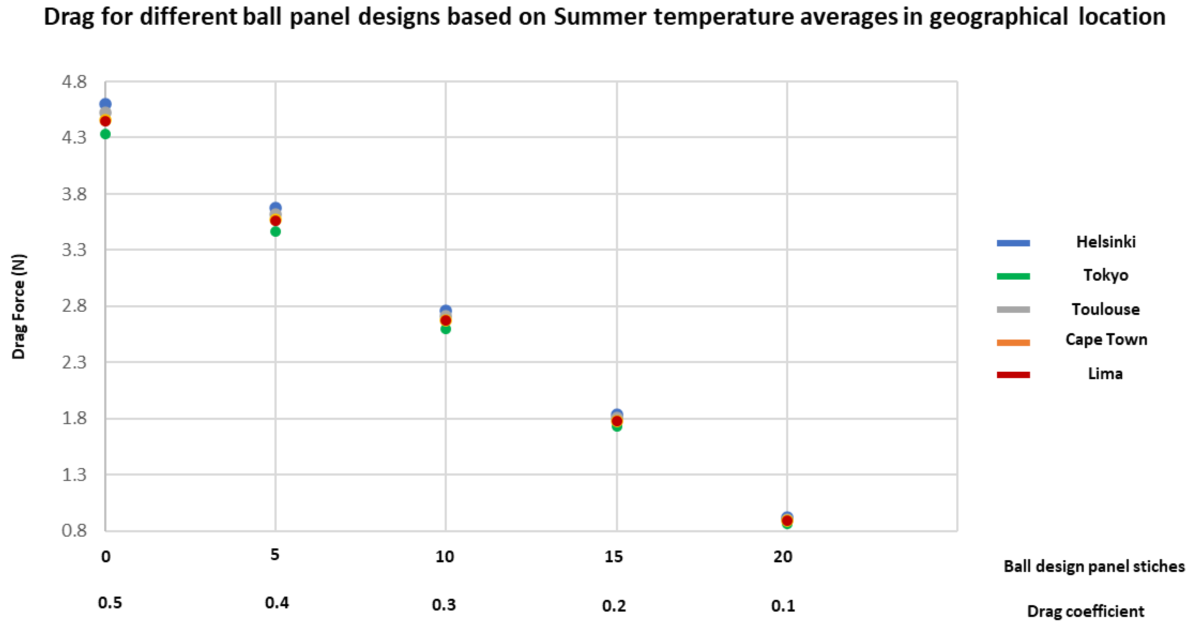


Figure 5.1.3: Drag for different ball panel designs based on summer temperature averages

Even when the same ball is used to kick at 20m/s, the environment plays a role. A footballer kicking the same football in Helsinki during winter would experience greater drag around the ball than a player kicking the same ball with the same velocity in Cape town. WT can use the location of a player, to determine external factors that could contribute to their kicking performance. If the player was to use a different size ball, this would also change as the diameter of the ball influences the cross sectional area, which in turn affects the drag coefficient calculation. If a player is training with a smaller football, this also needs to be informed within WT so it can understand the circumstances.

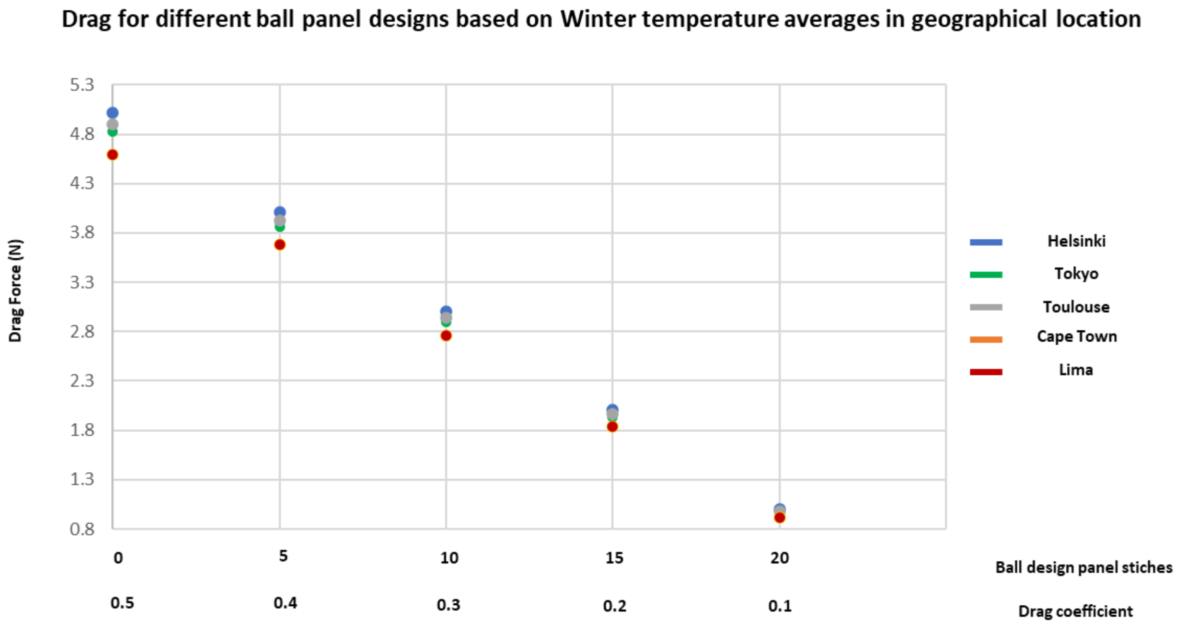


Figure 5.1.4: Drag for different ball panel designs based on winter temperature averages

Figure 5.1.5 show the Reynolds number that would differ based on the geographical location of a player. This is related to how much the kinematic air viscosity influences that locations, as it depends on the temperature during the peak winter and summer seasons. The density also affects Reynolds number, and this varies for different locations, where the plots show a bigger difference in cities that have a larger range of temperatures (between seasons) during the year. These cumulative data all aid WT in improving the accuracy of the player’s physical data. This becomes more important when more set piece tracking takes place which have greater distances of ball travel. Scenarios like those will then have ball trajectory being affected greater, as the drag experienced will have greater influence on accuracy of ball, due to greater distance. This theoretical development displays the potential for WT to increase its data validity, by implementing the environmental factors to make those calculations. The theoretical development shows that environment and ball design can influence WT data, hence inputting more information would allow the technology to increase in precision.

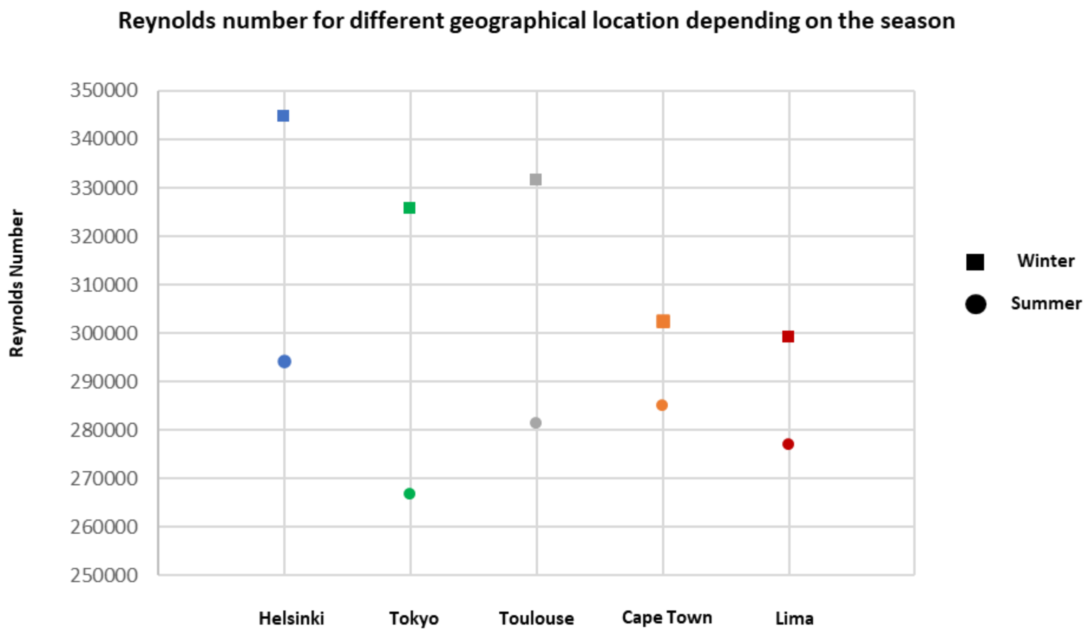


Figure 5.1.5: Reynolds number for different locations altering on summer and winter weather averages.

5.1.5 Ball Deformation

Energy cannot be created or destroyed as stated by the universal law in Energy conservation. The total energy from the player, kicking a stationary football, must be conserved somewhere. When the player's kinetic energy is used for them to generate the force to kick the football (backswing), there is slight gravitational potential energy as the kicking leg swings down towards the football, which then transfers onto the stationary football. The ball upon impact would experience deformation, as the material of the football allows compression, exhibiting elastic potential energy. Energy would be lost, as there will be some that transfers into thermal, where the ball would be a different temperature on the spot of contact, and sound (intensity depending on material of boot/ball surface). Hooke's Law principles, where strain of the ball is directly proportional to the applied stress (depending on the elastic limit of the ball surface), will come into effect after the ball projects in the intended direction. The elastic potential energy can be converted into kinetic energy, as the ball returns to its original shape.

Nunome et al., 2012 conducted an experiment which used high speed cameras, to understand deformation of the ball upon impact (ball contact phase lasting between 5-10 ms). The equations constructed were made from assumptions that upon ball contact, the deformation is vertically flat, and it was a perpendicular collision relative to the floor [Nunome et al., 2012]. W Johnson et al., abbreviated equations to compute the maximum deformation of the football for a velocity upon impact. It is also identified that the two ways to compute ball deformation are Mathematical and FEM. Analysis had been conducted to show the relationship upon ball contact and deformation by using Langrangian and Eulerian frames to study the interaction, where a manually stitched football underwent velocity of impact between 9-32 ms-1, that at high velocities, there are higher deformations, but COR decrease as well as contact time, hence, in terms of theory, the results are not surprising and behave exactly how expectations were [Asai et al., 1985][Price et al., 2007]. Both methods are heavily dependent on the ball's properties, which signify that kicking techniques can be dependent on the ball used, because of its behaviour.

5.2 Understanding how monitored physical data is computed to aid the transformation of meaningful performance data

5.2.1 Physical and Performance data

Measuring vital quantified values, like “passes”, “interceptions” or “tackles” are very useful for amateur footballers. This allows the user to be immersed with more data of the sport they like, whilst educating them. Having professional sports publish data of popular athletes’ performances, sets the constraints of what data WT can publish for consumer level products, to allow comparisons. WT has a wide tracking capability, where sensors compromise the bulk of the technology involved. This is integrated to track specific data, which is then used to relate to how the user is performing depending on a “data algorithm”. This is programmed specifically for the data sets that are monitored by the sensors. This not only increases the amount analytic data a consumer can study but gives them the data they desire, making it more meaningful with increases of user centred interactivity. This is communicated via smart phone applications.

When linking biomechanics to the constraints of what sensors can measure, designers can get an idea of where the parameters are. Table 5.2.A show some potential, of sensory embedding into football equipment, where IMU sensors can monitor. These are just examples and true parameters can only be identified through experiments and user testing. One user may prefer tracking technology as part of their top, another may prefer the shorts, and others, boots. Designer could think it’s important to create the technology to be compatible with all these equipment’s. Because the intended end user group are amateur level, price will be a concern. The problem is not just about making this advanced equipment affordable, but more value for money. This can only be proven if the data is very meaningful and can be edited by the designer or data scientist to keep adapting to how future gameplay or consumer adjusts. An attribute in the present day for strikers, is how well they track back (Defend running back). However, this was not always the case. Even high press tactic only became more used, due to how intense the game has evolved. To undergo this tactic, forward players must know how to defend well, this means they must improve on an attribute that is not associated with attacking. The game evolves, and hence the chosen data sets must be programmed to an extent where future developments (updates) can be made easily. A consideration must be applied to the user’s desire, this is what classifies how impactful WT can be.

Attributes IMU sensor measures	Application in Football Position	Potential sensor embedding equipment
Number of Sprints	Strikers, midfielders	Boots, Socks, Shin pads
Vertical acceleration	Forward wings, Full backs	Boots, Socks, Shin pads, Sweat band, Top
Top speed	Strikers, forward wings, wing backs, defenders	Boots, Socks, Shin pads
Distance	Forwards, midfielders, defenders	Boots, Socks, sweat band
Intensity Distance	Forwards, defensive midfielders	Boots, Sweat band
Vertical Jump	Forwards, defenders, goalkeepers	Boots, Top
Horizontal jump	Goalkeepers	Boots, Top
Hand speed	Goalkeepers	Gloves, Sweat band
Hip rotation (kick speed)	Power Kick specialists	Boots, Socks, Shin pads, Shorts
Trajectory	All (freekick specialists)	Boots, Socks, Shin pads, Shorts
Backswing	Power kick specialists	Boots, Socks, Shin pads, Shorts
Forward swing	Power kick specialists	Boots, Socks, Shin pads, Shorts

Table 5.2.A: Attributes monitored for football depending on sensor placement and player position

An example of performance vs physical data is shown on Tables 5.2.B and 5.2.C. These are split into team and individual attributes/stats. Team and individual performance stats work on average and total value. The averages can help identify the balance of team strength in certain areas.

Individual Performance attributes	Individual Physical attributes
Passes (completion)	Kick speed
Interceptions	Longest stride
Crosses	Number of powerful kicks
Shots / on target	Number of sprints
Tackles	Sprint distance/speed
Goals	Highest jump
Headers	Running time/distance
Possession/Dribble time	Acceleration
Duels won	

Table 5.2.B: Examples of how Individual football performance and physical data are different

Team Performance stats	Team Physical stats
Passes (completion)	Total Team distance run
Total Interceptions	Total sprints
Shots / on target	Average top speed running
Shots per min	Average jump height
Pass per min	Total Sprint distance
Total Tackles	Highest jump
Goals	Running time/distance
Possession %	Max heart rate
Turn over time	

Tables 5.2.C: Examples of how Team football performance and physical data are different

Data such as, highest jump, may be perceived as a technical attribute, even though it’s a physical attribute. This can be related to football also, where the highest jump can relate to how well outfielders can reach to head the ball, or goalkeepers to make saves. Defining the different type of stats are important. Measuring performance stats may require camera accessory, so a review of motion can only be related in physical stats. An example can be a player that sprinted 50% of 1km total distance run, during a game, but the user may have had poor performance in technicality. This means that even if the wearables say the user has performed well due to physical attributes, the actual performance does not match what the user has done for the game.

Sensors collect physical movement data, but there will always need someone to interpret this, to form a subjective opinion and offer any advice within sport [Broadbent, 2017] [Gobinath, 2017]. Zepp uses a camera to define some of their performance measuring capabilities. Filtering the monitored data gives the users a representation of their performance, where calculations are heavily dependent on if the user makes the intended movements [Zepp, 2019]. Therefore, wearables come with camera accessory because, it tracks the player, and acts as the “eye”, to give the automated response in performance. Sensors measure performance stats via data processing, where filters can convert the physical data in performance terms [Gobinath, 2019]. This requires calculations, where examples on Tables 5.2.D show how these can be computed. Other reliability concerns are whether real time data feedback is as accurate as post game processed data. A study from Victoria University Australia investigated how real time GPS data compared against post game data. There were more errors present in real time tracking, which means that there are still opportunities for electronic improvements for live time accurate monitoring and feedback [Aughey, 2010].

Individual influence in sport varies depending on whether it is a team sport. Therefore, there is complexity in defining some attributes by sensors and whether it can really help team play. Data monitoring shows key skills that can be tracked, but for a sports coach, they will always prioritize the collective team data [Broadbent, 2017]. Data scientists may always need to be viewing and analysing the sensory data and linking them to key performance attributes. This may require multiple sensors working together [Wundersitz, 2015]. Performance stats are more technical, and if advancements are made to allow data synchronisation between teammates in training, only then can a collective team progression be made. Even if this is successful, having a subjective opinion is always an important factor. Thus, in what context is an individual judged based on team performance, and whether they themselves are improving individually to help the team efficiently or tactically; are questions that can only be subjective [Gobinath, 2019]. Some wearables allow coaches input as part of the feedback. Psychology plays a big role in sports performance, and momentum is perceived as consistency of good form, but a method to monitor these terminologies implemented into WT helps build its smart value, as they are used as observational data.

How the data is protected, is an ethical concern. There are security measures deployed to prevent consumer data from being accessible by other parties. This is an important parameter that designers and manufacturers of wearables will have to consider if they are to release their product to the consumer market (biggest segment). Protecting the consumer’s identity and data relating to their personal wellbeing, but also the programming of the system requires priority due to how sensitive it can be to all parties involved. If data breaches do occur on a manufacturers system, then it is very easy to alter the algorithms, which can completely disrupt the data processing elements of the wearable (reading out wrong data to confuse or worry the user). Therefore, balancing the budget is critical in terms of how many layers of encryption they require to be safe and protect the sensitive data. this must be prioritised to comply with GDPR.

5.2.2 Calculations and Accuracy

Accuracy of wearables and transparency of the data published are fundamental elements. Producing calculations with precisely monitored body movements and quantifying them in a way that consumers understand is a smart procedure, but how well the sensors measure these body movements is another concern entirely. It is still considered that the wearables are not accurate in producing training data [Ferguson, 2019]. It has been perceived that sensor readings are moderately accurate to actual movements. Accuracy is higher when doing exercises of low to moderate intensities or when doing consistent movements, such as jogging [Xie et al., 2018]. This is also the case when the sensors are exclusively measuring one attribute [Husted, 2017]. The accuracy differs more when doing sport related activities where players not only experience high intensity, but they are constantly changing states (e.g. football), which leads to sensors not producing accurate readings [El-Amrawy et al., 2015]. Readings that users see are not just the quantities that are measured by the sensors but what the program is told to do with these data. The conversions, algorithms, and data process of the monitored quantity are all equally responsible for the accuracy of sensor readings. The calculations are programmed on the microcontroller, which process the raw sensor data to make sense of the new meaningful data.

Key formulas link distance (s), velocity (v), and acceleration (a) via integration/differentiation with respect to time (t). Integration allows this procedure to work from acceleration to distance in reverse order, where Tables 5.2.D displays which attributes are monitored by accelerometer and gyroscope, then calculated to produce more data [James, 2016].

- s[t]: distance is a function of time
- v[t] = S’[t]: velocity becomes a function of time (differentiating distance once)
- a[t] = v’[t]: acceleration becomes a function of velocity (differentiating velocity once)
- a[t] = v’[t] = s’’[t]: acceleration becomes a function of distance (differentiating distance twice)

Sensor	**Acceleration (ms-2)**	**Velocity (ms-1)**	**Distance (m)**	**Angular velocity (rad/s)**	**Angular acceleration (rad/s2)**	**Relative angle (rad)**	**Absolute angle (rad)**	**Force (N)**	**Moment (Nm)**
Accelerometer	Measured	Derived	Derived (2x)	-	-	-	-	Mass derived	
Gyroscope	-	-	-	Measured	Derived	Difference calculated	Integrated	-	Inertia derived

Tables 5.2.D: Accelerometers and Gyroscopes calculations in computing desired sport physical attributes [Gobinath,2019]

Tests have been done on fitness wearables where the accuracy of the data was perceived to be consistent amongst the different types [Shin et al., 2016]. This validated that the wearables were monitoring accurately but they differed from each other in that they were affected by various activity states [Murakami et al., 2016]. Inaccuracy can be judged against one wearable reading, using camera recording, and a computer (more powerful machine) to measure the quantities at the same time. This can directly link to what the data conversions are giving, to test how accurate the wearables are [Ferguson, 2019]. When intense activities do occur, the processing of raw data needs to improve in accuracy to give precise meaningful feedback. Football wearables like fitness wearables, advertise as tracking many factors, this can complicate the programming side, which results in more inconsistent accurate readings [Xie et al., 2018]. It is very appealing to say a wearable can track every attribute needed for football, but it will require a very complex coding algorithm to be able to distinguish the many different features (states). It may be a better alternative to split the technology, with the equipment worn. This simplifies what the wearable can "accurately do". Any wearables must be smart enough to detect the changes of activity states, as the current benchmarks already split categories of these in lifestyle activities [Gobinath, 2019] [Ferguson, 2019]. Accuracy of sport wearables tend to differ in that they are measured via camera tracking. This method gives a better subjective analysis and makes it easier to validate the quantified biomechanical movements [Gobinath, 2019].

Design for behaviour change is crucial, especially in sport wearables. This is where equipment implementation with electronics can have "new impact", on the perception of having technology involved [Gobinath, 2019]. It is easy for football players to not want to wear wearables. Even though technology has become more affordable, the question is whether it is a worthy investment, as the user must adjust to new belongings. There can be usability issues that hamper the success of wearables, but wrist worn devices showed their own ergonomic advantages which can be exploited for football [Shin et al., 2019] [Gobinath, 2019] [Kalantari, 2017]. How users adapt to the experience of having these new clothing as part of their football equipment, forecasts the sustainability of the wearable [Murakami et al., 2016]. New equipment design is equally responsible as the feedback on wearables, to determine positive behaviour change, and if the adaptation can be sustained for future innovations.

5.3 Parameters of research study revolving around football boot materials, penalty kicking biomechanical analysis and how video game assigns statistics of players kicking abilities

5.3.1 Materials and Boot Design FEA

Sustainability is a factor for design in the product sector and user experience of WT. This is heavily involved with materials and how embedding electronics can be an easy alternative to simple wearables. This would entail technology themes that develop in terms of sensor advancement on equipment and design themes of how the user adapts to new lifecycle of the product.

Conductive threads are a way of embedding electronics within fabrics. Nylon is a default material in this application, which has silver coating (conductive factor). The option to have a range of resistance means the designer has flexibility in circuit design, influencing the overall product. If the wearable is integrated onto a top, then the actual surface area is large. This means that the current distribution must be large, hence a smaller resistance. If the embedding equipment is on shin pads, the surface area is much smaller than that of a football Top, this means that the current doesn't require large coverage, hence higher resistance preferable. Stainless steel threads are more of an example of something that's difficult to sew due to their "twisty" structure [Learn.sparkfun.com, 2017] [Gobinath, 2017]. Considered "very reliable with low resistance", as "zig zag" stitching formation is preferred for this material. Soldering is a much more reasonable solution unlike the Nylon threads [Learn.sparkfun.com, 2017] [Reviseomatic, 2017]. This is still a complex procedure requiring more research and development to determine how well this can be performed. It would be ideal to embed them into football equipment, however if the product lifecycle and user journey is not efficient as existing standalone device, then the latter may still be the preferred alternative.

Basic equipment is enough to sew conductive threads, but football equipment is made of multiple different types of fabrics. It is important that the chosen fabric to be integrated with these types of circuits, is not only compatible, but sustainable. Wax treatment helps maintenance of the thread textures. When the edges of different strands touch, they instantly "conduct between them". Designing the circuit layout on any equipment will have to make sure that this doesn't happen. It is important to separate which conductive thread carries which signal. Making prioritised threads independent without contact to other threads, prevents short circuit. If the design requires “cross traces”, an insulating layer is needed between. [Gobinath, 2017] [Learn.sparkfun.com, 2017]

Figure 5.3.1; Table 5.3.A, shows the equipment that exist for amateur footballers. The items listed here are common, giving the opportunity of WT embedding, within them. During cold conditions, players tend to wear thermals inside, this is another opportunity to investigate further equipment, but it is limited due by the certain periods of climates, where they’re worn. Boots are more compatible as its worn regardless. Wrist bands are more worn in summer and can act as a traditional wearable like fitness tracker, due to position, but covered with fabric, where gloves can be an alternative for winter. Socks can also be investigated, but the ease of them tearing, makes it vulnerable. Weather conditions also affect sock fabrics and different pitch surfaces affect boot studs.

Equipment (inc. Inner thermals)	Electronics embedding possibilities
Top	Sensor placement, similar to vests (ECG sensors acting as Heart rate monitor)
Shorts	Threads linking to IMU circuit (e.g. for number of strides, jumps, monitoring muscle strain, impact)
Boots	Circuit placement, Battery (the weight will be negligible here and safer option than placing on thinner fabrics)
Shin Pads	Sensors and circuit can be placed here to monitor physical attributes.

Figure 5.3.1; Table 5.3.A: Method of potential WT implementation into football equipment

With material advancements, flexible sensors, conductive threads and smart material being embedded into clothing, can make sport equipment itself become a sensor [Anzaldo, 2015][Patel et al., 2012]. This is a way of including electronics without accessory on clothes, so the design is made exclusively fit for monitoring. There can be an argument which industry may benefit from this, however if the sensors are functioning precisely to their needs, then it can be used for injury monitoring as well as performance [Awolusi et al., 2018]. Injury monitoring will need precise sensing, as incorrect or inaccurate readings, can have impactful implications. If a player wearing a wearable has a reading where an injury has not been notified, but there is some injury, the player could make it worse. Giving a greater level of freedom to where key components can go, means greater design specification refining, but without compatibility concerns (easier testing phase). This may be useful for training or lifestyle applications to truly test different consumer types for the same wearable, deepening the understanding for engineers and designers for future considerations.

These following designs use research to refine boot material, which are analysed under FEA, to help outline research parameters. This is to allow any potential future decision matrix and design data framework to consider different weighing or alterations depending on boot chosen. The stresses are analysed to show if it will affect ankle rotation as well as solidifying if the FSR sensor should be placed on the outer sole of the boot, as the dissipation properties can affect readings. The outer sole is compromised of the upper sole, midsole and vamp regions of the boot anatomy, which can be viewed on Figure 5.3.2. This test is to proof the framework reliance and significance of monitoring ankle rotation in football shooting with sensors.

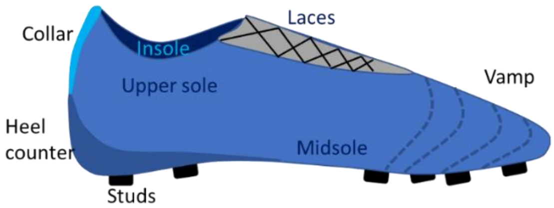


Figure 5.3.2: Football Boot anatomy

Boot Design FEA

With ankle being the key area of focus, and preliminary research supporting that boot have the heaviest investment from End users, a material study is conducted linking boot design features to player positions [Gobinath, 2017]. Materials are one of the fundamental components for users selecting their boot, as it's essential for comfort in allowing them to perform to the best of their ability in a safe manner. The first ever football boots were made from leather, where advancements saw synthetic material, mesh, knit and crystal polymer fibres which designers engineered to give excellent performance for different conditions. Screw in studs helped players adapt their needs with customisation in terms of playing on different pitch surfaces [Soccercleatsportal, 2021] [Unisportstore, 2017] [Thomas, 2017].

With the game evolving, boots are becoming more prioritised in human centred design, delivering greater opportunity for the player to adapt them to their gameplay style. As they are a complex equipment where each boot design has specific features for different positions in football, linking to actual game attributes those players may desire. The user, will choose regardless, depending on what they desire aesthetically, cost, comfort, who they support etc. This is something that designers must consider as a player's own interest means the features of the boot are desired by user to match their needs grants modular wearable designs to give more freedom. If the designer wants integrations of sensors on equipment, then they will have to analyse how it accommodates different boot properties.

Size and skin contact can be a concern depending on the individual. Aesthetics can be an obstacle to replace traditional sport accessories [Hildenbrand, 2019]. Football enthusiasts may feel they do not need them due to their success from traditional methods of training. Some players may want their own "Branded" equipment. When there are numerous materials out there, that they are comfortable with, it will be hard for them to try something new (adaptation process). This can be due to health conditions, such as sensitive skin, but it may also be endorsed by Brand reputation. There are reasons why consumers would want this technology in their football training programs, but whether that's as an accessory or smart clothing, only testing can determine it depending on value [Gobinath, 2019].

Players may choose to adjust parts which can improve their weaknesses, some may choose to increase their strengths. Overall, a player wants to continuously improve their game. This could be linked to attributes such as control, power, accuracy (passing, shots) etc. Additional material, or a combination of them are common for football boots, as a different part of the boot is used for different types of play in football. This means that material consideration must be in depth, to allow a user to adapt the shoes to their game. If player A has weak shooting and Player B has less curve on their crosses, they both use different side of the boots to execute these actions, hence the materials for their segments would be different. Boots may have become modular in terms of outer sole customisation to give use more freedom to keep single boot and change its anatomy. Greater technology manufacture powerful materials to give boots the best characteristics for optimal performance, which are composed of fibres and composites [Unisportstore, 2017]. The shape of the outer sole determines how well the ball can be struck. Some designers may choose different vamp, upper sole and middle sole materials, if the purpose of the boot is engineered for a particular player style. These are something professionals have greater influence where they have more research funding to experiment various material threads and stitching to compose the sole that allows peak performance. The anatomy of football boot alters the width of the soles to accommodate different attributes. The narrower sole is generally used by wingers, whereas the wider soles are used by goalkeepers. This could mean that separate boot designs may be a better solution when assigning it to a position where the materials rectify these factors.

More studies in Football specific shoe properties and how it affects performance were considered in redesign. The science of footwear conducted a survey where male football players were opiniated on the key properties of shoe design that enhances performance. The key 5 properties were “comfort, ball sensing, traction, stability and weight”. Comfort was perceived as the most important, this could be the insoles of the foot having good cushioning properties to sit smoothly against the skin as player manoeuvres, but also dampening upon impact to have the ability for sustained quality kicks. This resulted in suggesting that “the importance of boot material which affects the accuracy or power of the kick, is less desired”. Weight was the least important, however this study did not specify the position of the players that surveyed this [The science of footwear, 2012]. This could be important, as a defender, may have different football boot design desirability, compared to a midfielder. Even same position players, for example forwards, could prioritise different aspects of their game, which hinders the selection of boot, where one would want more traction for better dribble ability, and another padding for better dissipation whilst conducting powerful shots.

Moschini and Smith examined how the weight of the football boot could influence the velocity of the ball. Whilst monitoring laces shots, it displayed results where “the foot velocity decrease with heavier football boot” but the “ball velocity had no major direct differences”. The difference it did show was regarding was how much “hip and knee flexion was reduced whilst boot mass increased”. This is a key biomechanical element of kicking a football. The study highlighted how the material that could affect the density of the outer soles of the boot, would have minimal effect on how much ball velocity is exerted via laces kick [Moschini and Smith, 2012]. The concern would be how much dissipation the sole material can exhibit to prevent forces being felt on the metatarsal bones. Sterzing et al 2011., studied how the laces technique, where the foot is in full plantarflexion posture as the kick is executed, is affected by the boot material. Doing these kicks bare foot and with a boot, they concluded that the “Players that would kick with bare foot experienced a higher ball velocity”, meaning that the boot was a hinderance in achieving full maximum ball velocity [Sterzing et al., 2011]. Tang et al., studied how the boot collar around ankle biomechanics after the anterior and lateral leg jump. this resulted in high collar affecting ankle motion compared to an elastic and lower collar [Tang et al., 2020]. These studies show that Boot design needs to be implemented into WT physical to performance data Framework.

Ansys Granta CES EduPack Material Selection.; Appendix Section 5 displays Material selection diagrams with filters applied

Ansys Granta CES EduPack software was used to refine boot design materials, where the limit function can be applied for restraints, to meet specifications [Ansys, 2022]. The first limit function applied was mechanical loss coefficient to be between 0.5 to 1, where 1 being the best dampening property of a material. This showed that elastomer family is best suited for this. Water durability must be excellent due to environment conditions being broad when games are played. Density and price are added filters allowing greater material refinement, with End user consideration. The refined materials show Polypropylene foam (PP) and Polyurethane foam (PU) as best fit for inner sole. Both are used for insoles in footwear. In regards of price, polypropylene is better with excellent durability. Polyurethane is much more expensive however the mechanical, loss ecoefficiency is excellent, where a user may prefer comfort more than durability. These two selections give more flexibility in design, as there is a greater chance to publish both materials inner soles, letting the consumer choose. It can also be designated to position, where polypyrene may benefit goalkeepers, polyurethane benefitting forwards, due to density.

For the outer sole material, in CES, a search was made for all footwear adequate materials. Amateur footballers will have some limits on investment; hence price is a concern. Synthetic materials are part of the reason why brands such as Nike® and Adidas® have expensive boots aside from their brand's recognition and loyalty [Nike®, 2022] [Adidas® ,2022]. This would have required extensive research and testing, with patents on the structure if they were to be innovative. Further refining in materials such as density, price and durability eliminated materials that didn't meet requirements. Polyvinyl chloride (PVC) became a reasonable option which proved why renowned brands use this as their outer sole material. The price allowed more materials to be selectable, however with external research, it showed that PVC and Styrene butadiene rubber (SBR) were two materials already present in football boots in current market. SBR had lower dampening coefficients, hence it would give more feel more to the user. This may be preferred for some positions like forwards/strikers where they want to feel as much of the ball. This is important because if sensors are integrated, this can impact the sensations felt on feet, where user experiences different loads. This may require more adapting, which will only come once they're comfortable executing kicks continuously.

Shoe Design consideration for Test purposes

All Boot design anatomies aims to accommodate different position and attribute qualities for football. For this research there are 4 boot designs, one each for goalkeeper, defender, midfielder and forward. This is to consider how user's choice affects actual design to purchase depending on their intended position. For this it was important to identify which position would require which boot design factors. Using Table 5.3.D as a tool, designs for each position were made for a size 6 (UK) boot. These design considerations were based on research on existing boots as well as discussing with end users [Gobinath, 2017].

Design consideration for all boots is that they need to have good outer soles to give them good surface for a clean strike of the ball. This gives the player confidence that their boot can execute shots like they wanted to. Different position and attribute qualities could lead to different design of boots chosen. For this test, the boot design just focuses on the certain features needed, regarding the position of the players. The reason actual design and the material content would differ is to allow user to purchase depending on their interests regardless of their intended position. So, the factors considered important to identify which position would require which boot design factors, was based on current market boots for each position as well as their role. Design was not solely accommodated for shooting purposes, as gameplay needs were identified to come up with designs. They are different to not only highlight what different positional players want, but also their key potential needs. However, it should be highlighted that a single boot design, could also be favoured by two different positional players.

Boots were designed on SolidWorks® computer aided design software, as seen on Figure 5.3.1 [Solidworks®, 2022]. To distinguish features differently for different positions, the outer sole sketch was done first. The process, in trying to make the boot accommodate midfielder's requirements, allowed the sketch to be wider at the heel, but the dampening padding cannot be added via sketches. This is done with the thickness feature after creating a surface. To design the inner sole, the offset feature was used, with surface extension around the top edges. This is where two separate surfaces were created to emulate the inner and outer soles. The base sole was extruded inside, with a surface plane created on the outside to place studs (extrusion). Table 5.3.D explores how different position in football would require different boot design features and design considerations.

Position	Boot features	Boot design considerations
Goalkeeper	Strong striking surface Padding Wider outer frame Comfort interior Heavier	The width of the outer sole would be larger than other position Thicker outer sole Heavier base Extra padding
Defenders	Light Narrow Small outer frame Conical studs Agile	Thinner thickness of outer sole Tight fit Light weight Impact protective (desirable)
Wingers/Strikers	Soft soles Thin Tight fit Narrow base	Narrower outer sole More streamlined design Thin material
Midfielders	Precise control fit Padding Increased flexibility Asymmetric lacing	Padding for dampening Wider heel surface area Thicker laces

Table 5.3.D: Football boot features for different positions; [Gobinath, 2017]


Midfielder

Defender

Forward / Winger

Goalkeeper

Figure 5.3.1: Football boot designs for different positions; [Gobinath, 2017]

Midfielder

Midfielders have the most varied influence out of all position players in football. These players must maintain different roles within their position as the game goes between attack to defence, or vice versa. The adaptability in roles, means that boot design, would consist of multiple elements put into the process, where a balance would have to be made. This is to deliver a well-rounded boot that accommodates the multiple needs of a midfield player. A midfielder is the position that provides the greatest number of long / short passes and long distances shots. Making tackles will mean they are more likely to have frequent collisions with other players foot, albeit not as much as a defender. Multifunctional in terms of material properties that can be very durable, allow protection of the feet to consistently produce effective kicks, means that a boot design for a midfielder could be considered the hardest.

Defenders

Defenders can be split into Central and Full backs (wide players). Full backs are generally known to have more attacking responsibilities as well as defending, hence their purposes are different to that of a central defender. The roles which are the same, is being able to give long crosses at both high and low heights. This means that their passing accuracy and power will have similar importance where the main similarity is that they both are “defending”, hence tackling opposition players and frequent close contact results in a lot of impact being felt on their boots. Comfort of the boot which may need more protection, with good padding, gives the boot more mass, however there is a need to perform good passing, as full backs consistently would want this. The mass distribution could be applied on the outer or inner soles of the boot. Defenders are known to try score from headers and long shots, however with the game is evolving, more defenders are taking responsibility in executing penalty kicks, meaning their boot design should still consider some features that accommodates striking laces/inside foot shots. If you compare a Forward who is an excellent goal scorer, with greater accuracy, during the game, or at the end (when penalty kicks are normally taken), they will have greater kicking fatigue. A defender may not have performed as many high velocity kicks, hence their energy levels to execute a powerful yet accurate kicks, may be greater. The difference in designing for defender boots was to get a narrower base whilst not allowing the outer sole to be too thick, due to lighter requirement. The comfort and protection are equally important; hence the inner and outer sole layers shouldn’t have much difference. A no lace design, as focus group defenders mentioned how they wanted a tight fit, easy to wear boot [Gobinath, 2018]. A smaller offset was created so the inner sole is very close to the outer sole, with conical front.

Goal Keepers

Goalkeepers are surprisingly known to be good penalty kick takers, due to the fact their role in the game relies on them to perform long powerful passes, and they don’t run around a lot, which allows them to have greater endurance and less fatigue during penalty kick situation. In terms of boot design, strong grip is vital to allow their agility on the line as well as their traction to lift off for jumping, to be done frequently with minimal stresses. Design considerations can involve heavier mass around the toe caps, vamps, and middle soles, but this will be dependent on an individual basis. Like the midfielder boots, this had a wider sole and the top edge of inner sole surface were extended. The reason this boot had no laces, was to allow the player to access as much striking surface as possible. The inner sole has extended edges to allow a more wrap feel around the ankle, i.e., higher collar design.

Forward player Strikers and Wingers

Forwards are key players known for striking the ball and being the best at it. Their role is to be effective shooters who can deliver powerful accurate shots. Their needs will mostly be revolving around gameplay, such as having good traction to give the best agility, for them to make those sharp turns and run behind defenders. They also play central as well as wide, so they must strike clean to deliver crosses from the inner middle soles. This could be the same for wide defenders, who may prioritize their pace and clean passing ability with the inside of their foot. Forward player’s ability to shoot in impossible positions will also require great comfort and flexibility whilst wearing the boot. This also means that they will need to have good impact protection, because they will also be the players on the receiving end of strong tackles, whilst also hitting the football hardest. Having a relatively thin padding for weight considerations and for the feet to get a greater feel of the ball, was a good specification for this boot design. The outer sole is thickened slightly for dampening properties to have some protection. The no lace element is implemented the same way goalkeeper intended boots are designed. Narrower base is used for tight fit and more streamline. The feel of these boots should be a "suction" so that the feet have no room within the boots, to give maximum feel.

Testing FEA regarding Boot materials helped understand the stresses that could be experienced when loads are placed around the boot. The different boots have design considerations which were influenced from material, biomechanics, and human factors research. The selected designs are linked to potential position player desires. This can also be the case for the type of football gameplay the user wants to play, and their striking ability. The following analysis are comparing 2 outer sole materials in PVC and SBR with force being applied on the side for inside foot shots, forward for laces foot shots, around the full boot to understand how their impacts will be experienced. This is to understand material properties, and if there would be any difference when considering Decision matrix design to consider different weighing of attribute ranking methods for different boots worn.

The boot designs that were created on SolidWorks® software, consists of built in FEA [Solidworks®, 2022]. The force value is chosen as one of the higher possibility forces that can be experienced in kicking. This considers ball mass being approximately 0.4kg and as penalty kicks are stationary (ball initial velocity 0 m/s), typical high-end kicks can reach approx. 30m/s, where the acceleration needed would be around 3000m/s^2, resulting in 1200N [Mathematicshed, 2021]. 1000N was assigned to give a fair estimation of constant load across the different planes tested. This examines how the materials will behave, for different shot types around the vamp and midsole region. This is important as the decision matrix will need to be considerate for WT calculations to be "smart", regarding boot material weighing. The outer sole has stresses experienced on them and the base of the sole, is a fixed position, as with shooting, the base is generally something that does not experience any bending or is very minimal. Strain and Displacement results were all taken to provide greater comparison factors.

The test procedure after assigning boot design to Test follows:

1. Choose linear static analysis
2. Apply material to the selected boot outer sole
3. Apply mesh control on outer sole
4. Apply fixed position on the bottom layer of sole
5. Apply force of intended direction on outsole
6. Run the study
7. Repeat by changing the force direction Plane (I.e., right plane for Inside foot shot / Front Plane for laces foot shot)

Results

FEA analysis showed that Vertical forward force on the boot experienced least amount of stress, which supports why players prefer to use laces as a form for greater power, as they would feel less. This study also showed how the inside stress felt, would be almost identical to the overall stress felt. The likelihood of having inside foot shot with the same power as laces, would occur depending on the angle of contact and where the ball's intended trajectory would occur. This would mean that when placing sensors on the inside midsole region, there should be some consideration and expectation that more stresses could be felt for the same kick velocity, depending on boot anatomy.

Midfielder boots are also the only design to consider laces on them, and this resulted in the stresses being felt closer to that region on outer sole (upper sole). When inside foot shots occur, if the player has eversion with slight dorsiflexion when striking the ball, and there are sensors in between the upper sole and vamp, this will give a high reading (FSR). The reason for this would be that the contact point will occur where there is less surface on the boot material, hence greater force in a smaller area, i.e. higher pressure. This means that when designing a decision matrix, that considers kicking attributes, the type of boot worn will have some factor affecting it's weighing, because the overall forces felt will not be the same for the same kick velocity, as a non-lace designed boot.

Even though defenders had the greatest stress distribution, in terms of Hot spot (peak stresses), these were mainly occurring during the base of the soles. This could be due to the FEA setup having placed a fixed position here. This means that even though their boots are designed for both type of defenders, this design may be preferred by wider defenders. Central defenders may find it better to use the goalkeeper version out of these 4 designs, depending on their intended gameplay.

Goalkeeper boot showed very low static stresses, which proves how a thick outer sole, provides greater dissipation. Football boots which have great thickness or are heavier, will need to consider different sensor data processing, to make sure it's outputting reliably. This is something User experience researchers will need to show in their flowchart of how data is communicated depending on the user's desired boot, e.g. if it automatically change the scales of any weighing depending on the thickness of outsole, and density of material.

This test also suggest that boot designs will affect how much stresses are felt on the outer soles. This is because, even with the same materials, but different distribution across the anatomy, there are different stresses experienced. This can be linked to the thickness of the outer sole; however, the hot spot regions prove that the design dimensions also affect where most stresses will be felt. PVC and SBR comparison display different stresses, which for future sensor integration options needs to have viable data processing consideration.

The boot FEA test confirmed that the Decision matrix will need to accommodate boot design consideration for longer kick set pieces. For penalty kicks, as the distance is small to target, the effect may not be entirely fair. However, regards to ranking attributes with a decision matrix, it may only be viable for sensors placed on the surface of the outer sole, which monitor pressure or force, i.e., FSR, as the stresses on inside will require greater material analysis showing the stresses felt inside (probe placed on the interior will show inside stress). Even if IMU sensors are placed on the outer soles, the function of this sensor makes it unnecessary to have a weighing factor relating to its monitored attributes. When considering monitoring other non-shooting attributes, the possible weighing could differ as "agility" can be affecting the ankle range of motion, by having different collar lengths. For WT to monitor attributes an FEA test is essential prior to any data configurations.

Figure 5.3.2 – 5.3.5 show a sample of FEA results for different boot design, with respect to their force direction. This compliments Figure 5.3.6 which shows where the Peak stress hot spots were regarding boot anatomy. Blue represents PVC and Orange is SBR, and "o" is the overall stress around the whole outer sole. Arrows show which way the stress is highest, depending on the force direction, where both side and top views are given to show precisely where peak stress occurred.

Full FEA screenshots are in Appendix Section 5.

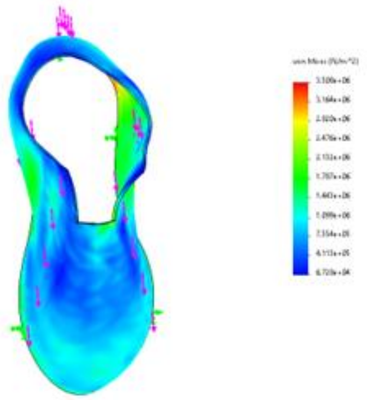


Figure 5.3.2: FEA Sample of Defender boots Forward force

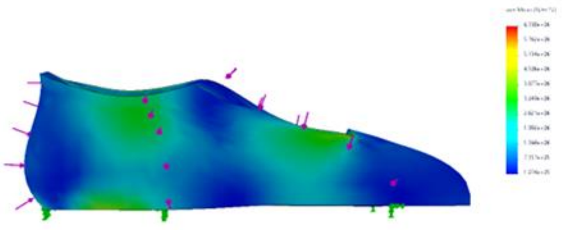


Figure 5.3.3: FEA Sample of Midfielder boots Overall force

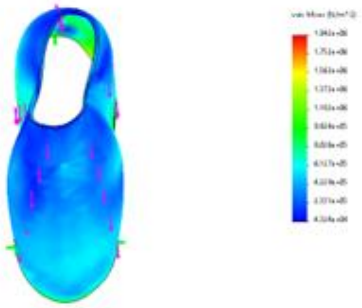


Figure 5.3.4: FEA Sample of Goalkeeper boots Forward force

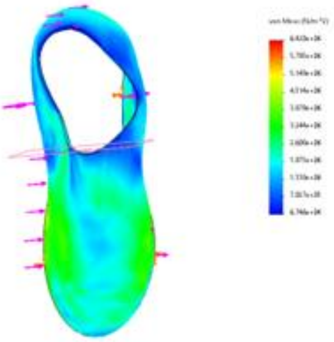


Figure 5.3.5: FEA Sample of Forward/Winger boots Side force

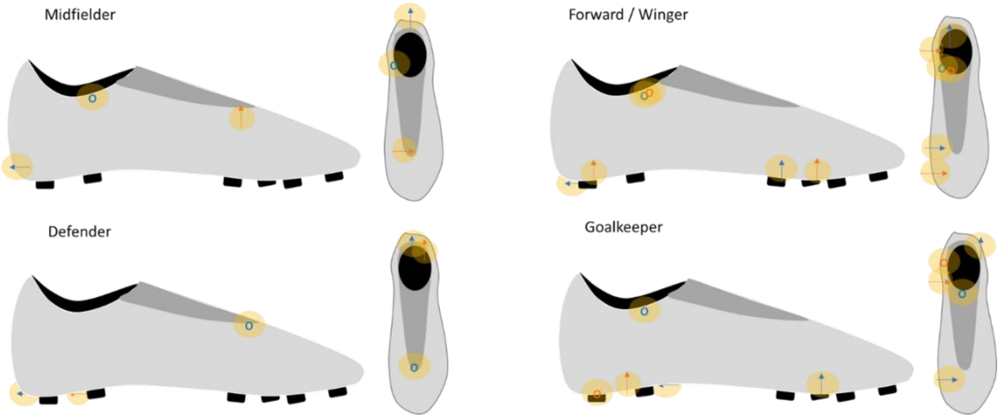


Figure 5.3.6: Hot spot points for different Stress variations

Figures 5.3.7 and 5.3.8 display the stress distribution variation for each position boot design. The overall stress variation displays the range in which the stresses are felt across the whole boot. The vertical forward stress was intended for forces that would be felt when laces shots were executed, and inside stress for inside foot shots. From Figure 5.3.7, what can be deduced is that the stress variance range between PVC and SBR are similar for both midfielder and defender boot designs, with SBR experiencing higher stress values. Figure 5.3.8 shows that for forward/wingers boot design, the materials have different stress variation. Vertical forward stress is greater on the forward/winger SBR boot, compared to PVC. This shows how boot anatomy can impact what is felt on the player, dependant on how much dissipation the material experiences. Hence, composition of boot anatomy will affect sensor readings if they are placed on the inside of the boot. Goalkeeper boot design showed the least stress variance as expected, due to a larger outer sole thickness. The boot designs are filtered with positional player design requirements, but this can be flexible depending on the user's choice, where a midfielder may prefer to the goalkeeper's boot design. For theoretical analysis, the split was done to compare and give some context to differentiate by positions.

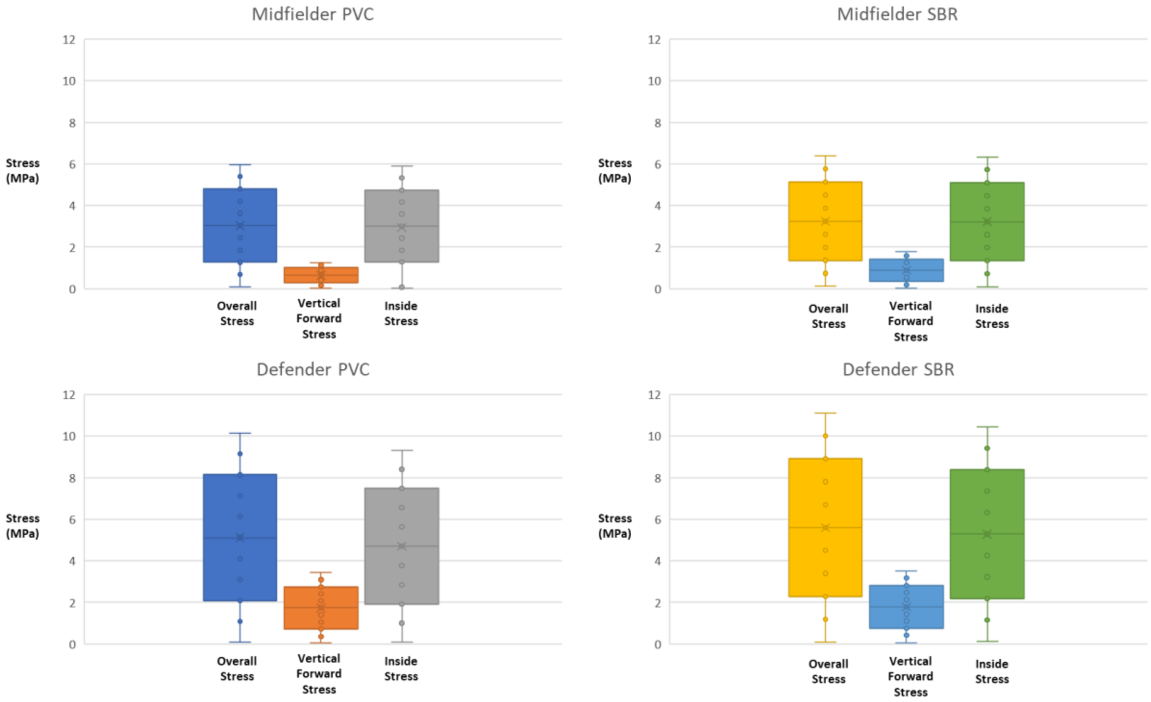


Figure 5.3.7: Stress distribution variation Graph plots for Midfielder and Defender

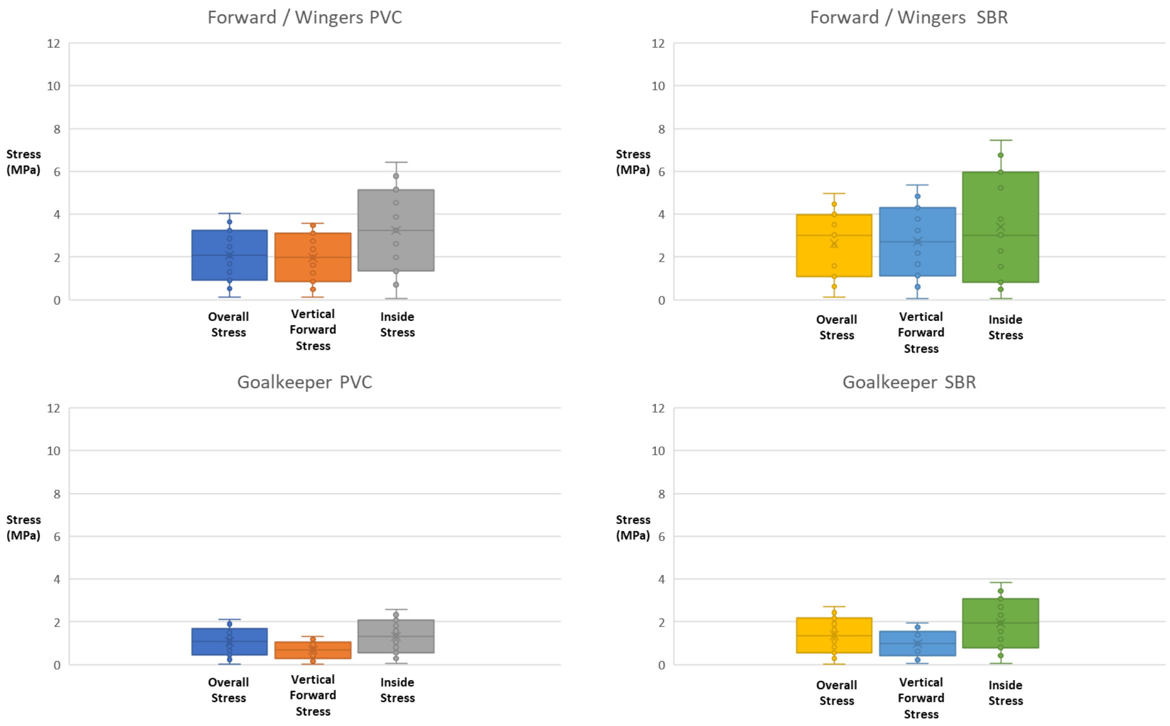
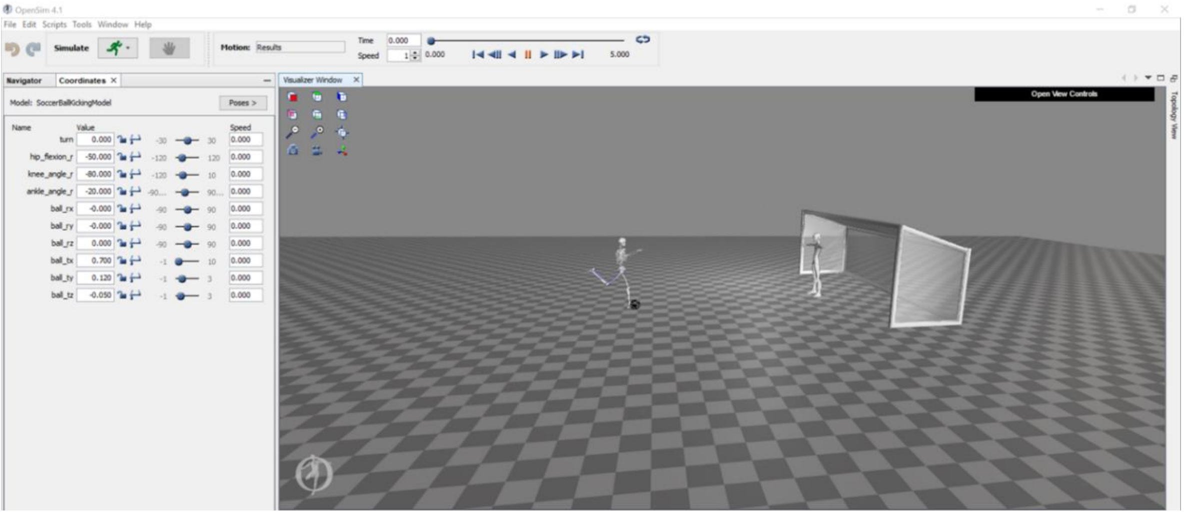


Figure 5.3.8: Stress distribution variation Graph plots for Forward/Wingers and Goalkeepers

5.3.2 OpenSim Penalty Kick analysis

Open sim software contained a football simulator as shown on Figure 5.3.9 which allowed human factors to be tested in a control environment. Even though this is not an accurate version of the experimented data, the biology involved can be analysed to know which parts of the body have greater influence. The software allows plots to be made, so that specific forces involved such as fibre and tendon, could be analysed. This data set can then allow a linkage between the movement of the footballers and their respective body part. This will allow WT to have greater data, because the placement of the sensors will be more "meaningful". This test would also allow confirmation of how important ankle motions are in relation to football shots.

The limitation for this, is that with the script written, the biomechanics had limited capacity. The software would only work on an older Windows® personal computer, hence the testing was slow albeit results showed some confirmation about which muscles are relevant to kicking and how ankle angle affects the kick speed, when altering different hip flexion (key existing kicking biomechanics) and knee angle [Microsoft, 2022]. Ball velocity could not be calculated in this simulation.



Motion: Results

Time 0.000

Speed 1

0.000 5.000

Model: SoccerBallKickingModel

Name	Value			Speed
turn	0.000	-30	30	0.000
hip_flexion_r	-50.000	-120	120	0.000
knee_angle_r	-80.000	-120	10	0.000
ankle_angle_r	-20.000	-90...	90...	0.000
ball_rx	-0.000	-90	90	0.000
ball_ry	-0.000	-90	90	0.000
ball_rz	0.000	-90	90	0.000
ball_tx	0.700	-1	10	0.000
ball_ty	0.120	-1	3	0.000
ball_tz	-0.050	-1	3	0.000

Figure 5.3.9: OpenSim Penalty Kick simulation window

The test needed some control measures regarding how much angle can the hip flexion, knee angle and Ankle angle rotate at the start of the backswing phase, so that it will produce kick speed values. Hip flexion ranged from -60 to -10 degrees, knee angle -80 to -30 and ankle angle -90 to 0. Alternating combination gave 216 readings resulting in different kick velocities. Figures 5.3.10 – 5.3.12 below illustrate how the range compositions are, showing how their angles are worked upon, as the kick is executed. Figure 5.3.10 shows the hip flexion angle range relative to the hip joint, Figure 5.3.11 shows knee angle range relative to the knee joint and Figure 5.3.12 display the ankle angle range relative to it's joint. The negative values tend to be anywhere generally when the rotation at start of backswing is onto the left or upper side from Joint of angle. Therefore, there were no positive value in angles, as it would make it biologically impossible to have a bone anatomy with joints beyond the range of flexibility. For graph plotting purposes, the ankle angle was converted to positive.

The start of the backswing is the control measure applied. The script will then instruct the bone to execute the kick, where different combinations will produce different kick velocities. Comparing the hip flexion, ankle angle, knee angle and kick velocities, give a greater analysis of what lower body biomechanics can produce in terms of data sets. This is where refining and prioritisation for the end user, who may want to work on certain elements of their kicking, would be able to learn from, should the user experience communicate effectively. Having a data set is a good foundation for what future user experience flows can work from, giving early constrains and specifications to the overall system.

Hip Flexion Angle range compositions

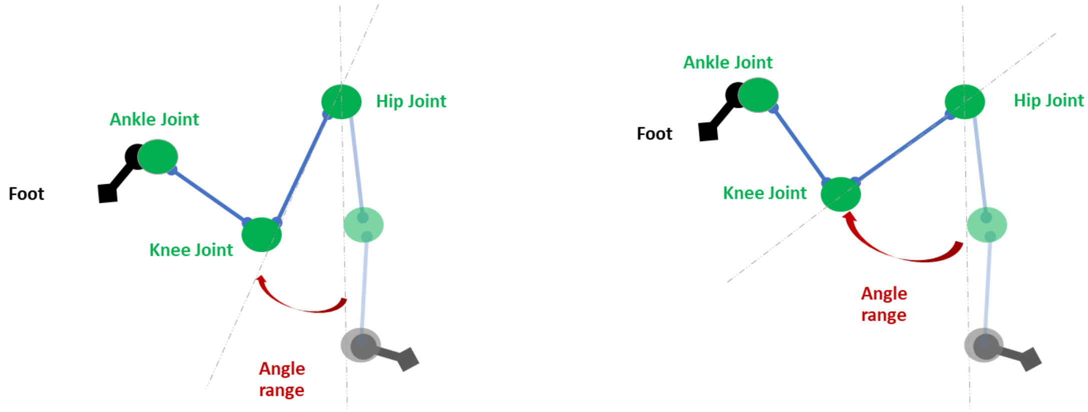


Figure 5.3.10: Hip Flexion Angle range compositions

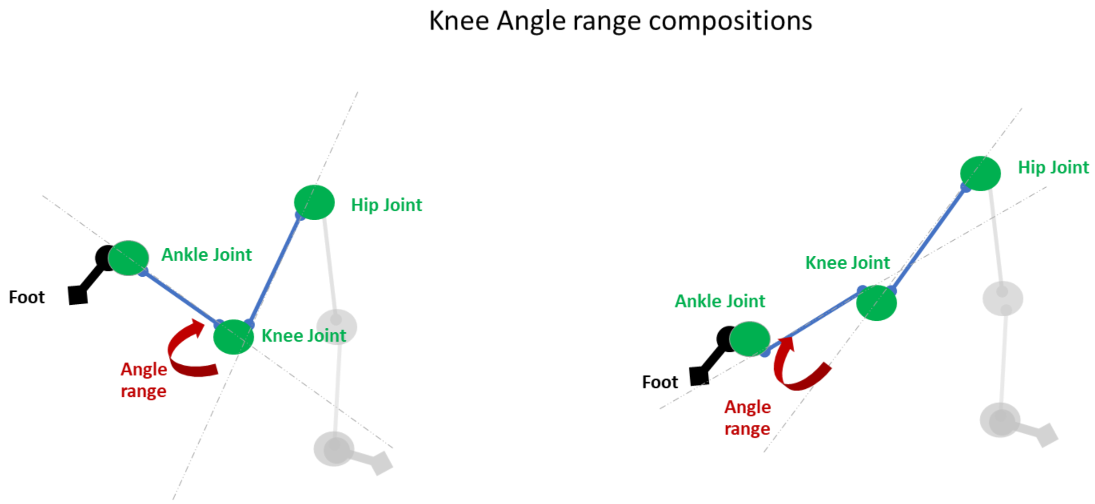


Figure 5.3.11: Knee Angle range compositions

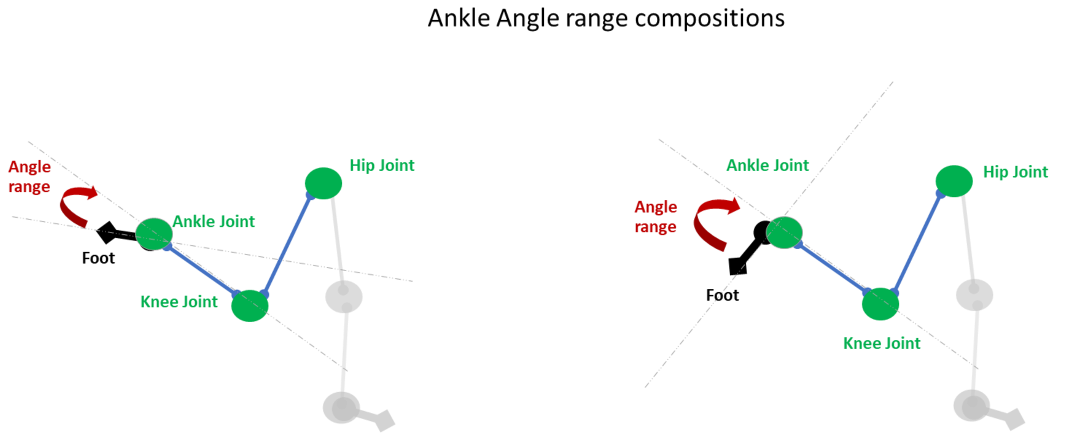


Figure 5.3.12: Ankle Angle range compositions

Figure 5.3.13 shows the Test procedure, which consists of the following routine:

1. Kick setup
2. Alter hip flexion whilst keeping knee angle and ankle angle the same
3. Execute the run command
4. Calculate the kick speed
5. Repeat Step 2 but only change hip flexion by 10 degrees
6. Change knee and ankle angle in alternations to produce a full range of kick velocity results

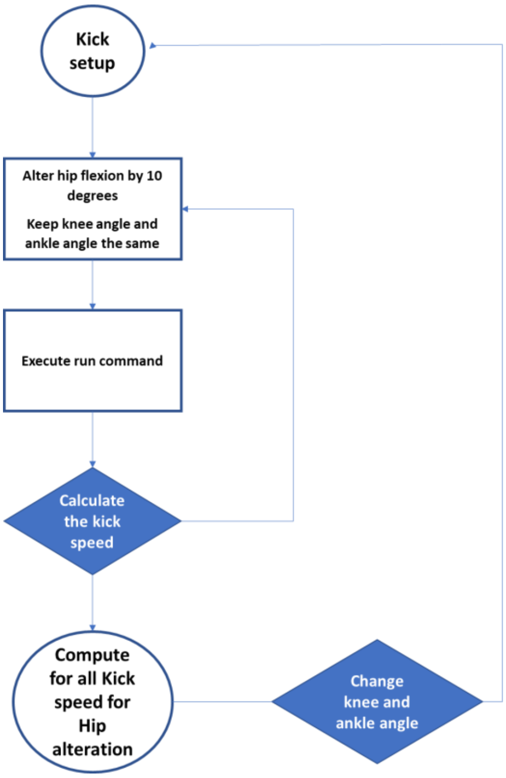


Figure 5.3.13: Test procedure flowchart

From Figure 5.3.14, all the graphs that between -50 degrees of hip rotation to -20, where the knee angle is -70 to -30, the simulation showed consistent results only altering depending on the ankle rotation. Considering the simulation, the rotation of the hips acts consistent in producing kick velocities proportionate to knee angle. As the hip flexion angle goes from -60 to -10, the velocities do decrease with similar characteristics, and it simultaneously does this as the knee angle increases. Figure 5.3.14 also indicates how the transfer of momentum to the ball will be different depending on the body posture, where different ankle, knee and hip flexion angle affect the kicking process.

The greater the ankle angle, the more plantarflexion there were, and this should generally allow larger kick velocities, as there is greater surface upon ball contact. This test showed that when the plantarflexion was around the -30 to -50 range within this setup, the kick velocities were at its greatest. Therefore, ankle angle, is fundamental even when rest of the biomechanics are in sync to execute a good shot. The consequences are hinged on the ankle stance upon contact to deliver sufficient speed. From this test, if the motion axis is to be replicated when doing IMU tests, then this is data set can give some more “inside information” to WT, which can use the sensor data to calculate a player’s relative motion. Linking this to the success of the kick velocity and target, would indicate a good starting point for the system to build into a viable solution in producing meaningful data.

At -60 degrees hip flexion, there were a lot of fluctuations of kick velocities as the ankle angle changed, meaning that this starting range may not have been adequately programmed for this simulation. It also indicates that -60 degrees of hip flexion is not an ideal starting point for backswing. When the hip flexion was -10 degrees, and knee angle was -30, this also showed some inconsistencies in the kick velocity as ankle angle increased.

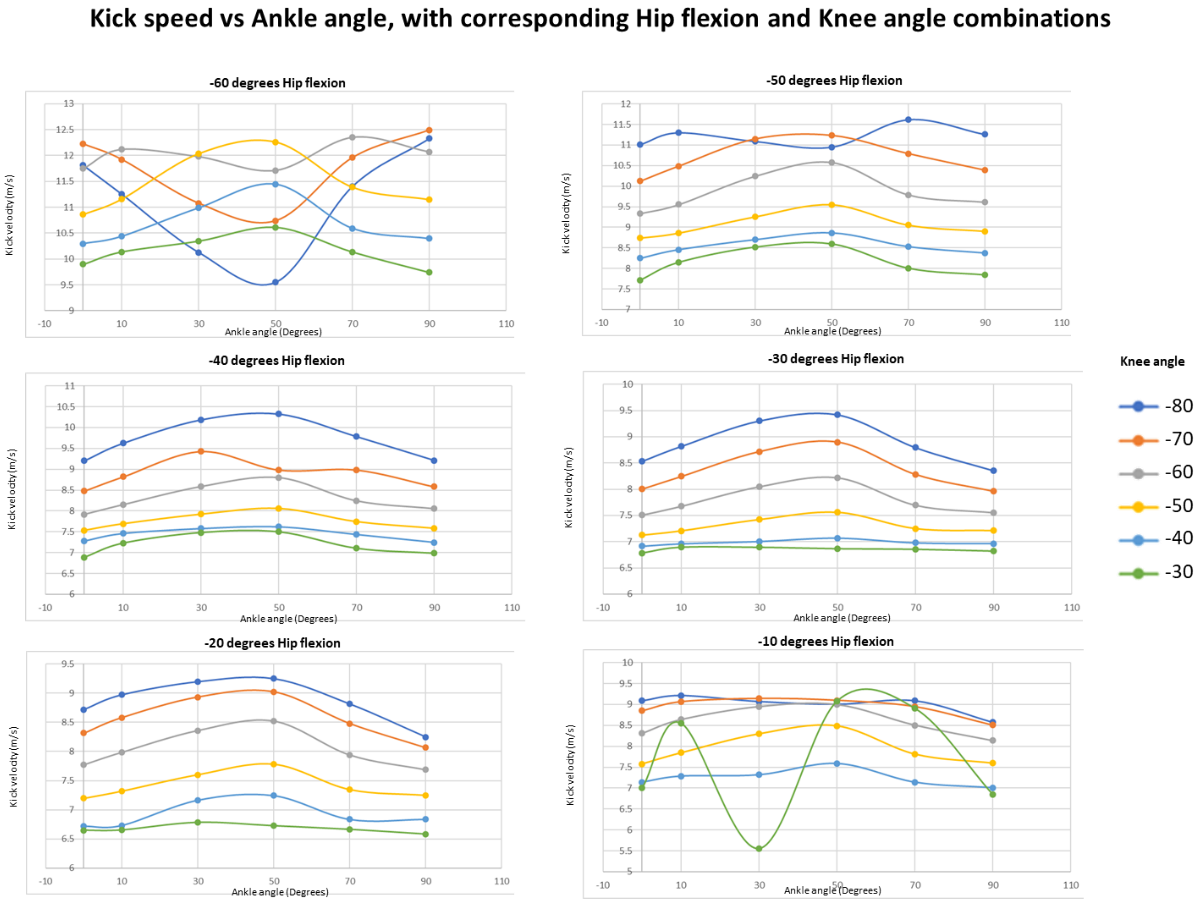


Figure 5.3.14: Graph plots showing variation of different biomechanical adjustments

From Figure 5.3.15, when the kick was executed and comparing how the ankle angle changes depending on the force felt of the muscle and tendon fibres, identified which ones have the greatest changes during shots. The Bicep Femoris Long Head, Tibialis Anterior and Gastrocnemius Medium Head, showed the most changes throughout. Bicep Femoris Long Head showed the greatest force felt for both muscle and tendon. This human factor analysis showed that sensor placement on these regions is feasible to sense changes as the kick goes through.

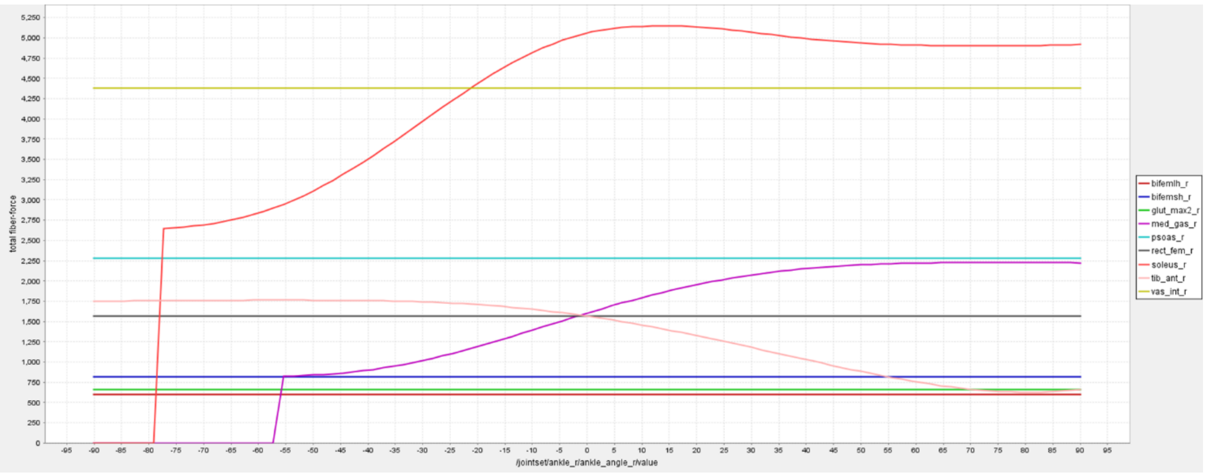


Figure 5.3.15: Total Fibre Force felt as Ankle angle changed during OpenSim Kick motion

In conclusion, knee, hip flexion, and Ankle angle showed combined significance in how a kick is taken and its velocity. However, the graph plot shows more affects are occurring when the ankle angle changes. This is an important step for this research as it confirms how having sensors in this body part as well as making it a key attribute to determine how well a kick has been taken, proving the importance of ankle study regarding this thesis.

This test showing some good data on lower biomechanics, even when the software may not be the most up to date, produced substantial information to take forward in terms of creating a data model for WT application. This test will have greater impact on IMU sensor study rather than FSR, as the rotations involved and subsequent speed of the bones through the kick, fits nicely with IMU sensor's core functionality. This step is also something that should be considered when creating the Framework for WT analysing to compute meaningful data for a football attribute.

5.3.3 Video Game penalty data extraction

Escapism comes in many forms, where video games have been a standout medium for this with increasing popularity, due to its immersive content. Users (gamers) are known to spend money on consoles and hi-tech computer machines to play games at the highest available quality. Social media increased its impact, where revenue is generated from individuals who stream gameplay and compete in tournaments such as E-Sports. Video game also uses real life motion captures, to give a more authentic feel to the game, when the theme is deployed for a certain purpose. This can make gaming educational to those that can experiment within gameplay, to learn something new.

As football being the most popular sport in the world, it also boasts hugely popular Video game from EA Sports® FIFA and Konami Pro Evolution Soccer®, who have consistently generated big sales every year [EA Sports, 2022] [Konami, 2022]. These games use professional player data and give them a rating (typically out of 100), which affects that player's mobility and performance in game mechanics, as the gamer controls them during gameplay [Stealth Optional. 2021]. EA® and Konami®, both analyse yearly performances of professionals across the world, with complete data for 18,000 players, to give gamers a unique and accurate experience of each individual professional [Early Game., 2021]. For this experiment, a simulation environment is built under penalty kicking training, linking player rating data of attributes, to how well they've executed laces and inside foot shots.

EA® and Konami® don't give the same player ratings. This may be due to sponsor deals, and rights to team data. EA® has complete list of authentic rights to player, stadium, team names, logos, and stakeholders around. Konami only has rights to a few, and team licence rights are not obtained hence, their authentic names don't exist in game, although the player driven data specifically tends to be an accurate representation of the athlete, (i.e., a high rated player will be a world class footballer).

EA® uses frostbite® engine to gather motion capture of player movement [EA Frostbite 2022]. They use this to impersonate the CAD biomechanics of the game design, so that the artificial intelligence can authenticate accurate movements of the individual player. This unique set of instructions make the game very accurate, hence its popularity, due to realism. These games are known to have discrepancies, such as game lag, and glitches, which requires software updates via patches, to reduce user distress, and improve user experience.

WT is breaking barriers in allowing consumers to gather more data about them, at an affordable cost. Monitoring body movements allow the user to understand their physical capabilities and how they can improve on attributes they desire. Amateur level footballers look to gaming as a choice of entertainment, but also to study certain gameplay techniques that they can emulate. Because they are free to explore their tactics, this in turn, educates them like "trial and error", where the user can keep adapting different methods, to see which gives the desired or intended outcome.

Video games have been used as benchmarks for stats where consistently quantifying ratings of professional footballers garner much attention for every new edition released. However, the quantity of players is large, that there are players who aren't of high-end professional level. The ratings that the player receives are based on real data on that individual. E.g., A footballer with 92 overall rating, and a sprint rating of 98, that has an average "real life" speed of 24 km/h, means that any player than can run at 24km/h should be given the 98-sprint rating in game. Data can be collected and viewed in the way they're assigned in this term, using it as a quantity-based monitoring of a physical stat, and giving it a rank to allow what that player can do within game simulation. Games sometime give more rating, due to their relationship with the player and team, and how much international recognition the player receives, computing with over 35 attribute related stats [Stealth Optional, 2021]. This can cause a slight bias in relation to real world data; however, a highly quality player will always be of higher in game rating. This will only result in slight uncertainty, but the quantifiable data can be trusted.

To monitor performance related stat, this would be related to how well the player has done that task successfully, in recent form. If a player has a short passing rating of 90, that will mean they are consistently very accurate in short passing. This could be computed as an average value, where the player completes every 9/10 passes attempted, making the ratio, percentage based. However, because there is also a qualitive assessment in how difficult that pass may be, there could be a weighing factor, that affects the overall rating, which gives benefit to the player, who attempts more difficult passes, hence they could be considered as a better passer of the ball.

In game, there are modes in which you can improve one player. You are in control of a single player's journey (Pro Clubs/Be a Pro), where there are requirements needed to get the attribute values higher (e.g., 500 completed short passes grants +5 attribute rating of passing). This simulation must rely on what "attributes are prioritised" in game, which is controlled by the user (gamer) who has their own style of playing. This will then allow the player they are controlling to progress based on gaming performance, to allow the system to advance to the next stage. As attributes increase, the player in control will start to perform better in game. This algorithm and programming use the quantification method to build progress where increasing attributes of a player based on how well they have done certain tasks, increases their rank. This can be transferrable to WT application which monitors the same skill sets. This will be a driver in quantifying achievements and personify stronger performance capability for the amateur footballer, who can rely on task completion at consistency to gain "higher real-life rating" of the same stat, which WT can quantify.

Understanding how game uses real life player data and impersonates football motions is studied to analyse how a higher rated player differs from a lower rated one. At the time of the analysis, EA sports FIFA 20® and Konami PES 2020® are the latest editions of their respective titles, hence these were considered. FIFA 20® did not have easy control mechanics of penalty kicking scenario; hence Konami Pes 2020® was chosen with 60 FPS where the PC ran the game beyond their minimum system requirements, hence no latency in gameplay was affected. Screen recording and analysis were easier to make with PC, to show the exact point of ball contact, player stance and how much power is generated. Adobe Premier Pro is used to calculate the ball's time taken to reach targets.

With video games, being accurate with professional players, in their attributes, this test used a game, doing penalty kick trials with laces and inside foot shots and analysed how they were different for the different level of player. This is to understand how player data influences what a simulation does. This may not give accurate specific output that a player may perform but understanding how an attribute stat assigned between players that perform differently can generate some data in where WT could also emulate, to grade amateur level players in a similar way.

Method of application professional data

Figure 5.3.16 shows the analysing features of the setup and Figure 5.3.17 displays the flowchart of how player data is produced from the influence of game developers, sport scientist and data analysts. Figure 5.3.18 displays the intention and overall structure of this test, from how the researcher extracts key variables to understand how application of professional football data can be linked to biomechanics. Figure 5.3.19 further enhances this, with description of the intended impact this test has on the study. Gaming analysis has advantages because a penalty environment has already been built with smart algorithms in place, which impersonates real motion of professionals. The video game performs with a bias which gives abilities of higher quality players, to perform better, i.e. greater kick velocity per minimum effort, and easier control over intended target. This shows how players who have greater physical capability, have greater game mechanics within the environment. Creating a data such as shot power, can be formed by kick to ball velocity difference, as it shows how with minimal kicking speed, the ball travels at a greater velocity, resulting in more transfer of energy onto the ball. The accuracy regarding if it hit the target, also allows the ankle motion upon ball contact to signify if there were any influences.

Figure 5.3.16: Display of Gameplay on PC and analysing features using Xbox controller.

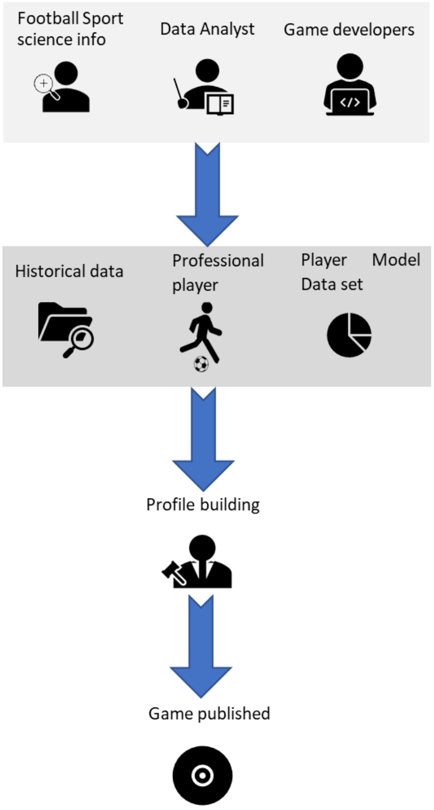


Figure 5.3.17: Player data flowchart

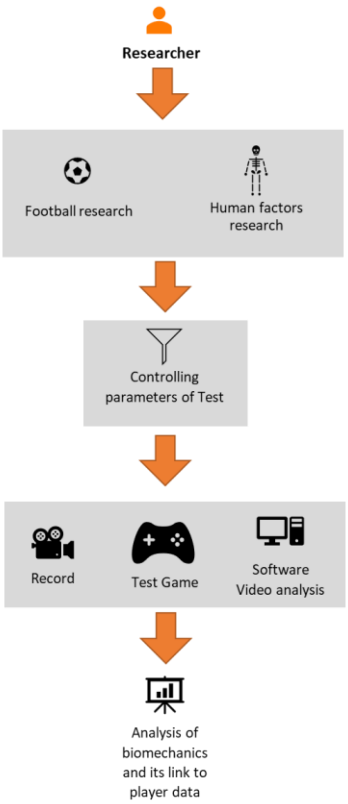


Figure 5.3.18: Structure of this test

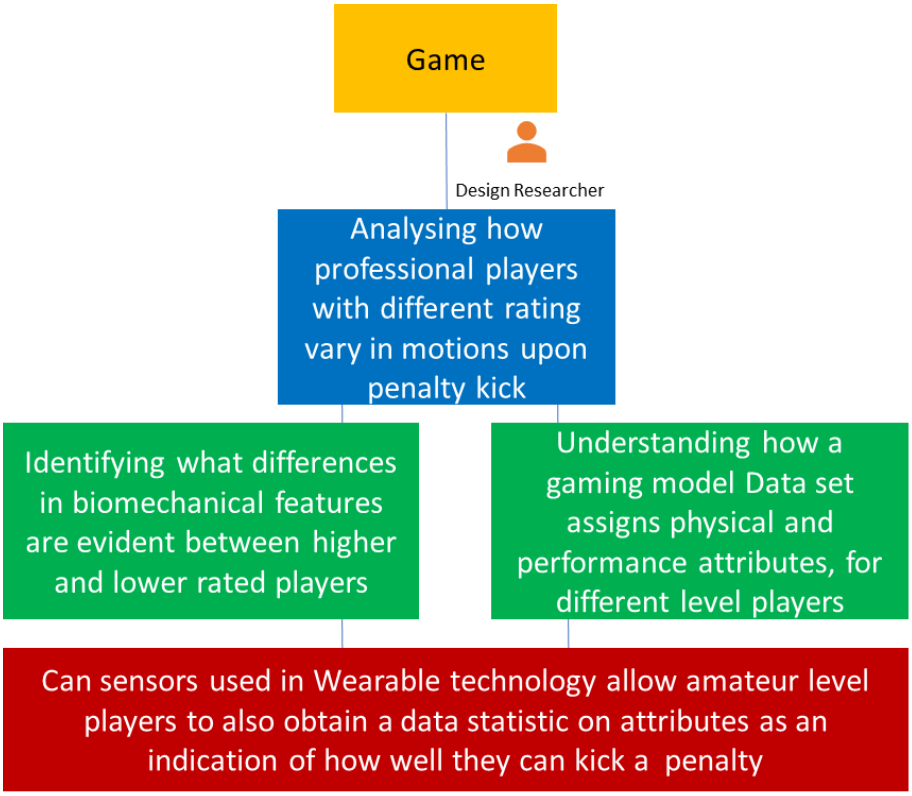


Figure 5.3.19: Block diagram outlining application of professional footballer biomechanical data through video game analysis

Experiment set up and parameters

The setup has control parameters under penalty kick set piece. This is because there are limiting factors in a penalty kick, which are fixed parameters making calculations easier. Adobe premiere pro was used to measure the exact time taken from ball contact to target.

Kick trial method:

- The effort bar is a control parameter where the force of the kick is applied (via Xbox controller). This is computed as a percentage of the overall Kick Power rating of the player.
- There are 4 targets, 2 Bottom(blue), 2 Top(red), on left and right sides. Each player hits each target 5 times.
- 3 right foot, 2 left foot players chosen. (The best 2 were chosen as accurate as possible regarding height, and weight)
- Laces shot is executed by pressing the shoot command on the controller
- Inside shot is executed by pressing the “finesse” + shoot command on controller
- The ball speed, contact angle, landing foot is calculated
- The ankle movement on ball contact is also analysed

Each player has different ratings for certain attributes which are listed out on Table 5.3.E. They are defined as follows:

Finishing: Indicates how well player shooting accuracy is

Shot Power: How much force their kicks produce in relation to ball velocity

Curve: How much curve the player can generate on their kicks

Dead Ball: Technical attribute Rating how well player kicks any Set piece

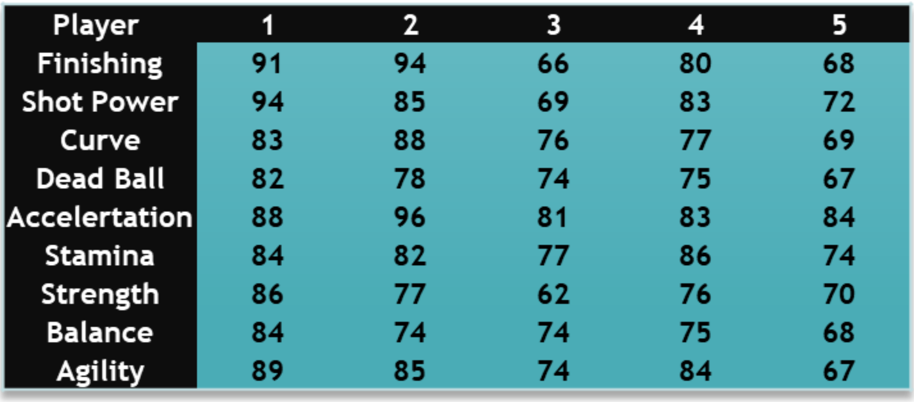
Acceleration: Rate of change in spring velocity

Stamina: length of prolonged physical activity

Strength: capability to withstand/generate force

Balance: how well player maintains correct/healthy posture in different game situations

Agility: Ability to move directions quickly and efficiently



Player	1	2	3	4	5
Finishing	91	94	66	80	68
Shot Power	94	85	69	83	72
Curve	83	88	76	77	69
Dead Ball	82	78	74	75	67
Accelertation	88	96	81	83	84
Stamina	84	82	77	86	74
Strength	86	77	62	76	70
Balance	84	74	74	75	68
Agility	89	85	74	84	67

Table 5.3.E: Player profile Attribute data

First analysis is to show how each players body position is per type of shot, where the intended target of ball is the lower left. A sample of this can be viewed in Figure 5.3.20 which outlines a layover of the body position at ball contact. All the analysis that is shown here is done for every target and player trial. Each player will have a line drawn above them, to fully understand their positioning upon different target kicks. The ankle contact is further analysed later for the different shot types. Colours with players, remained consistent throughout all graphs and charts. This is done for right foot and left foot players for both laces and inside foot shots. Effort calculation is a term generated as quantity of the total “Shot power” percentage in relation to actual rating given by PES. With the ball size and environment conditions in a practice mode simulation consistent, the time taken for the ball to reach targets gives an idea of the speed the player generated, with the power assigned by the researcher. Scales are created to form data of angle of ball contact region and landing foot distance.

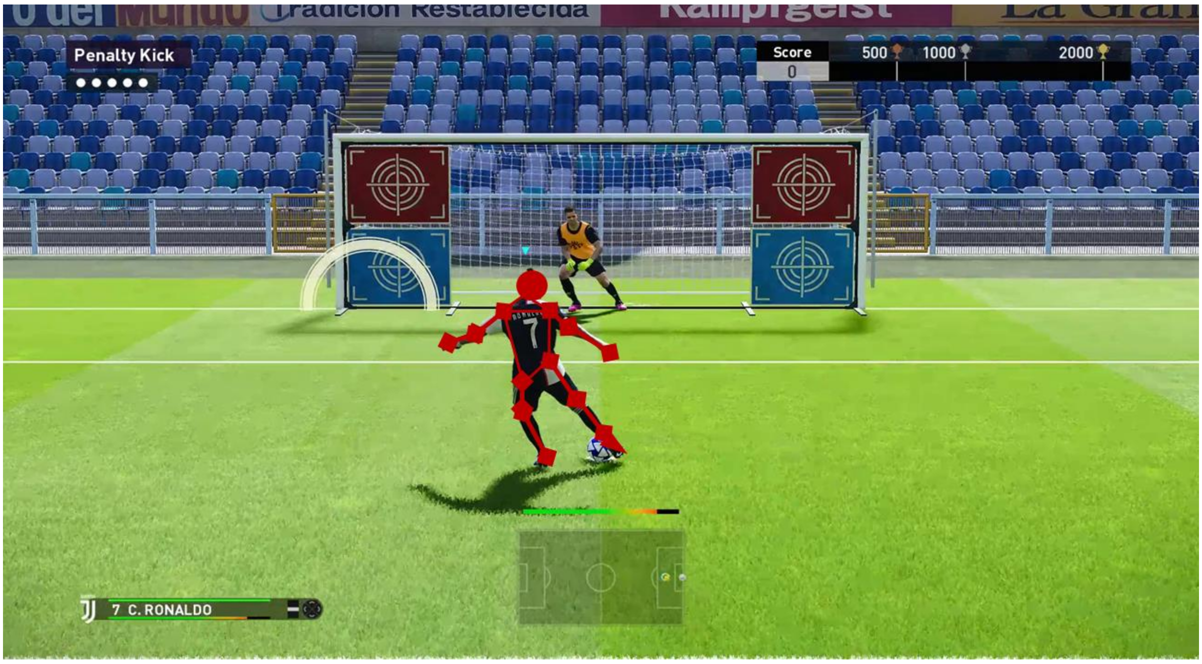
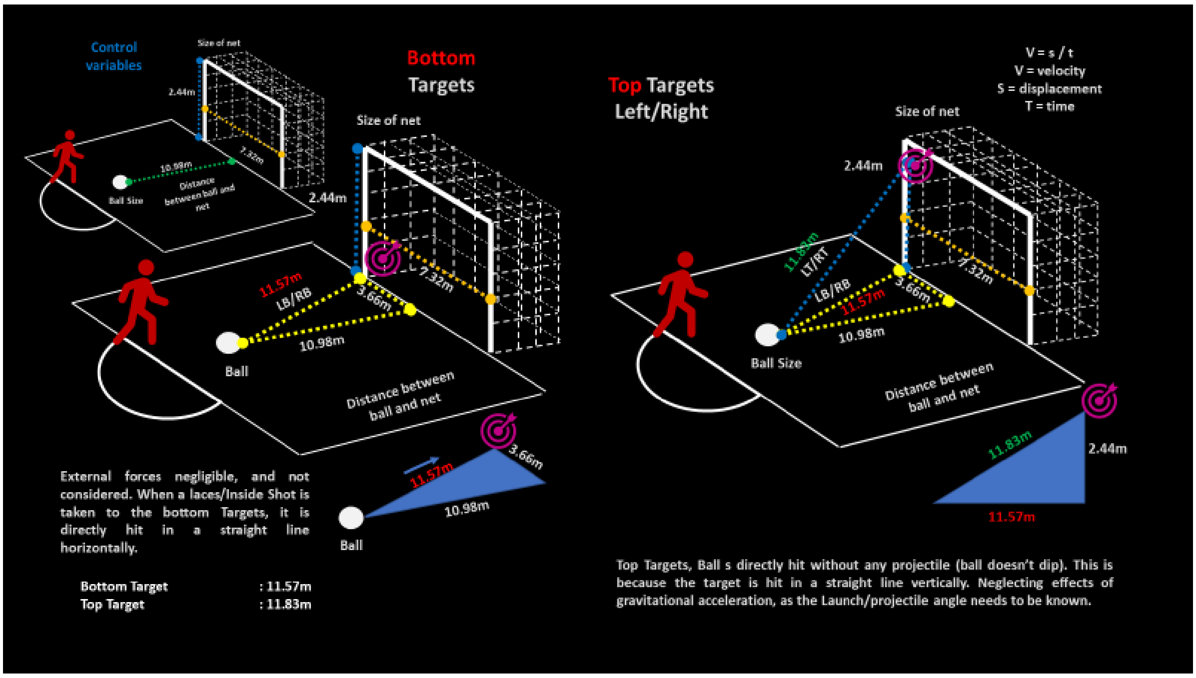


Figure 5.3.20: Display of Gameplay on PC with body markers

Figure 5.2.21 show how the theoretical calculations are computed when the ball hits both the low and high targets from the penalty spots. Figure 5.3.22 shows the custom scale designed to compute the landing foot distance of the non-kicking leg.



V = s / t
V = velocity
S = displacement
T = time

External forces negligible, and not considered. When a laces/Inside Shot is taken to the bottom Targets, it is directly hit in a straight line horizontally.

Bottom Target : 11.57m
Top Target : 11.83m

Top Targets, Ball s directly hit without any projectile (ball doesn't dip). This is because the target is hit in a straight line vertically. Neglecting effects of gravitational acceleration, as the Launch/projectile angle needs to be known.

Figure 5.3.21: Calculations for Penalty kick in game environment

Figure 5.3.22: Landing foot custom scale

Figure 5.3.23 displays a custom scale made for ball contact angle around the ankle. This is done from the project behind player view. Figure 5.3.24 shows the ankle position for lacs and inside foot shot respectively.

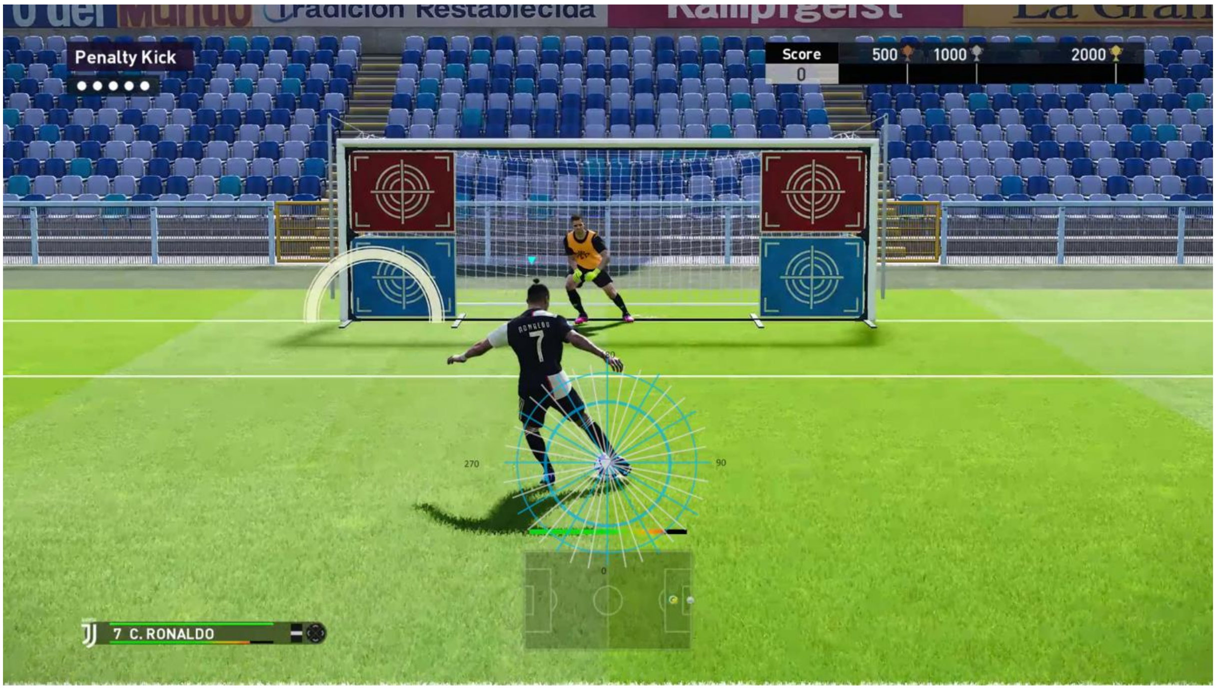


Figure 5.3.23: Ball Contact angle custom scale

Laces shot

Inside foot shot

Figure 5.3.24: Ankle position on contact analysed

Analysis and Results

An overlay of the body posture upon ball contact is drawn to analyse how different stances are experienced for the players. Right footed players are shown on Figure 5.3.25 and left footed on Figure 5.3.26. This visualisation allowed behaviour to be monitored in approach, and tried to link their balance and acceleration stats, to view if they were factors that affected these variables. Ball contact scale is shown on Figure 5.3.27, with key to inform what player struck (colour), how much effort (%) was applied. Graph plots are created to show effort on kick against landing foot distance, velocity of ball at target, ball contact region and angle of ball contact.

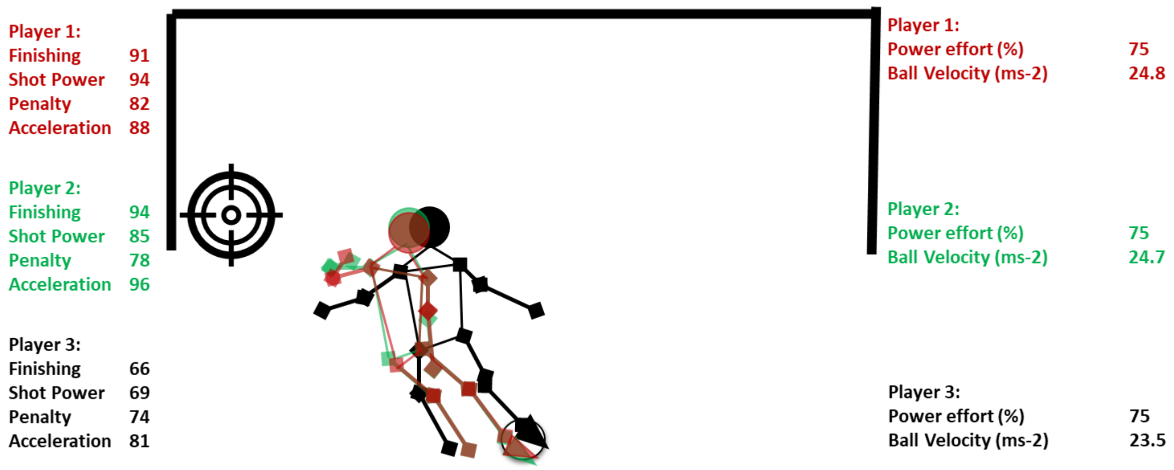


Figure 5.3.25: Comparison of right foot players on lower left target for laces shot

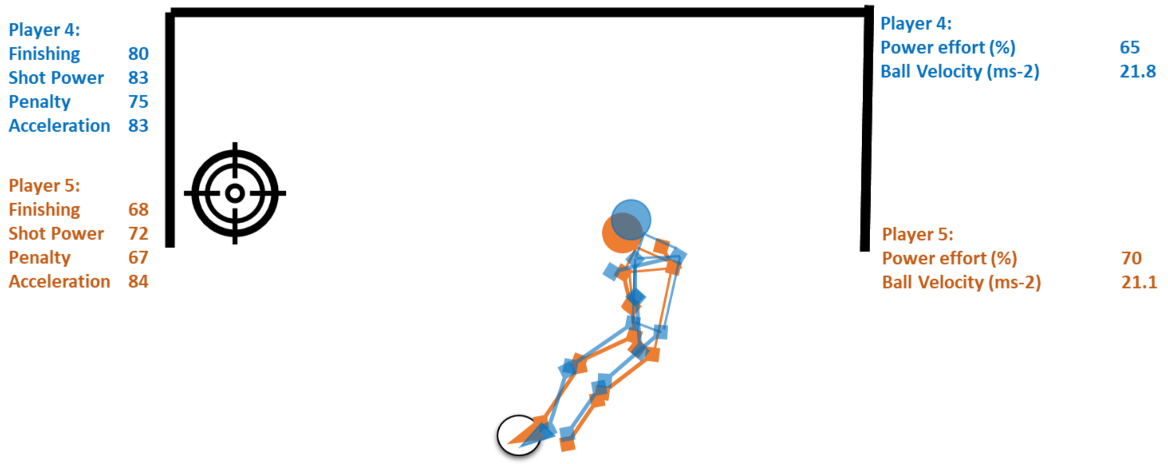


Figure 5.3.26: Comparison of left foot players on lower left target for laces shot

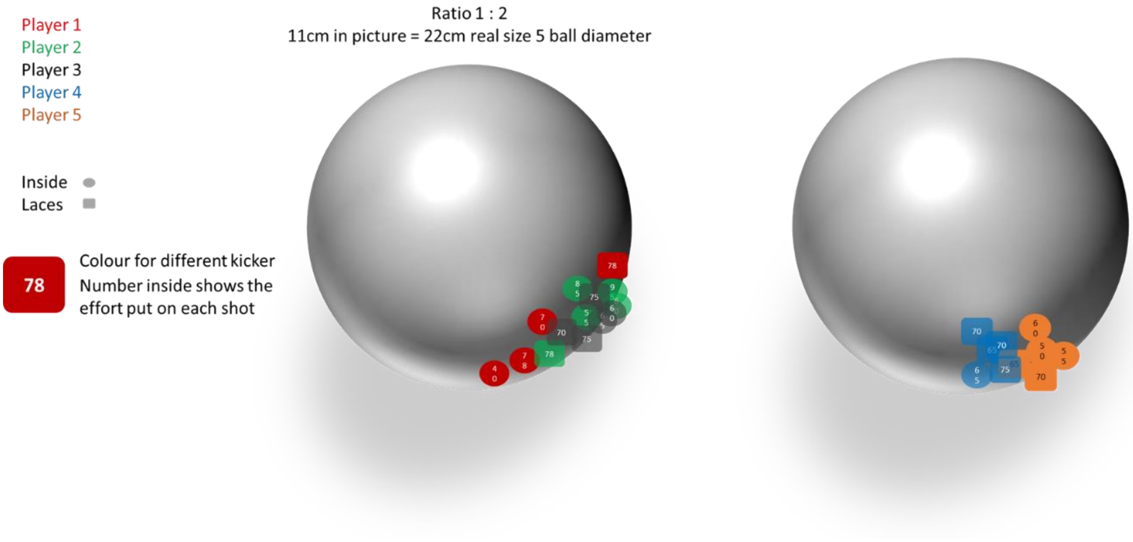
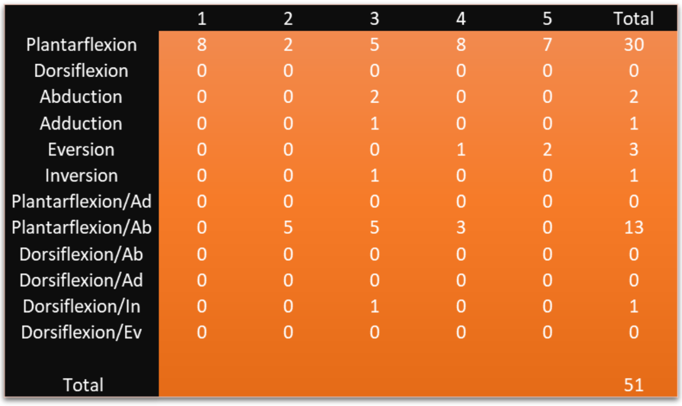


Figure 5.3.27: Ball contact scale

Table 5.3.F shows the different ankle biomechanics upon ball contact for laces shot, with Figure 5.3.28 showing the frequent plantarflexion stance that the AI simulates on players. Table 5.3.G results show abduction being the most frequent ankle stance experience, both stand alone and in

combination with other biomechanics upon kicking inside foot shots. Figure 5.3.29 displays this with more result spread consisting of abduction ankle stance are upon kicking.



	1	2	3	4	5	Total
Plantarflexion	8	2	5	8	7	30
Dorsiflexion	0	0	0	0	0	0
Abduction	0	0	2	0	0	2
Adduction	0	0	1	0	0	1
Eversion	0	0	0	1	2	3
Inversion	0	0	1	0	0	1
Plantarflexion/Ad	0	0	0	0	0	0
Plantarflexion/Ab	0	5	5	3	0	13
Dorsiflexion/Ab	0	0	0	0	0	0
Dorsiflexion/Ad	0	0	0	0	0	0
Dorsiflexion/In	0	0	1	0	0	1
Dorsiflexion/Ev	0	0	0	0	0	0
Total						51

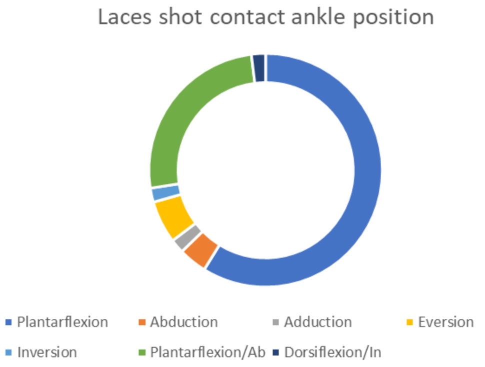
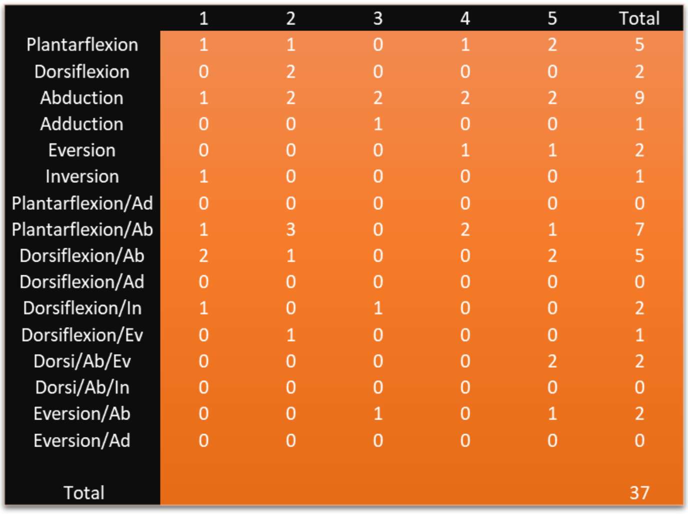


Table 5.3.F; Figure 5.3.28: Ankle biomechanics results upon ball contact for Laces shot



	1	2	3	4	5	Total
Plantarflexion	1	1	0	1	2	5
Dorsiflexion	0	2	0	0	0	2
Abduction	1	2	2	2	2	9
Adduction	0	0	1	0	0	1
Eversion	0	0	0	1	1	2
Inversion	1	0	0	0	0	1
Plantarflexion/Ad	0	0	0	0	0	0
Plantarflexion/Ab	1	3	0	2	1	7
Dorsiflexion/Ab	2	1	0	0	2	5
Dorsiflexion/Ad	0	0	0	0	0	0
Dorsiflexion/In	1	0	1	0	0	2
Dorsiflexion/Ev	0	1	0	0	0	1
Dorsi/Ab/Ev	0	0	0	0	2	2
Dorsi/Ab/In	0	0	0	0	0	0
Eversion/Ab	0	0	1	0	1	2
Eversion/Ad	0	0	0	0	0	0
Total						37

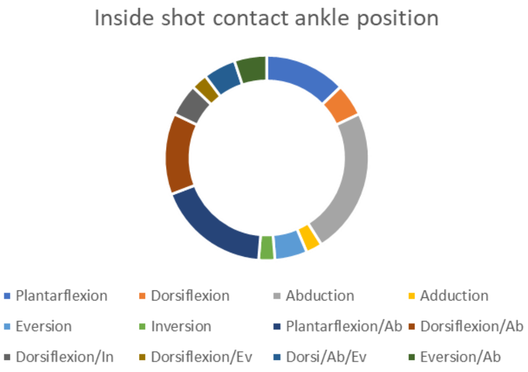


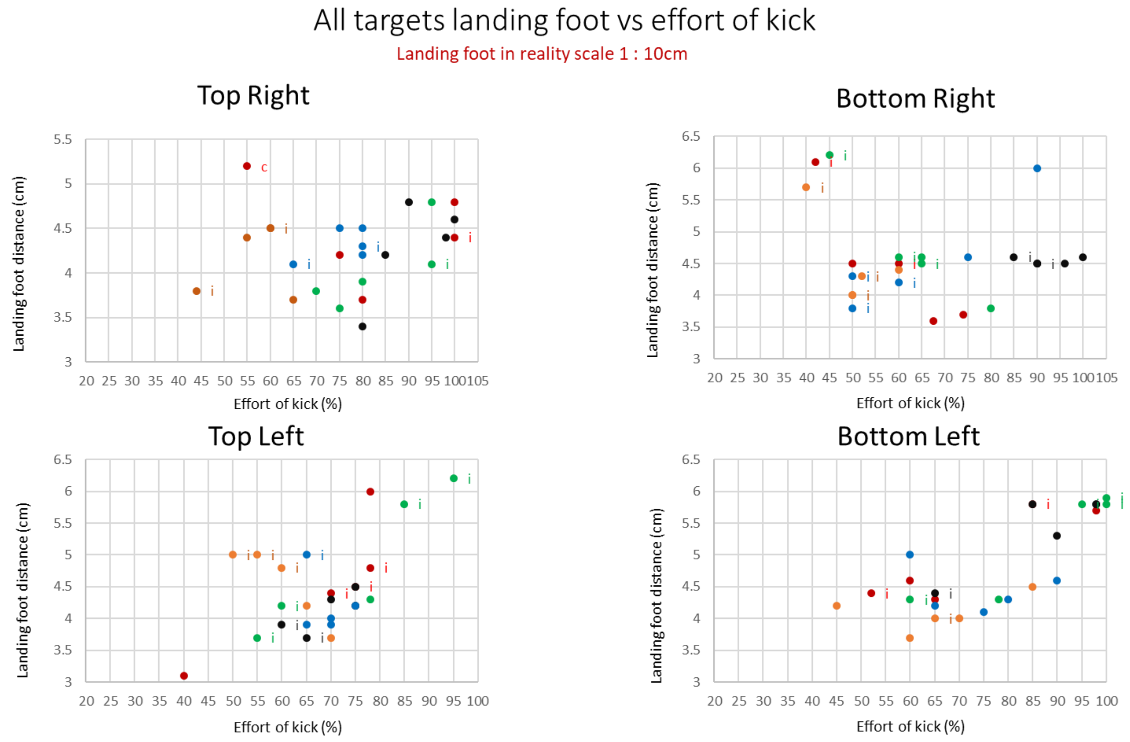
Table 5.3.G; Figure 5.3.29: Ankle biomechanics results upon ball contact for Inside foot shot

The controls themselves grants the opportunity to for the gamer to shoot laces or inside. When executing inside foot shots, the game configuration allowed commands for the controller to perform “finesse” along with the shooting command. This shows how this terminology, is linked to accuracy, and that there is greater emphasis on inside foot being more accurate.

Grading the shots could be defined between the Power v Accuracy trade off. Players who executed ball velocity with minimal effort proved how their superior capabilities are in real life, which is shown via game mechanics. This was done for both Laces and Inside foot shots, which wanted to compute if players behaved better or worse with the change in type of kick.

Optimum power within game AI is around 75 – 85% effort. The Player wants the gamer to be within range, for the controlled player to exert the right quantity of power for the target to be reached, before the goalkeeper interferes. This shows that when too much power is applied, it risks the accuracy of the ball not being within the target. Player 1 has shot power rating of 94, Player 2 has 84; so, at 100% effort, their “quantity of power” will differ. Power = Force x Velocity; so, this is dependent on the force and velocity of kicking, and Force = Mass x acceleration.; so, mass of leg and acceleration possible influences this data. Players 1 and 2 have the same height and weight, but their body composition in terms of muscle mass is different. This could have caused the difference in allocating shot power. For WT to be truly accurate it will need “personal data”, i.e., player’s leg weight information to truly get more out of consumer data. Highly rated players can generate more power with less effort where greater speed of the ball and how their contact was more consistent, for their respective monitored quantities.

From Figure 5.3.30, the optimal landing foot range from penalty spot around 34cm from middle of spot (Y axis graph scale multiplied by 10 for reality data and ball diameter 22cm, assuming 11cm is centre of penalty spot). Figure 5.3.31 displays the velocity of ball (m/s) against the effort of kick (%) for both kick types, where player 1 and 2 who have the greatest shot power rating, generate higher ball velocity.


All targets landing foot vs effort of kick

Landing foot in reality scale 1 : 10cm

Figure 5.3.30: All targets Landing foot v effort on Kick

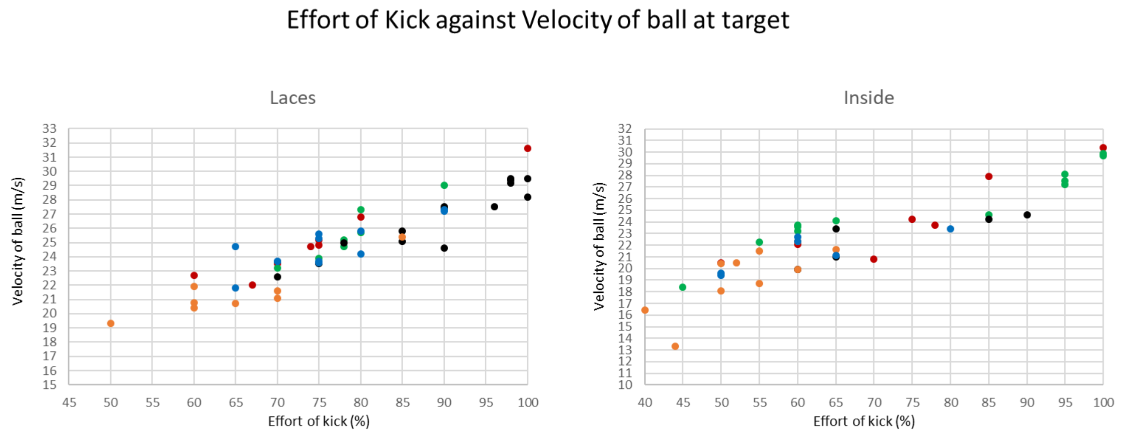

Effort of Kick against Velocity of ball at target

Figure 5.3.31: Laces / Inside shot speed against effort

Figure 5.3.32 shows the ball contact point with reference to the horizontal and vertical distance on the football. Figure 5.3.33 show the angle of ball contact against the effort of kick. Both these figures are in reference to the custom scales created.

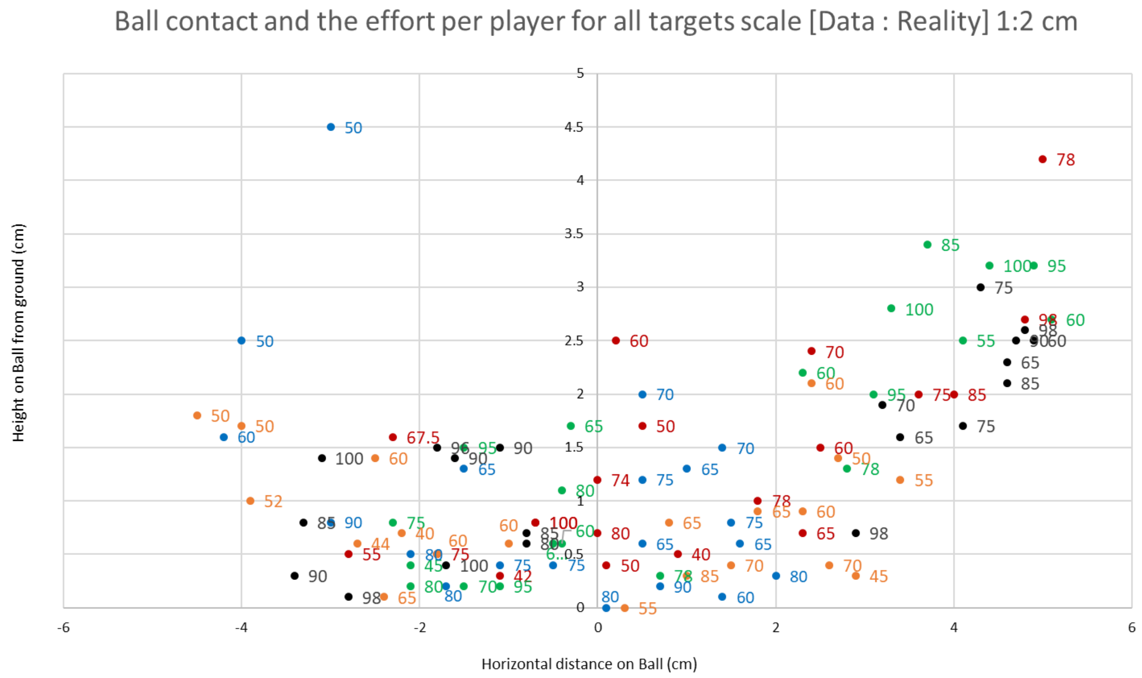


Figure 5.3.32: Ball contact and the effort per player for all targets scale [Data: Reality] 1:2 cm

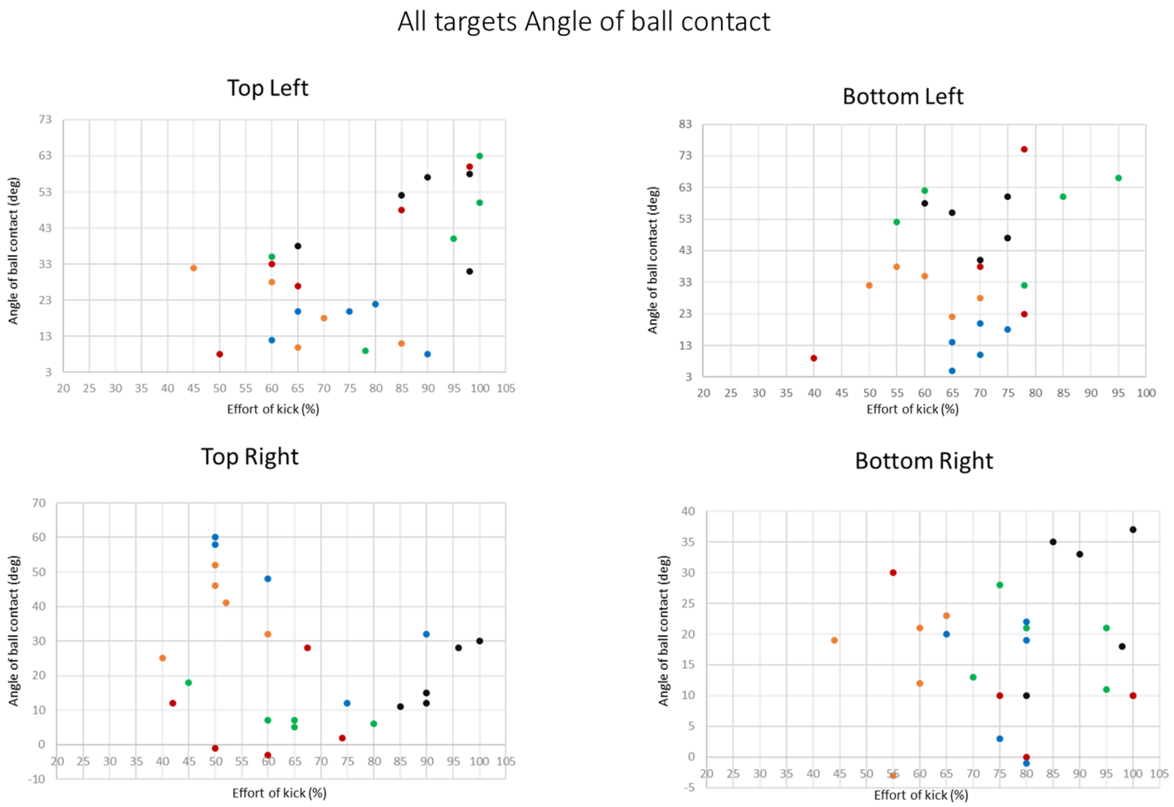


Figure 5.3.33: Effort of kick against Angle of ball contact for all targets

These results can build a data set for WT to implement so that an amateur level kicker can also gauge their landing foot within this range, assuming that they are of the same height as the test game players. This shows a small sample of data, which can be transferred into applying more meaningful data calculations within WT applications, where different height players of different levels can be tested, to produce a larger data set for WT to rely upon.

When more effort is applied, the angle of contact greater from centre of ball for higher rated players. With reference to the custom scale used to analyse the angle of contact, this same measuring tool can now be applied for a WT application, as the results can use this set of references to guide the ankle position biomechanics upon ball contact. Lower rated players have lower point of contact from custom scale; hence this could educate the players in knowing that their contact angle must be within its designated region, allowing them to practise their technique to perfect this sort of response.

One of the limitations in this study was that the camera point of view only from behind the player, so a different position would have allowed monitoring of the backswing and follow through biomechanics. This could have allowed greater visualisation of techniques that differ from higher rated players to lower. Sensor looking at landing foot shows promise, as this will link to how well they plant this foot to swing through their kicking foot. If smart scales can also be implemented to build a full profile of the amateur footballer for WT, then this can further enhance its capabilities of linking body quantity, with performance. This game analysis has shown how higher rated players behave differently to lower rated players, and the factors which showed in terms of biomechanics, is something WT can use as reference to guide amateur footballers in shot monitoring. When building a data set for WT, the camera positioning during penalty kick testing can be experimented to allow multiple scales calculating precise ankle angles with the aid of sensors.

Momentum Test

Every player has a unique kicking technique. This will be dependent on their posture upon key biomechanical kicking motions throughout. Having an efficient motion allows the player to transfer their energy for best kicking results. The posture can directly affect the transfer of momentum onto the ball, with different stances affecting how much force is struck onto it. To compute how the transfer of momentum on ball can be affected by the different body weight applied upon ball striking, landing foot distance is chosen as a metric to distinguish the posture variations. This is to understand the variance that the kick will differentiate when the effective foot mass and velocity being different can impact the force felt on the ball. The game simulation allowed the calculation of final ball velocity (Vb), and as mass of ball (0.46g) is constant, the acceleration is computed based on time taken (~0.2 s). The aim of this test is to advance theoretical development analysis in transfer of momentum being affected by posture, using landing foot metric

Players 1 and 2 have the same height and weight, however player 1's foot mass is assumed to be larger, to distinguish how body composition (greater leg muscle mass) can also show difference in momentum results. The foot mass is an assumption that it is 1.43% of the bodyweight of players 2 and 3, but 1.7% for player 1 [Robslink, 2020]. What this means in terms of different body weight applied on kick due to muscle mass differences, is that there would be a unique kinetic linkage that enables momentum to be built from run up and how the player flows through their kick upon contact. This is done to visualise how different the results could be, for players of the same overall height and weight.

For this theoretical development, the posture variation will be dependent on the landing foot distance of a player, that are affected by the different approach speeds, thus influencing their overall posture upon ball contact. Top right target ball velocity results are used for this test, and the three right footed players are chosen for analysis. This is to form a linkage between the force of the kick to different posture variations, which in this case is indicated by the landing foot distance of the player.

Figure 5.3.34 shows how two very similar players in height and weight, who have different muscle mass distribution, show different forces because of their posture, upon ball striking. The result show how two players of same weight, and similar simulation rating also differ greatly when their landing foots are not in optimum range. Player 2 has less force experienced when their posture is not ideal, with landing foot being too close to the ball.

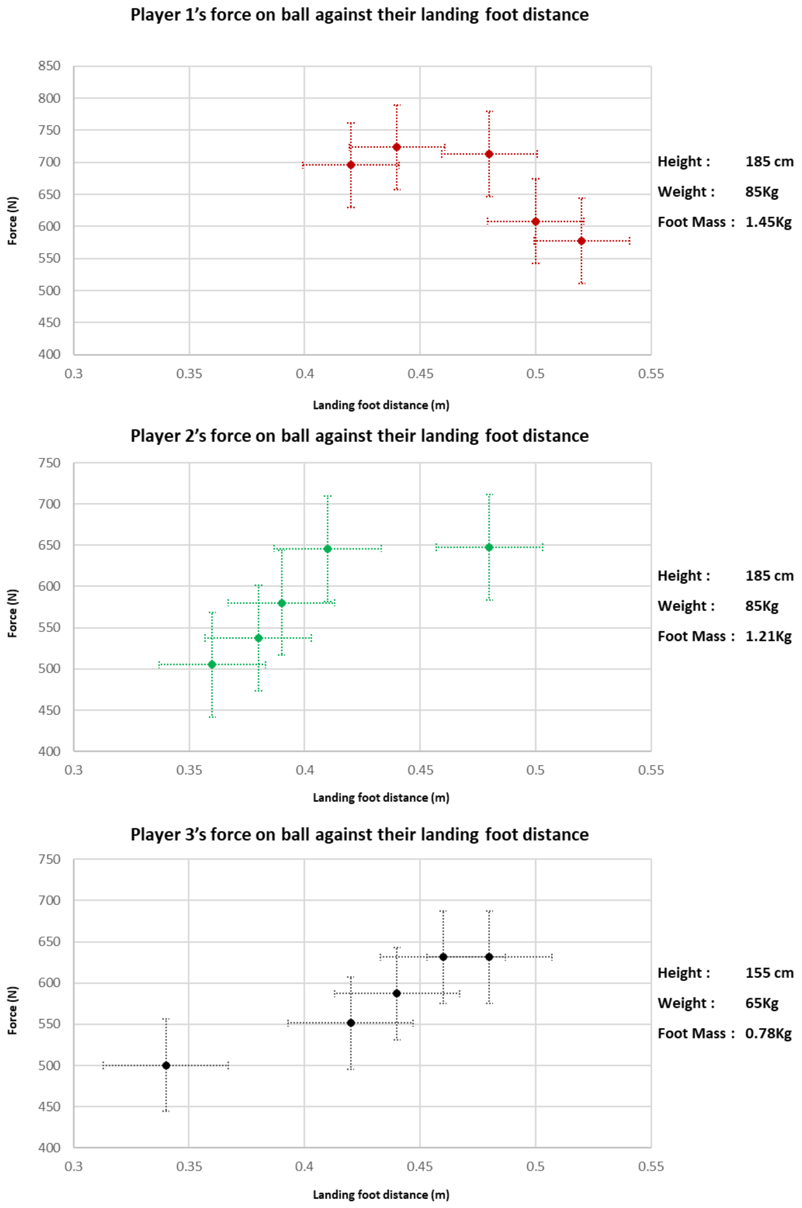


Figure 5.3.34: Force on ball against landing foot of 3 right footed players to show how momentum affects occur

These results are based off game simulation data, and the lower rated Player 3, exhibits greater estimate of variability. This could be potential programming of the game that shows how lower rated players may have inconsistent kicking techniques as opposed to higher rated players. This is another important assessment to aid WT from video game data, as exhibiting similar biomechanical range, will aid to notifying consistent kicking abilities. Through the use sensor tracking and video camera observations, more data can be fed into WT to increase its impact on amateur level footballers.

From results, it can be deduced that the transfer of momentum to the ball is affected by overall change in body posture, dependant on the landing foot of the player. An estimate of variability in kick force show that a player who has optimum landing foot range, exerts greater ball velocity. This is different to each player and must mean that they hone their technique to successfully transfer kick momentum. When landing foot presses down on the ground, kicking force goes through the ball, and exerting more of this depends on their weight influencing their kinetic linkage behind the kick.

Providing landing foot distances for each player and linking to force, showed more data on what the player's likely best landing foot regions are. The overall data collation this would have for WT, means more data processing would occur to capture and calculate on key performance kicking attributes. This test shows how a simple video game analysis, has potential to form data based on key biomechanical features of kicking (landing foot), and link it to performance (kick force felt on ball). For WT to make a clear personal judgement of the player, there needs to be some key information inputted. The smarter and accurate this information, such as muscle mass distribution rather than just their overall weight, would allow WT to differentiate between player body compositions. This would impact the calculations greatly because there is emphasises of the user's physique that affects the biomechanics of kicking, thus making WT calculations more accurate to the player.

Summary

Formulas such as coefficient of restitution (COR) and momentum are important in building a data set for WT to transform physical into performance data. These formulas are important to link player biomechanics with relevant data and the surrounding factors that could affect the accuracy of them. It highlighted how monitored data from sensors can calculate other quantities with right programming to gather more information about the kick of a player. COR is a good example that can be used to work out a new performance stat related to shots. Extracting the data of professional players within game environment and the method of applying these attributes, showed how "higher rated" players can generate greater speed of the ball and how their contact was more consistent for their respective power and speed. Analysing how "Quantitative Data" is assigned for a professional player, can help build an understanding of how WT for amateur footballers, can also use their physical attribute. The quantification of data allows WT to set benchmarks, this can inspire to grade the shot types, and give it a value, so footballers can have some numerical benchmark that shows progression of their kick techniques.

Software analysis helped build parameters for IMU and FSR sensor tests. OpenSim Biomechanical analysis proved the significance of ankle monitoring as even when most of the lower body works well to execute a kick, this can all be undone when the ankle stance is not correct. The Boot designs which were backed with research to refine material showed that they experience different stresses upon different region of contact. In terms of future decision matrix ranking kicking attributes, there needs to be a consideration in the type of boot worn, as materials can affect different levels of stress throughout the outer soles. This means during the Framework design there needs to be a mention of it influencing some input data. FEA analysis outlined that for framework design will need to consider material properties for the ball contact phase parameters. This is to allow the Design Framework t display how it can be altered for different boot weighing. This consideration element allows human factor design principles to be valid in the framework layout. Important to increase the reliability of the framework and its significance to ankle rotation movement.

Use of camera recording, and a PC allows quantities to be monitored in real time, with sensor data for thorough monitoring. This will be implemented for future experiments where camera placement could generate more observed data.

6.IMU Penalty Kick Test

6.1 Brunel university women's football team penalty kick analysis user test

6.1.1 IMU Sensor Test

Kicking is the fundamental skill in football with 2 most common shots in laces and inside (Side foot). Key biomechanical features are Hip flexion, Knee extension, Backswing, Force on landing foot, ball Contact (BC) and follow through (FT). In this experiment, a simple kick study with Brunel university football team regarding their technique upon BC is analysed.

Football has high physical demands and traits. Endurance depends on how much a player runs with varying intensities, but also how their kicking alters with fatigue [Ferraz et al., 2012]. Players in different positions require different physical needs. Outfield positions identified by where they play on the field; e.g. defenders, midfielders and forwards (goalkeepers the only non-outfield position) [Jens,2014]. Each position has a responsibility, and within that position there are different types of roles, which can vary depending on team tactics or individual preference of gameplay approach. General skills typically associated with player position, can influence how their kicking abilities are based around [Aroganam G, 2021].

Midfielders and forwards generally are known to have greater accurate striking ability where defenders are known to have power. Defenders may not prioritize on accuracy of shots, as other attributes such as short passing, has great importance. Long-range passing could be used to "enhance" their kicking competence, (depending on which defensive position they play). Midfielder's role is the most varied, ranging from position (e.g., central/wide), and role (playmaker/defensive/box-to-box) [Jens,2014]. Forwards have the most influence for type of kicks that are associated with shots, making sure they have the best combination of power to accuracy. Kick methods, and skills required to continuously do this over time, means that the body must build resistance, to maintain the quality of kicks, even after fatigue settles. Same positional players with contrasting gameplay approaches can influence their kicking approach depending on what they are more required to do. If a player was always required to have greater short passing accuracy, their skills are honed to match those needs compared to a player focusing more on length of ball travelled, prioritizing power. These responsibilities mean they will need to work on different physical elements during training. To link how their gameplay needs effect their kicking ability, is crucial to finding which factors upon kicking biomechanics can they improve [Aroganam G, 2021].

This experiment's aim was to understand each player's technique regarding their position profile and if the opinions based on observation matched video analysis and sensor data. The "1-step" penalty kicking analysis was done via video recording, importing into an application, plotting the motion of kick, and its velocities. The study desires to dissect how to compute performance data using sensor and video analysis of ankle biomechanics in 1 step amateur footballer kicks. This is to build subjective opinions on amateur footballer via 1 step penalty kick by analysing their ankle biomechanics. Based on existing opinions on players, could technology analysis, with camera and sensor support observation assessment?

Objectives:

1. Can opinions made on player by observation in 1 step technical kicks be supported by data findings from IMU sensor and Video analysis
2. Identifying gameplay influences in player approach to kicking ball at a set distance

Studies conducted on other biomechanical kinetics are good indicators for analysing football kicks, which involve distance of landing foot, approach angles, velocity of hip abduction and knee extensions [Sakamoto et al., 2016][Ismail et al., 2010][Lees et al., 2010]. Crucially ankle movement help distinguish different types of technical kicking in football. The type of shot taken is monitored to understand the corresponding ankle rotations upon BC, and its ball effects. This is because the type of shot taken, depends on the ankle stance (AS), at the point of ball connection.

Camera recording enables to review player movement, to know what is needed to improve technique. What a good kicker executes, does not automatically mean a poor kicker should follow the exact form, it is about understanding their own biomechanics and how consistency can lead to greater refinement in delivering good kicks. Accuracy and projection of the ball is not directly tested in this study but is referenced to grade if the kick is successful. The condition was that the ball should have passed the goal line (6m target). Assessing kicker's technique in relation to biomechanical tracked features gets ranked chronologically [Aroganam G, 2021].

In sport, subjective opinions always have an important influence when analysing performance [PDHPE, 2021]. A subjective assessment is used as an evaluating tool to determine the manner of shot execution. Data itself does not display the overall performance of an athlete as some parameters cannot be monitored with WT. Having observations in certain scenarios produce more relevant monitoring of attributes, validating a player's performance rather than judging on monitored physical capabilities (quantifying). If a player is consistent in certain element of biomechanics, then this can be referenced as a point for comparison in reviewing a player's kicking ability.

Laces shot types has greater reliance on the "landing foot" biomechanical element, where the non-kicking leg is placed to allow great flexibility and energy transfer (power) for the kicking foot whilst connecting the ball using the upper sole region of it's boot. Laces and Inside foot terms are used as these are what "football players" refer to. Laces shot is the type of kick that produces the highest velocity of the foot and ball compared to any other type of kicking technique [Levanon & Dapena, 1998] [Nunome et al., 2002]. Ismail et al., 2010 researched to identify the ranges for maximum laces kick velocity, estimating them to be between 18m/s to 35m/s [Ismail., 2010]. Laces shots were further analysed by Asami et al., 1983, researching into semi-pro and professional players, where different boundaries were defined in grading velocity ranges for laces shots [Asami et al., 1983]. These were considered as highest velocity of ~38m/s and lower velocity of ~24m/s [Zulkifli et al., 2015] [Asai et al., 1996]. These are semi pro- and professional averages, hence the range for amateur levels could be considered lower, however, to improve and achieve the next state higher, these ranges could prove that these players can produce capabilities of higher levels. This principle again relies on quantitative data which is still used to grade how well a shot is executed.

Laces kick contacts the ball around and top of the metatarsal, Navicular, cuboid, and phalanges region on the foot. Players instruct ankle rotations (abduction/eversion), guiding the ball to a specific direction, dependent on the approach. Contact can also happen if the ball is not on the ground, as the laces part of the boot can be angled to contact the ball at an intended point [Ismail et al., 2010] [SportsRec, 2019]. Plantarflexion is generally experienced by ankle approach, giving a degree of freedom to follow through (FT) efficiently, (less chances of dorsiflexion straight away). Keeping the plantar position, the flexor digitorum brevis muscles are also required to be flexed along with lateral malleolus when executing shots, to give that extra rigidity to the foot positioning upon ball striking, to reduce the chance of losing shot power (isometric contraction) [Live Strong, 2020]. Correct form/training reduce stress and increases resistance on the required muscles/bones. The angle of decline (bottom – plantarflexion) and its rate, needs to be adequate to allow maximum possible chance of contact. This is influenced by quadrus plantae muscle which provides the angle of feet, controls laces shot direction for intended ball movement.

The Inside foot shot is typically used in short passing methods or when there are greater accuracy priorities for the user. Quadrus plantae muscle can allow the rotation of the ankle joint to execute a side foot shot (inside/outside) [Aroganam G, 2021]. Phalanges, just between the metatarsal joint and the Distal (toes), have key responsibility, in keeping a rigid position upon BC. Inside shots uses the inner side of the first metatarsal and medial cuneiform bones of the feet, typically in most situations for passing. Prioritizing accuracy, where pace of the ball can easily be influenced by the player to determine how much effort they should exert. Combination between Eversion/Abduction to Inversion/Adduction can be experienced due to the nature of ankle movement. To elevate projection, slight plantarflexion, to get underneath the ball, allows the ball to go higher. Inversion and eversion ankle movements both work around the subtalar joint, but with different muscles. Tibialis with flexor hallucis brevis for inversion and peroneus with flexor digiti minimi brevis for eversion [VCU, 2019] [Anatomy Zone, 2012].

6.1.2 Experiment setup

Six University U20 Women's Football Team members participated in this study. Before attempting kicks, overseeing training sessions (2x/week), consulting with two team coaches, built the "subjective" factor on the players used. The experiment session occurred after completion of stretches and warm up drills during a training session. The players were given freedom to their approach, and how they would attempt to make sure that they would clear the target line without constrained instructions (flexible). This was done, to understand how that player's gameplay approach type, could influence what they perceive was enough to clear the target line, linking it to position profile. The experiment occurred on a full-sized football pitch (~101 length and ~64 width in metres), during winter season, with no adverse weather conditions (no winds) [Net world sport, 2022].

Each player was tasked to kick a "1 step" penalty shot. This meant that there was no run up to the ball, hence influence of their physical running speed would not influence the intended analysis, just landing foot and kick. Players could generate certain levels of kick speed due to run up, which causes another element to consider when trying to analyse, so this is solely to understand their ankle motions upon BC technique (ball stationary on ground).

An IMU sensor was placed on the front outer sole of the football boot to monitor the ankle rotations upon ball contact. The Nano 33 IoT composed of IMU LSM6DSL (Accelerometer/Gyroscope) including microcontroller all on one board (reduce components); 104hz output data, 9600 baud-rate, connected via 2m wire to HP® n019-Touch laptop (visualise data as player kicked) [ST, 2020]. Integrated environment from Arduino 1.8.19 software, automatically imported into Libre Office Calc Spread sheet [Arduino, 2022]. Trial tests were done prior, without control measures, to "calibrate" sensor, so they work during experiment (axis configuration to represent ankle biomechanical direction). For experiment data, code considered electronics conversion. Accelerometer produced results in G force, hence multiplied by 9.81 ms^{-2} to obtain acceleration value. Gyroscope had the sensitivity range set at ±2000 deg/s, with ±70mdps/LSB conversion (precompiled settings-Arduino LSM6DSL library).

The LSM6DSL IMU sensor has a power consumption at 0.65mA in high performance mode. This optimises high sensing precision for motion tracking with ultra-low noise for both gyroscope and accelerometer [ST, 2019]. The accelerometer works at noise density of 130 µg/ √HZ and root mean square noise in normal power mode of 3.0 mg. Gyroscope root mean square noise in normal power mode is around 75 mpds, with the noise density independent of the output data rate. The precision of the measurements is sufficient for this experiment as the change in angular velocity of the ankle is the most important biomechanical study for this research, as the gyroscope data is monitoring within the sensitivity range. High resolution sensors could increase the monitoring specification, but this would require a higher budget. For this current test, as the analysis is monitoring ankle motion, the chosen technology, is sufficient.

The LSM6DSL has 16-bit converters, with gyroscope configured at a sensitivity range of ±2000 deg/s (dynamic range is 4000 deg/s), and sensitivity rate of 70 mdps/mg. The resolution (quantization error) would be 4000 (dynamic range) divided by 2 to the power 16 (bits), giving it 0.06 deg/s bits [Tamagawa, 2022]. Linear acceleration sensitivity against the temperature (range from -0 °C to +85 °C) is ±0.01 %/°C, with angular rate sensitivity change against temperature of ±0.007 %/°C. The sensor is calibrated within these parameters for monitoring purposes. The repeatability within this setup will depend on the sensitivity range set within Arduino configuration, and precise location of the experiment to occur during winter season in United Kingdom (minimal wind). Placing the same video camera and having the same goal line distance is desirable to have complete metrics to compare.

IMU board connects onto miniature-breadboard, attached to a stretchable sleeve, placed over the kicker's boot. The thin material was fabric from tights, and they were cut into the appropriate size. This allowed flexibility for the player to use their boots when kicking for this experiment. The tights were elastic enough not to cause any wearable distress (tightness). 1 step kicks meant traction was not affected. Trial periods gave opportunities for modifications to improve experiment setup. Insulation tape used over the board to secure the connection, allowing kicks to be done without any detachments. Foam covered electronic components with only LED light showing (protection). Figure 6.1.1 shows a diagram of the experimental setup and control measure.

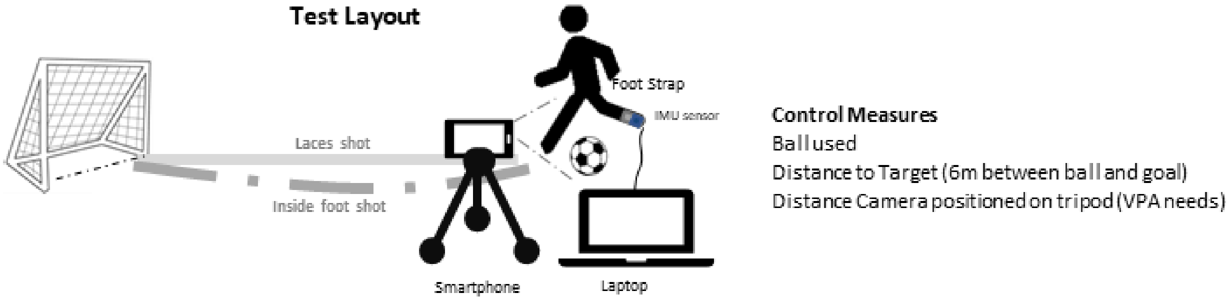


Figure 6.1.1: Experiment setup and Control measures

After all participants finished, the post kick analysis took place looking into Vernier physics application (VPA) (calibrates distance based on pixel) and Sensor data [ST, 2020] [Vernier, 2020] [Topend Sport, 2019]. Video taken from iPhone-6 1080p/60fps (VPA only Apple IOS compatible at time of testing). Each shot sequence is cropped for VPA, before controls applied within this software, as seen on Figure 6.1.2(a). The Axis must also be kept in the correct position for all kicks, as this makes the application's results more valid. The Y axis is placed on the edge of the ball to know the exact distance of backswing and ball contact height. It is important to assign a dimension which is constant. In frame, the ball size was all the same with a diameter of 0.22m (Size 5).

Figure 6.1.3(b) shows the results of the plot points for a shot sequence. Figure 6.1.2(c) are the subsequent graphs of displacement and velocity formulated by the VPA based on plot points. Figure

6.1.2(d) magnifies the key Arduino board being placed on the sleeve [Arduino docs 2022]. Trials were done first, before suggesting "3 examined" laces and inside kicks that can be chosen for analysis. The ball is hit towards a target line (goal), set from a distance (penalty line). A profile was created for each participated player, where their position and type of playing style was noted during the early trial sessions and training observations. These are summarised on Table 6.1.A, which helped understand greater about each player's approach to their kicking technique[Aroganam G, 2021].

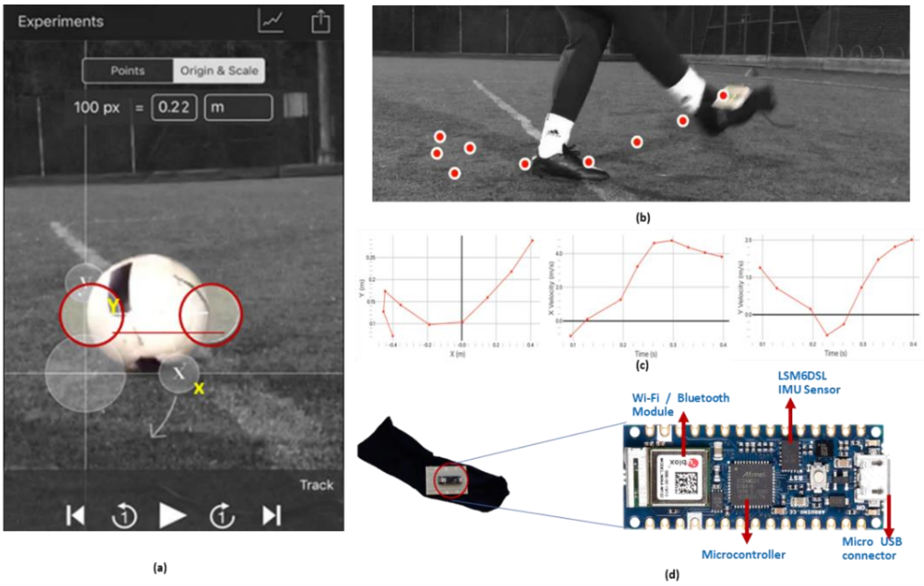


Figure 6.1.2: VPA Scale and control(a), Plot points (b), Displacement/Velocity graphs (c) and Arduino board (d)

Player	Training notes	Trial periods / Experiment Observations
Player 1 Forward	Precise finisher High endurance	Really good power FT seemed high for almost all laces kicks. Inside kicks more consistent than laces
Player 2 Defender	Short passer Powerful kicks	Kicking was fast and powerful, but ball did not have the best launch speed Inside shots seemed much slower Puts a lot of effort but kicks technique was not consistent
Player 3 Midfielder	Good technique in shots and passing. Very physical in plays	With less effort, the ball was travelling at a great speed with low BSs and FT Best kicker based on observation Technique seemed very honed, as every kick was consistent in how it delivered
Player 4 Forward	Fast runner Finisher Unique skill sets	Had erratic kick actions Kicks seemed to be faster than the ball, and gave the illusion that the outcome could be powerful. Very inefficient, with excessive effort applied through all laces kicks, An unorthodox approach, a unique forward position player.
Player 5 Midfielder	Smart player Precise passer Attractive play style	Effortlessly kicking with minimal effort. Seemed very efficient. Did not feel the need to kick with effort to pass the line
Player 6 Defender	Strong long shots Good long passer	Laces shots seemed quite powerful. Consistent technique throughout all kicks Technique better for inside kicks

Table 6.1.A: Assumptions on player profile

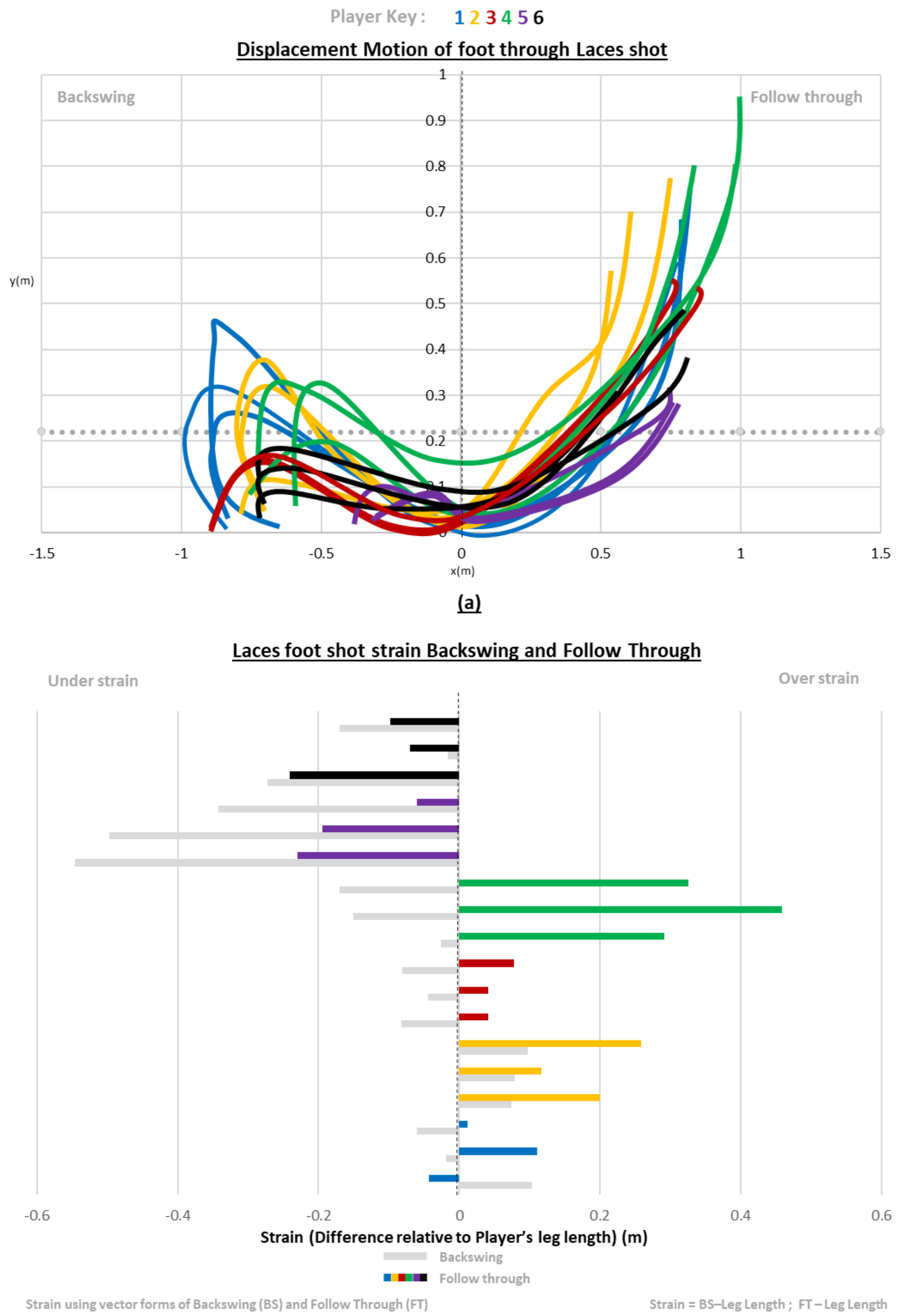
6.2 Women's team IMU sensor analysis of ankle movement for a 6m penalty kick

6.2.1 Results

For the following graphs, analysis was made regarding performance parameters against the biomechanical features for both type of shots. Table 6.2.A shows the key methods of obtaining required calculations which would help analysis. Laces/Inside Shot graph plots for Kick velocity, BLV, BC height against BS/FT are all created for visualisation of monitored results and are Available in Appendix Section 6. [Aroganam G, 2021]

Tracking Feature	Method of calculation
Backswing / Follow through	**Calculated as vectors, through VPA X/Y Displacements Plots (Track point on Ankle). Furthest point in BS and FT were regarded as max displacements.**
Initial kick velocity	**Calculated as vectors, through VPA X/Y Velocity Plots (Track point on Ankle). Plots done until BC.**
Final Kick velocity	**Calculated as vectors, through VPA X/Y Velocity Plots (Track point on Ankle). Plots done after BC.**
Ball contact height	**Whilst doing VPA X/Y Displacements Plots (Track point on Ankle) height on ball is the Y axis reading on BC (x = 0m)**
Ball launch velocity	**Calculated as vectors, through VPA X/Y Velocity Plots (Track point on BALL)**
Strain	**VPA measures Leg length. This is then compared from the BS BS / FT vectors.** **Strain = BS – Leg length ; FT – Leg length**
Kick Efficiency	**Derived from Newton impact law, defined as a variable between 0 – 1, without any units (1 being most efficient – elastic collision). Football kick is how the speed of separation between the stationary ball and boot upon impact, is related to the speed of player's kick.** **COR = (Ball Launch Velocity – Final Kick velocity) / Initial Kick velocity**
Angle range on contact	**Videos were imported into Adobe Premiere pro; capturing BC AS. Frame drawn around, using IMU board LED as reference. Custom scale designed for Inside/Laces shot for analysis**
Angular velocity range	**IMU plots from LSM6DSL showed peak values of BS/FT around point of BC. Rotations prior show Ankle adjustment in Deg/sec, linked to ankle biomechanics rotation. VPA could only consider horizontal and vertical plots based on video frame position. The Sensor's Axis are based around the device, (additional Z axis analysis).**

Table 6.2.A: Tracking feature calculations to be used as Performance parameter with Biomechanics.



(a)

(b)

Figure 6.2.1: Displacement Motion of foot through Laces shot and strain

Figure 6.2.1 (a) shows the players displacement motion for laces shot. Figure 6.2.1(b) shows overstrain and under strain displacement of the players in reference to their leg length. From these the significance of Player 4's drastic kicking methods, where FT was very high, and overstraining over 0.2m as seen on . Player 1 whilst kicking did appear to show great FT, however comparing it regards to strain, this player had the capacity to achieve those lengths. Player 6 evidently more consistent in minimal BS. Player 2 exerted a lot of effort in both, which explains why their kick swings appeared very fast. Player 5 kicked without applying much effort, something Player 3 looked like as well, however when looking at the Vernier physics data, evidence of effort exceeded is shown.

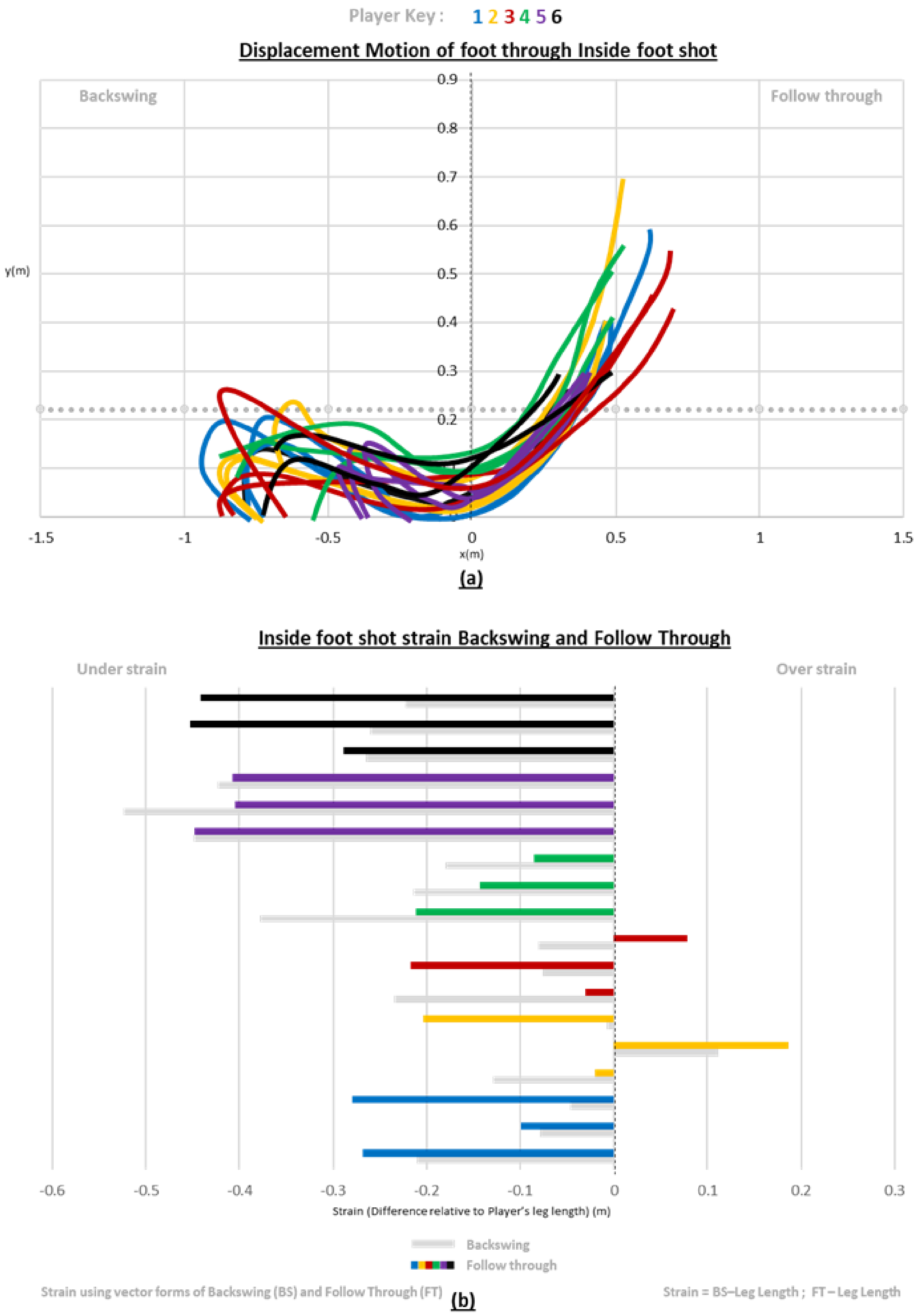


Figure 6.2.2: Displacement Motion of foot through Inside foot shot and strain

From Figure 6.2.2 (a); the displacement graph it may appear that players 1-4 all exceeded their effort, however with the comparison to their relative leg length, only Players 2 and 3 over strained, as seen on Figure 6.2.2 (b). Justifying the key reason why this analysis was included, to give better context, unique to each player. An argument could be made that the taller players require more effort, to reach the bottom of the football, however, as this experiment looked at 1 step kick, the BS, FT are constrained, with the stationary ball. The strain measurement visualises the excessive effort being applied by the players, that's unnoticed during observation, as immediate focus would be looking at success of ball launch.

Drawing a frame around the boot shape to understand better how different players faired, highlighted each kicker’s preferred technique, these overlays are shown on Figure 6.2.3 (a) and (b). Figure 6.2.3 (c) and (d) shows the custom contact angle scale is designed for both type of shots. When looking at inside shots, the angle value, is not the lateral rotation of the ankle (Abduction) or hip Abduction but can identify how much the player has had to manoeuvre to connect the ball at that angle. The point of contact for reference must be the same for all kicks, hence the IMU breadboard was chosen as the ideal object due to the LED light appearing as dot. Figure 6.2.3 (e) and (f) are graph plots for the angle of BC (custom scale) against the ball launch velocity.

Players 3,6 allowed their front “outer sole” to hit with a smaller angle of Plantarflexion, opening the width for broader connection (eversion). Player 1,4,5, focussed their efforts in delivering more of the front sole only, hitting within 40-50 range. The defenders (Players 2,6) naturally struck the ball in the lower region, something that could be accustomed during their gameplay, in trying to kick far, but different ankle angles. The camera being placed in a horizontal view, meant these projections show how low players reach for their kicks. Inside shot BC point of view could have been better behind the kicker for Plantarflexion projections, and on Top to show how much the ankle moved away (Abduction) [Aroganam G, 2021].

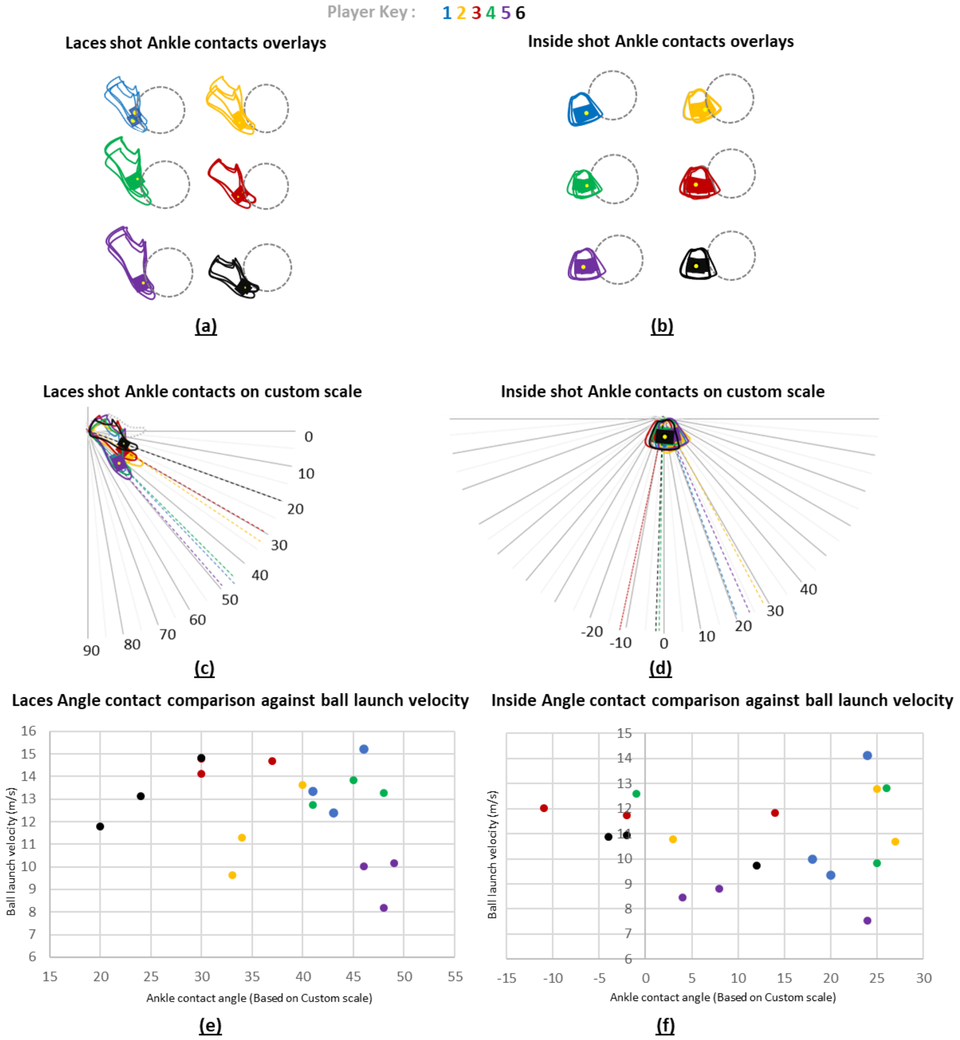


Figure 6.2.3: Ankle position overlays for laces(a)/inside(b); Ankle contacts for laces(c)/inside(d) shots with Custom scale; Angle contact comparison against ball launch velocity for laces(e)/inside(f) shots

Figure 6.2.4 (a) shows the initial kick velocity against ball velocity. These are plotted based on data from VPA tracking points of the ball and player's foot. Figure 6.2.4(b) shows the COR of each of the respective shots, which links to kick efficiency using the formula presented on Table 6.2.A.

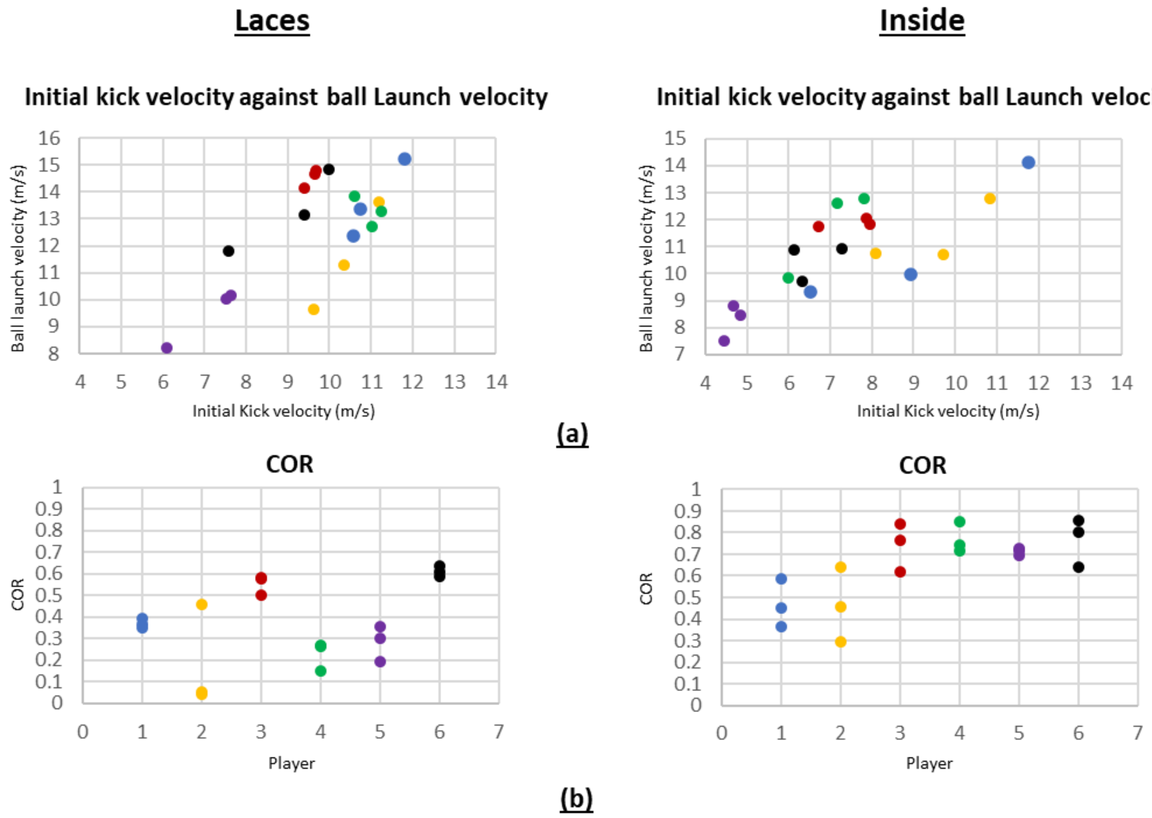


Figure 6.2.4: Initial Kick velocity against Ball velocity (a) and Coefficient of restitution (b) of each player

To understand IMU plots, the peaks showed the point of BC, as this moment is when BS would become FT, hence change in linear acceleration/angular velocity direction (Appendix Section 6). Analysing IMU Figure 6.2.5; Gyroscope graphs plot "peak value", is assigned after a certain number of seconds, to "emulate" how the shots would have looked, had all players started their kick at the same time. This is to give direct comparison in how each player kicked.

Players 1-3 maintained minimal rotation, as they went through their kick. Players 5 and 6, stressed more inwards, where inversion was more likely to have occurred at the start of the BS. Player 5 had low BS, but had a greater angular velocity around the ankle to connect the ball. The drastic motion of player 4 was also evident, as the kicks could be described as "snap shots". Players 4/6 had greater number of smaller peaks, which showed how as the kick was going through, their ankle rotations altered prior to BC.

Player 5 took big plantarflexion angles as the kick phase started and did not kick with great speed or BS distance; hence this shows the technique emphasizing the AS they are accustomed to. Player 2 showed one of the highest BS for Inside shot, and it shows that the ankle experienced this, maintaining their position of Dorsiflexion upon kick, with low BC point. During the BS phase, the Lateral rotation showed how some players "opened out" their foot, as the X axis going down showed abduction (Players 1,3,6). Player 5 stressed more inwards, where adduction was more likely to have occurred at the start of the BS. This could suggest more stresses felt around the first metatarsal – phalange joint.

Players 2 and 4 show that as the kick went through, they shot “inside-out”, meaning they applied effort on an inner angle upon contact before FT brought their ankle back out.

Prior to peak values, which show the shot taken, the potential ankle changes are shown as difference between the angular velocity before the kick phase starts, displaying AS at the start of the kick phase and how it manoeuvred, under player control. Graphs of X/Y/Z on Figure 6.2.5 show the rate in angle changes of ankle position before the kick started. The “adjustment” is monitored to understand how ankle changes could have differed to the final BC stance.

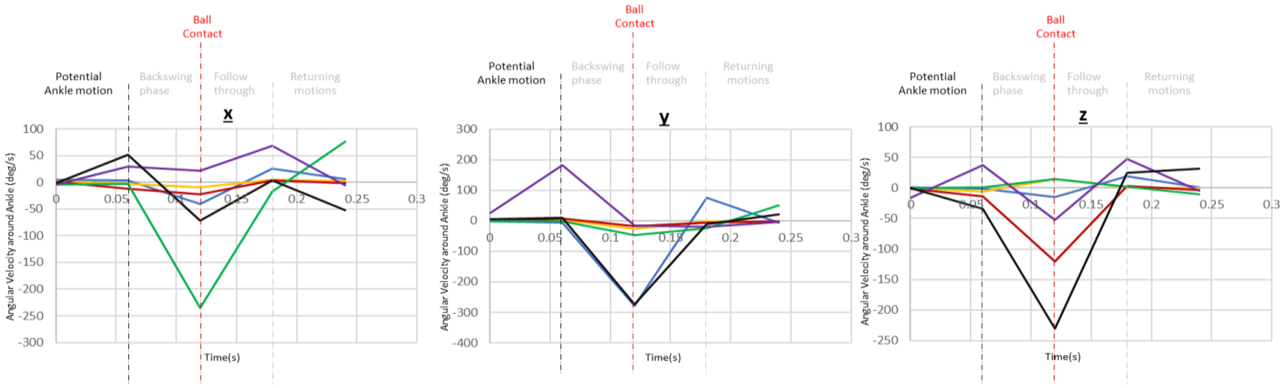


Figure 6.2.5: IMU Gyroscope Graph plot - Sample shot graph analysis

Figure 6.2.6 displays each shot with some reference indicators. The colours represent the player, and each shot taken has its own unique plot line markers on top (box, line, circle, diamond), corresponding to each axis movement, to identify the same shot upon the 3 axis graphs. Each identifier can be recognised by these pointers, when analysing the graph plots, e.g., Player 1 (Diamond), will have a blue plot with a diamond marker on each of the axis. This is highlighted with blue circles on Figure 6.2.6, alongside Player 4 (box) in green circles on the X and Y axis. This method identifies the same shot taken on both axes, where these can show the degree of ankle biomechanical movement. The bottom marker starts at Initial kick velocity, and top marker, resultant BLV. The greater this difference the better the kick, as the player managed to launch the ball at a higher velocity whilst kicking with lower velocity, as illustrated from Player 3 (line) in Figure 6.2.6.

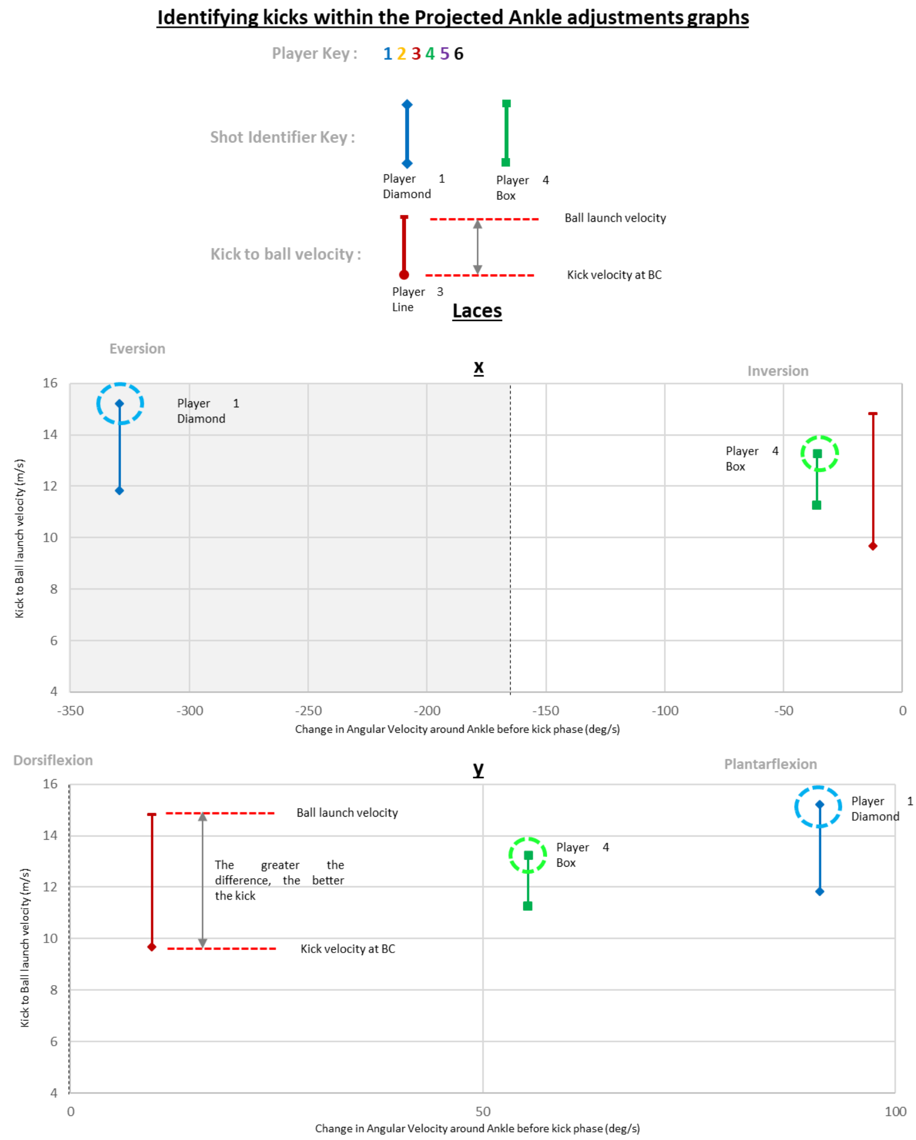


Figure 6.2.6: Shot identifier graph plots for all players

Figure 6.2.7; From the ankle rotations Player 3's consistency can be seen as all axes have shown a similar region of changes, with very similar initial kick to ball velocity difference. Based on this set of results, Player 3 has a strong claim to being the best kicker. With rate of changes, Player 1 showed the most variance, but still managed to connect the ball in a similar region. This player through their powerful swings, still managed to adjust the ankle in time to match consistent hits.

Player 5 (circle) vs. Player 6 (box); started with similar ankle rotations to get Eversion/Plantarflexion. Player 6 managed to get a slightly higher BLV, with more BS but less plantarflexion angle stance at BC (-26), allowing more of the first metatarsal connection being angled to distribute more surface area onto the ball. Player 6 is another good example, of how consistency in their ankle rotation of Eversion/Inversion and BC, allowed their natural ability to strike the ball well, producing good kick to ball velocity ranges.

All players at the initial phase rotated for a plantar flexed stance, however when closely looking at the smaller peaks, Player 4 experienced dorsiflexion and plantarflexion inconsistently, which could indicate why upon viewing kick, the technique seemed unique. All of Player 4's shots show that they were "forcing" inner ankle movement (supination), which adds stress onto the first metatarsal.

Player 2’s weakest kick (line) suggests that the AS was almost executing a “toe kick” with very low contact (0.04m), highlighting potential risk of injury to the phalanges. Player 3 is like Player 2 but had very different shot outcomes. Major difference was contact angle being 10 degrees greater plantar at point of contact for Player 2, at similar BC height. The muscle mass could have affected this, had that been taken into consideration analysing could have shown greater difference. However, Player 2 displayed they could generate sufficient speed with their other kicks, including a larger BS, justifying importance in BC.

Comparing Player 6, two shots with almost identical Adduction (box vs. line), emphasizing the stiff posture, shows that the differences are marginal, in Eversion and Plantarflexion experienced. Kicking at the same height on ball, contact angle within approx. 4-degree difference, resulted in similar kick to ball speed change (2m/s). This shows that the technique is consistent for Player 6, as they exerted lower BS for the weaker shot (approx. 16cm), but with very similar FT.

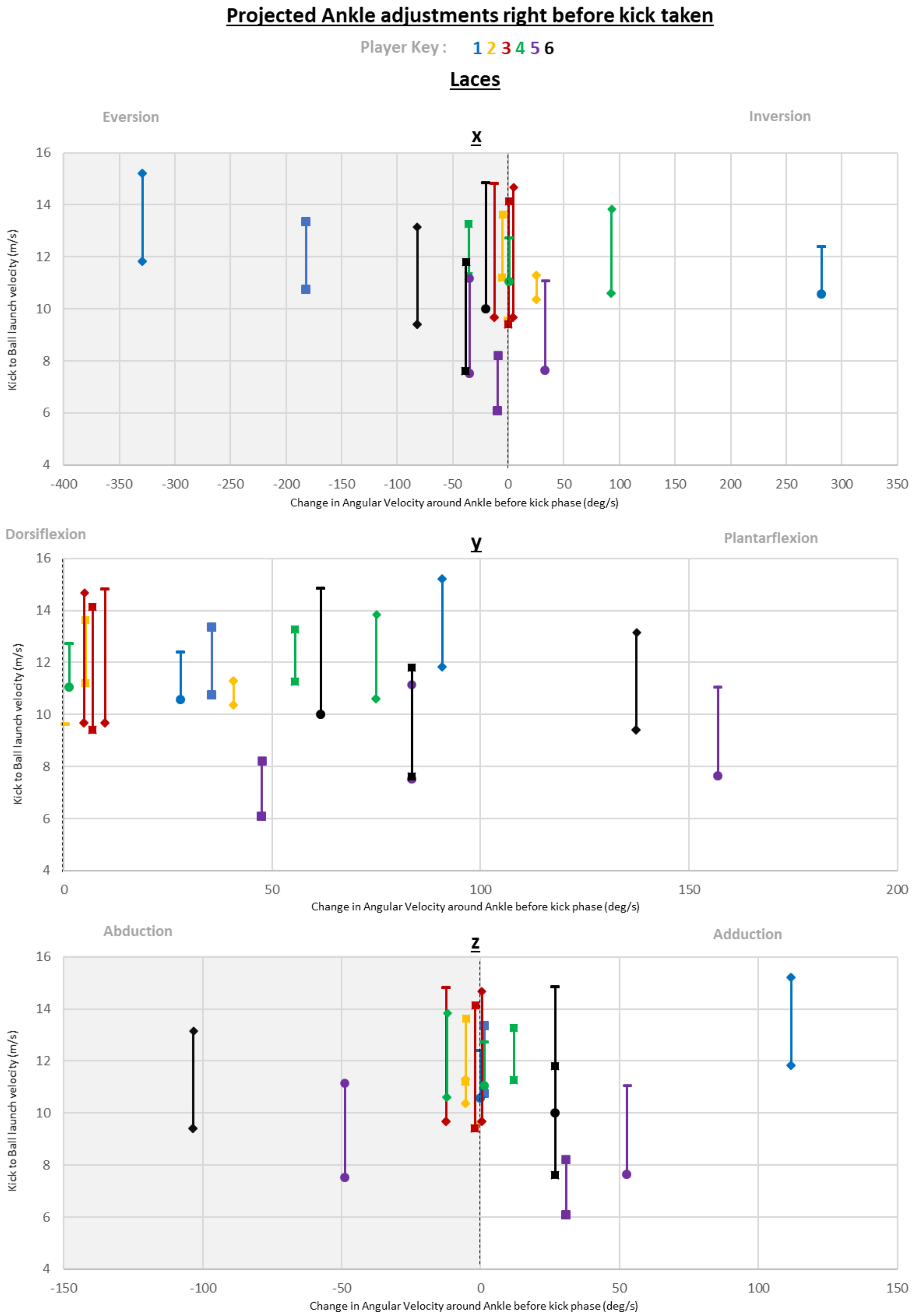


Figure 6.2.7: Laces shot change in Angular Velocity experienced by ankle with kick to ball speed

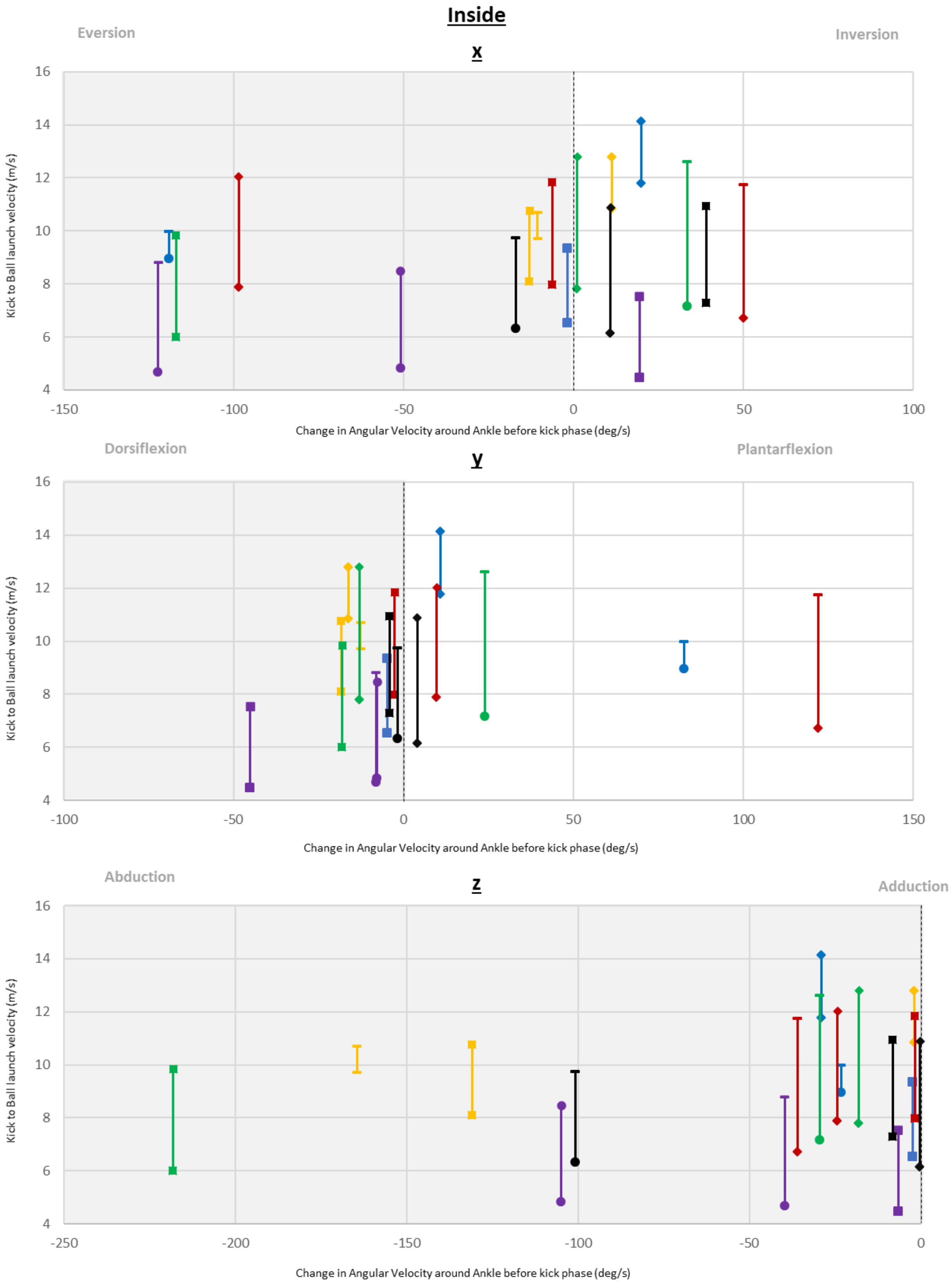


Figure 6.2.8: Inside shot change in Angular Velocity experienced by ankle with kick to ball speed

Figure 6.2.8: The ranges between Eversion/Inversion were similar between players, as were Plantar/Dorsiflexion. This suggests their ease of approach for this type of shot, and how laces are difficult to execute correctly. Player 5 approached with the least effort, still experienced more rotations but made sure they matched similar BC, which suggests they are used to delivering 1 step kicks. Player 5 was known as someone that like to play “with flair”, and this showed in how they knew they could achieve set distance with the least amount of effort. This was because their roles in the team, and their gameplay, effectively gave a “football personality” associated with this. This should be considered as it links to how a player profile is built for the team, and how their physical parameter links to this. Player 3, who was considered the best kicker, had a varied range in inside kick analysis, with BC and AS, but still manages good BLV, suggesting this player’s best attribute would be their power quality.

Player 6 is the most consistent comparing to all axes; their range was the lowest. Player 4 experienced more rotations, which would emphasize that even when BS is not exceeding the limits, the rate of change shows that they are applying excessive effort on forcing that rotation of the ankle to connect the ball. Even with inconsistency in BC, the actual kick to ball velocity has been greater. This shows how analysis made by video and sensor, could lead to understanding unique player ability, something those subjective opinions may not highlight.

All players initially experienced Abduction, emphasizing rotation laterally before they struck the ball. Player 2 showed their significant difference in this ankle rotation compared to their others. Player 1 had consistency in angle range of BC and rate of Abduction changes. Like Laces shots, this player adjusts quickly to match consistent BCs, however their BLV are not the best. This player has bigger potential, because they know what their leg must do, to deliver consistent kicks.

6.2.2 Football data transformation

The Decision matrix is designed to consider all tracked features (attribute weighing in column bracket). The attribute weighing was briefly discussed with coach only, where a higher score for Laces kick properties are given to accommodate its difficulty, in comparison to inside foot. For this set, the scoring worked in reverse principles because the ranking was based on best given a score of “1”; (lowest total is regarded as the best kicker) [Aroganam G, 2021]. Laces shots are harder to execute than inside, hence all their tracked features have a higher weighing. The validity of the actual values is based on VPA and IMU data, however this gives more context to how close subjective opinions match data. Low standard deviation was used for anything IMU related, due to 3 axes being involved. For standalone analysis, average calculations were made, before ranking chronologically.

Player 3’s claim to be the best kicker relies on their consistent form, and how even if the player has taken a lot of FT strain, the consistency shown and the execution meant that this player is able to do this, without hindering performance. How frequently they can achieve this, can calculate a “fatigue factor”, relating to loads experienced. Player 6 is a defender who was known to be a good shooter; Player 2 (other defender) was known to be more powerful. Analysis between them supports the claim that, even for the same position player, attribute traits are different. When comparing their respective velocity graphs which illustrate how well the acceleration/deceleration phases are, it is easy to see how the more powerful kickers achieved a greater BLV due to good BC.

*PL = Player; La. = Laces shot; In. = Inside Shot; IR = Initial ranking based on observations; EFF = Efficiency of BS/FT; AR = Angle range on contact; AVR = Angular velocity range; KB = Kick to ball velocity range; BCC = BC consistency; DS = Decision matrix score (low ranks highest).

Player	Player 1	Player 2	Player 3	Player 4	Player 5	Player 6
Initial Rank	4	6	1	5	3	**2**
La. KB (10)	3	6	1	5	4	**2**
La. BCC (8)	5	4	1	6	3	**2**
La. ST (6)	4	5	3	6	1	**2**
La. EFF (6)	3	6	2	5	4	**1**
La. AVR (4)	6	2	1	3	4	**5**
La. AR (2)	2	4	5	3	1	**6**
In. KB (9)	5	6	2	1	4	**3**
In. BCC (7)	5	2	4	6	1	**3**
In. ST (5)	4	6	5	3	1	**2**
In. EFF (5)	5	6	3	1	4	**2**
In. AVR (3)	3	2	5	6	4	**1**
In. AR (1)	1	5	4	6	3	**2**
DS	275	313	167	277	195	**159**
Final Rank	**4**	**6**	**2**	**5**	**3**	**1**

Table 6.2.B: Decision Matrix table ranking Player tracked attributes.

VPA upon 2nd analysis redo, stopped tracking. This mean plot points for VP app had to be made manually. This reduced the chance of systematic errors, but because human errors being more prone, this step was done 3 times, and checked if the values were close (<0.04m/0.2ms^{-1}). Player 4 was the only player who was left footed; hence the camera was turned around for analysing, the values had to be inverted (negative – positive) as the horizontal axis is flipped to match the right footed players. VPA data would not have affected these results as the ball size was manually adjusted based on pixels for every cropped video.

To understand the acceleration of a kick, the mass of leg should be known. The weight of the players were not calculated. This is different for each player, and even though, a leg's relative weight is approx. 6% body weight (male/female differs) the ball launch speeds get judged as performance, rather than kick speed [Robs link., 2020]. Hence kicking efficiency is computed with COR for this experiment which shows significance in design of performance data for WT.

The IMU sensor had to have adjusted weighing where the tolerance at standstill showed; accelerometer 0.15 m/s2 ±0.03 ; Gyroscope -1.03 deg/s ±0.09, which were not too drastic. The Z axis on the accelerometer was reading approx. 9.8m/s2 (gravitational force). There were 11/72 accelerator readings had error, as they seemed "too low": unreliability of that part on sensor. The gyroscope was more consistent in showing more realistic values. Anomalies occurred more in trial tests and could have been more visible with greater sample. The landing foot was naturally in line of where the ball was placed, and this something all players did.

If the decision matrix scoring had considered higher scoring for sensor readings, the perception may have allowed Player 3 to be the best kicker, without COR consideration. The Gyroscope changes showing consistency for Player 3's laces kick, signifies the qualities of a player that knows how to transfer their energy properly upon BC. Player 1 and 3 knew what their body's capability is. IMU sensor showed that there is more dependency in linking shot types to Gyroscope readings when attached to boot. This is because the rotation of the boot, was monitored for BC purposes. Placement of sensors in other parts of the leg, could be a better source of data collection regarding physical attributes such as kick speed. However, when trying to distinguish the type of shot taken, there is always a need to know the stance of the ankle upon BC. More sensors are needed for analysis, to show different body movements linking to kick attributes.

After analysis, each player was given some feedback. VPA Data, was shown, with what their motion was, and how their kicking could be improved. Player 3 and 5 prior to starting, already had promising prospect of delivering good shots. Upon analysis, Player 6 has the best kicks, regarding efficiency, BLV and strain. It was also important not to change too much on their techniques, like Player 4, who was hard to judge, but still managed good ball velocity.

What monitoring has shown is that a footballer like Player 4, who could experience unorthodox kicking methods, can still produce good ball launch speeds. Kinematic analysis of how the knee bends with BS, and extends in FT, could have developed more insights in unique player techniques, and whether it can be a positive performance indicator.

Overseeing training, Player 3/5 had promising prospect of delivering good shots. During observation, Player 3 did look like the best kicker. Revaluating collective data for this experiment, multiple reviews of video and understanding the different factors of tracked features relating to biomechanics, Player 6 is graded as the best kicker. The results also show that Player 3 overexerting their hip flexion, as they are executing powerful kicks, yet their ball contact is letting them down. This shows how the ankle stance upon contact is vital. Player 6 being graded as the best kicker is relative to the decision matrix scoring principles set. Post analysis data feedback was given to players, regarding their motion, discussing what they do well, and how their kicking could be improved. Players that can remind themselves of what they have done well, gives them "reference points" in relation to biomechanics to recall, as they perform kicks. With the aid of video and sensor analytic data; improvement in consistency and maintaining quality of good kicks is possible.

Only BC was monitored as this was chosen as a refined element to truly differentiate laces and inside foot shots. The other 5 biomechanical features do not directly involve the type of shot taken. However more experiments can help grade other body parts behaviour in relation to quality of football kicks depending on sensor placement [SportsRec, 2019]. How much it can be hindered by the ankle position, where the hard work of allowing efficient transfer of energy, experiencing minimal strain of other muscle groups, could be undone if the BC execution is poor, hence this study's focus. Understanding the sensor could have benefitted with a Test rig; where the "kick speed" is used in a controlled environment, testing reliability of sensors used. Type of sensor depending on location could increase biomechanics involved linking body parts to attributes [Sakamoto el al., 2016] [Deros, 2012][Hussein, 2019]. Use of a stadiometer and electronic scale can further enhance the analysis between players in forming more relevant data to compute against subjective opinions. Kick power could be tracked regarding how far it travels (defenders/midfielders) [Taha et al., 2013]. The ball used were Size 5, the same brand, pumped to a satisfactory standard (manual pump), however the precise pressure of the ball was not measured (aerodynamic effects with pressure linking to the stitch designs on footballs) [Hong et al., 2015]. Boot design also affects ball deformation upon BC [Pueo, 2016]. Indoor tests can have reduced concerns of air resistance.

With multiple targets, and varying distance, the kicker rank could have altered, as perception of players could change. Not having a run up could be a factor in them not giving their "best possible kick", so various approach methods will need to be planned. Phone camera not being able to view the whole length from ball to target, means the actual ball velocity at target was not calculated, which could have been greater after a certain distance (acceleration dependant). BLV was monitored, how quick it reached passed the camera screen, which the application still computed, (Ball tracking). Upgrading to sports cameras and additional placement with processing software from PC; are all future alternatives and control measures [Fitzpatrick et al., 2019].

The positions were relative to the 3 outfield options. To delve deeper into understanding football personalities associated with specific player position, future tests will need participants to specifically desire their dominant position, such as "Left back" defender, or "centre back defender", further enhancing how gameplay and roles of positional players can have different physical attribute demands, towards technical kicking. Other shot types which require same part of inner foot, such as curled shots have importance for wide players, regardless of position [Robs link., 2020]. Hybrid shots of laces and inside, where more connection of first metatarsal and navicular bone with plantarflexed stance, studies can relate to how the kick affects around the surface of the boot. More features or modification to calculating current features can also come from adding more sensors.

Subjective opinions were influenced by observation and coaches. More methods to apply multiple views on players could benefit widening player profile. Different position player has different perception regarding kicking for a set distance. Results supports that data monitoring does show similar perspective on actual player data, but also highlighted other factors that weren't found in observation. Findings were relayed back to team coach, broadening used player profiles. Data analysis proved very important when reflecting players who have unique techniques, so their performance can be compared fairly. More testing is needed with different sensors and linking it to position traits, which can further build football position personalities. This can help team selectors; identify the type of player they want. Amateur footballers can learn more about themselves, for progression.

After full analysis it was shown to the players who participated in this study. A full review and analysis of the consultation given is shown on Table 6.2.C. This was done educate players, relative to their position and to understand their motivation for their approach to gameplay. Hence the impact of this experiment, was greater to the players understanding their data, (physical capability as performance parameter). Evidently players who can generate greater ball speed with minimum effort (BS) showed that they better shooters. Players who were known not for their power, but finesse also showed this in the way they approached to take these kicks. Defenders who were known to kick powerfully, generated higher trajectory to cover more distance and achieve more height for clearances. After computing efficiency, Player 6 become higher ranked with this decision matrix scoring. A Decision matrix was created to rank each kicker against tracked features linking to biomechanics. After reviewing video and sensor data, 2 players showed differences compared to initial observed rank. At Initial observation, Player 3 did look like the best kicker, when analysing the sensor data and video that showed the different factors of tracked features involved, Player 6 would be graded the best kicker. The decision matrix ranking was consulted via coach; hence this input is more relevant to the style they want their players to incorporate.

Player	Review / Advice given post Analysis
Player 1 **Forward**	**Good kicker, with better potential if Player improves their FT. They know what they must do, to kick well, hence working with efficiency could help increase quality of kicks. Laces kicks do not need to require too much effort.**
Player 2 **Defender**	**Improving "BC" needed, as the kicks were fast relative to ball. Showed signs of consistent ankle rotation rates, suggesting they know what makes a good kick, just needs to consider applying less effort to maintain better ball connection**
Player 3 **Midfielder**	**Technique honed for laces, has "raw power" and could work on efficiency in inside kicks. Can just work on maintaining power after fatigue settles**
Player 4 **Forward**	**Technique seemed unique but managed to get good ball velocity. Could improve a lot on efficiency, but unique approach should stay due to promising results.**
Player 5 **Midfielder**	**Due to nature of gameplay and role; kicks did not require effort. Natural ability in striking well but would want more of the Managed to have better BLV with low BS. Would be interesting to see performance regarding long passes.**
Player 6 **Defender**	**According to data, was a better kicker than initially visualised. Inside foot shots, does not always need trajectory.**

Table 6.2.C: Review and Advice given to players

Study approved by Brunel Research Ethics Online. Due to the Global Pandemic, all experiments were postponed, limiting participants (Result set used; completed before Pandemic and United Kingdom National Lockdown).

Summary

IMU sensor proved its role for computing what motions the ankle went through, in relation to player's kicking technique relevant to their style. The angular velocity range of the ankle illustrated how higher technical players kicking have the similar range continuously, enabling the consistency attribute to be derived. Player 3 and 6 showing through IMU data how well they consistently matched their ankle angular range, highlighted how IMU sensor monitoring ankle biomechanics, can generate a data to show how well a player is executing their Laces and Inside shots. The best kickers showed very similar ankle motion characteristics, which is something that WT can rely upon to "grade" kicker attributes. IMU has proven to produce more shooting data, that was not considered before, which means this experiment has shown potential of contribution to knowledge of how ankle motions should be considered as one of the key biomechanics involved in football kicking. This is very important as now it validates how Ankle monitoring can be used as a performance indicator. COR calculations is used to design a new performance stat in Kick efficiency. This is done by calculating ball launch velocity and the difference it was from the final kick velocity, divided by the initial kick velocity before ball contact. Using sensor and video capture, the formation of new performance data is a crucial impact in contribution to knowledge. Observed data also derived a new stat in Kick strain derived from Backswing and Follow through distances around BC. Analysis between same positional players supports that attribute traits are different. The Decision matrix scoring proved how subjective opinions can systematically rank selected kicking attributes. This is something that WT can process with performance data to give a personalised output for amateur footballer.

7. Force Sensitive Resistor Pendulum Test

7.1 Preliminary test of Kicking pendulum rig to emulate football kick with FSR sensor attached to boot analysing potential sweet sport regions.

7.1.1 Test Rig

A preliminary test is done with a weight rig to analyse two kick types in laces and inside shots, which are distinguished by ankle stance upon kicking a ball. This is followed by a test of repeatability to understand variance between different kick forces and provide error bars. This second test will execute the same experiment with additional treatments, and provide multiple height drops to assess repeatability of the results. The specific sensor types that resulted in consistent data capture from preliminary test, will be used for the test of repeatability.

The chosen test rig ideally must emulate the biomechanics of kicking on the shooting leg itself. For this experiment, ankle rotations between backswing and ball contact aren't controlled. The rig will have treatments that give the angle of the ankle, to strike to ball in a designated stance, linking it to the contact region of the boot. Depending on different sweet spot regions, how close they were to intended target for inside and laces foot shots, helps build a data set. This is very important for the decision matrix and framework, as an FSR sensor would monitor different factors compared to IMU, and these will also need to communicate how it transforms different physical data into performance terms. This test results of the ball velocity, aren't authentic to real life kicking scenarios there would be far greater kicking velocities. However, a smaller scale of the intended experiment, tests how the distribution of ball contact, monitored by FSR, can produce meaningful football related data.

To analyse these kicks, FSR sensor is used to emulate potential WT applications on the outer sole of a football boot. The placement of the FSR sensors would be on the upper sole, midsole and vamp regions of the boot (Figure 5.3.2). To control the motion of the kick, a test rig is built influenced by weight discs to strike the ball at a set intensity, which will help analyse how contact region affect ball launch velocity for similar kick velocity. Providing attachment to a weight rack mimics pendulum behaviour, displaying a genuine football kick, regarding lower biomechanics involving backswing, ball contact and follow through. Ankle stance upon ball contact is the new biomechanics that this thesis is trying to prove to grade laces and inside foot shots. This is to study how a specific analysis of ankle stances upon ball contact produces sport related performance data that are extracted with sensors embedded onto the outer sole of a football boot.

Kicking is the most important attribute in football. Every kicker has their strengths and weaknesses, hence when testing with players there are many factors that could affect sensor readings. These can be the muscle/bone mass of the kicking leg, the technique of the player, the material of the boot, environmental conditions of the experimented area, ball surface, sensory settings when test is conducted etc. This study aims to understand the default sensor values in a controlled manner, which increases sensors refinement, and how much can be obtained from a simple analysis, for a bigger purpose. Building a test rig to understand about what the FSR sensors can output, educates the limits to what this WT application could entail. This experiment is to further enhance opportunities of a sensor to explore it's potential to support more findings and help analyse greater depths of football kicking.

Aim of preliminary test:

Analysing the impact FSR sensor can have on a football boot outer sole region, via testing on a kicking rig, to produce football related performance data.

It is important to understand what FSR sensors are, how they work and their application purposes for this experiment. Their structure possesses a flexible substrate with printed electrodes as shown on Figure 7.1.1, which allows easy application onto a football boot. The electric signal sensed from an FSR relies on variable resistance, where an increase in force reduces the resistance, giving more current. A conductive adhesive layer is sandwiched between flexible substrate and a pressure sensitive layer [Adafruit., 2021] [Tekscan., 2021]. This method of monitoring the electric changes, allows usage where loads can be applied in different ankle stance scenarios to output relevant data for this experiment. This sensor can be used to detect electric changes upon boot to ball contact, as selected regions can have significant influence as a performance indicator in how well the ball is struck for both laces and inside foot shots.

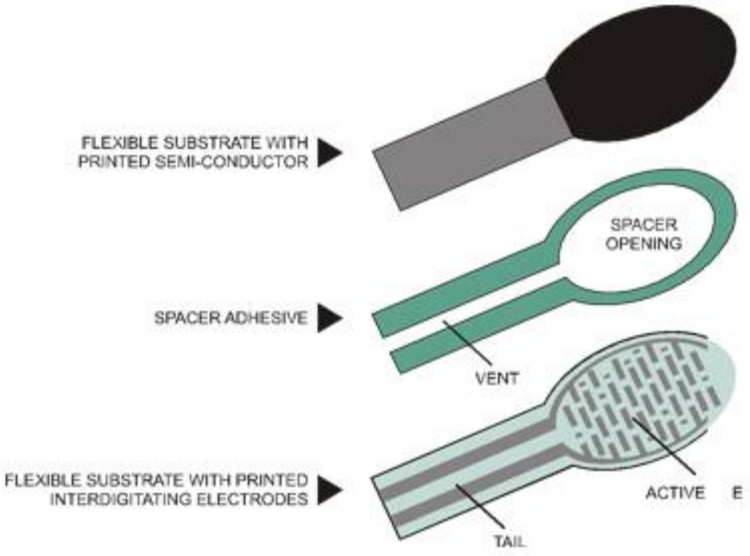


Figure 7.1.1: FSR structure, Image Courtesy of [Tekscan, 2021]

For preliminary test, four different sensors are tested. Square FSR which has a bigger surface, aimed to identify sweet spot regions of the boot. Circle FSR were connected in triplets and pairs, to understand the distribution felt from the ball onto the boot, to test the regions of the soles, that perform good ball trajectories. Flex Sensor are like FSR and was used as an additional measuring tool to understand how detecting bend on the surface of the boot could indicate success of the shot. They work by resistance change depending on how much they're flexed [Adafruit., 2021]. This was used for inside shots to understand if the resulting angle change detection can relate to dissipation of the contact, linking to success of the kick. Long FSR sensor was placed along the perimeter of the boot to compare it to smaller FSRs. This would help advance WT on football equipment know which sensors are more useful for tracking shots. The reason long FSR and Flex sensor was not used on Laces shots, is due to its shape, not being a viable option to place for good contact. This is a limitation of the setup, and the results did not show any correlation to sufficient readings to analyse.

7.1.2 Pendulum set up, Calculation and Calibration

A squat rack is used to give perfect counterbalance for a swinging barbell to mimics the kicking leg, whilst the resting barbell acts as the hinge for the swing to occur around. This enables the kicking downward motion from the shank of the leg. The boot positions are altered according to different region of contact target. The simplicity of obtaining the parts and assembling was a factor in choosing a design of pendulum in this manner. The chosen weights were also influenced by human factors research, to accommodate a scaled down version of this test to study within indoor environment, to reduce as much resistance as possible, and to conduct the test in a safe manner.

The reason why a pendulum is optimal for testing, is due to its characteristics in emulating a kicking motion, where the weight applied to the pendulum swing is controlled(pre-set). This allows a clarification of the sensitivity range on sensor and how well it can output the necessary data. Results would be obtained under controlled environmental conditions to make sure that extraction of the sensor data can be more reliable. The opportunity to have kicking analysis take place under constraints, grants an in-depth study into FSR, relating to its placement on boot outer soles.

Figure 7.1.2 displays the pendulum design, that consists of a weight rack, which is typically used in gyms, for bench press or squat press, where there is a barbell sitting along it. The resting barbell will have weights attached (10kg) each end to stabilize the set up during the motion. The "kicking" barbell is composed of dumbbell extenders to allow weight distribution of the barbell to be uniform, making it easier to lift and release. This is attached to resting barbell via a retro fit clamp. 50th percentile male in Europe will have ~4.4kg leg mass, with 0.5m in shank length. The kicking barbell is comprised of 2 dumbbell handlebars at 0.6kg, with 2 extenders weighing 1kg each. The length is 1.2m so adjustments were made for the height to make intended ball contact. The clamp fixture is made to accommodate the height adjustment; to give appropriate experimental height drop for the kicking barbell. The weight disks are added, to provide the downward acceleration.

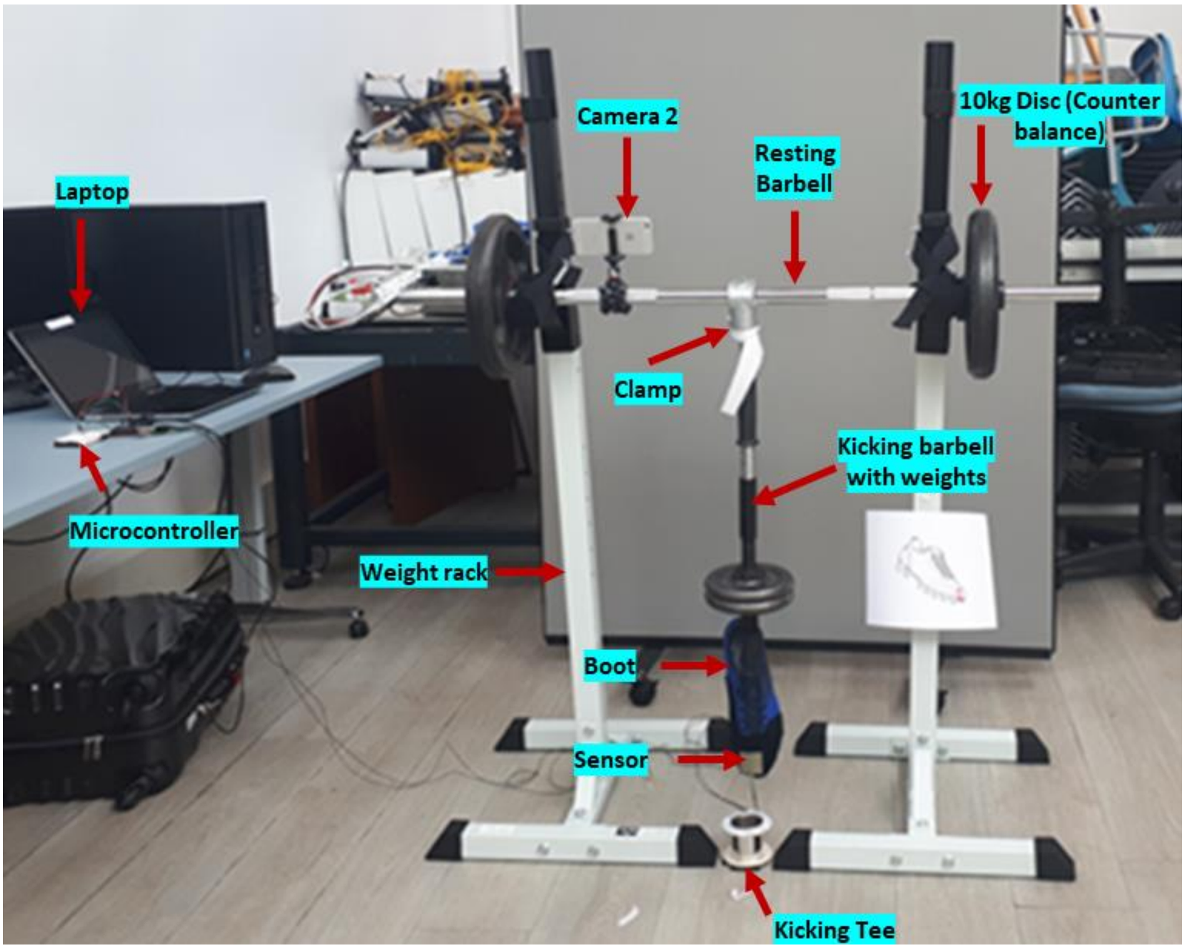


Figure 7.1.2: Test rig setup and equipment

This will give the first indication of how a simple pendulum, illustrating the biomechanical movement of backswing and follow through for kicking a football. Calculating how FSR monitors this movement, and how similar or different they could be with actual human monitoring, provides a data set to work around. For safety reasons the total weight of kicking barbell could not exceed 15kg, hence 13.2kg was used, and the maximum horizontal ball velocity shouldn't exceed 10m/s with ball mass weighing in at 260g (400g limit). These precautions were taken seriously due to testing room conditions to undergo this experiment. Vernier Physics PC application was used to track the ball and boot, velocities, and trajectory on target, producing data that can be linked to FSR readings, and publishing the relevant results [Vernier., 2021]. Figure 7.1.3 shows an illustration of the overall experiment setup. This displays the schematic of the pendulum test rig motion and connections from sensor to laptop, whilst having two cameras monitor properties.

Figure 7.1.4 shows the ball travelling sequence of the test rig kick from side camera. This video capture aids the calculation of ball and boot velocity, which are later inputted onto the excel file alongside the FSR data. Using timestamps, allow the exact moment of shot to be identified, to reduce chance of human error when compiling the large data set. Figure 7.1.5 shows the ball trajectory towards the goal, an additional element of tracking to understand how accuracy is dependent on place of ball contact. Table 7.1.A lists the bill of materials and control measures for this experiment.

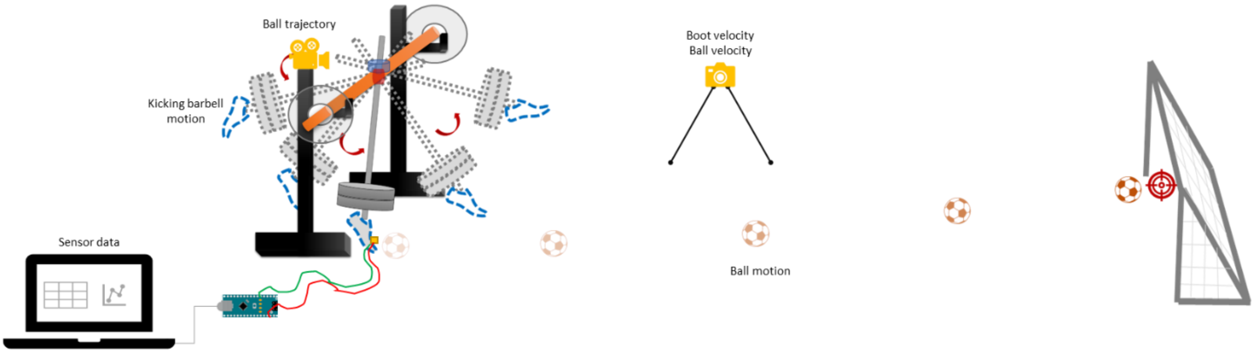


Figure 7.1.3: Setup illustration of equipment and it's monitoring

Figure 7.1.4: Ball travel sequence from test rig kick (side camera recording)

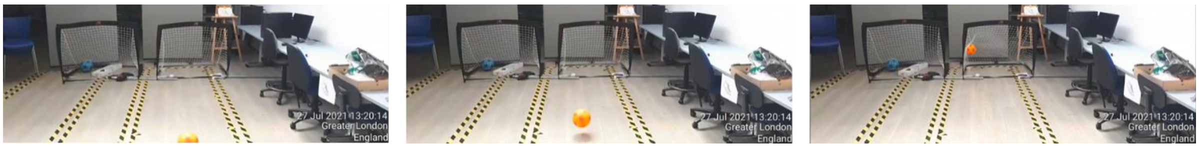
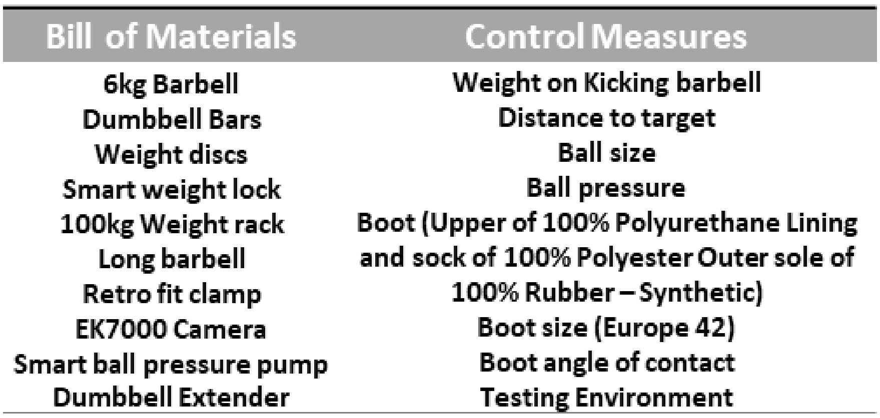


Figure 7.1.5: Front camera recording ball trajectory to goal

Control measure and Bill of materials (Links to items Appendix Section 7)



Bill of Materials	Control Measures
6kg Barbell	Weight on Kicking barbell
Dumbbell Bars	Distance to target
Weight discs	Ball size
Smart weight lock	Ball pressure
100kg Weight rack	Boot (Upper of 100% Polyurethane Lining and sock of 100% Polyester Outer sole of 100% Rubber – Synthetic)
Long barbell	
Retro fit clamp	
EK7000 Camera	Boot size (Europe 42)
Smart ball pressure pump	Boot angle of contact
Dumbbell Extender	Testing Environment

Table 7.1.A: Table showing equipment and control measures.

<u>Connections to boot and Sensor.</u>

Figure 7.1.6 shows the different boot and sensor attachments. The soft side of the Velcro is stuck onto the boot (a), which allows the rough side to be attached and removed easily. The sensors have the rough side of Velcro cut out to attach and detach different parts of the upper sole, midsole and vamp regions as testing progressed. Flex sensor (b) and 2 circle FSR sensor arrangement (c) are shown for inside foot configuration. 3 circle FSR sensor arrangement for laces foot (d) show how the wiring goes above the boot and stuck with tape on top, to stop wires moving when the pendulum swings.

(a) Velcro attached to boot

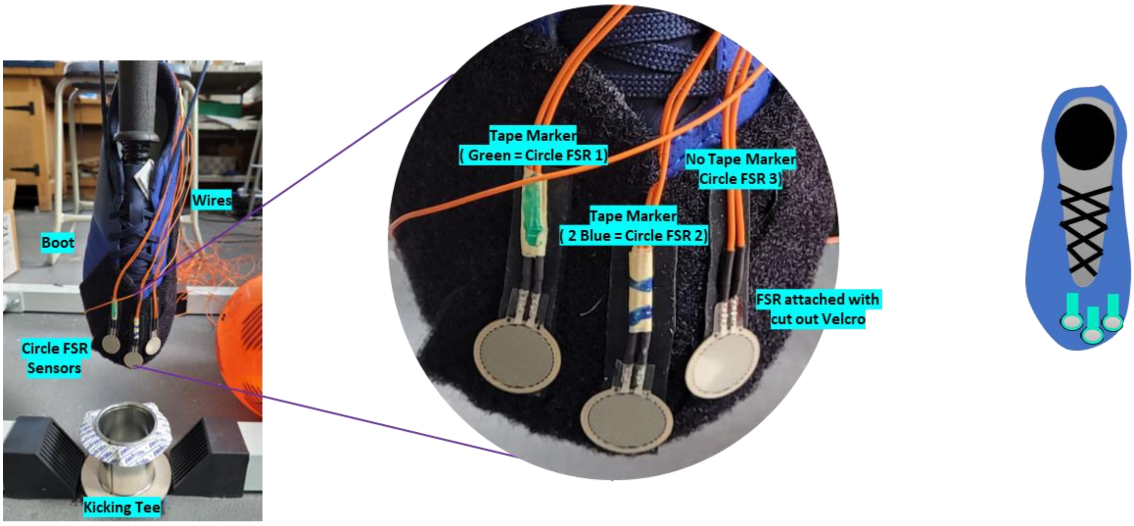
(b) Flex sensor attached to boot

(c) 2 Circle FSR sensor connected to Inside foot configuration

(d) 3 Circle FSR sensor connected to Laces foot configuration

Figure 7.1.6: Boot and Sensor attachments

Figure 7.1.7 magnifies the scope of sensor attachment onto boot. This example is shown for 3 circle FSR setup (a), which have tape markers (b) to help researcher identify which specific sensor is programmed to output, aiding the calibration on laptop. The schematic (c) is drawn for graph references linking to sensor arrangements.



3C FSR Set 1 setup

(a)

3C FSR Set 1 identifiers

(b)

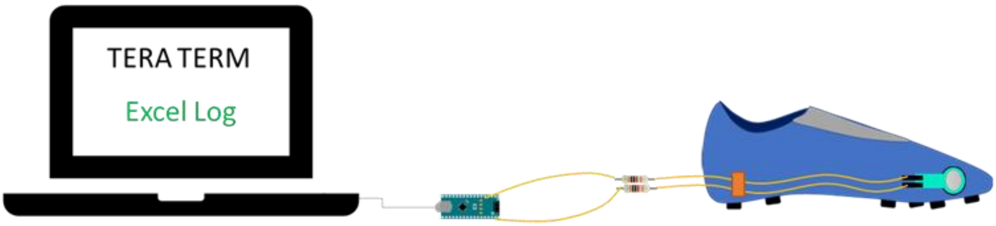
3C FSR Set 1 schematic

(c)

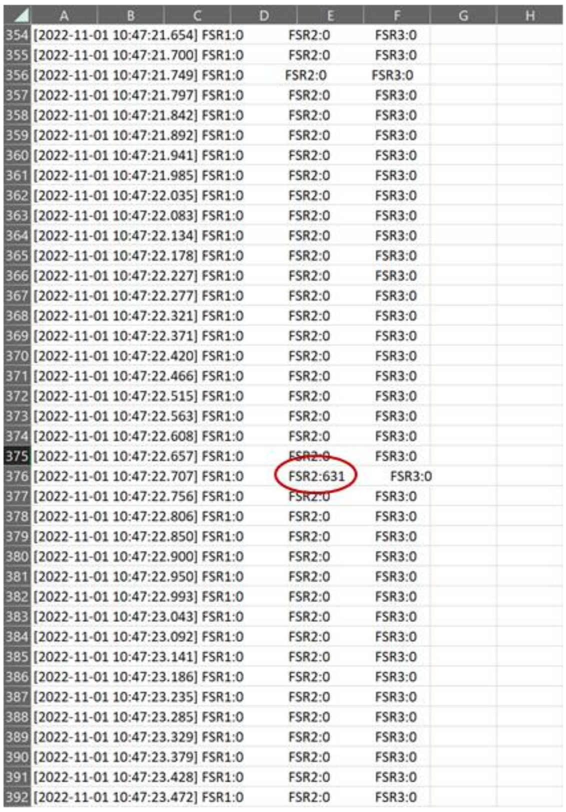
Figure 7.1.7: FSR sensor attachment identifiers and schematic

Figure 7.1.8 (a) diagram shows how FSR connects with microcontroller onto the laptop via micro-USB connection. The FSR sensor pins are soldered to long wires, which connects to Female jumper wires through to a 10K ohm resistor, before Arduino UNO. The serial data is collected via Tera Term software, which logs as a CSV file, that is opened via Microsoft Excel. Figure 7.1.8 (b) shows the data logger results and how timestamp feature enables to identify the exact moment there has been contact. In this result of 3 circle FSR setup, a shot can be seen when FSR 2 has an analogue reading of 631 (~2.3N).

Table 7.1.B shows the calibration conversion between FSR analog reading to force felt in newtons. The sensitivity range of the FSR use limited it to identifying up to 12N and provided the outcome of the sensory readings. Table 7.1.B is important for FSR calibration as it shows what the FSR Analog readings are in relation to Newtons experienced. This table will be used as a reference to identify the quantity of distribution felt on the outer sole of the boot regarding the shots. Figure 7.1.9 are the default resistance calibration provided by FSR manufacturer [Adafruit, 2021].



(a)



	A	B	C	D	E	F	G	H
354	[2022-11-01 10:47:21.654] FSR1:0				FSR2:0	FSR3:0		
355	[2022-11-01 10:47:21.700] FSR1:0				FSR2:0	FSR3:0		
356	[2022-11-01 10:47:21.749] FSR1:0				FSR2:0	FSR3:0		
357	[2022-11-01 10:47:21.797] FSR1:0				FSR2:0	FSR3:0		
358	[2022-11-01 10:47:21.842] FSR1:0				FSR2:0	FSR3:0		
359	[2022-11-01 10:47:21.892] FSR1:0				FSR2:0	FSR3:0		
360	[2022-11-01 10:47:21.941] FSR1:0				FSR2:0	FSR3:0		
361	[2022-11-01 10:47:21.985] FSR1:0				FSR2:0	FSR3:0		
362	[2022-11-01 10:47:22.035] FSR1:0				FSR2:0	FSR3:0		
363	[2022-11-01 10:47:22.083] FSR1:0				FSR2:0	FSR3:0		
364	[2022-11-01 10:47:22.134] FSR1:0				FSR2:0	FSR3:0		
365	[2022-11-01 10:47:22.178] FSR1:0				FSR2:0	FSR3:0		
366	[2022-11-01 10:47:22.227] FSR1:0				FSR2:0	FSR3:0		
367	[2022-11-01 10:47:22.277] FSR1:0				FSR2:0	FSR3:0		
368	[2022-11-01 10:47:22.321] FSR1:0				FSR2:0	FSR3:0		
369	[2022-11-01 10:47:22.371] FSR1:0				FSR2:0	FSR3:0		
370	[2022-11-01 10:47:22.420] FSR1:0				FSR2:0	FSR3:0		
371	[2022-11-01 10:47:22.466] FSR1:0				FSR2:0	FSR3:0		
372	[2022-11-01 10:47:22.515] FSR1:0				FSR2:0	FSR3:0		
373	[2022-11-01 10:47:22.563] FSR1:0				FSR2:0	FSR3:0		
374	[2022-11-01 10:47:22.608] FSR1:0				FSR2:0	FSR3:0		
375	[2022-11-01 10:47:22.657] FSR1:0				FSR2:0	FSR3:0		
376	[2022-11-01 10:47:22.707] FSR1:0				FSR2:631	FSR3:0		
377	[2022-11-01 10:47:22.756] FSR1:0				FSR2:0	FSR3:0		
378	[2022-11-01 10:47:22.806] FSR1:0				FSR2:0	FSR3:0		
379	[2022-11-01 10:47:22.850] FSR1:0				FSR2:0	FSR3:0		
380	[2022-11-01 10:47:22.900] FSR1:0				FSR2:0	FSR3:0		
381	[2022-11-01 10:47:22.950] FSR1:0				FSR2:0	FSR3:0		
382	[2022-11-01 10:47:22.993] FSR1:0				FSR2:0	FSR3:0		
383	[2022-11-01 10:47:23.043] FSR1:0				FSR2:0	FSR3:0		
384	[2022-11-01 10:47:23.092] FSR1:0				FSR2:0	FSR3:0		
385	[2022-11-01 10:47:23.141] FSR1:0				FSR2:0	FSR3:0		
386	[2022-11-01 10:47:23.186] FSR1:0				FSR2:0	FSR3:0		
387	[2022-11-01 10:47:23.235] FSR1:0				FSR2:0	FSR3:0		
388	[2022-11-01 10:47:23.285] FSR1:0				FSR2:0	FSR3:0		
389	[2022-11-01 10:47:23.329] FSR1:0				FSR2:0	FSR3:0		
390	[2022-11-01 10:47:23.379] FSR1:0				FSR2:0	FSR3:0		
391	[2022-11-01 10:47:23.428] FSR1:0				FSR2:0	FSR3:0		
392	[2022-11-01 10:47:23.472] FSR1:0				FSR2:0	FSR3:0		

(b)

Figure 7.1.8: FSR connection schematic with data logger results

FSR Analog reading	0	100	200	300	400	500	600	700	800	820	840	860	880	900	910	920	930
Newtons	0	0.1	0.2	0.3	0.5	1	2	3	4	5	6	7	8	9	10	11	12

Table 7.1.B Calibration information of FSR Analog reading to Force felt in Newtons

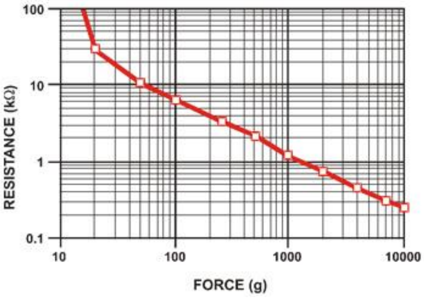


Figure 7.1.9: FSR Resistance calibration [Courtesy of Adafruit]

A feet mannequin was bought to fill the boot. To connect the dumbbell extender to the boot for Laces and Inside shot configurations, there had to be slight adjustments. For laces kick setup, the dumbbell extender slotted in firmly behind the mannequin. For inside shot posture, a Q clamp was needed before squeezing with the mannequin into boot. An illustration of these differences are shown on Figure 7.1.10. Both shots required bubble wrap to make sure the boot did not come loose, as the trial runs did experience these before modifications were made.

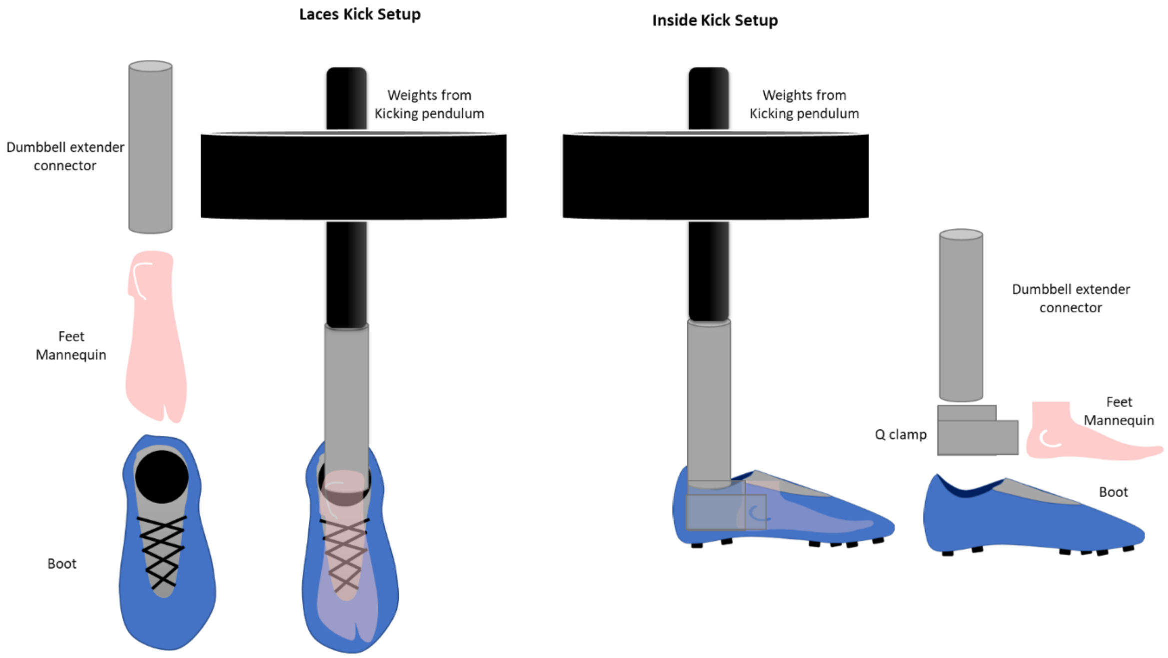


Figure 7.1.10: Laces and Inside kick setup with Dumbbell Extender to Boot and Clamp

After assembling the weight rack, further control measures are added to the ball/boot to make sure the sensor placement and ball contact can be consistent in striking. This is done so that the ball is struck at the exact place with the boot being in a different contact stance. The Size 5, balls were pumped at a pressure of 3.6 PSI with a smart ball pump, giving it adequate air for ball to be as firm as possible, as shown on Figure 7.1.11. The panel design on the football used were labelled to know exactly which part of the ball will be contacted, increasing the control measures to make this a fairer experiment. This is to make sure that the air resistance inside the ball, “balloon design” and the contact deformation does not affect the readings. Each day of testing, the Pressure test was done at the beginning to maintain consistency in ball behaviour. Velcro is stuck onto the outer soles and under FSR, which firmly holds its place. The boot stance upon contact is adjusted slightly by turning the dumbbell handle in screw motion within the extender. For inside foot shots the adjustments were “loosened” so the boot can be lowered to allow sensors to hit the ball. A small tee is stuck to the ground via Velcro, to not let the boot hit the floor, where the height had to be 1.2m from retro clamp fit.

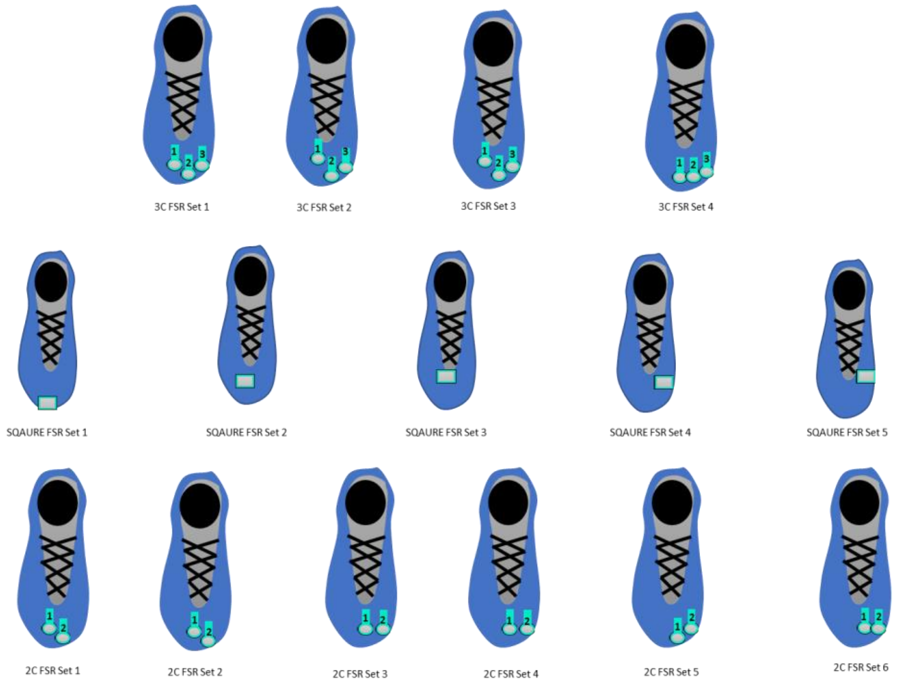
Figure 7.1.11: Ball pressure reading before the experiments

Setup

1. Weight rack assembled
2. 10kg support weights are placed on resting barbell for counterbalance support
3. Kicking barbell composed of dumbbell connectors to get precise height for ball contact
4. Intended weight added to kicking barbell
5. Ball pumped to 3.6 PSI and Kick Tee stuck to ground (Highest point 1.2m from Clamp)
6. FSR type placed on given region of boot (Velcro attached)
7. Boot attachment adjusted by rotating dumbbell handle with extender for appropriate stance
8. Boot region labelled for video purposes
9. Camera switched on for recording
10. Sensor reading tera term application on
11. Kicking barbell lifted at height of fixture to standing barbell (perpendicular)
12. Kicking barbell released to allow ball contact
13. Next ball placed on holder
14. Kick repeats, with another ball replacing after
15. Video and sensor tracking stopped and saved
16. Repeat from Step 7.

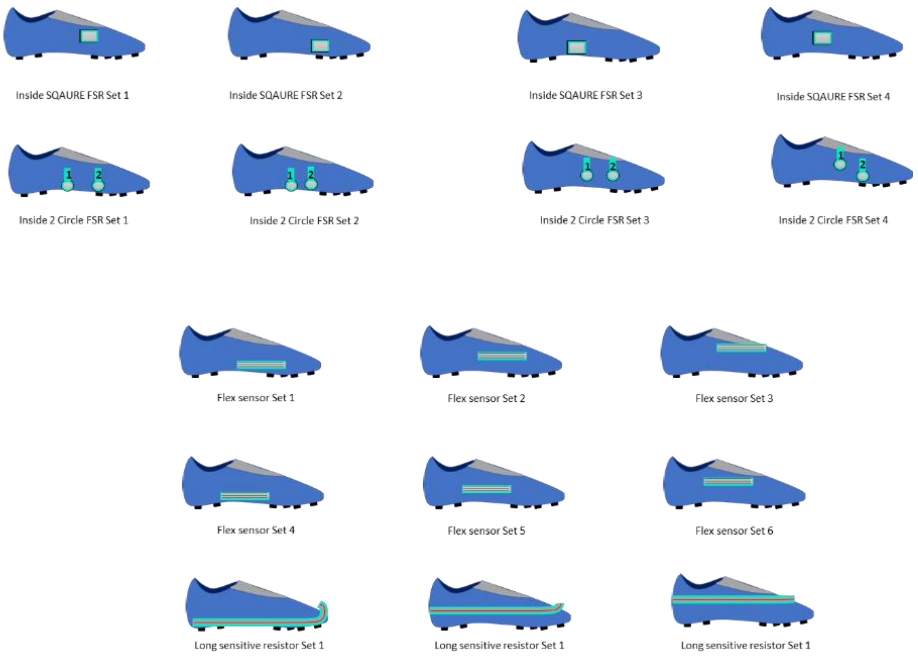
The positioning of the FSR gives an indication of where on the boot sensors can be placed for best kick tracking. To form a potential decision matrix, to understand how data can be perceived, the sensors were placed to emulate different ankle posture upon laces and inside foot shots. This results in showing how different sensor placement, equates to different ankle stance. This is important to emulate how players may have approached the ball and struck with a different region of their foot. These are projections based on if form was precise to execute the shots.

Figures 7.1.12 and 7.1.13 show the FSR sensor arrangements for laces and inside shot respectively. These are done in combination of 3 circle FSR, 2 circle FSR, Square FSR, flex sensor and long resistive sensor around the vamp and midsole regions for both shot types. These sets are important when analysing the graphs to identify which region of the boot aids to better shots.



3C FSR Set 1
3C FSR Set 2
3C FSR Set 3
3C FSR Set 4
SQAURE FSR Set 1
SQAURE FSR Set 2
SQAURE FSR Set 3
SQAURE FSR Set 4
SQAURE FSR Set 5
2C FSR Set 1
2C FSR Set 2
2C FSR Set 3
2C FSR Set 4
2C FSR Set 5
2C FSR Set 6

Figure 7.1.12: Laces shot sensor arrangements.



Inside SQAURE FSR Set 1
Inside SQAURE FSR Set 2
Inside SQAURE FSR Set 3
Inside SQAURE FSR Set 4
Inside 2 Circle FSR Set 1
Inside 2 Circle FSR Set 2
Inside 2 Circle FSR Set 3
Inside 2 Circle FSR Set 4
Flex sensor Set 1
Flex sensor Set 2
Flex sensor Set 3
Flex sensor Set 4
Flex sensor Set 5
Flex sensor Set 6
Long sensitive resistor Set 1
Long sensitive resistor Set 1
Long sensitive resistor Set 1

Figure 7.1.13: Inside shot sensor arrangements

In a real shooting scenario, players may have slightly different ankle biomechanics stance, yet still strike the ball well, however the listed movements can be considered the "ideal" contact position to execute the shots within the chosen contact area. Figure 7.1.14 shows the example of how sensor placement would define ankle position and their contact regions upon different shots. Tables 7.1.C – 7.1.D shows the ankle biomechanics compared to the contact region. The experiment applies different treatment of boot attachment onto pendulum, to emulate these different effects of ankle angle upon ball contact. This influences how the regions of the boot will impact the kicking process of the player as they would alter their kinetic linkage to apply the desired contact on the ball.

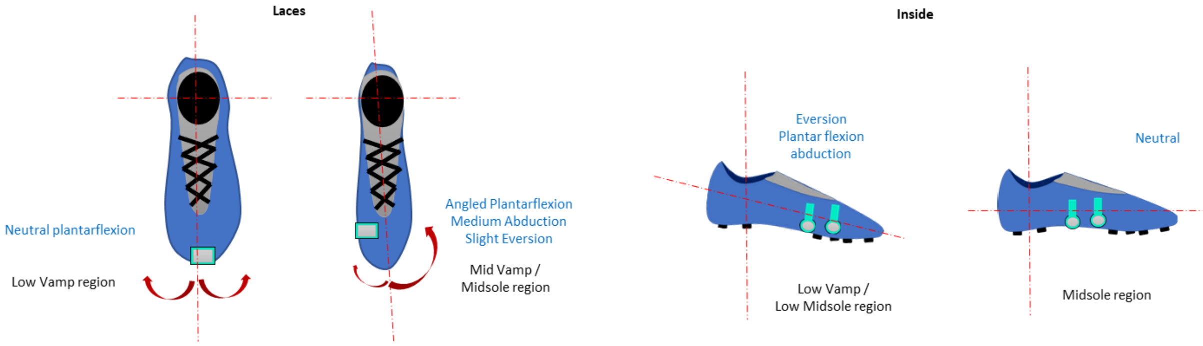


Figure 7.1.14: Laces and Inside foot setup of Boot that shows ankle biomechanics upon contact area

Laces Sensor Placement	Ankle Biomechanics Upon Contact
Low Vamp	Neutral Plantarflexion
Mid Vamp	Neutral Plantarflexion
High Vamp	Neutral Plantarflexion
Low Vamp / Midsole	Low Angled Plantarflexion Abduction Slight Eversion
Mid Vamp / Midsole	Angled Plantarflexion Medium Abduction Slight Eversion
High Vamp / Midsole	Plantarflexion Abduction Greater Eversion

Table 7.1.C: Sensor placement of laces shot analysis and their projected Ankle biomechanics

Inside Sensor Placement	Ankle Biomechanics Upon Contact
Low Midsole	Neutral
Mid Midsole	Neutral
High Midsole	Eversion
Low Midsole / Low Vamp	Eversion Plantarflexion Abduction
Low Midsole / Mid Vamp	Slight Dorsiflexion Abduction Eversion
Mid Midsole / Mid Vamp	Neutral
Mid Midsole / Low Vamp	Slight Plantarflexion

Table 7.1.D: Sensor placement of Inside shot analysis and their projected Ankle biomechanics

The testing compromised of 164 videos, where a minimum of 3 kicks were repeated for exact location and FSR type. Enabling the same kick versions to be executed for reliability purposes helped total over

500 kicks, withing the different FSR arrangements. The videos are inserted into Vernier physics Pro, where the ball diameter (22mm) was assigned as a constant size, which allows the software to compute the calculated variables, via knowing the screen pixel. This allowed the following features tracked:

1. FSR reading depending on boot placement (Analog reading / N)
2. Boot velocity (m/s)
3. Ball horizontal velocity (m/s)
4. Ball trajectory distance from target (m)

<u>Pendulum calculations</u>

For calculation purposes, friction is negated to find the max possible kick velocity between the 2 weight sets. As this motion is a pendulum, theoretically the gravitational potential energy of the kicking pendulum becomes kinetic energy at the point of ball contact, which is illustrated on Figure 7.1.15. Then conservation of momentum is derived to implement the final pendulum kick velocity at ball contact point. The kinetic energy conservation then allows the ball's launch velocity to be computed, as with penalty shots, its initial velocity is zero (stationary). The total pendulum maximum weight considered both, the discs, Dumbbell handles, Dumbbell extenders, Q clamp, the mannequin, and the boot. The bubble wrap was too light hence, the figures were rounded to the closest possible total weight. This also was important to stick under the 15kg limit for the test to commence. The force of pendulum would equal to acceleration do to gravity, multiplied by its mass, and the angle between Resting barbell and Kicking barbell. Because at point of contact, these are perpendicular, i.e. Angle of contact Is 90 degrees, then Sin(90) = 1.

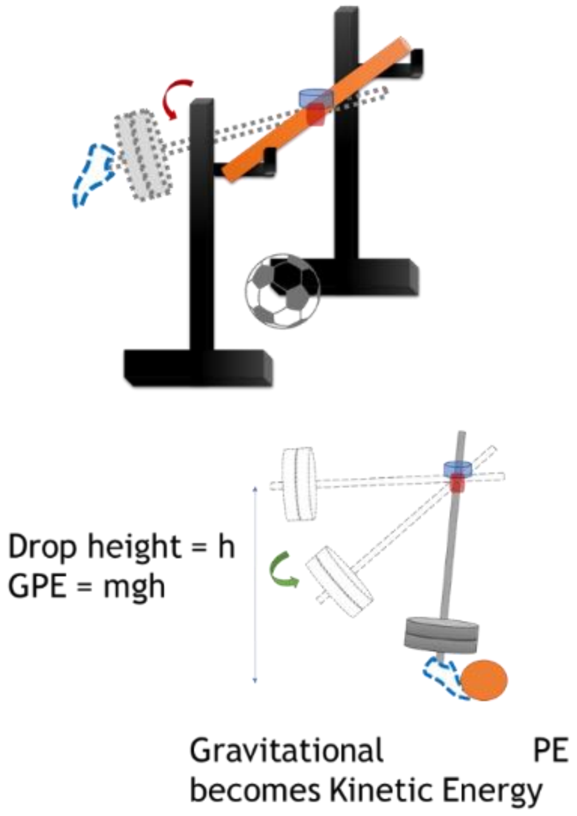


Figure 7.1.15: Pendulum showing the energy transfer during ball contact

Mb = Mass of Ball; Up = Initial Pendulum velocity ; Vp = pendulum Velocity ; Vb = ball velocity, Total Mp = Max Mass of Kicking barbell, h = Height of drop ; GPE = Gravitational potential energy; KE = Kinetic energy

Ub = 0 m/s (ball stationary)

Mb = 0.26kg

Mp = 13.2kg

h = 1.2m

$GPE = mgh = (13.2)(9.81)(1.2) = 155.23\,J$ (Equation 7.1)

$KE = \frac{1}{2} mVp^2$ (Equation 7.2)

Rearranging Equation 7.1 into 7.2:

$GPE = KE = \frac{1}{2} MpVp^2$ (Equation 7.3.1)

$Vp = 4.85\ m/s$ (Equation 7.3.2)

Conservation of momentum:

$MpUp + MbUb = MpVp + MbVb$ (Equation 7.4)

$(13.2)(4.85) + (0) = 13.2Vp + 0.26\,Vb$ (Equation 7.4.1)

$64.02 = 13.2Vp + 0.26Vb \quad (make\ Vp\ subject)$ (Equation 7.4.2)

$Vp = 4.85 - 0.0197Vb$ (Equation 7.4.3)

Vp becomes Up as collision occurs (Ball contact)

Kinetic energy conservation:

$\frac{1}{2}MpUp^2 + \frac{1}{2}MbUb^2 = \frac{1}{2}MpVp^2 + \frac{1}{2}MbVb^2$ (Equation 7.5)

$155.23 + 0 = 13.2\,Vp^2 + 0.26Vb^2$ (Equation 7.5.1)

Vp from (Equation 7.4.3) goes into (Equation 7.5.1)

$155.23 = 6.6\,((4.85 - 0.0197Vb)^2) + 0.13Vb^2$ (Equation 7.6)

$155.23 = 6.6\,(23.52 - 0.191Vb + 0.000338Vb^2 + 0.13Vb^2$ (Equation 7.6.1)

$155.23 = 155.23 - 1.261Vb + 0.130338Vb^2$ (Equation 7.6.2)

$0 = 0.130338Vb^2 - 1.261Vb$ (Equation 7.6.3)

$0 = Vb\,(0.130388Vb - 1.261)$ (Equation 7.6.4)

$Vb = 0 \quad or \quad 0.130388Vb = 1.261$ (Equation 7.6.5)

Vb = 9.67 ms^{-1}

The **maximum ball velocity** under no friction when pendulum mass is **13.2kg**, would be **9.67 ms^{-1}**

7.1.3 FSR Sensor Analysis

The graph for the following FSR's have been designed for clearer visual understanding. The axis is labelled, with selected quantity of monitoring, i.e., Analog resistance reading (linked to loads experienced in newtons). The X axis is consistently kept as Kick to Ball Velocity (KTB), this is to show how well the ball has been launched upon contact, relative to the Kicking pendulum swing. The Start point plot is taken from the kick velocity, and finish point of this plot shows the ball velocity. The longer the plot line, the better the efficiency of the kick, resulting in greater ball launch. The numbers beside each plot point are the Zeroing distance difference from target, where the ball was intended to reach. The closer the value is to 0, the closer it was to its intended target. This was an additional monitoring element, that was added for greater performance data building. The negative FSR values are kicks that did not achieve any readings, therefore the contact was not made precisely, and was given these values for visualisation purposes.

A sample data showing what a Square FSR result look like is shown on Figure 7.1.16. This dataset displays how the Low vamp region sensor placement, produced FSR Analog readings (linking to Newtons on calibration Table 7.1.C), regarding the KTB velocity (better transfer of energy). The square FSR data set was easier to create a graph representing the tracked features, to allow an ergonomic visualisation of analysing the sensor data.

There are nine shots for this sample data set shown on Figure 7.1.15, with annotations showing key variables in kick velocity where trackers were placed on boot, and ball velocity, with tracking points placed on the ball. The greater the horizontal line across the x axis, i.e. KTB velocity, the better the kick, as more ball velocity is produced per kick velocity. Zeroing distance being negative means the ball went to the left of the target as the tracking axis were set being positive from the left goal post.

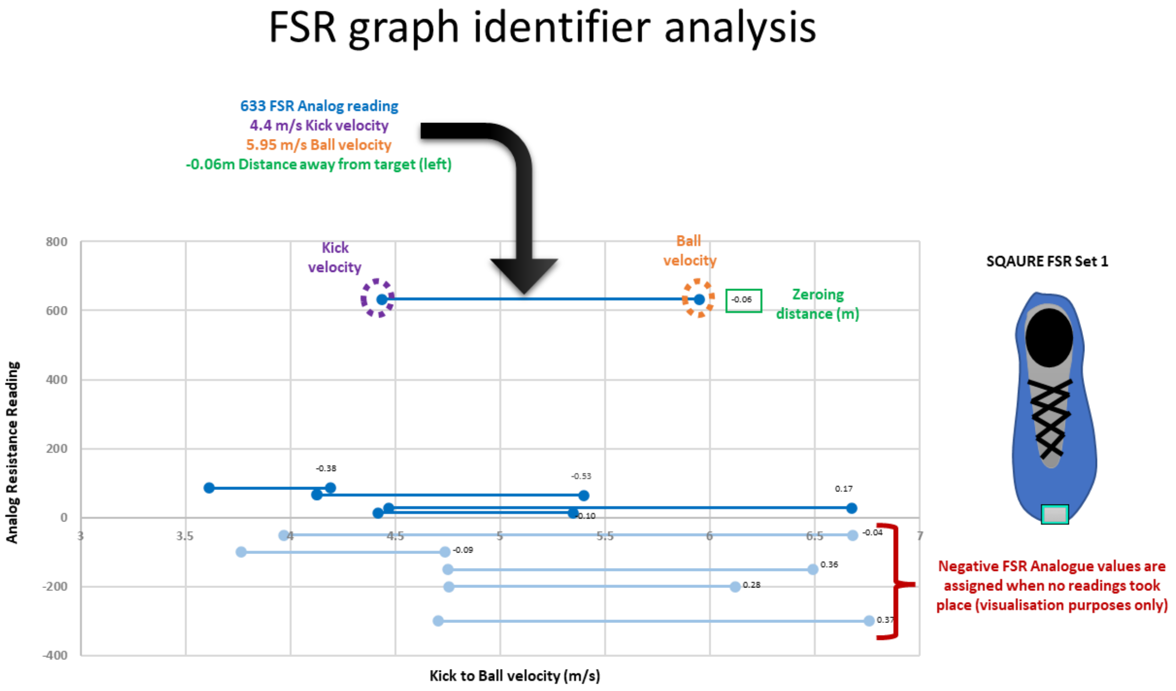


Figure 7.1.16: Kick identifier graph sample data for square FSR placed in low vamp region

Full set of results from the sensor readings are in Appendix Section 7.

Square FSR readings showed some signs of good contact on the sensor placed, with some inconsistencies in accuracy. Projections were close to target with different placement regions signalling contact. The mid vamp and midsole region position, showed very good accuracy and high analogue reading, confirming that this is an optimal sweet spot area. However even with this position some very good accurate kicks, i.e., three -0.01 kicks which were not picked up by the sensor. Position 4 and 5 also show how the stance of the ankle should have allowed more inversion to produce better readings, due to high vamp midsole region of sensor placement, the kicks barely grazed the sensory panels, proving how it's vital that the ankle rotation upon contact needs to be adequate to strike at intended region.

The same argument and reasoning for laces square FSR can be applied to Inside foot analysis too. Any sensor positioning around the Midsole, produced consistent readings from the sensor. 34/44 shot trials outputted sensor readings, yet the accuracies were very drastic. This could be that when the rig was optimised for inside foot shots, the handling of the kicking pendulum was not comfortable as the lace's configuration. It is evident that a larger surface of the senor was felt upon ball contact, compared to laces shots, so the midsole region is almost guaranteed to need sensors embedded within. When comparing Position 3 Low Midsole, an almost perfect kick, produced excellent KTB velocity, precise hit of target (0.00), experienced over 900 Analog reading (>9N), which would indicate how well FSR can be applied. When comparing this to Higher Midsole, another kick which showed good Analog reading, with KTB velocity, was so far off the target. Because Inside foot shots have a greater surface area from where the ball can be struck, one FSR may not suit the best for tracking these. This shows how important contact regions are, hence, WT can garner greater information.

3 Circle FSR

3 Circle FSR arrangements allow significant tracking capabilities both for laces and inside shots. The distribution of the loads experienced by the ball contact on the boot, is a very good indicator in relation to the accuracy. Because there are more "sensing points" this grants greater opportunity to distinguish the amount of contact on the boot surface. Providing more information of ball contact, creates an opportunity for the sensor to link to football performance data by combining other sensory findings. Within the 3 circle FSR setup, Midsole to Mid Vamp region sensor placement experienced 17 readings, when the accuracy was within +-0.2 and having more than 400 Analog reading. This precision, meant, there is a potential Sweet Spot, giving optimal ball launch, and adequate KTB velocity, within this area for laces shot.

Graphs are split into 3, each for the specific Circle FSR. This allows the plots to show for each sensor reading, for the same shot, giving a greater visual understanding of how the sensor combine to produce data. This is something User experience designers will need to communicate with Data scientists to educate how the sensory readings match ankle biomechanical stance upon ball contact. Having these roles to create a system WT can rely on using FSR, influences how an ergonomic experience can be made, with educating ankle position's importance in shots.

2 Circle FSR

As with the 3 formation, 2 circle FSR produced "better" readings. A slight bias could be formed when closely looking at the fact, better boot to ball velocity differences were consistent during this and it displays how well the test rig kicks underwent. The 2nd Circle FSR arrangement produced consistently good readings, regarding all features, and it's the placement was also in between midsole and vamp, further justifies why this area and choice of sensor can help identify successful shots. This is a serious consideration to justify, because in a potential attribute decision matrix, the placement of this 2nd FSR sensor arrangement being sensed, could have a greater weighing, when judging if the player has struck the ball. This is because under the same condition with 3 Circle FSR, their positions produced consistently good readings.

When comparing Inside foot shots with the same sensor, the 1st circle FSR arrangement produced better results, which was also in the region of the vamp and lower midsole. This could entail greater justification of the sweet spot region for inside shots; however, the consistency was not the same as laces shot. The shape of the boot being hollow in this region meant that the designers had human factor research elements implemented, with biomechanics studies and consultation from chiropodist, leading to anthropometrics to provide sufficient inside volume [Decathlon, 2021].

With Circle FSR readings, the plots were split for each specific sensor to give a better understanding of the output data. Figure 7.1.17 shows how the same shot, i.e. green plot with +0.32m zeroing distance, can be identifiable via both graphs, each representing different circle FSR respective to their position. This is done to reduce the cluster that could arise when too many readings are present in one graph. The split allowed much clearer learning of the sensor reading, based on boot region placement. The graphs are matched with the same plot colour, and zeroing distance, to identify the same shot type taken. E.g., When viewing the graph, yellow plot point from the Circle FSR 1 shows a zeroing distance of 0.09, with just under 800 Analog reading, and Circle FSR 2 for the same shot shows a negative value, because there was no contact (negative values purposely assigned for graph visuals). This process was the way of displaying what the sensor read as outputs.

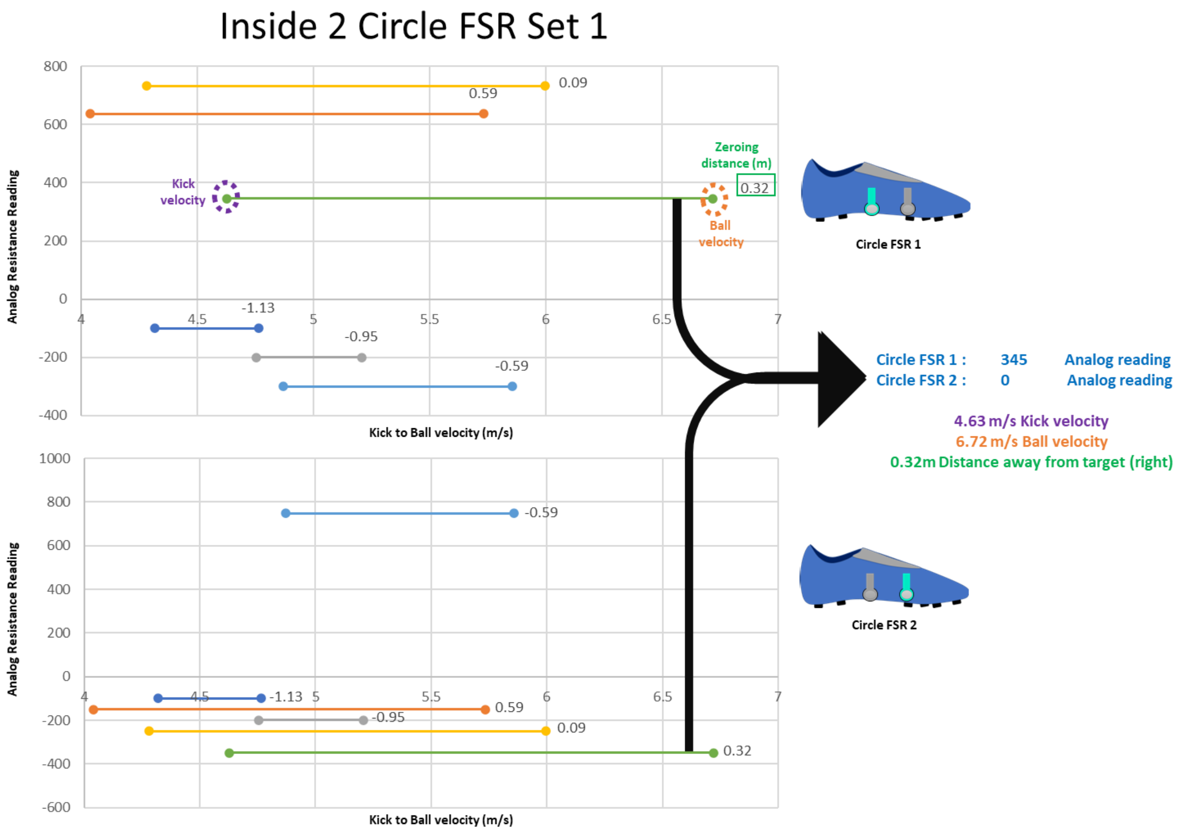


Figure 7.1.17: 2 Circle FSR graph inside shot identifier with sensor placement in low midsole region.

During the configuration of placement, greater midsole and Lower vamp regions produced 8 and 10 readings within this specification, which suggests how sweet spot could be something that gets integrated into WT to identify better shots (Figure 7.1.18). This also shows how Circle FSR would be a preferred choice of sensor for embedding onto outer sole, regarding monitoring the impact force of the shot.

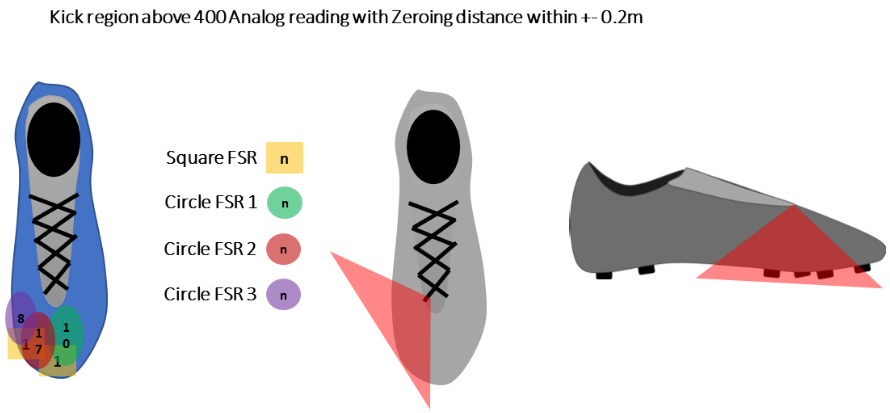


Figure 7.1.18: Potential Laces shot Hot Spot region from Sample data

7.2 Test of repeatability using Circle and Square FSR to provide variance and error bars of pendulum kicks.

7.2.1 Test of repeatability of Circle and Square FSR

The pendulum test rig showed good analogue signal readings for ball contact upon laces and inside shot setups. Square and circle FSR provided sufficient data that would be meaningful in linking boot contact regions upon kicking the ball at the same place (labels on panel design), and its influence in trajectory. These two are the only sensors used to carry out the repeated experiments as long FSR and flex sensor did not produce enough meaningful data, for ankle analysis study.

The same test rig (Figure 7.1.2) is used for an additional experiment to demonstrate the repeatability of these kicks. This is done so the pendulum FSR test can be performed for reliability, where an estimate of variance on the different kicks can be provided, depending on the factors surrounding the experiment procedure and sensor setup. The distance between pendulum rig to the goal remains at 4.5m. The intended targets are altered between lower left, middle and lower right sides of the goal. This is an accuracy element to determine how far off the ball trajectory deters upon kicks.

An analysis of variance in results are formed from the replicate kicks, which have different treatments that relate to the sensor arrangement on the outer sole of the boot, and how its positioned within the kicking barbell to emulate ankle biomechanics stance (Table 7.1.C - 7.1.D). Additional changes in the drop height of the pendulum and placing more sensors to detect when the wrong part of the boot strikes the ball, provides greater analysis from results.

The experiment environment (room) was different to the initial pendulum test. This was due to availability and having the right space to conduct the experiment in a safe manner. The flooring was laminate (same as previous room), which was maintained in good condition and swept before the experiments, to now allow any debris affecting potential friction of ball trajectory after bounce. The windows were closed as, the experiment was done during the autumn season of United Kingdom, so there were no influences from any weather (wind) that could alter ball behaviour.

Kinovea software is chosen to compute the ball and kick velocities after it provided a smoother and more accurate tracking feature compared to Vernier physics application (used in the preliminary test) [Charmant, 2022]. The result analysis was performed with Microsoft excel software package [Microsoft, 2022]. This experiment is repeated for the different points of contact with respect to the centre of the ball (panels labelled), so a more precise assessment of repeatability is obtained.

The differences between the initial pendulum experiment, are as follows:

- Three different height drops are used for kicking pendulum (1.2m / 0.9m / 0.6m)
- Kinovea software (version 0.9.5) used to compute trajectory and velocities(ball/kick).
- Samsung S20 smart phone (wide lens) used as side camera to capture video in 60 FPS.
- Only Square and Circle FSR arrangements were repeated.
- Square and Circle FSR treatments have additional sensor placements to identify if wrong part of the boot has been kicked.
- Each treatment of kick is repeated eighteen (18) times.
- The line graphs are displayed of average FSR readings with error bars.
- Box and whisker plots are formed to outline the FSR contact distribution for the shots.

The new setup procedure:

Setup

1. Weight rack assembled.
2. 10kg support weights are placed on resting barbell for counterbalance support.
3. Kicking barbell composed of dumbbell connectors to get precise height for ball contact.
4. Intended weight added to kicking barbell.
5. Ball pumped to 3.6 PSI and Kick Tee stuck to ground.
6. Highest drop point of 1.2m from Clamp.
7. Treatment applied in placing FSR on given region of boot (Velcro attached).
8. Boot attachment adjusted by rotating dumbbell handle with extender for appropriate stance.
9. Boot region labelled for video purposes.
10. Camera switched on for recording.
11. Sensor reading tera term application on
12. Kicking barbell lifted at height of fixture to standing barbell (using chairs as reference)
13. Kicking barbell released at allocated height.
14. Next ball placed on kicking tee.
15. Kick repeats 18 times
16. Video and sensor tracking stopped and saved.
17. Height now adjusted to 0.9m
18. Video and sensor tracking starts.
19. Kicking barbell released at new height.
20. Video and sensor tracking stopped and saved.
21. Height now adjusted to 0.6m
22. Video and sensor tracking starts.
23. Video and senor tracking stops for 1 treatment setting.
24. New treatment is applied and procedure repeats from Step 7.

Lab chairs were used as reference which provided accurate drops from the underneath of the highest seat setting. This was measured using a tape measure and recalibrated three times before setup, for validation. The chairs were not removed and restacked, instead each height configuration with chairs was kept separate. This is to make sure no differences are made in the drop height in reference to the chair height setup, and there is consistency in the equipment used. The different number of chairs used was aimed to reference the height drops differences. During the trial phases, the conditions for these kicks to be executed consistently was practised to allow the reliable testing to be done.

Figure 7.2.1 shows the pendulum height of 1.2m, where the underneath of the boot is brought back to be in contact with the edge of the chair. Tapes are placed on the ground to make sure that the chairs are in the same position relative to the rig, so the release height doesn't have any discrepancies. Figure 7.2.2 shows the release height of 0.9m, which uses 2 chairs. Figure 7.2.3 shows the use of a small stool, to guide the drop height of 0.6m. For all drop heights, the lower end of the boot was placed at the tip of the chair, which also had tapes to know exactly where the boot should be touching prior to release. Calculations repeated from equation 7.1 - 7.3.2, to find the maximum kick velocities of the pendulum at height 0.9m (4.2 m/s) and 0.6m (3.94 m/s).

Figure 7.2.1: Pendulum drop height of 1.2m

Figure 7.2.2: Pendulum drop height of 0.8m

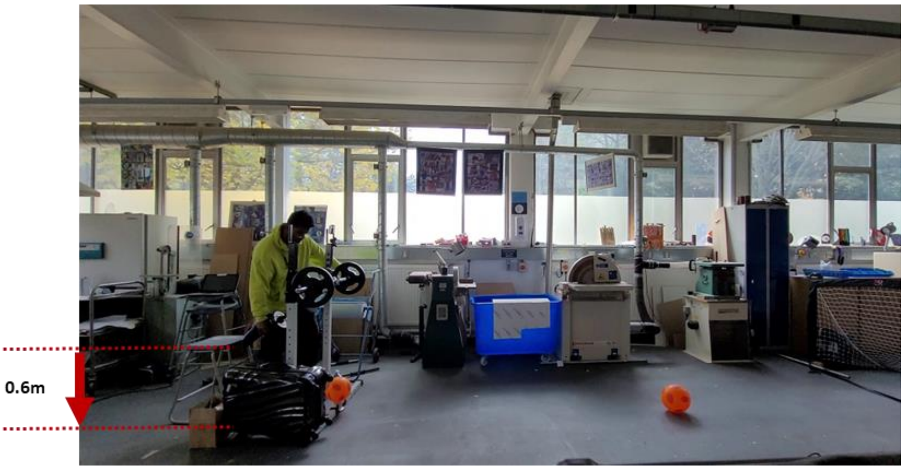


Figure 7.2.3: Pendulum drop height of 0.6m

Kinovea setup

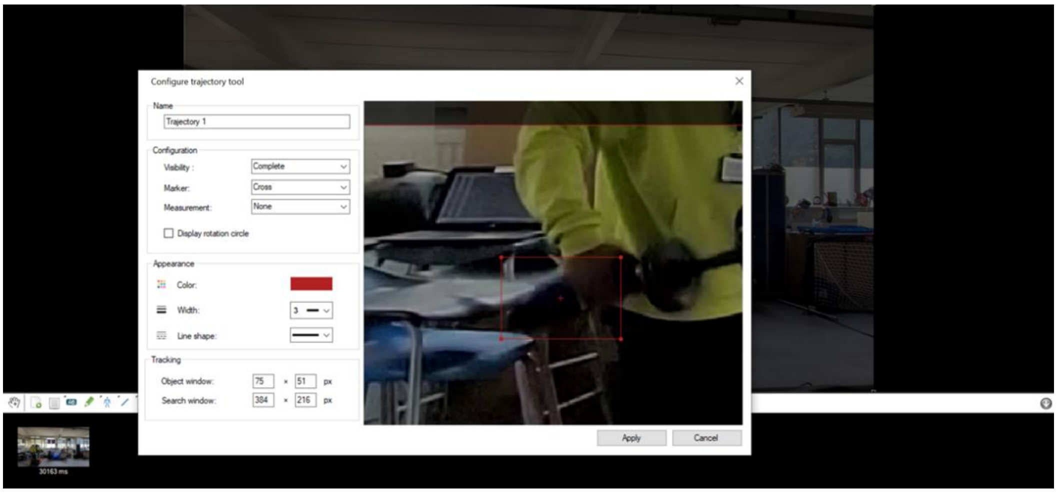
Tracking with Kinovea worked similarly to Vernier physics application but displayed improvements in its image tracking capability. The video is imported into the software, where a reference measurement is calibrated. The ball was used for this again, to keep the consistency from previous experiment's software setup. The tracking feature was much more smoother, in terms of user experience as once a placeholder is assigned, the mouse just needed to be scrolled to proceed the video by a single frame. This allowed the tracking to be done much more systematically but with some human influence in monitoring if each tracking is done consistently and correctly. The following figures display the procedure of working with Kinovea.

Figure 7.2.4 shows the ball calibration that informs Kinovea calculate the scale of what object is being tracked. This was the same reference as used with Vernier physics application and was done at the beginning of every video file. Tera term was used to output the serial data from Arduino UNO to register the FSR readings.

(a) (b)

Figure 7.2.4: Ball calibration setting in Kinovea.

The boot is selected within software as a point of tracking. Figure 7.2.5 shows how the configure trajectory tool is placed on the boot, which identifies it as the tracking object. Figure 7.2.6 shows the software when the tool has saved the object of tracking (smaller box around boot) and has a larger box representing the area of tracking. The larger box is the region of tracking area per frame as the boot moves through its kick and produces a kick trail which provides a linear kinematic velocity value, which is calculated using the ball size as reference. This is shown on Figure 7.2.7, where the sequence started from release height of 0.8m (sample data), and until the ball contact has occurred. The software can lose track of the boot in certain occurrences, however this is why the frame sequence being controlled by researcher allows it to be corrected. This approach was more ergonomic and allowed a more accurate representation of the boot velocity using Kinovea as opposed to VPA.



Name
Trajectory 1

Configuration
Visibility : Complete
Marker: Cross
Measurement: None
☐ Display rotation circle

Appearance
Color: 🟥
Width: 3
Line shape:

Tracking
Object window: 75 × 51 px
Search window: 384 × 216 px

Figure 7.2.5: Selecting boot for tracking.

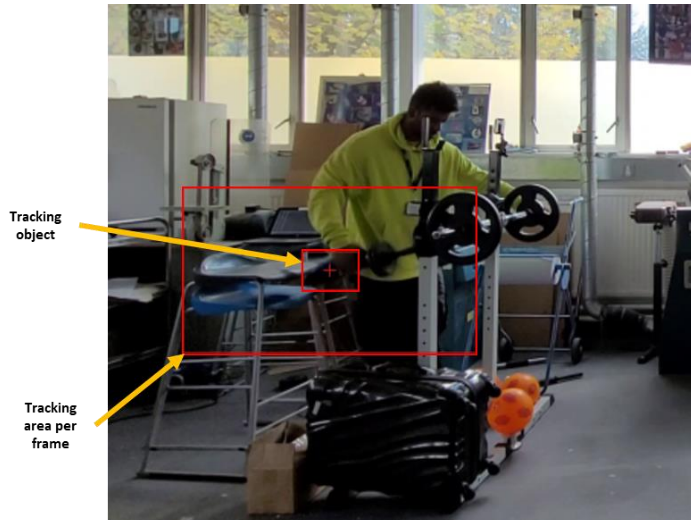


Figure 7.2.6: Tracking object and area for boot

Figure 7.2.7 Tracking path of the boot

The same procedure is repeated, after completing the tracking point of the boot with placing the tracking point on the ball, to calculate its velocity. Figure 7.2.8 shows how the tracking area is relative to ball being identified as object and Figure 7.2.9 shows the tracking sequence as ball moves through video.

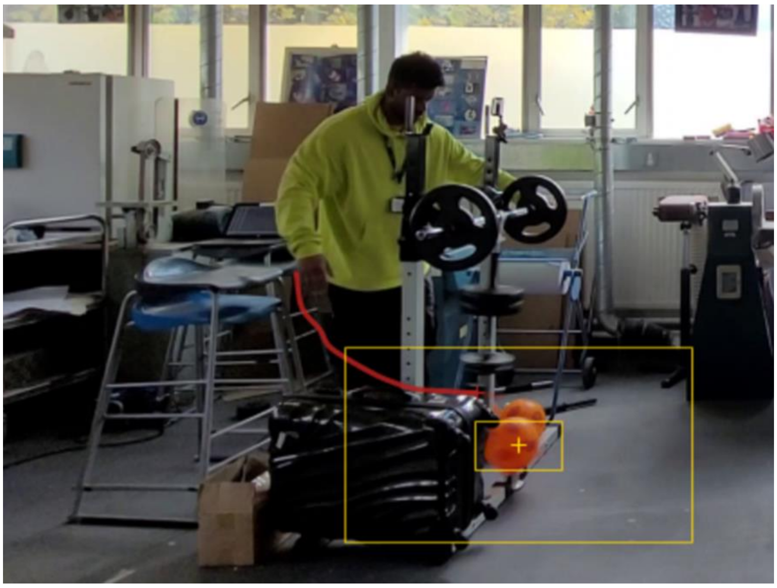


Figure 7.2.8 Tracking object and area for ball

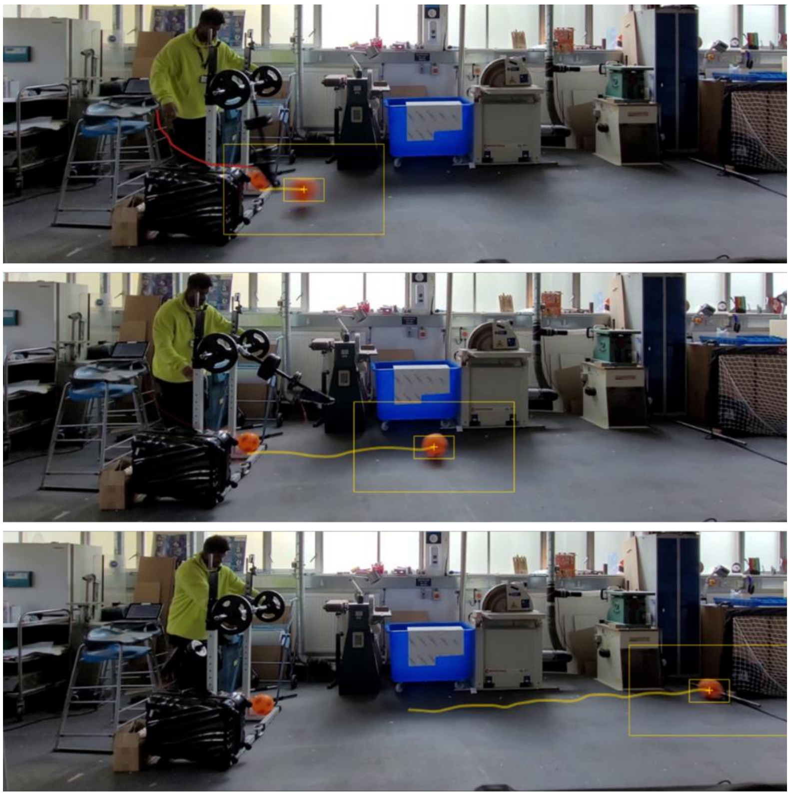
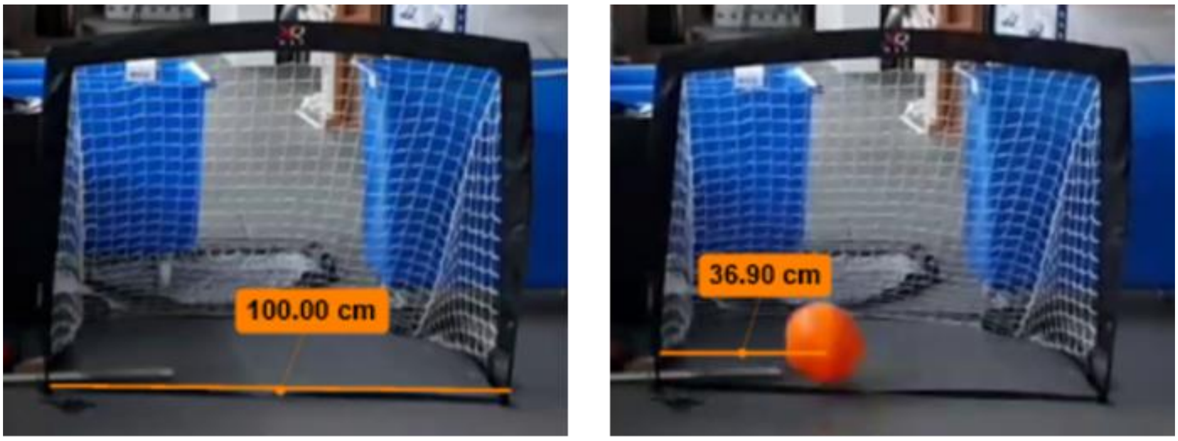


Figure 7.2.9 Tracking path of the ball

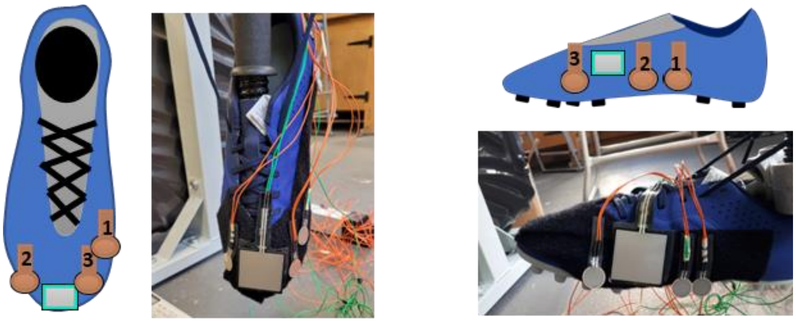
As accuracy was an additional monitored feature, the front camera helped calculate where the ball landed respective to the goal. Figure 7.2.10 shows how the reference is created with goal width of 1m (a) and measuring the centre of the ball from the left post as a scale of where the trajectory moved along the X axis (b). The linear kinematics feature within Kinovea tools, calculates the velocity vectors of the boot and ball. These results are collated onto an excel spreadsheet with FSR data, to analyse results and produce graphs.



(a) (b)

Figure 7.2.10 Ball accuracy calculation with reference to left post of goal.

An element that is done differently to preliminary pendulum test, is placing more sensors to identify if the wrong part of the boot is contacted. This notifies the researcher whether on certain treatments, there are any error in terms of regions hit, and how often it may have occurred. Figure 7.2.11 shows two sample sensor arrangements which implements this strategy for laces and inside kicks. The schematic highlights how for laces FSR setups, the circle FSR (orange filter) are used in additional regions to identify when wrong places are struck per treatment setup. This is applied on all 2 circle and square FSR sensor arrangements.



Laces Square FSR Set 1

(a)

Inside Square FSR Set 1

(b)

Figure 7.2.11 Extra sensor arrangements that are used to identify if wrong region of boot is contacted.

7.2.2 Experiment repeatability analysis

A major benefit of repeating the pendulum experiment was how well the square and circle FSR showed consistency in providing data for ball contact. These were important because it validated that these sensors perform well for shot analysis and there is potential that they can be key influencers within the WT space.

As this experiment consisted of different drop heights, there needs to be extra consideration when analysing the results. The lower the drop height, the easier it is to release the pendulum as less weight is lifted for release. This meant that providing estimate of variability for the replicate kicks, the error bars need a fair weighing factor alongside the standard deviation, which is greater for higher release heights. Having a release mechanism as a trigger was too dangerous with the weights inside the given testing room, hence the user had to hold the kicking barbell behind to perform the pendulum swings in a safe manner, like the preliminary test.

From an analysis perspective, different graph types are created to display test of repeatability results. The FSR readings are used as an average of eighteen replicate kicks for each treatment. The same line plot styles are used from preliminary test with this chart as it helps visualise the differences between the contact regions and how it affects for different heights. The graphs are designed in this way for ergonomic communication of the FSR reading in relation to boot and ball velocity. A primary reason for the repeatability experiment was to provide an estimation of variance using error bars, where if this test was repeated, expected results are shown.

The error bars are given for both the x and y axis. The X axis error bars are split from before and after plot, as the boot velocity (controlled) is expected to be more consistent than ball velocity. For the boot velocity plot point, as its velocity is dependent on the release height, there is an additional weighing value on negative error, which is given in ratio of release height. This allows there to be consistency in relation to a defined release height value (control parameter), where the results of kick velocity depend on this data. For ball velocity there are greater elements that needs to be considered, such as the pendulum friction, the fixture of the boot to the kicking barbell and contact region on ball panel. The kick velocities experienced greater consistency than ball launch velocities, hence a greater error bar range in the positive X axis, (after the plot point).

$$X\ axis\ Error\ bar\ before\ plot\ point\ =\ Standard\ deviation\ of\ kick\ velocity$$

$$X\ axis\ Error\ bar\ after\ plot\ point\ =\ Standard\ deviation\ of\ ball\ velocity\ +\ Veloctiy\ Weighing\ factor$$

$$Velocity\ Weighing\ factor = \frac{Release\ Height(m)}{10}$$

For FSR readings, standard deviation variance is used respective of the range of values from the eighteen replicate kicks.

$$Y\ axis\ Error\ Bar\ =\ Standard\ deviation\ of\ FSR\ data\ +\ Weighing\ factor\ dependant\ on\ height\ drop$$

$$Weighing\ factor\ dependant\ on\ height\ drop\ =\ Height\ drop\ (m)\ x\ 10$$

With Y axis, the error bars are positive and negative of the same value. E.g. For an error bar of 1.2m drop the weighing scale factor would be ±12, hence the plot itself has +6 in positive error and -6 in negative error that's added to the variance error bars. This consideration applies the difficulty levels, in pulling and holding back higher release drops, so there is distinction between 1.2m compared to 0.9m and 0.6m. When the release heights differ in 0.9m (±9) and 0.6 (±6), the factors regarding kick and ball velocity would also be smaller as the range of pendulum swing is less, meaning lower acceleration where kicking pendulum has less chance of fluctuating. This accommodates the differences between the height adjustments and works in ratios so that the data from sensor arrangements are directly fed into the standard deviation error calculation. Standard deviation is used for error bars, instead of standard error which divides by number of samples, i.e. 18, because there needs to be direct relation to the data itself. Error bars given extra weighing further emphasises the specific pendulum setup.

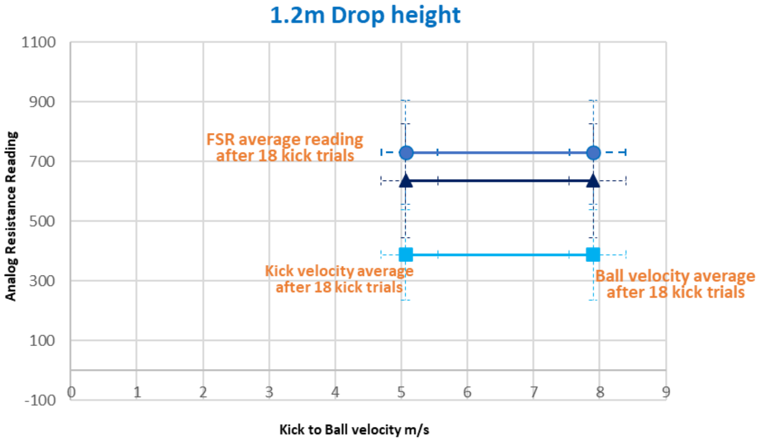
Figure 7.2.12 shows how to interpret the graph plots, where a data sample of Laces 3 circle FSR set 1 is used as guidance to display the features of the chart identifiers. For circle FSR, the results are shown with 3 plots, each for the respective FSR, with shapes assigned under their legends. The error bars identify which kick setups may have experienced more errors with less consistency.

A single plot point, with horizontal and vertical error bars display the expected readings of both the FSR and boot/ball velocities, where the replicate kicks have formed reliable outcomes. This area is where readings can be expected for the specific sensor treatment within this pendulum setup, should it be repeated. The FSR analogue readings are large by default resistance values, but when considering the force in newtons (calibration table 7.1.B), the error bar variance would be lower.

Figure 7.2.13 shows the full schematics of the FSR arrangements for the test of repeatability. These arrangements only consist of square and circle FSR, with additional placements for error detection. The "sets" sensor placement is consistent with preliminary test.

Interpreting graph

Laces 3 Circle FSR Set 1



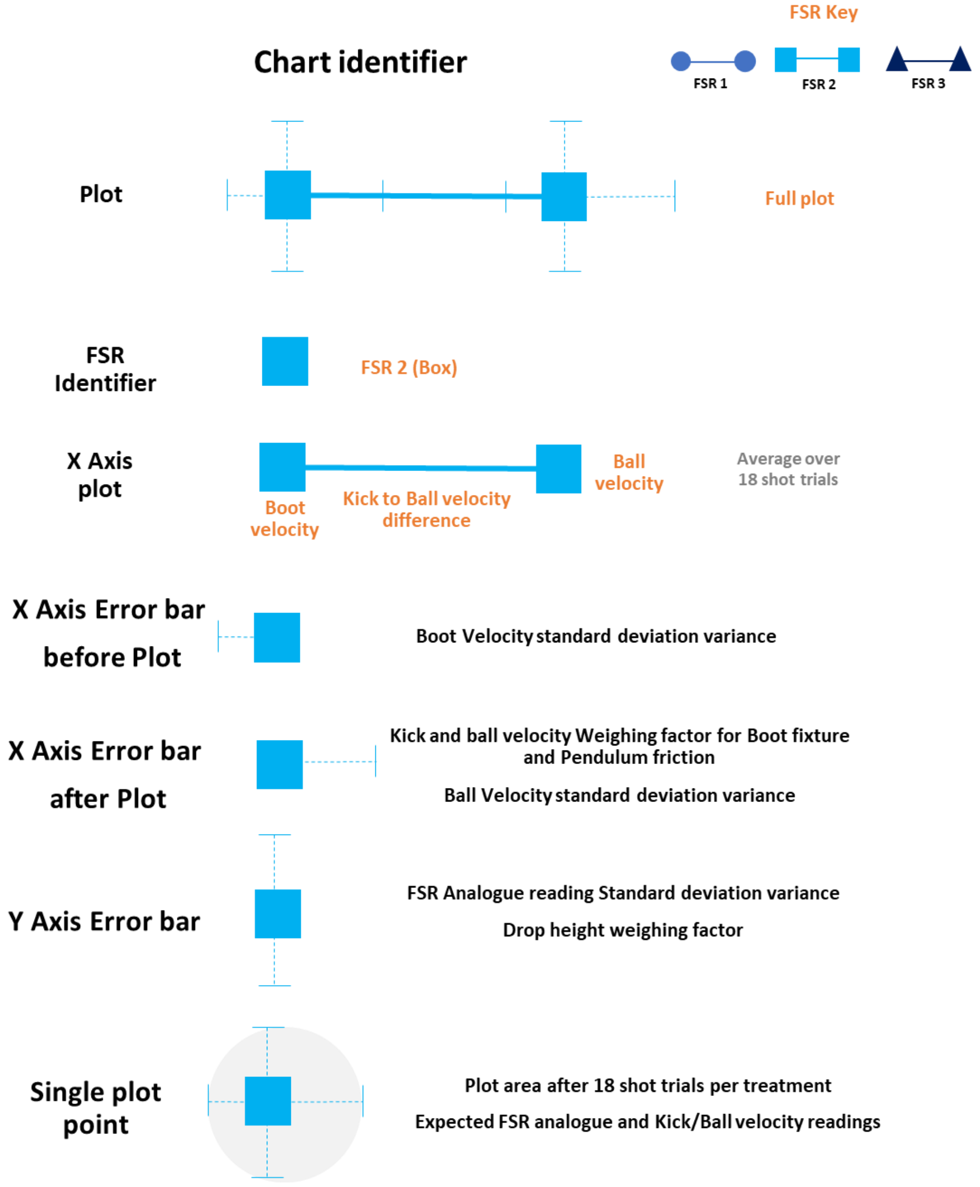


Chart identifier

Plot — Full plot

FSR Identifier — FSR 2 (Box)

X Axis plot — Boot velocity; Kick to Ball velocity difference; Ball velocity; Average over 18 shot trials

X Axis Error bar before Plot — Boot Velocity standard deviation variance

X Axis Error bar after Plot — Kick and ball velocity Weighing factor for Boot fixture and Pendulum friction; Ball Velocity standard deviation variance

Y Axis Error bar — FSR Analogue reading Standard deviation variance; Drop height weighing factor

Single plot point — Plot area after 18 shot trials per treatment; Expected FSR analogue and Kick/Ball velocity readings

Figure 7.2.12 Interpreting FSR graph plots with error bars per sensor arrangement.

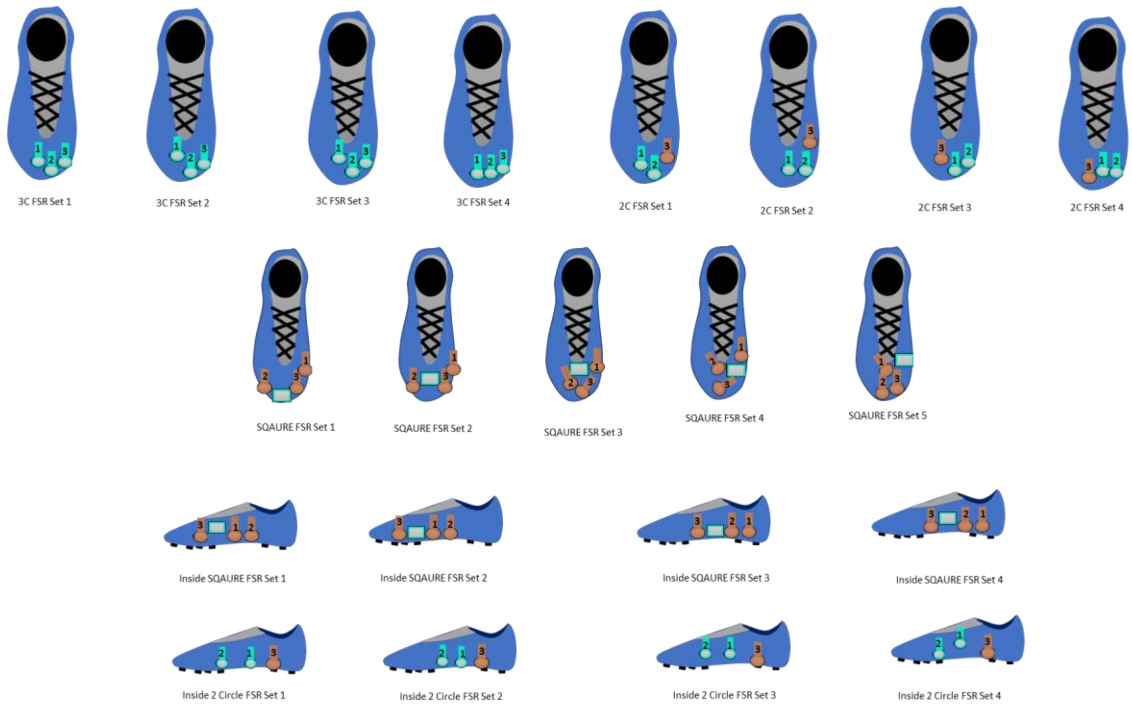
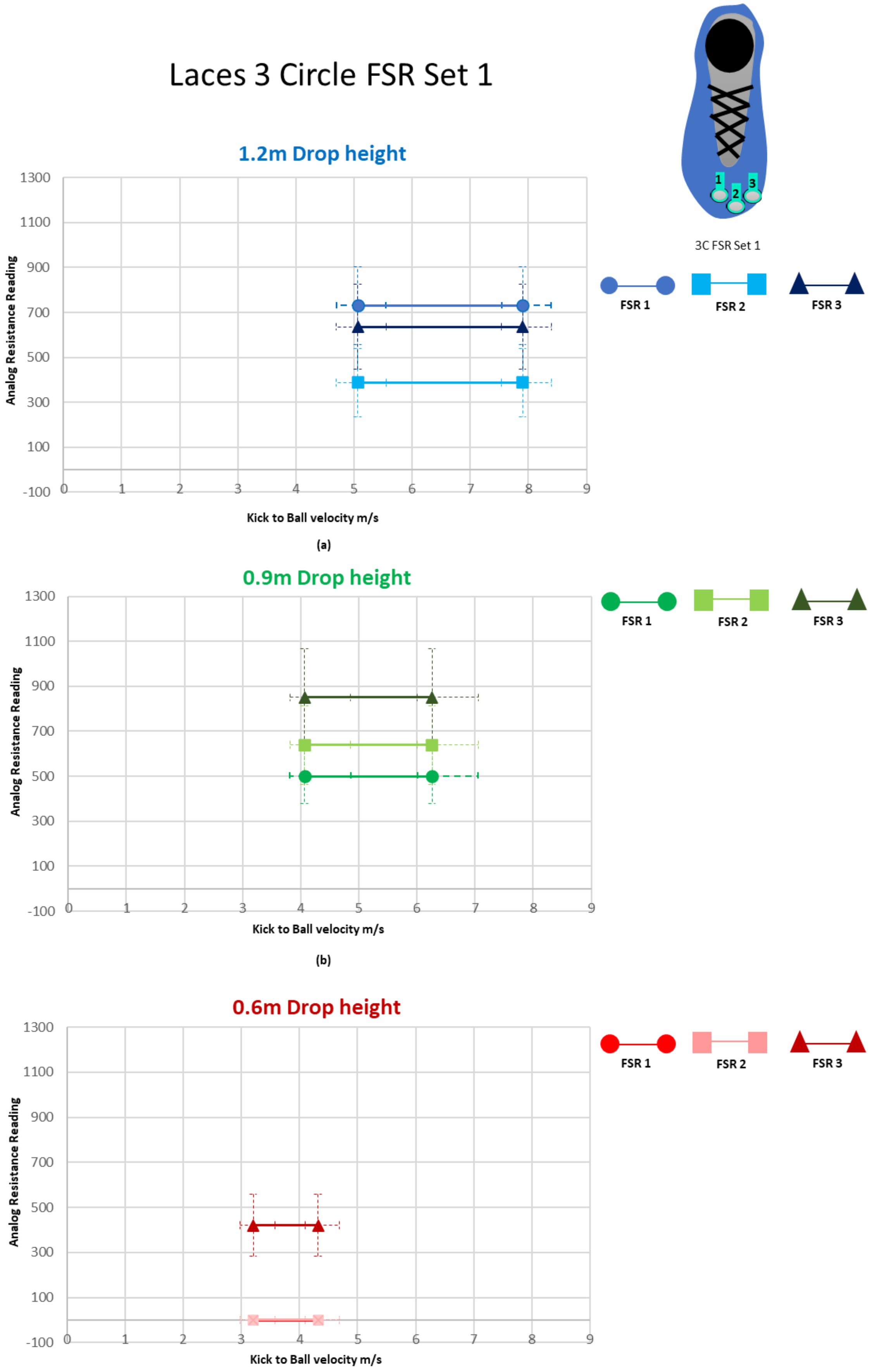


Figure 7.2.13 Sensor arrangement schematics for test of repeatability

Figure 7.2.14 displays a full data result of 3 circle FSR arrangement sample comparing the three drop heights. This new plot shows the error bars and how altering the height, influences the average kick to ball velocity difference, which decreases as the height drop decreased.

From the data collation, additional filters are applied onto excel spreadsheet with accuracy being ±0.2m from target. The targets were assigned between lower left, middle and right targets for different treatments. This is to help validate how contact regions of the boot are linked to how well ball travels to intended area. The reference horizontal distance was assigned at 10 cm for lower left, 50 cm for middle, and 90 cm for lower right targets, so calculating accuracy of ball is linked to these values. To display these, additional box and whisker charts are created, where FSR contact distribution is shown before and after accuracy filters are applied within the data set. This gives a much clearer representation of the FSR data, as it won't rely purely on the variance, but if the shots were not accurate within the intended ±0.2m range, the contact distribution can show when greater force is felt per treatment, and if it influenced the ball trajectory. This helps validate if the treatment applied supports ball accuracy based on force felt on FSR, and whether the wrong sensors contacting influenced any outcomes. This will support how projected ankle biomechanics movement that a player experiences as they strike the ball, to execute accurate kick trajectories, can be dependent on the region of boot contact.

The box and whisker plot on Figure 7.2.15 shows the sample data for 0.9m drop height of 3 circle FSR laces shot, whereby FSR 2 produced higher range of analogue resistance upon contact when the ball travelled with greater accuracy. In this example, the lower 0.9m (green) drop height shows a greater range of contact for FSR 3. These regions are identified within the main line graph plot as it links to the specific FSR sensor. From this what can be deduced is that even when the plot points from Figure 7.2.14 have a greater Y axis error bar, when considering accuracy, greater contact on the lower vamp to midsole region (FSR arrangement for this treatment), influences better shot outcomes. This review is for one data sample, based on eighteen kick treatments applied. Further analysis will delve deeper into how reliable the replicate data can show for different sensor arrangements.



(a)

(b)

(c)

Figure 7.2.14 Laces 3 Circle FSR Set 1 result sample.

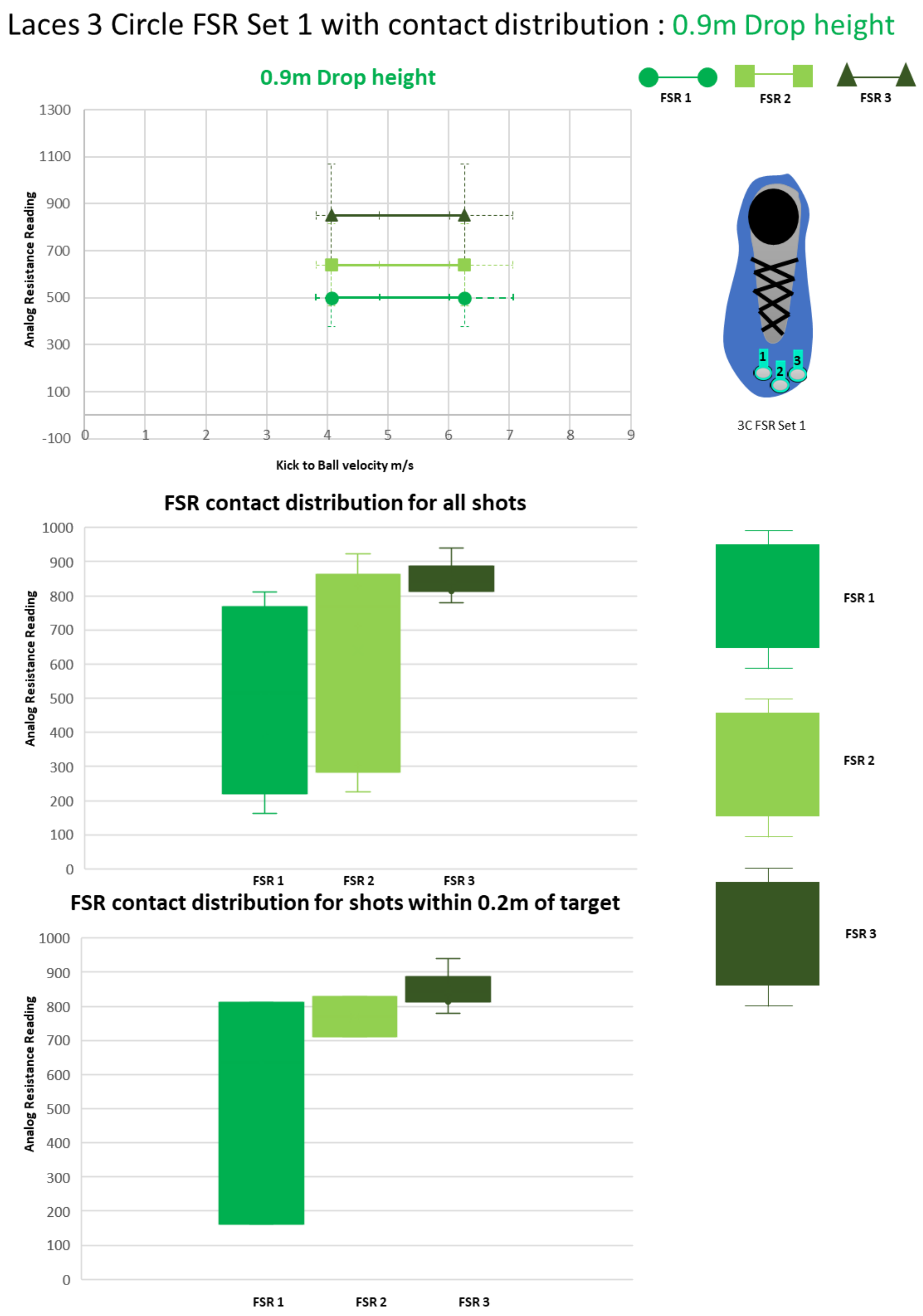


Figure 7.2.15 Laces 3 Circle FSR Set 1 box and whisker plot sample.

Full sample of results are provided in Section 7 of Appendix which link to the following analysis

Laces 3 Circle FSR

This arrangement was the first analysis that showed the effects of drop height. Both the kick/ball velocities were smaller as height decreased as did the error variance along the X axis. The importance of the box and whisker graphs is shown with these results, as the accuracy filter applied within the data set, reduced the range of contact distribution, showing higher analogue resistance readings. This is something that was consistent amongst all the laces 3 circle FSR sets, where contact distribution FSR graph readings seemed to show greater range, but reducing after the accuracy filter is applied.

Set 2 showed that when the lower heights were dropped, there is greater contact on FSR 2, which shows how low vamp connects alongside FSR 3 being placed on midsole. Even when accuracy filter is applied, the readings show that both FSR 2 and 3 experience forces felt on kicks. Only when all 3 FSR were in the mid-vamp region did the results show consistency after accurate filter was applied. This shows that for laces shots, this is a possible strike zone, as with reliability of eighteen kicks, there is consistent forces being felt in this region providing accurate shots. The same observation was made after preliminary tests and could justify sensors being placed in this region.

Having 3 different height drops has advantages when comparing the factors that change in terms of kick to ball velocity as well as FSR readings. Only Laces 3 Circle FSR set 1 showed 0.9m having a higher variance than 1.2m. This was the first test after trials, and with this in mind, this could have enabled a bias in providing greater variance for the analogue FSR readings.

Laces 2 Circle FSR arrangement

The benefit of displaying the box and whisker diagrams show greater importance when visualising these sets of graphs. There is immediate recognition of when the wrong part of the boot has been struck as it relates to not having an accurate shot. This shows how the test of repeatability produced some advances in testing procedures to justify sensor placement, around the low vamp – midsole region. The height drops also show greater consistency regarding the monitored parameters where frequent contacts are made in the mid-vamp to midsole area as the heights decreased.

When analysing the box and whisker plots, what was immediately noticeable was that on one of the plots, the accuracy filter showed a very drastic difference compared to it's initial FSR distribution chart. When looking at the data set closely, a human error was identified in copying the wrong data set onto excel sheet. When this step was repeated, with the correct data input, the accuracy filter showed the same values as its parent FSR distribution chart. This signalled that accuracy filters are very important in displaying FSR force contacts. Similarly, to the 3 circle FSR arrangements, the box and whisker diagrams show that when accuracy filters are applied, the contact distribution for shots within ±0.2m target, the chart displays higher FSR analogue readings. This strongly suggests that key areas of the boot must be struck to get desired trajectory for player.

An experimental factor that should be considered when analysing this data set, was that the ball launch velocities were larger as opposed to when the 3 circle FSR arrangement kicks were conducted. This shows that the researcher understood with greater trials how well to release the pendulum swing to obtain sufficient contact.

Laces square FSR

Square FSR produced higher analogue readings, due to its larger surface area, hence greater possibility of sensor contacting the ball. These signals were prominent in all height drops. The trend of box and whisker plots showing higher FSR analogue readings when accuracy filter was applied, also followed suite. The accuracy filter showed that having more sensors placed, was an advantage in understanding the vamp area being most important for laces shots, as the additional circle FSR sensors placed showed their importance even when accurate shots were executed. This is very important, as when applying greater area of sensing, more data is obtained on which regions of the boot, influence better shots.

The use of circle FSR in areas to indicate when the wrong part of the boot is struck, showed signals even after the accuracy filter was applied, which highlighted the advancement in test of repeatability, being a crucial research task. Laces square FSR sets 2-5 showed that mid vamp region has a high accurate shot conversion rate. This is supporting the initial preliminary pendulum test that displayed sweet spot region for laces shots being in this area (Figure 7.1.18). Now with greater kick repetition, and accuracy filter, this statement has greater validity.

Inside square FSR

Inside sensor arrangements took longer trials to correct the technique of dropping the pendulum at 1.2m. The lower height drops were easier to perform the kicks, and it felt lower in over ball velocity, compared to laces shot upon viewing in person. Setting up shots with more sensors, for greater tracking, showed more regions that are being contacted when non accurate shots were executed. This pattern also repeated where 1.2m height drop, displayed more contacts from other(circle) sensors.

The box and whisker plots for Set 1 shows strong contact for circle FSR sensor 1, which was placed in the midsole-vamp region. As both the square FSR and circle FSR was placed within these areas, when higher pendulum swings occurred, greater forces were felt in this area of the boot. This also remained constant after the accuracy filter.

Set 2 and 3 being placed lower on square FSR arrangements showed accuracy filter only remaining for low midsole, which suggests that when that region of the boot is desired to be struck, it aids to accuracy. This is something that the inside foot shot prioritises, as they are used for short passing where the trajectory of the ball has greater importance than the speed at which it travels.

The biggest difference compared to laces shots was how much greater the decrease in FSR analogue readings and kick/ball velocities are as the height drop decreased. This also impacted the variance with much lower standard deviation and error bars. To repeat this specific setup, there is more importance in understanding and honing the technique of releasing the barbell, even when the torsion between the fixtures is constant and doesn’t need any tightening. The inside foot, boot configuration tends to have greater stability upon contact; however, they need to be aligned accordingly to allow optimum sensor tracking in their required treatments.

Inside 2 Circle FSR arrangement

Circle FSR generally produced much more consistent data for the 2-sensor arrangement which indicate potential performance of how well this sensor type can be used with WT embedding. The setups are intended for contact monitoring within the midsole region, where the additional error tracking sensor experiencing no contact with the ball, signified how the midsole area is important for inside foot shots. FSR sensors being placed in this region for monitoring will benefit football WT.

The 2 circle FSR arrangement shows consistently that whilst the accuracy filter is applied, both box and whisker plots remain the same. This is a strong indication that inside shots are generally preferred for accurate kicks, but also that the circle FSR is a good sensor type to track precise locations of contacts. The smaller sensing area meant that identifying specific spots of contact is greater, which shows the advantage in having a network of circle sensor arrangements, across the boot anatomy.

Emulating the sensor arrangements for testing with real participants, will also require different regions of the boot for coverage, and if a player who has a specific inside foot technique, where they may use a different part of the midsole, then sensors can identify what they do well. This is the main impact sensor embedding should have within WT, and the consistency shown from this smaller scale pendulum test, produces enough trends to suggest the future iteration of testing with users.

For all sets, FSR 2 being closer to the vamp showed greater variance, as opposed to FSR 1 being placed more within midsole. This shows that the typical sweet spot for laces, will not be the same for inside foot shots. The extra coverage has aided to this analogy, as the ball in a real situation, will deviate depending on how it has been struck, and sensors being placed in the midsole for inside shots can be regarded as important indicators to judge it.

Set 4 distinguished greatly between each FSR result, as the placement of the circle sensor FSR 1 being higher midsole, not experiencing any contact, per eighteen trials. Having more sensor coverage where some showed contact, and some didn't, provided very useful insight for inside shots. This impacts WT as future sensor integration which covers the area of the boot can be programmed to identify when better regions are struck, which aids to greater accuracy. This is subjective to what the user would want however, as some may require contacts in different parts of the boot, that they normally would not want to, hence sensors on a ball would be the next advancement of this setup to increase the WT impact.

Pendulum retest summary

The use of circle FSR to indicate if the wrong part of the boot was struck did not just highlight an error kick, but also showed areas where good accuracy resulted in key areas of the boot being struck. This expansion of testing methods allowed greater depths to justify sweet spot areas of the boot, which mainly consisted within the mid vamp – midsole region. The use of box and whisker plots were impactful as it visually eliminated errors being considered in data analysis and pinpointed which sensor arrangements produced reliable data.

Overall, when square FSR analogue readings were high, meaning higher forces felt, greater accurate kicks were tracked. However, there were 4 occurrences where the analogue reading was below 200 (0.2N), even when the ball had an accurate trajectory. This is only slightly higher than circle FSR arrangements where it occurred twice for 3 circle FSR (Set 3 height 0.6m / Set 4 height 0.9m).

In terms of sensor output data, the FSR analogue readings were lowering as the heights drop decreased. This implied that less forces were experienced on the sensing region of the FSR when less kick velocities were swung. However, this varied between the different sensor arrangements where the height being 1.2m had more inconsistency of producing similar analogue readings. This showed that the pendulum being dropped higher had a greater chance of error being present, where the variance was also higher on average for this height drop. The direct correlation on the actual value of analogue readings to how well the kick has been struck, only was highlighted when the accuracy filter is applied. This showed very consistently, that when the kick is intended to target, the FSR analogue sensor values were higher, which meant for the line plot, the variance shows the range in which non accurate shots also exist.

In terms of kicking technique of users, the retest showed from trends, that there are key areas of contact for laces and inside shots. This means that the ankle biomechanics upon ball contact can be honed by the players to execute accurate kicks. Sweet spot regions can be used as an identifier amongst a sensor network, so WT can know when those contacts signal the correct form. This is subject to the player's technique, as with IMU user test, a player's unorthodox approach was only identified once the signals were processed and understood, so making sense of the data can aid to greater understanding of a player's kicking methods. This is another tool that can be applied for more educational elements within WT using sensor application within sport specific environment.

There is sufficient justification of how accuracy filter being applied, helps analyse the data in obtaining where on the boot contact, influences better shots. This is very important for WT, as this test of repeatability exemplified how important it is to have sensors across the boot for ankle analysis. Low vamp and mid vamp are important contact areas for laces shots, and when there are forces being felt by the midsole placed sensor, more accurate shots are experienced, benefitting inside shots. This important observation has more reliability behind these statements, due to test of repeatability and will impact FSR integration onto football boots.

7.3 FSR sensor data analysis from test rig integration and how it influences football kicking data.

7.3.1 Relevance to Football Data

With the pendulum experiments there needs to be an element which converts these sensor data into meaningful performance data. For enabling football relevancy, a set of attribute ranking tables are formed to emulate as if the pendulum kicking data was actual user data. This is to start visualising how these physical data can be applied in performance terms. The tables are split to differentiate KTB relating to Power, and accuracy relating to Finesse attributes of the shots. This is to exhibit how potential WT feedback data would output differently, that alters the perception by the user to what their best kick would be. This is to understand how data will be perceived depending on player priority.

The purpose of the attribute ranking tables is to analyse what the impact of FSR output data would be perceived as if the shot is graded purely based on KTB (exhibiting more efficient kick), comparing it to if the user would have wanted more priority in the accuracy of where the ball had travelled to. This is dependent on the decision matrix that the user could potentially choose in ordering attribute importance for themselves. Because football always consists of subjective opinions, and this form of matrix quantify and rank the attributes the user wants to have greater priority in, the 3 best KTB and accuracy shots are compared to distinguish how the WT data output would look like. To make this sensing “smarter”, these extra analyses make the data more human centred, and why separate scoring tables are computed, that would have been influenced by user choice of output in WT application.

The graph plots give a representation of the distribution of contact amongst the sensors. These “hot spots” are implemented on regions of the boot (i.e. High vamp, Low vamp, Midsole). What can be detained from this is that where there are greater % of the ball felt, and how it influenced the kick either being efficient or accurate, can help deepen the impact FSR sensor embedding can have. This is a form of inputting a pressure sensor onto football equipment, as a way of displaying an advancement in sensing. The following block diagrams displays what this experiment dissected from FSR regarding contact regions of the ball. Figure 7.3.2 block diagram shows how user input with would affect the Attribute Ranked Table (design element), which outputs different data depending on their choices. This is important for WT as it focuses on what the user needs would have been. The overall experience felt by the end user and how their subjective opinion would have altered which shot they would have chosen as their best ones, is fundamental in making the output data more user oriented. This can also be something their coach chooses instead, giving even more guidance on what type of player they are nurtured to become.

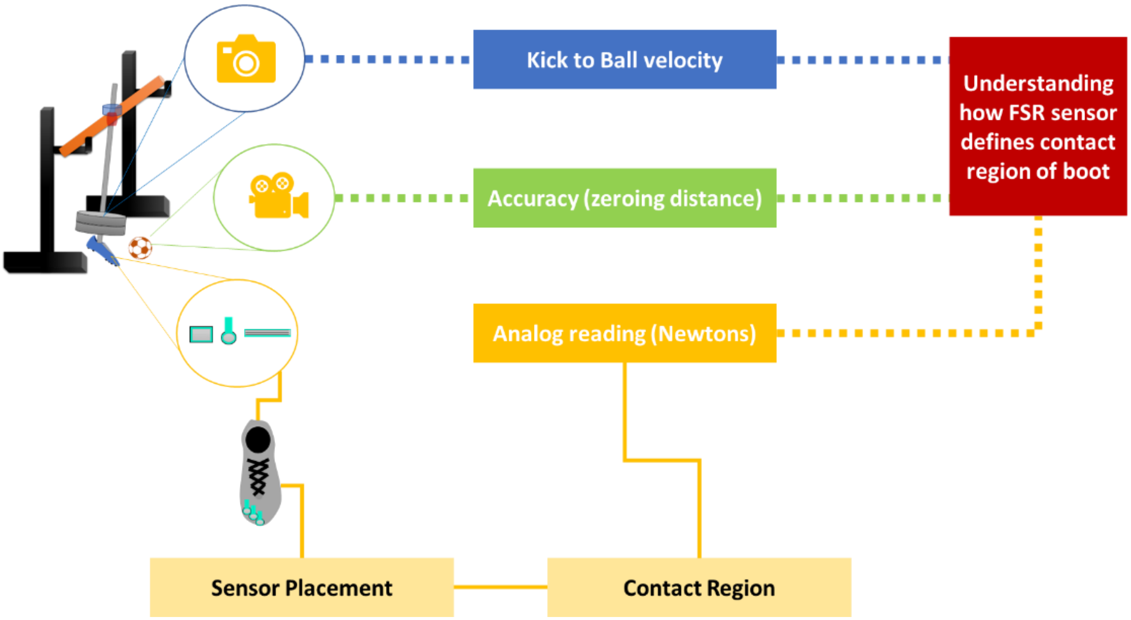


Figure 7.3.1: Block diagram of computing FSRs impact as a sensor on boot for laces and inside shots

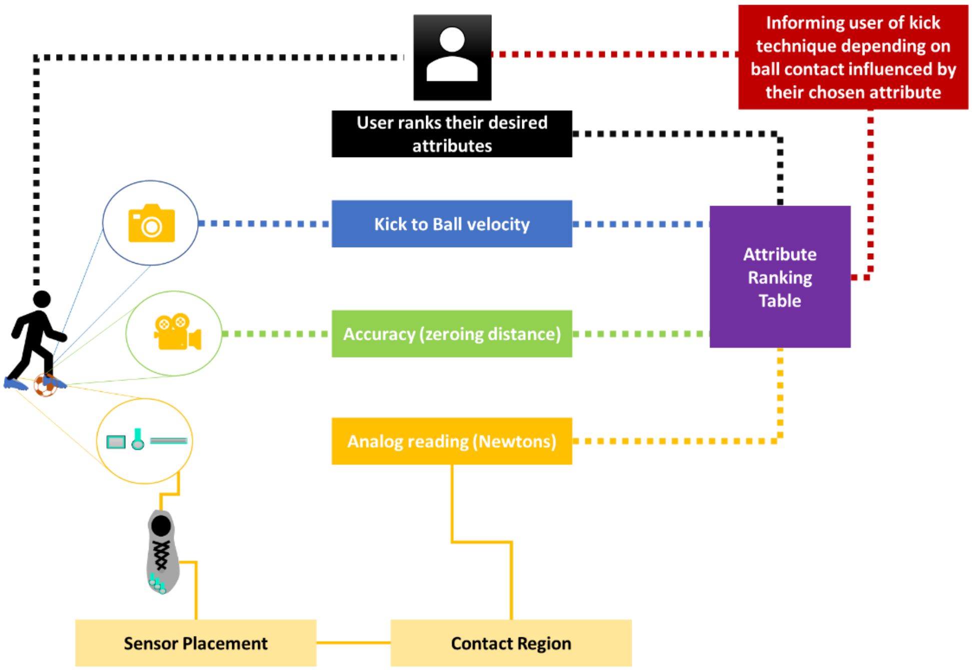


Figure 7.3.2: Block diagram of assigning FSR data as player data to show potential influence as WT

Table 7.3.A shows if the player had prioritised KTB speed difference, this can be linked to attributes of kick efficiency and power. This is because the difference in the kick speed relative to how the ball launched, is greatest, meaning that the energy transferred was greater. Kick efficiency is not an existing known attribute however, players do prioritise making the most ball launch with minimal effort (i.e. kick speed). Players who want to prioritise the accuracy or the attribute “finesse”, will most likely give a higher weighing (priority) for this in the decision matrix scoring. The difference in results is shown on Table 7.3.B. Hence the second set of shot data for best accurate readings are chosen based on their Zeroing distance (close to target).

Attributes	Player 1			Player 2			Player 3		
Kick to ball speed difference	2.67	3.38	3.05	2.95	3.21	2.33	3.21	3.09	2.33
Vamp Low %	0	0	0	0	0	0	0	0	0
Vamp High %	27.9	0	20.3	0	0	0	3.7	24.2	21.3
Mid Sole %	0	26.3	23.4	26.8	25.0	24.8	27	1.77	0

Table 7.3.A: Attribute table ranking with KTB regarding FSR contact %

Attributes	Player 1			Player 2			Player 3		
Kick to ball speed difference	2.675	2.442	3.057	3.016	3.218	2.334	1.869	3.212	2.335
Accuracy to target	-0.04	0.04	-0.25	0.15	0.18	0.18	0.07	-0.13	-0.24
Vamp Low (FSR 1)	0	0	0	0	0	0	0	0	0
Vamp High (FSR 2)	27.9	23.6	20.3	28.4	0	0	0	3.7	21.27
Mid Sole (FSR 3)	0	26.8	23.37	0	25.03	24.77	0	27	0

Table 7.3.B: Attribute table ranking with accuracy to target regarding FSR contact %

The following table and graphs are emulating as if the preliminary test rig results were actual player kicks, and how the analysis would have been had these been done by amateur footballers.

Figure 7.3.3 shows a sample of how these tables looked like and the corresponding graph plots, which show the changes depending on contact % of each sensor. The graph plots made it much easier to deduce how contact percentages altered when accuracy had a weighing.

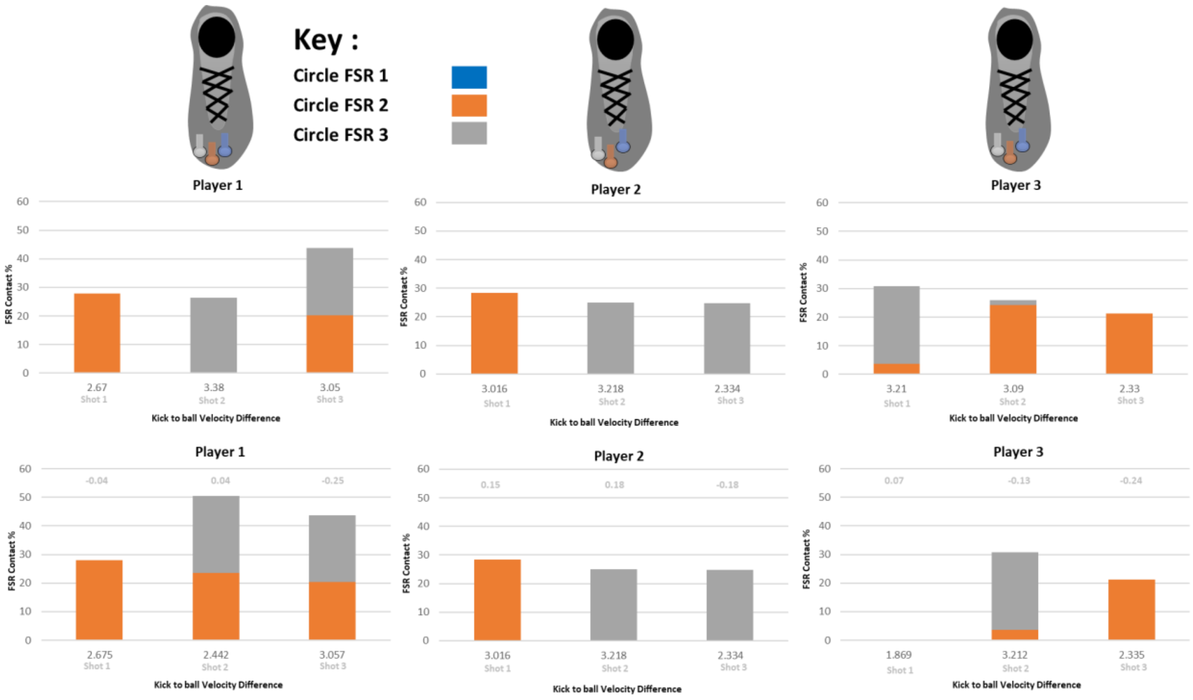


Figure 7.3.3: Laces shot 3 Circle FSR Contact distribution % comparison for 3 projected players

The circle FSR also outputs percentages of contact regions. This is calculated in ratios, assuming 1000 analogue reading was the maximum possible contact felt and working each specific reading as a total of 3000 when 3 FSRs are used; 2000, when 2 FSR involved. This is to give an output of the distribution of contact and how it influenced the KTB and accuracy. The aim of this Table is to clearly "judge" if the FSR can contribute to performance data conversions by using just ball contact.

Each FSR has its own detecting definition compared to real world numbers. The sensitivity of each is calibrated by up to 100N which is set by Adafruit (supplier) where the resistance is at its lowest the closer this value is reached (Appendix Section 7) [Adafruit, 2021].

Sweet spot is a term given when the striking of a ball has been hit at its optimal region with the required speed for it to travel at required/desired pace and trajectory. For this experiment, to design how data can be driven in terms of performance, relating to a footballer who has struck the ball with technology integrated boots, the direction and speed of the ball hitting the intended target (or not) gives an indication of where on the boot sensors are beneficial.

Long FSR sensor produces readings with minimal detection across its sensing panel. This makes it hard to gauge any characteristics in determining precise resistance change and location of ball contact on boot. This was trialled on Inside foot configuration, however the results were not feasible to make sense out of the attributes tracked (Appendix Section 7 shows these result graphs).

Laces

3 Circle FSR shots analysis immediately deduces that none of the players have contacted the high vamp region during Laces shot. The low vamp and midsole were mostly contacted, showing that all 3 players experienced some eversion to connect with ball. It also displays that they contacted generally a bit Lower and inner side of the boot, above the phalanges near metatarsal. The distribution of contact also shows that when more than 1 FSR is in contact with the ball, there are no direct links to it being a more efficient kick. The only difference between Player 1 and 2 is that 1st circle FSR position, was higher for Player 2. In the overall readings, Player 1 did connect with 1st FSR, which was generally in the higher side of the mid vamp height, compared to high vamp height of Player 2. 1st Circle FSR for Player 1, were not part of either their best power or accuracy shots. This shows how high mid vamp to high vamp regions are not an ideal striking zone. When the midsole regions are involved, there is a slighter greater KTB speed difference. From this first sample data, Player 2's best kicks in terms of energy transfer, is also their most accurate, signalling that the contact distribution being the best when these forces are present in given area. Consequently, this will impact WT data, as these early tests, can inform WT what the best contact area is for laces shots, and the quantity each sensor reading has, if it is a 3 FSR setup.

With accuracy to target now influencing which shots are selected as best three, there were some similarities. Having a shot which was closer to target, yet not as powerful, gave readings of both Low Vamp and Mid sole for Player 1. Player 2 had identical shots irrespective of the accuracy. Player 3 had an accurate shot that did not pick any reading, which could be that their connection was lower than its placement, something like Player 2. The KTB speed was also very low compared to what the average range were, hence, this could be something that has been biased purely based on accuracy. The shots which were selected were based kick power (efficiency) or accuracy standalone, but for most of the sample, both considerations together gave same results. This shows how FSR can display when the correct kicking technique and ankle tilt on ball is executed, and to distinguish different standards of kick. This also shows how the best kicks irrespective of accuracy were the same throughout. This is the first sign, that the contact area influences how well a ball is struck. Laces Kick 3 Circle FSR Distribution graph which shows how much each FSR % consisted of contact. This is compared to ones that considered accuracy as well, which shows the zeroing distance at the top of each plot bar. The FSR % distribution graphs were given same axis limits to show a clearer representation when comparing each kick.

2 circle FSR Laces shot

With both Square FSR and 3 circle FSR showing how the high vamp region was not having ball contact, 2 circle FSR was placed in combination around the midsole (FSR 2) and low to mid vamp (FSR 1) areas, to make best use out of these sensors. These provided varied results and showed how they correspond when accuracy became a factor. For this comparison, it is assumed that Players 5, 6 and 7 have been kicking within these regions, to see how similar placement of sensors, that correspond to slightly different ankle stances based on contact distribution, affects accuracy. Players 5, saw a decrease in KTB when they prioritised accuracy, but their best shots did consist of good accuracy. Player 6's best 3 shots were the same regardless of if there was greater interest in KTB or accuracy. Player 7 when exerting more force onto the ball contacted midsole region, which shows that they prefer to have eversion and axial rotation with less plantarflexion when striking for greater emphasis on power. This ankle behaviour is also the same for Player 5. This supports that the inner side of the boot, i.e., midsole, which is typically preferred for inside foot shots, do grant greater accuracy properties when striking the ball. This set of results, if programmed smartly with WT, can exhibit player behaviour in shooting. This also confirms how the midsole – lower/mid vamp regions have a generally produce good contact.

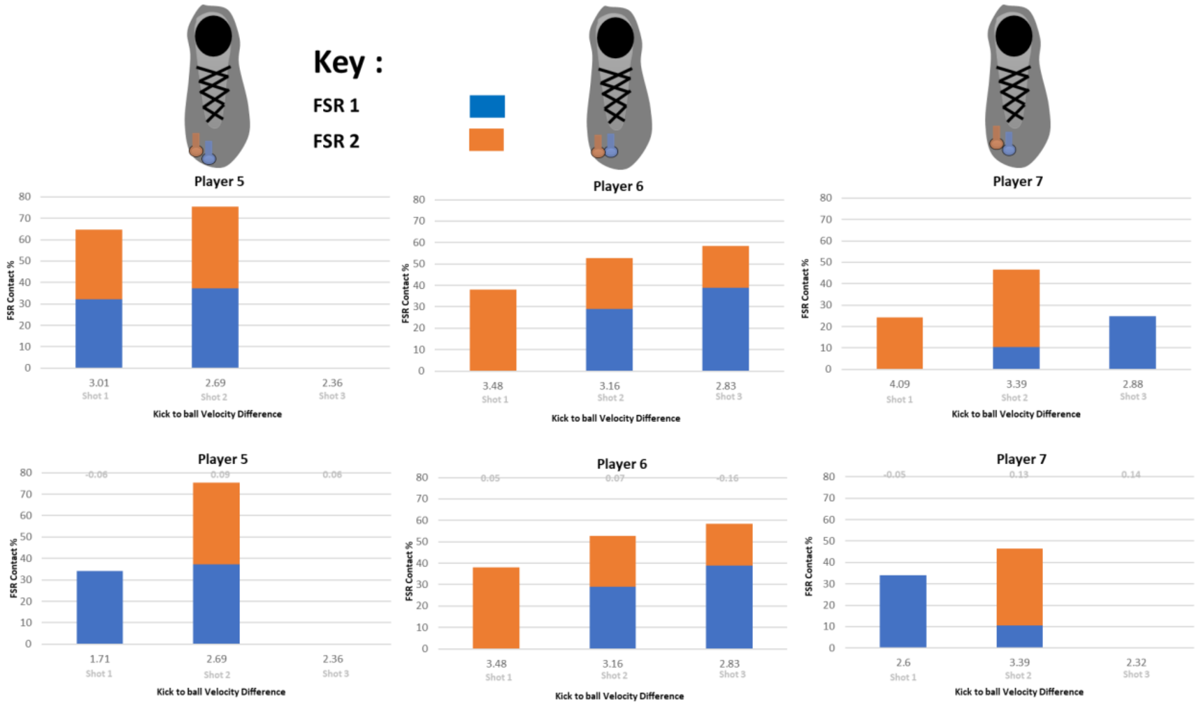


Figure 7.3.4: Laces shot 2 Circle FSR Contact distribution % comparison for 3 projected players

Square FSR Laces shot

With square FSR readings, the assumptions are made if each player struck from different vamp region of the boot. This is to display how grading of the kicks would work when different vamp regions are struck. Comparing all 3 players, instantly it shows how vamp low and vamp middle produce readings from FSR sensor. Vamp high is a region that is not in contact with the ball, and as such, shows the setup of the pendulum has been optimised for better contact, where even in plantar flexion ankle stance, the contact doesn't occur on top of the ball. Player 3 did have a reading with good accuracy, but the analogue FSR reading was quite small which shows how the ball must have contacted more on the mid vamp region. The placement of the sensor was chosen as if that was the intended point of contact, however this shows that there were no readings in that area, hence, it can be deduced high vamp region for laces shots are not the ideal contact spot. An argument can be made why this was not "tested", however in this test, the best possible pendulum kick contacts were setup, hence if Vamp high was to contact the ball, which it did in some cases, the resultant KTB and accuracy were not as good as the middle and low vamp contacts. The consistency shown by the middle and low vamp regions further justifies how important contacts being made here result in better shots. WT will use this information to make calculations of player's kicking abilities, and possibly link it to boot designs.

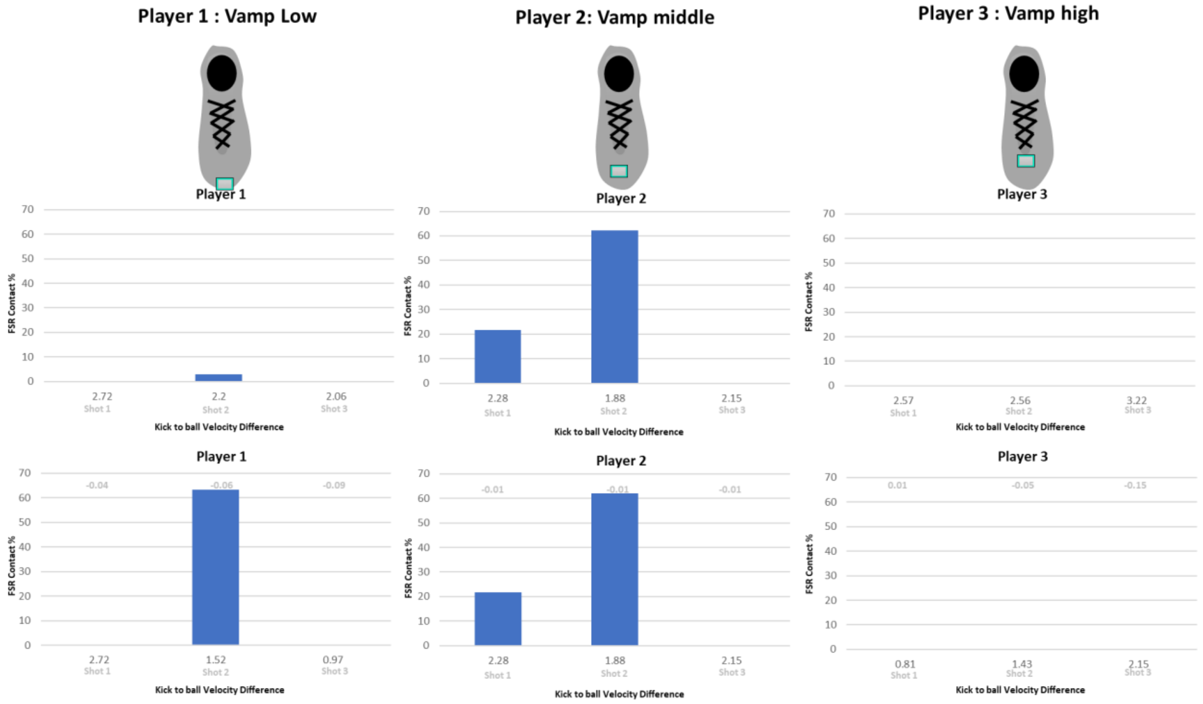


Figure 7.3.5: Laces shot Square FSR Contact distribution % comparison for 3 projected players

<u>Inside 2 circle FSR</u>

From Figure 7.3.6, inside foot shots, 2 circle FSR was placed on the midsole and midsole-vamp side. These terms are changed as the orientation for an inside foot heavily revolves around the ankle being horizontal. Out of the 9 comparative shots between 3 players, only one had a difference when accuracy weighed in on picking the best kick. Player 2 had better accuracy when there was greater Midsole region of the boot, however it was a much less KTB velocity. This shows how FSR can be used to gauge the accuracy vs. power trade off, for finesse attribute of inside foot shots, as opposed to the powerful laces shot, just by monitoring the distribution between midsole – vamp regions. This data set confirms significance in that contact region of the boot can influence how accurate inside shots are.

Players 1 and 3 had their best shots being the ones with the best accuracy, however their contact % were not the same and their KTB was not as good as Player 2. Even though Player 2 had outstanding KTB (pendulum dependant), their accuracy was not the best, which means that the sensed data, showed their ankle stance to have Eversion and slight Dorsiflexion to get over the ball upon contact. Data outputs like this could help WT build character out of the players. These are the traits that can be deduced from the sensor picking up big contact % and their KTB. Such assumption could be that Player 2 is more physical as they have strong KTB, with lack of accuracy concern, hence their position may not be an attack minded player. This could also mean that Player 2, should work more on accuracy, hence WT can now apply potential training methods, or communicate this data to the relevant coach that now has quantified tools to program a routine for Player 2. The same argument can be applied for Player 1 who has weaker KTB but better accuracy, hence they could have a training program that optimises their physicality. With Player 3 not striking any of the FSR 2, the high midsole region, this confirms that for inside foot shots, this area is also not ideal for any good ball contact. This is also something that was observed from the pendulum test of repeatability, that showed square FSR arrangements, signalling lower KTB and did not aid to greater accuracy.

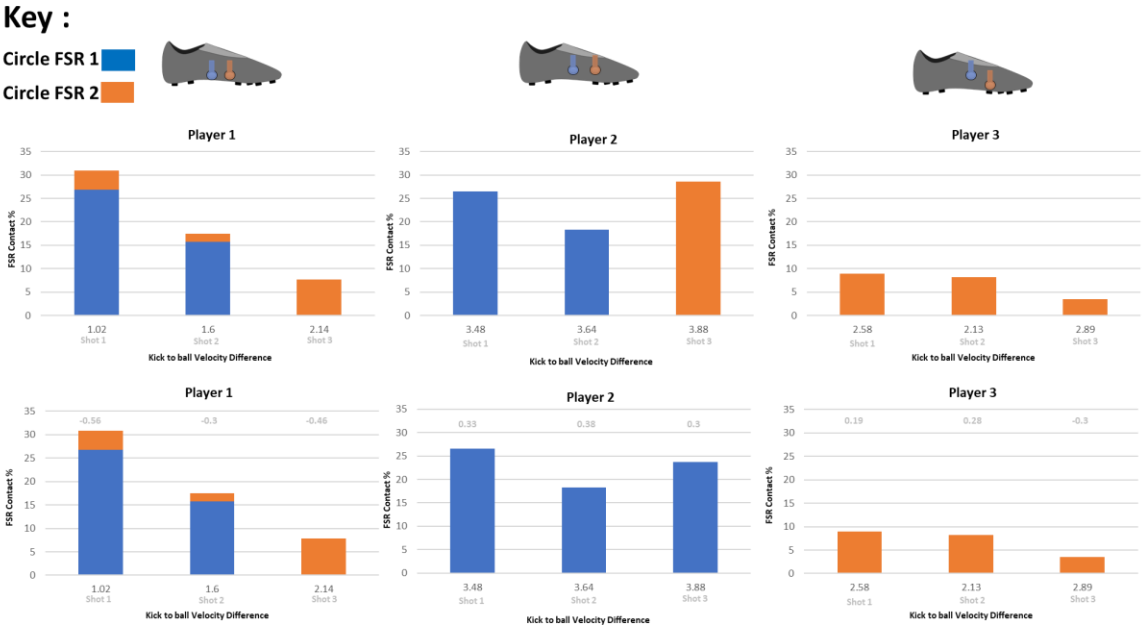
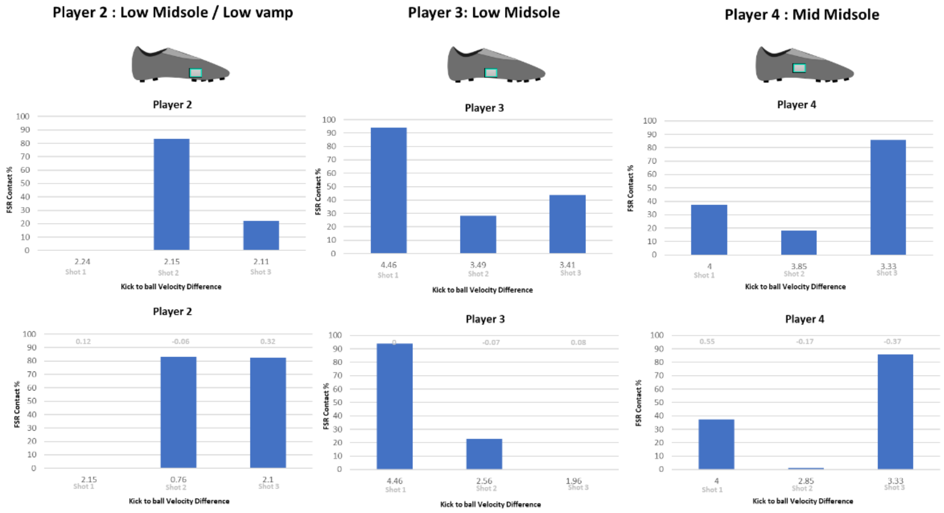


Figure 7.3.6: Inside shot 2 Circle FSR Contact distribution % for 3 projected players

Inside Square FSR produced good results for all players. Midsole region placement were all present in inside foot shots, where best shots relating to accuracy, were almost the same as the ones for KTB. The readings also show how the contact %, were almost at maximum for all their best shots (maximum amount of force felt per sensor). Player 2 showed lower KTB when going for more accurate shots. Player 3 had consistently high KTB, as did Player 4, who can be viewed as a better kicker where their kicks were almost the same for both monitored properties. Mid midsole can be regarded from this set of data as an optimal point of contact, however Low midsole/Low vamp region combination showed almost the same % contact as the standalone midsole contacts, even with a considerably less KTB. This could indicate that midsole require more sensors to differentiate the exact area of placement for monitoring purposes, hence the Circle FSR setup seems more feasible.

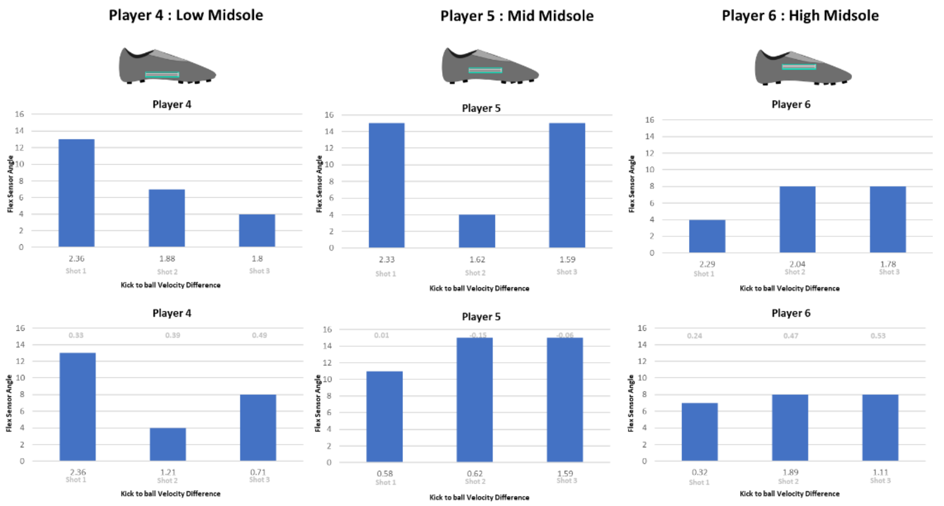

Player 2 : Low Midsole / Low vamp

Player 3: Low Midsole

Player 4 : Mid Midsole

Figure 7.3.7: Inside shot Square FSR Contact distribution % for 3 projected players

Inside Flex sensor outputted results differently to all other FSR sensors. It worked on how much bend existed upon contact, hence for this set of results contact % distribution is not quantified. With the higher angle readings coming from low and mid midsole region, the continuous trend follows on from previous FSR sensor readings. To quantify the amount of force felt was difficult, as this is judging more collision felt by angle of deformation, which can be another method of displaying force felt. There are some indications to show how flex sensors can be used in WT application on boot, as the ankle motion to connect on the required midsoles would cause eversion, with lesser plantar flexion and slight abduction when vamp is involved. Greater angle difference would indicate more flexion, hence more force on the intended region. Player 4 having almost the same angle difference as player 6 in some shots, show that this reading is not as strong as FSR. This is because the difference in flex sensor angle for 2 very different regions were outputting consistent angle readings. The code for this converted resistance felt as angle quantity, and this is not something that was reliable, because when it was placed on boot (via Velcro), the default angle reading was different, therefore the angle difference was monitored from the initial value, prior to contact. This is something that WT can adjust in calculation, however the application would be better not on the boot, but on the feet bone/muscle of the user, because this sensor can signal miniscule changes of body movement, to output more meaningful physical data


Player 4 : Low Midsole

Player 5 : Mid Midsole

Player 6 : High Midsole

Figure 7.3.8: Inside shot Flex Sensor Contact distribution % for 3 projected players

7.3.2 Experiment data analysis

Discussion

The readings between the kick power and accuracy from tables occasionally showed no differences, which is positive for FSR. However, the choice of choosing the better kick from preliminary test is to understand how single kick data can be processed within WT. Any biases in choosing the selected kick for analysis, has the test of repeatability for the adequate sample data that produced greater trends within these specific shots. A greater sample data could identify inconsistencies throughout the results as anomalies. When both kick power and accuracy considerations are applied, the key regions of Low/Mid Vamp and Midsole are struck dominantly, without any High Vamp regions, confirming that where there is more “sweet spot” involvement, generally produced accuracy.

When looking at 2 circle FSR readings, “different players” had a mix of sensor readings when adding the accuracy element with kick power. This means that each pendulum swing did not identify if the specific regions in placement of sensor aids more to power or accuracy. The orientation of the mannequin inside, and the Q clamp, were bubble wrapped, and did not have any of the surface inside sticking out, as this would make the ball in contact with the inside more, leading to greater KTB velocity. This control measure took longer to implement but had to be done, with sufficient bubble wrap coverage so that there are no possible “better” contacts in relation to what was inside. The pendulum swing was prone to human errors such as release height and it deviates as the kicking barbell moves around the resting barbell with Retro clamp repetitively secured as the kicks were repeating. The screw was constantly strengthened, and the tension inside the bolt could not be monitored hence this could have aided to more friction in between the kicking barbell and retro fit clamp. Even with foam placed in between, the maximum that was screwable was done until no more could be possible. This could have been affected on the specific day of testing and the fatigue factor of the researcher who may have not applied enough torsion on the screw to be the exact tension for every possible kick. Although this is a minuscule difference, when trying to assign the best kicks, this could have affected 1 or 2 kicks chosen.

The square FSR did take good amount of space when placed in Vamp region, hence initially this was perceived as the most promising sensor to be tested. Although it showed potentially good readings when monitoring inside foot shots, there were inconsistencies. Being bigger in surface area did not help to find any behaviour patterns that would impact data collection. For the future the sensor could be better placed on the palm of the feet, including the Landing foot. This is one of the key biomechanical elements of football, as the loads and tension in the muscles of this feet, allow maximum transfer of energy onto ball contact. 3 Square FSR sensors being placed on the palm, to view the distribution upon foot plant can generate data, linking loads to KTB. Even when comparing inside foot Square FSR, the Attribute table analysis showed how there would be better benefits if there were more sensors to distinguish contacts between Low Midsole to Mid Midsole, and Vamp regions. This is so that the finer details of contact can be defined to which is more important in terms of KTB and Accuracy, for User WT application.

Circle FSR was very robust when testing, and evidently produced substantial amounts of consistent data. These were easy to configure and define, to make it an application for football. The small sensory regions showed promising results, both for Laces and Inside foot shots. Because of its size, the way it was experimented around the midsole and vamp regions of the boot, generated a better understanding of how loads are experienced on the surface of the boot regarding ball contact. This can be viewed as the best sensor used in this experiment. It will continue to be the choice of sensor for future outer sole and ball contact sensing for WT purposes. The potential will be even greater when combined with IMU sensors to link the kick speeds with how well the contact regions on boot link to performances of shots taken.

Flex sensor was very stagnant. It produced results which could be analysed to make sense for possible boot monitoring WT application. However, the results did not seem too reliable, and there was not much it offered for this experiment. This is why they were discontinued from test of repeatability. Ideally, the best placement of these sensors would around the phalanges or lumbricals. This is because for the type of shot, although quadrus plantae muscle provides the angle of ankle, the flex sensors monitoring the phalanges and lumbricals would have a higher impact and effectiveness in how meaningful output data would be. This specific area of movement is crucial to how well shots are taken, generating more purpose in monitoring how the muscles on the feet adapt to match satisfactory ball contact upon kicks, therefore this sensor should be tested under different conditions to fulfil its potential.

Long FSR was used to track inside foot shots. However, the data that it transmitted did exhibit linkage to change in resistance, but the precise contact points could not be “pinpointed”. This made it hard to understand what the data meant in football terms. This can be viewed as the least favourable sensor used in this experiment. For future WT application, placing this sensor from the Tibia to the Quadrus Plantae, can help how identify “strains” when changing the ankle posture. This can be useful for injury monitoring, as poor form of kicking can be linked to excessive incorrect loads. This will need greater testing, as the sensor is better suited to be placed in the socks, which will need to be in contact with the skin to monitor changes upon striking a football.

Hot spot imaging identification showed that when kicks were above 400 Analog reading (0.5N) with an accuracy within ±0.2m, both low and mid vamps were the best kicking region. This is further supported by the test of repeatability where midsole to mid vamp also had very good kicks when sensor arrangements were placed in these regions. This was comparing all the kicks in the test that were laces, but just looking into a single sensor. When trying to assign each set to a player, and then create the FSR tables, the midsole region showed more consistent readings, that were chosen as better kicks. To reduce bias, the reasoning was detailed, in that it should have the best KTB velocity difference. This proved that a single FSR reading purely based on the outputted Analog/newton, and linking just that to accuracy, is not suffice. A combination of FSR showing the distribution of contact on the outer sole regions are the best way to grade the best kicks.

The user flow is an important step in producing the data that sensor outputs, to be meaningful. It gives the opportunity to make sure there are considerations for the end user to implement their needs. The purpose of the hot spot diagram is useful in knowing the overall strong contact points, but WT needs greater user centred thought process in its flow, and for this, it is believed that if the kicks were graded, having reliance on multiple FSR, rather than a singular square FSR, this would be the “smarter” option. User research has qualitative measuring tools, and the method applied to select the best kicks, was done in a quantitative way. This is because WT has made it desirable to quantify achievements and have some sort of scale to monitor progress and benchmarks.

Circle FSR showed that position of sensors does affect the readings. For WT application, FSR can be used as a tool to monitor how well the ball has been struck for both laces and inside foot shots, because when trying to form the attribute ranked table, the pendulum swings being viewed as different player kicks, showed how mostly the best shots in terms of KTB produced good accuracy. KTB cannot be tracked by FSR, but the analogue readings of these can be applied with IMU to get overall data about the player’s kick.

In terms of assigning how accurate shots were, the negative values show how much it was missed by, even if it ended up in the goal. The positive values also showed where the ball could have been drastically missed but still have a positive distance scale assigned on plot point. This is in relation to axis definition of the Vernier Video physics setting, where Target was changed for different kick types and the differences were calculated along the X axis. For the FSR Attribute Ranked Table, the consideration of having the ball in the net is neglected, as for the purpose of analysing accuracy itself was defined, e.g. bottom left corner target, ball just missed with a value of -0.1 is better than, +0.2, even though the latter went inside the goal.

Subjective opinions influence which kick is “better”, and because on numerous occasions the best kicks even after accuracy was prioritised, showed the same results as KTB option, proves the contact region of boots influence how well a ball is struck. Placing sensors in these “sweet spot” regions, can help WT identify if a player has been striking the ball in its ideal zones. The potential to measure more and thus increase the scope of sensing opportunity to garner more data working with other sensors only makes the case for WT in amateur football shooting tracking, stronger.

As the sensors were placed outside, the boot material does not directly hinder the results. Different boots being tested can have bigger differences if the sensors are placed on the inner sole, as the dissipation felt or the coating of the sensors in between the boots, could affect readings. The angle dimension of the outer sole boot design could impact the attachment of FSR sensors, WT will need to have the boots predesigned and installed during the fabrication with WT integrated in those specific designs, to monitor how FSR placements can be made. This is so that the sensor data readings won’t be affected if during Test protocols, WT relied upon a different boot with different dimensions, to generate data based on Midsoles and Vamp regions.

The ball being heavier would have caused more “collision” to be felt, hence reading on FSR would differ. However, for safety precautions, the ball was selected for the experiment to be conducted and kept the same throughout. In a bigger test environment, different balls could also be tested to confirm the contact regions of ball behaviour at the same speed, within the same kicking setup.

The release height is prone to slight error, as the drop was trying to be kept consistently at the same height. This method was trying to be as fair as possible, with the release height being in perpendicular to the resting barbell (1.2m). The kicking bar was hard to control initially, as it had weights which causes fatigue as frequent kicks were executed. Eventually, it was easy to stabilize, and substantial data was produced, in a controlled manner. The initial kick velocity of the boot was not consistent, which shows there were human error. Some of the kicks exceeded the 4.85m/s velocity that was expected without friction. This shows human error being made on possibly holding the kicking pendulum higher, or when manually applying Vernier physics tracking the boot at a different spot, which was done to reduce any systematic errors. Most of the readings however are reliable as the data showed consistency in producing kicks ranging below 4.85 m/s where no ball velocity exceeded 9.67 m/s. The pendulum is heavy, and the precise height of the drop, may not always be the exact height, with some differences only in cm, which would directly affect the pendulum velocity upon ball contact

As this test rig is a scaled down version of what the experiment would be with end users, the force differences are expected to be smaller. For test of repeatability, the forces felt still display similar values for 1.2m and 0.9m, which shows that FSR can be used as a contact sensing indicator. This is something that can be applied for WT, where working with IMU sensors, can show correct region of contact, alongside kicking biomechanics. If this test was repeated, the FSR choices for laces would be better considered if there were sensors that accommodate the boot stance. The future advancement of this test rig is having an electric motorised shank that is bolted in well onto the shaft, where a motor sets the designated RPM to be Kick velocity. This may also require some oil to lubricate the contacts to keep the friction to a minimum. The electronics involved will allow the kick velocity to be consistent, without fluctuations.. For future there could be a level or stand which acts as the trigger for the kicking pendulum to be released.

The clamps are cast iron, with metal dumbbell extenders and barbells 100% Steel. Their different structures and texture meant that as the kicking pendulum was moving along the clamps per kick, there will be friction that affects the total possible velocity of the kick and ball launch. The testing occurring over 2 weeks each for preliminary and repeatability, also meant that slight wear could also lead to more friction, hence polyester foam was placed in between to keep the rubbing of the clamps and pendulum bars, to a minimum. If this test was repeated with different metals as part of rig equipment, then the friction would differ, depending on if they are the same or different [Afrilcate,2021] [Hypertextbook, 2022]. The use of stainless steel with iron meant less friction, as opposed to iron with iron. Therefore, when creating positive error bars in the X axis, there could be a greater weighing alongside the height drop that can be applied to accommodate this element.

Standard error could have been used for error bars, however standard deviation and weighing factors with scales relating to the height drops were preferred. The weighing factors worked in ratios in relation to drop height, as this considers the control parameter dimension to the results. This is a decision done by the researcher to allow some form of consideration when this test is repeated, with different drop heights, these can be applied proportionately. Error bars used in ratio of ball and boot velocity difference between height drops was also considered, however there was no consistency, and these scales were assigned to aid any test repetition to have a form of continuity.

X axis error bar consists of a weighing factor dependant on kick and ball velocities and dividing by 10, whereas FSR reading's Y axis error bar is multiplied by 10. These are influenced by the unit scales, where the velocities experienced are around single digits with two decimal places, and FSR readings having 3 digits. This weighing element is subject to researcher assigning a scale that can be consistent, where ratios of the respective ball and boot velocities can depend on the increment of height changes.

The significance of placing more sensors as opposed to the initial pendulum test confirms the sweet spot regions of contact and validates that this test of repeatability can justify the statements made. It can be repeated with the exact equipment, where the estimation of variance gives a clearer representation of what the results of the FSR data in these arrangements can be. Cluster algorithm charts are not used for any of the graphs, as the data needed to be extracted with required monitoring of kick and ball velocities working alongside the FSR data, before and after accuracy metric.

Eighteen kick trials per treatment was given as it allowed six kicks to be taken aimed at the three targets each, to allow the test to have more situational based approach. This could have contributed to the variance; however the difference was negligible as the pendulum treatment setup was very easily adjustable to allow the desired contact for the required target trajectory. The additional sensors placements aided to understanding the different signals per treatment, and it displayed when those areas were important, i.e. more accuracy. For 2 circle FSR arrangements, a future consideration would be placing square FSR as the error detecting sensor due to its larger surface area. FSR sensors displayed they have a role in identifying football shooting attributes relating to ankle motions.

As the accuracy cannot be judged with WT alone, this means that a potential integrated system must be able to detect where the ball has hit target. If an Attribute Ranked Table was made without any consideration for accuracy this would show results that tell the user their kicking in the right zone and must rely upon their own memory if they had kicked where they wanted to, or video recordings. For future implementation of the FSR to be “smart”, there needs to be a consideration of how the accuracy of ball launch will also be tracked. This can be having sensors on the ball or the target, where the overall technologies involved must pick this up to state whether the kick has been successful.

With a real user test, the flex sensors combining with FSR could produce even more ankle stance data upon contact. The precise angle of eversion, dorsiflexion, abduction etc, were not calculated, as it was more visual based and rotating the dumbbell extender bar to match correct FSR region contact. Flex sensors and IMU can provide this information, which will be produce a thorough ankle motion analysis upon contact, linking to the change in its biomechanics and how it affects the power or finesse of shots. Flex sensor and Long FSR can have even greater biomechanical analysis, regarding football kicking in terms of hip flexion and knee extension. The kinetic linkage between the backswing and landing foot phases of shooting, can be tracked via smart sensor placement. However, the true impact of these can only be determined by experiments. Having placed these sensors around the ankle and boot allowed new performance data derivates, and such, when implementing similar methods for knee extension and hip flexion, control studies will help improve sensor accuracy, and the meaning of the transmitted data. This will help review if flex sensor can be influential for knee extension and hip flexion.

This thesis is working on ankle rotations to gauge the success of laces and inside kicks, and ball contact is being used as a feature to grade how well FSR sensors can be implemented to define how well ball is struck. The FSR cannot guide the user on the ankle rotations, however when reviewing the data, there is a chance to educate the user about the ankle stance. This is because the sweet spot regions of contact, enables the ankle to move, to allow the final point of contact to be at a particular region. In this case, the user would want to have good connection around the Low/Mid Vamp to Midsole area. A strong assumption can be made that this would influence the user’s behaviour to change enabling that ankle movement to be precisely allowing the sweet spot region to be struck.

Inside shots prioritise finesse, and Laces shot prioritise power, meaning the attribute ranking table should potentially have different weighing for any future WT decision matrix, which factors in these considerations. The table assigns each FSR as a region of the boot, relating to Vamp and midsoles regions. The example set uses FSR data from experiment, to impersonate if a player had struck the same way. KTB and Accuracy to Target is not sensed with FSR but has been put on the table for analysis. The two different attributes are ranked to understand how FSR alone, gives out performance data, and what influence it has when accuracy is also a factor. This splits the potential outcome of WT performance data where one player may choose to prioritise accuracy over power (vice versa). The user input is key to WT data application, hence this experiment showed how sensing via pressure type sensors being placed on the outer sole of the football boot, can generate relevant data in WT. This will now move forward in showing where it applies to the Decision matrix and how the Ankle biomechanical model framework will utilize FSR data smartly. This is something UX design will need to resolve as the Usability testing and reiterative User map data journey can define which attributes should have higher importance relative to End user rank.

Summary

All 4 sensor types showed potential for future WT applications regarding football shots. Circle FSR was the best sensor for monitoring laces and inside shot, due to its smaller surface area to identify precise contact regions. Square FSR can also be used for sensing in the outer sole of the boot however it could work better being placed on the plant of the foot. This could monitor loads of the landing foot biomechanics as it can show where the loads are differing across the foot plant, as the player strikes.

Even though they were discontinued in test of repeatability, the flex sensor and long FSR showed promises of data capture that can be applied within football biomechanics study. In the study itself, it did not have as much of an impact as the square and circle FSR however it can be applied for other WT football biomechanical analysis. The Flex sensor and Long FSR can potentially help monitor knee extension by placing on the shin, and around hip flexion, linking the changes in resistant values from how well they have executed a kick. This thesis is analysing within penalty kick environment, but when researching other set pieces such as freekicks and corners, these sensors could output more purposeful kicking data, which can translate to different passing attributes.

Using the kicking pendulum was an interesting apparatus to simulate football shots. The pendulum applies a form of control, in terms of initial kick velocity. This allows more focus on what sensor data is read for these respective velocities. The effectiveness has been that it allows data transformation context around FSR. Within this research scope, the technology elements have been applied using a kicking pendulum method which can be replicated for any further FSR investigations within football ankle biomechanical studies.

Sensor placement is important to understand certain data for laces and Inside foot shots. To derive performance data, FSR sensor placed on outer sole of boot and there is a strong indication that this could be used to determine greater advancement of knowing a player’s contact technique. The best setup is a combination FSR sensors around the Low/Mid Vamp and Midsole contact regions, distributed on the outer sole to grade the successful kicks.

Converting physical data into performance data can be in the form of sweet spot region contact, which the block diagram and Attribute rank table shows, applying this experiment as if it was done with Amateur footballers. When computing the Hot spot region initially, the data outcomes did not give a full representation of how WT would have judged these results. This was one of the primary reasons for creating an attribute ranking table, as there is greater extraction capability of defining shot types and its success. This is a key Design element, as it uses something that the End User will assign in priority, to program the WT to output data that is relevant to their needs.

8. Design of performance data framework

8.1 User experience of football kicking performance data through survey analysis to identify priorities of end users regarding

8.1.1 User Experience of Data

There are numerous factors when it comes to User Experience (UX) and User interface (UI), where key protocols such as user journey and the psychology of interface design, must be thoroughly analysed, so that the user feels the true ergonomic value of the wearable. This is because the feedback is communicated through this experience, and their opinion on the wearable hinders on how well the UX performs. UX process starts with a user centred design approach. This is when the project is solely around the user, giving them full control of the product through it's service. In wearable terms, there is an ethical concern of personal data being sent to a provider's "cloud" (processing) before the user's device (output). WT is considered as a human centred project; hence it will revolve heavily around user research. This is a core factor, as without it, the designer cannot find a need, hence won't provide a solution. Design is not entirely about creating something new, it is about observing, and eliminating factors that are conflicting, which can breed to simplicity, leading to successful UX outcomes. Without evaluating these design elements, the product delivered may not be satisfactory, causing a loss of valuable time and cost. This will only increase if later in the process, more modifications are needed. Coming up with a design plan for an application, requires flexibility for extensive user testing, which is a reiterative process.

The role of UX is crucial to how successful a wearable device performs. Football Wearable devices, in monitoring how well a player Strikes a ball, can easily be understood by the designer and sport scientist, but the method and needs to communicate this data to the player, is where UX impacts. How does a user know what the kicking data is showing them and is it relevant to what they want regarding their technique, is something that designers and researchers aim to answer. The method of answering this, is structured through UX. Data monitoring is easy, as sensors such as accelerometers, gyroscopes and heart rate monitors produce accurate enough data for scientists to distinguish movements [Gobinath, 2019]. The connection between consumer and product is the UX and UI. This is where WT data produced, can be processed for the actual user to be educated of what those readings are, and how it should matter to them. The complex part is where the users prioritise in what they want from the wearable. This must be done ergonomically, so the user can control and analyse their own data better, i.e., their need to learn correct form of kicking technique that links to different biomechanics involved.

When researching to design a sport wearable, Engineering (scientific) elements consist of the topics that influence the product. Planning how to conduct research for user needs with constant reiterations with the intended consumers, helps build a platform for what the product can or should do. Their feedback is important to "filter" the necessary details of the product. The designer wants to build from these findings as that influences the service (e.g., mobile application) they want to provide.

Figure 8.1.1 shows the design process where meaningful data allows a smart football wearable to be more refined. The crucial element is conducting a user study, to really define product specifications. The wearable should not only be about doing multiple things, but it needs to do certain things well that distinguish it to the wearables it competes with. It needs to represent the specific amateur footballer market. The greater the size of the consumer, the more varied needs it would need to meet (inclusive design). For WT project, the 2 key Subjects that Figure 8.1.1 method shows are Technology and Design. Themes that arise from this are very broad, however, the procedures are like what any wearable design would follow. Technology investigates what Data can be monitored by the electronic equipment, and the Materials. This sets the specifications for what the product's hardware would consist of and what it's made of. The Design would cross over with Technology, when creating design ideas for the Product. However, the crucial segment in design would be the Consumer research that obtains user requirements of the product, which feeds into the UX needs. What data can be monitored in terms of football kicking via the Technology used, and the type of data those amateur footballers prefer will define the wearable. This sets the needs which gets reviewed through a reiterative process by end user, before they feedback in terms of the product used, and the experience of the service. This feedback structures the reiterative process where ideas advances as the product takes shape. The reiterative process itself consists of continuous feedback from user and testing the different parameters revolving around the whole design where all the stakeholders are satisfied with the outcome, before a business proposal can be made to set the forecast of the wearable.

Figure 8.1.1 : Example design process for a Football wearable

It is very important that the program where the data is communicated to, such as smart phone APP or wearable screen, is user friendly. This is what controls the perception of the output data of the wearable system. This is also where producing meaningful data can be judged, and how consistently it can adapt for new user needs. Reiterating human centred principles is a challenge, so a refined methodology in primary research techniques for UX and UI wireframe concepts, produces a successful design process, whilst completing the technology research.

UI is what the user must interact with, i.e., feedback medium. For designers to really deliver well with immersive technology, football consumer study must be made to great lengths. This will help them understand their needs in interacting with the product and service. Helping come up with solutions, and mapping customer journeys, where the lifecycle of the product can be forecasted along with the user's main reasoning of investment, builds a story board. What must be noted, is that without consumer study in UX, the UI will not have any meaning. The technology already exists where human senses interact with technology, but to make it meaningful, researcher must really know how the amateur footballer wants the product and service to be, i.e., how ankle biomechanics analysis relating to foot shots produce more data on their own movement [Sherman et al., 2003].

The method of user acceptance through WT should be forecasted to plan how the intended product will transform end user's physical data into meaningful performance data. The aim for smart wearables is to improve an element of the consumer's lifestyle. With technologies influence increasing on daily tasks, users can be complacent to rely on wearables to motivate and alter their behaviour or attitude. The framework that impacts behaviour, needs to be refined for WT. Perception of a smart wearable that a user has is what will allow them to invest in it [Suphan et al., 2018]. The simplicity of influence in daily tasks, is where the electronics used, needs to prove itself. Designers could have an alternative issue if the design is successful enough, where greater behavioural changes from the user, breed further needs.

Some wearables have a display attached which gives the user visual feedback in data. Examples of these are smart watches, where the screen has touch sensitivity for the user to experiment their way around the interface. Some wearables are programmed, consisting of an APP as part of the whole product, where the user uses their smart phone for interactivity with wearable and its data. Having a mobile application may be needed in some wearables as the feedback they want to give to their users may not be applicable to a smaller screen size. This is where complexity occurs, in knowing exactly how the user wants feedback, for ergonomic cognition. The review for a wearable heavily depends on the UX and UI capabilities.

If a different need occurs, how the wearable device adapts to be sustainable, forecasts its success. If the wearable's function perception does not match the actual use, then the wearable won't be desired. To what extent should having a strong function perception be, in having a positive attitude change, is something designers must calculate. How much a user needs to adapt, their willingness for it, comes into decision making for investment. The ergonomics can be the catalyst for consumer purchase. There needs to be an element of simplicity in feedback for ergonomics which can be identified by pain points. If a negative review could directly impact one feature, the rest could also be affected. Figure 8.1.2 shows how technology acceptance model involving WT for this study would follow (based on User acceptance of computer technology) [Davis, 1989].

UX and UI both play a role in the perception of monitored data [Endeavour partners, 2014] [Fritz et al., 2014]. The user will only judge these results in comparison to their physical activity. If the wearable outputs raw data without making it user friendly, then the perception of accuracy will be questionable. This ergonomic consideration is what accuracy of wearables is judged upon [Gobinath, 2019]. Where the user sends and receives data is a sustainability factor. Users can share their quantified achievements to relevant people. This can be a motivational or educational, reason by viewing other's feedback on progress [Fritz et al., 2014]. Social interactivity increases immersion and learning experiences [Gobinath, 2019].

It is important to rectify the market research of football apps to see what the current landscape is like. Design would depend on the WT itself, as these hardware shows the limiting capabilities of what the software can feedback. How to illustrate the features related to football performance stats will drive the UI. Icon research is also needed giving it precise functions and a place throughout the interface. The specifications of a potential App must be clear, as it should do the things it says it can. If the app has multiple uses and features, it's going to be harder to design, so it's important to research specifically the features the intended consumer would benefit from. In any App, the wireframe design is important. This can allow the interaction to be tested, providing the designer a clearer structure of how the core layers involved in building the UX/UI. The use of a football App would be different depending on the type of users, e.g. Central Midfielder wants to maintain and improve their endurance, whilst a left back wants to work on top sprint speed. The specifications must clearly state the key stats which will be communicated to the user, and this must be adjustable as updates follow, to keep up with needs.

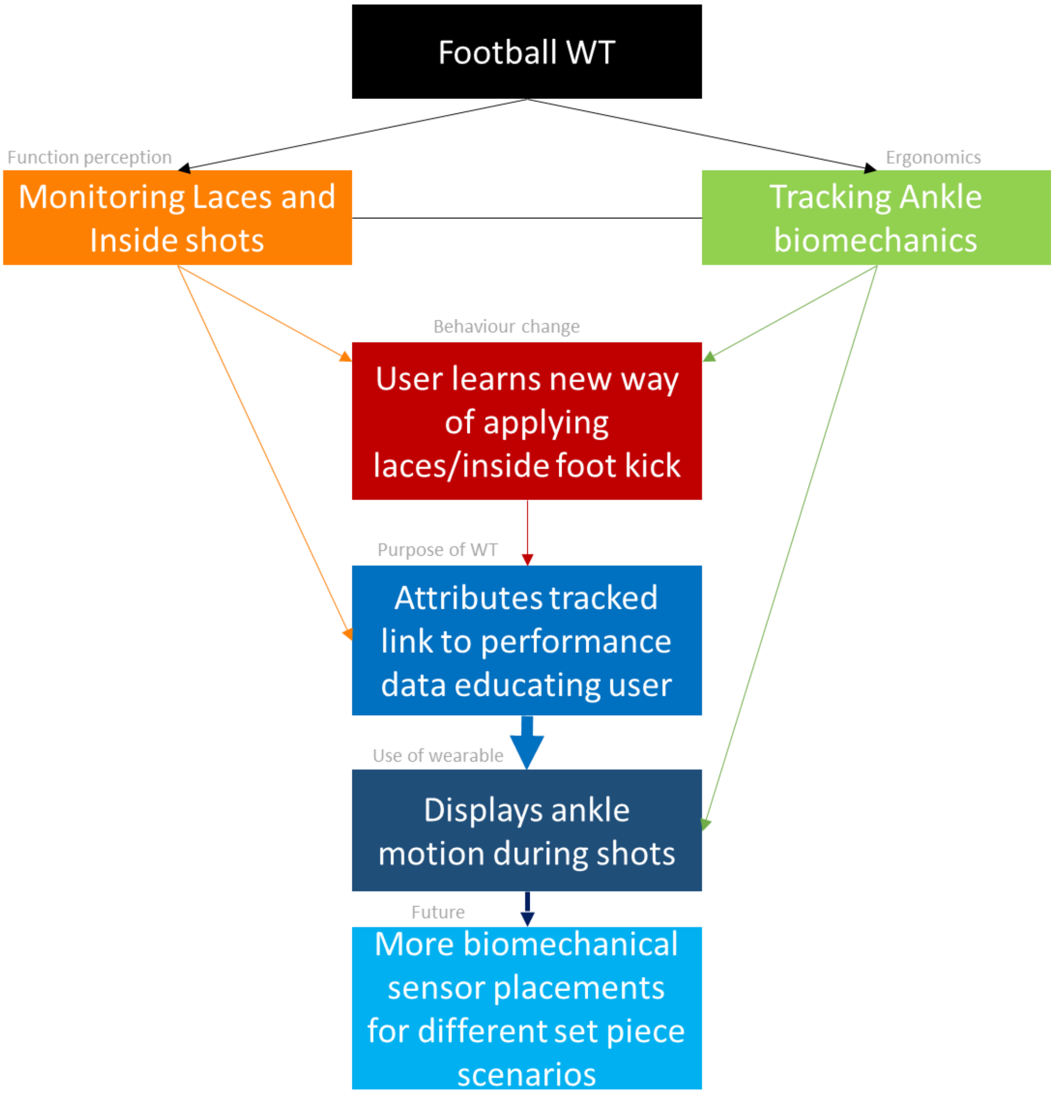


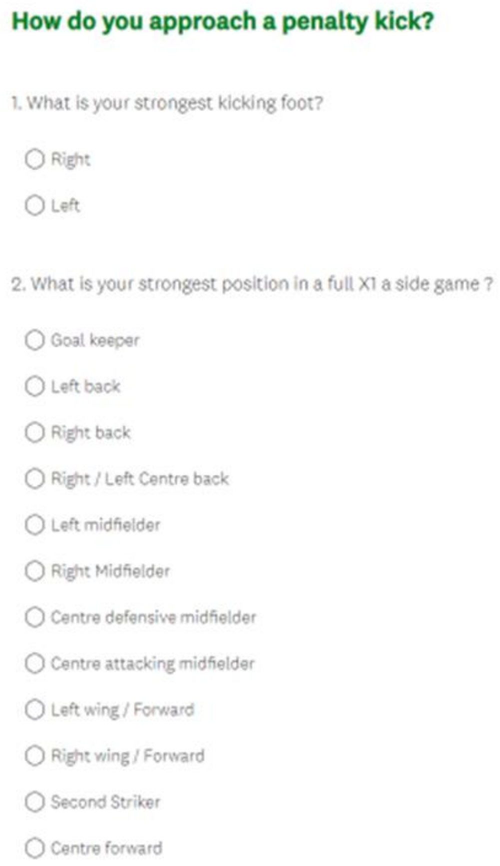
Figure 8.1.2: WT acceptance model for this study; inspired by Pete B.Shull

8.1.2 Survey outline

This project involved technical elements which were tackled via engineering methods, that analysed body biomechanics, sensory readings, and linked to how well laces and inside foot shots were struck. The Design elements, although present throughout the project, still needed a focus group user study to confirm important amateur footballer data needs, around penalty kicking. This meant strategic primary research methods had to be implemented to collect an in-depth analysis on amateur footballer's thought process and experience when they execute football shots.

For this to be done effectively, a usability study needed to be conducted in hybrid with a survey. This is to allow qualitative research to take place where closed end questions were followed by discussion within selected focus group. This allows smart adjustments to be made with follow up questions directly after completing the questionnaire, which generates more insights to find what similarities and differences are in feedback, that amateur footballers provide about penalty shots. If the End users can have a greater understanding on how the sensors would be applicable to track the specific features of ankle biomechanics, then it would have proved in assisting meaningful feedback.

The survey was designed online and sent to amateur footballers to understand their process of approaching a penalty kick. This is to measure the key attributes that they prioritise when shooting. The questions were filtered to match attributes against one another to see if they understood how they impact each other and how they consequently meant the same definition. The following images dissect the survey questions and their intended function of gathering insights on amateur footballers.



How do you approach a penalty kick?

1. What is your strongest kicking foot?

○ Right
○ Left

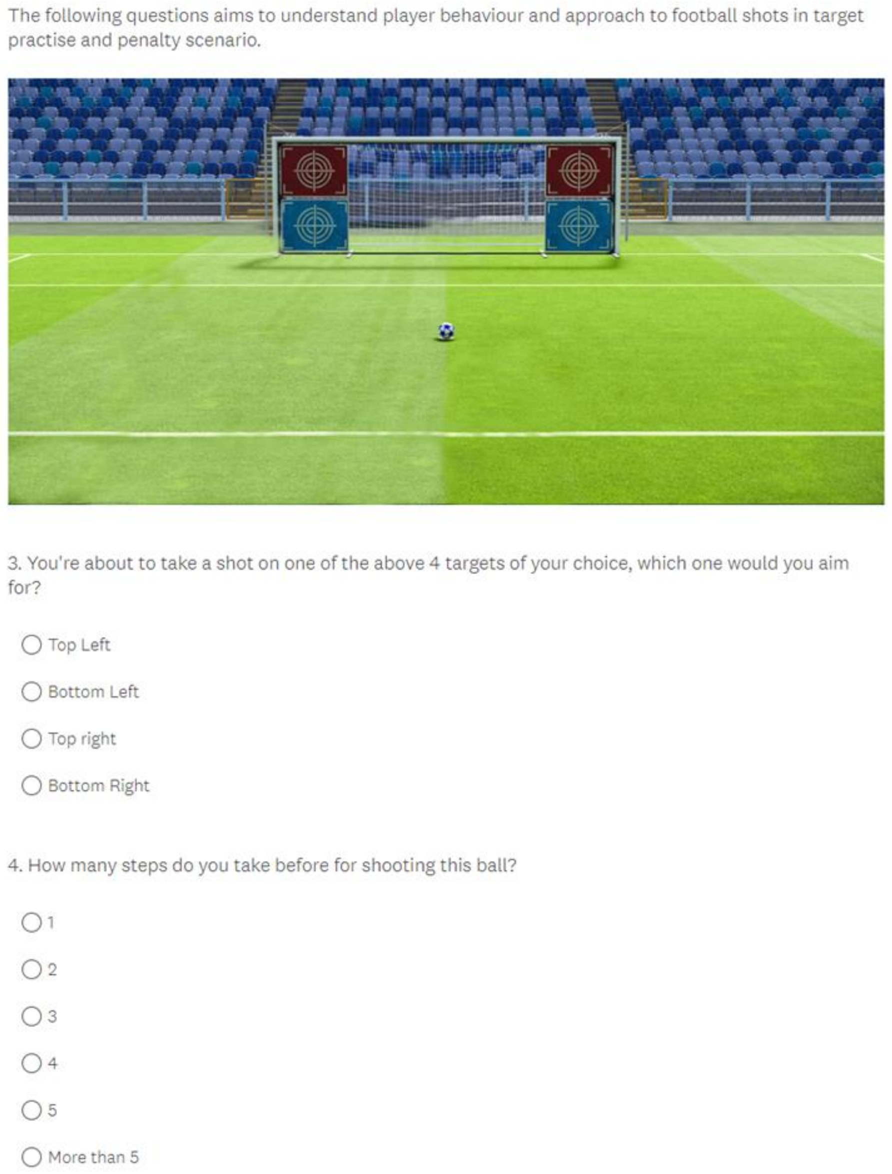
2. What is your strongest position in a full X1 a side game ?

○ Goal keeper
○ Left back
○ Right back
○ Right / Left Centre back
○ Left midfielder
○ Right Midfielder
○ Centre defensive midfielder
○ Centre attacking midfielder
○ Left wing / Forward
○ Right wing / Forward
○ Second Striker
○ Centre forward

Figure 8.1.3: Survey Questions 1-2

1.Understanding their dominant feet is a crucial data on amateur footballer. Players who are ambidextrous, will still have 1 foot they prefer. During early observations, few players were crossing with right foot but shooting with left, and for this scenario, as penalty kicks are definitive in range, a selected foot must be chosen.

2. Link the approach of penalty to a player, to understand if there are differences depending on position. This will help WT to function differently should the analysis support findings that link different approaches by certain position of players. This is building the data set to make WT make smarter decisions in the User experience it outputs. There are players who may have multiple positions, but the question directs them the opportunity to self-evaluate where they think they're best at. A coach’s view may defer, because during early observations on amateur footballer (Chapter 4), saw a situation where a Central Attacking midfielder, was better at Central Defensive position. This shows how bias based on player’s self-perception affects the choices they make. This argument can also be countered, where if a player wants another position to be their strongest, then WT can influence in that. Therefore a Usability study is fundamental for a WT project, as it links to the precise End User goals, and how much of that is a necessity.



The following questions aims to understand player behaviour and approach to football shots in target practise and penalty scenario.

3. You're about to take a shot on one of the above 4 targets of your choice, which one would you aim for?

○ Top Left

○ Bottom Left

○ Top right

○ Bottom Right

4. How many steps do you take before for shooting this ball?

○ 1

○ 2

○ 3

○ 4

○ 5

○ More than 5

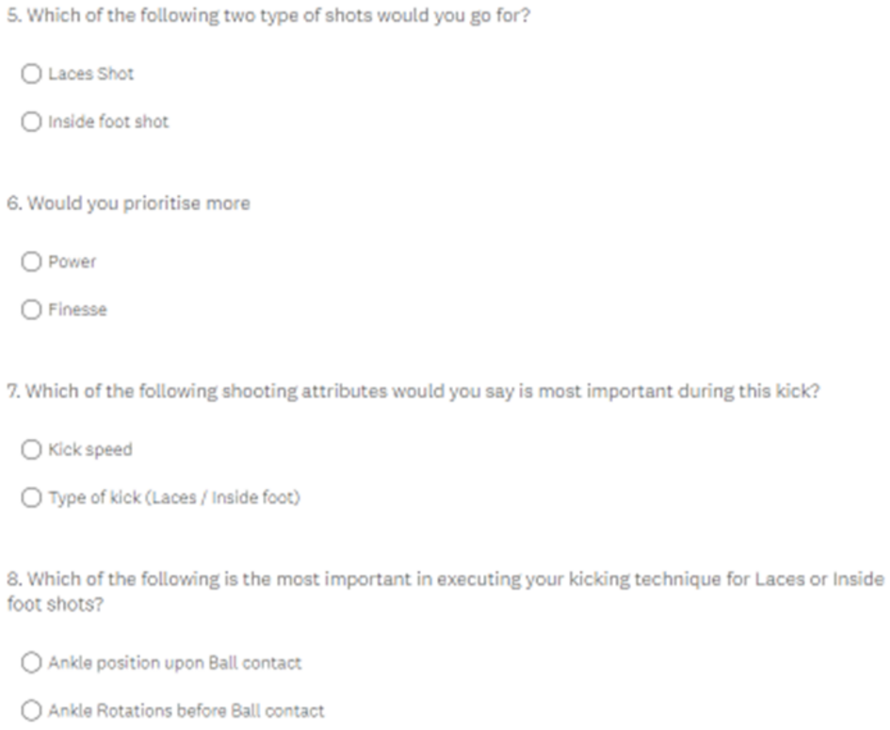
Figure 8.1.4: Survey Questions 3-4

Setting the scene of the Football shot training within penalty environment shows the four targets are definitive areas which can be considered “closed” selection, as some players may like striking in the middle, however this is to “force” them to kick at one of the corners, which require greater skill with accuracy dependency.

3. This question identifies how the dominant foot and position of a player, instinctively choose their desired target. This is important as it will lead to assumptions of how player behaviour affects their shot choice, i.e., ankle position upon contact, making it a key user input, and something the Design process aims to understand greater.

4. Obtaining number of steps before penalty kick links to existing biomechanics; the landing foot. Based on the approach of a player the loads of the landing foot will defer depending on their manner. This can be linked to the number of steps a player takes to execute a penalty kick.

The following questions are asked to purposely put amateur footballers in situations that require them to choose one attribute over another, aiding to the trade-off between shot Power and Accuracy dependencies. Some players may feel they have the capability of executing a powerful penalty kick with precision, but to dissect their thoughts to make physical data definition simpler, a selective decision is needed in how a player would pick one attribute over the other.



5. Which of the following two type of shots would you go for?

○ Laces Shot

○ Inside foot shot

6. Would you prioritise more

○ Power

○ Finesse

7. Which of the following shooting attributes would you say is most important during this kick?

○ Kick speed

○ Type of kick (Laces / Inside foot)

8. Which of the following is the most important in executing your kicking technique for Laces or Inside foot shots?

○ Ankle position upon Ball contact

○ Ankle Rotations before Ball contact

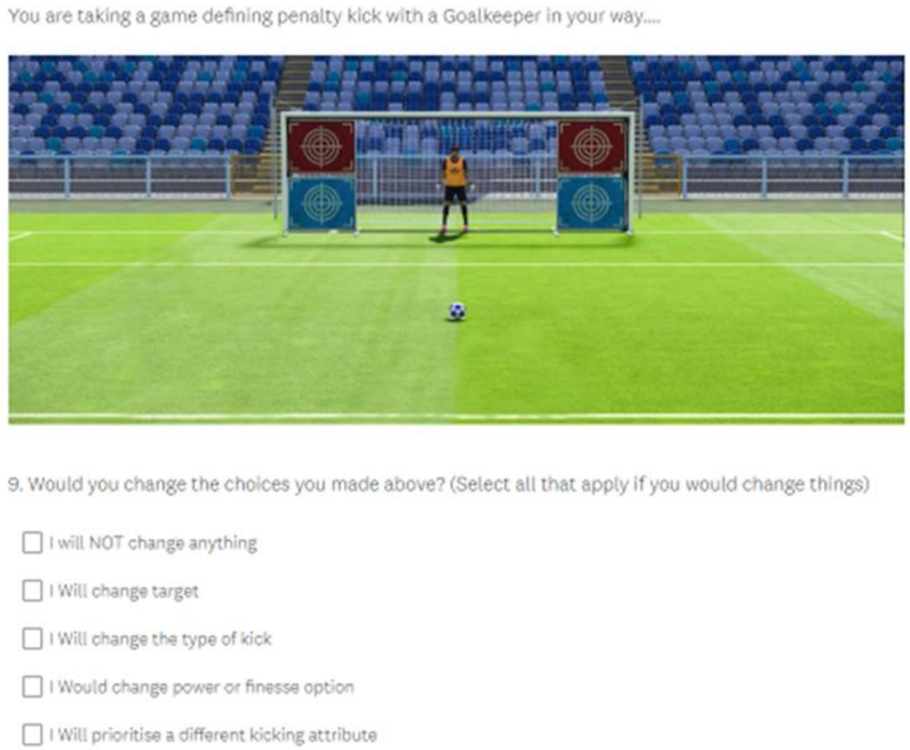
Figure 8.1.5: Survey Questions 5-8

5. The User is tasked to pick between the two types of shots that are analysed in this study. When a player approaches a penalty kick these are the 2 most predominantly used. Chip shots are a technical kick that can also be a choice, however the risk to reward ratio will play a factor, when the player wants to perform this kick. To understand further for this study, these close end options are given, which increases the depth of linking the User and Design principles of this project, to the technical and engineering side. These are important qualitative assessment tools which will build a robust analysis of shot choices to subsequent ankle movement from kick techniques.

6. To select between power and finesse (accuracy) attributes, is to see if players who choose laces or inside shots, end up picking the ideal attribute for their shot type. Laces is generally ideal for players who want to prioritise power, and inside foot shots for finesse. What this aims to understand is, does these shot types guarantee the attributes which are expected to be from them.

7.Kick speed and the type of kick can be linked to power and finesse attributes. But this is more to understand if the player striking, desires to be more physical, i.e., kick speed, over technical. WT aims to convert physical stats into performance stats, and with expert interviews also highlighting that meaningful data is what builds the smart value of WT, this was a decisive question in the broad context of this project. Both kick speed and type of kick can gauge the "kick performance" of a player, but should they prioritise a more physical attribute component, this allows WT to accommodate the needs of its end user. This reiterates why survey is a vital qualitive assessment tool, where post discussion is essential to further understanding amateur footballer mindset, in sport data.

8. Question 8 holds huge value in this project. This research studies ankle motions and aims to identify if this could potentially be a new Biomechanics in football kicking. The ankle position upon ball contact hinges more reliance on the final impact of boot to ball. The ankle rotation before ball contact is how the ankle has moved from point of backswing to ball contact, and if those specific motions are of greater importance when executing the right form of chosen kick. This question desires a response to show if players that understand kicking techniques and its attributes, know that there is heavy influence dependent on their ankle movement.



You are taking a game defining penalty kick with a Goalkeeper in your way....

9. Would you change the choices you made above? (Select all that apply if you would change things)

☐ I will NOT change anything

☐ I Will change target

☐ I Will change the type of kick

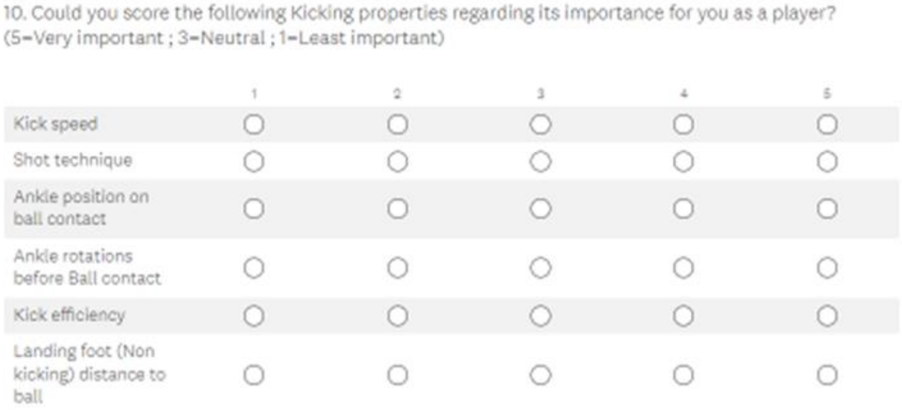
☐ I Would change power or finesse option

☐ I Will prioritise a different kicking attribute

Figure 8.1.6: Survey Question 9

9. When a player is in a situation to take penalty kicks, there are deciding factors that change their mentality. Therefore, this question puts them in a position where they must think, if they go with what their approach to training would have been, as it is something they're accustomed to, or would the consequence of the situation, and the weight of the game, play a part in changing their approach. The psychological impact this would have can be monitored depending on if they have changed their

results based on the choices, they made under training scenario. Depending on what they modify in choices, would result in the factor that has the greatest ease in change. This means that the selected change of choice, influences what is the quickest and easiest element to reduce psychological impact of penalty kicks.



10. Could you score the following Kicking properties regarding its importance for you as a player?
(5=Very important ; 3=Neutral ; 1=Least important)

	1	2	3	4	5
Kick speed	○	○	○	○	○
Shot technique	○	○	○	○	○
Ankle position on ball contact	○	○	○	○	○
Ankle rotations before Ball contact	○	○	○	○	○
Kick efficiency	○	○	○	○	○
Landing foot (Non kicking) distance to ball	○	○	○	○	○

Figure 8.1.7: Survey Question 10

10. The decision matrix is one of the key components to quantify subjective opinions, so that WT has added value. This scoring question makes the footballers rank which of the kicking properties are most important to them. What this does to a decision matrix is that the score given to a selected attribute will be decided by the user themselves. This is crucial because it reduces any assumptions of what attributes are of greater need, and puts greater control on the user, i.e. human centred design. This User feature in ranking their attributes makes WT flexible and adaptable to meet a diverse set of amateur footballers, making this an inclusive design principle.

Footballers who rank ankle position upon ball contact, different to shot technique would show the evidence in the research gap, where there is a lack of knowledge to in how they both complement each other to define the type of shot. Ankle rotation before ball contact is expected to be lowest, as there is not enough information educating the users on the importance of this. This would also form better discussion post survey, to educate the impact WT would have to follow up on end user perception and what more they can obtain with monitoring. Kick efficiency was an attribute that was formed with COR calculation (Chapter 6) monitoring how it well energy transfer occurs from shooting with resultant ball speed, and if this was low scoring, then it would highlight further gaps that would require research. Landing foot is not a researched topic in this study, but was inputted to understand how it would fare, as this will directly compare existing biomechanics to a new one in ankle position and rotation. The landing foot distance is predicted to generally be an average score. Therefore, this scoring would help identify if there are any potential of WT informing amateur footballers on the importance of ankle monitoring.

8.1.3 Survey Analysis

The amateur football demographic responses totalled 58. This was a good sample to find trends and analyse the role that WT could influence with shot monitoring. The results below are selected to summarize the survey, with key indicators of the selected End Users. Further analysis is made when individual responses are monitored to dissect how player position affects approach and what choices they made within the training and penalty kick situation. This built insights into how WT can be implemented to make smart decisions and output meaningful data to Amateur footballers.

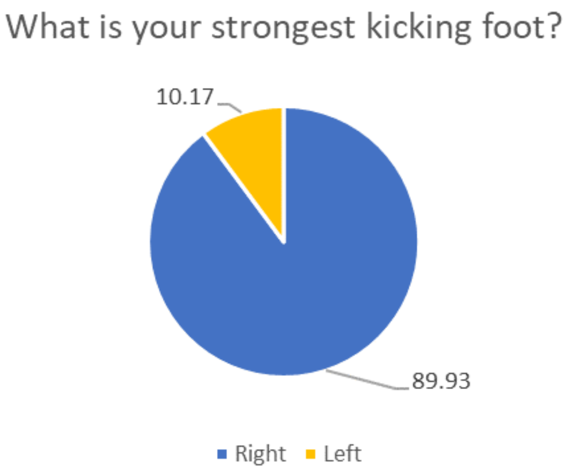


Figure 8.1.8: Dominant kick results from participated End User

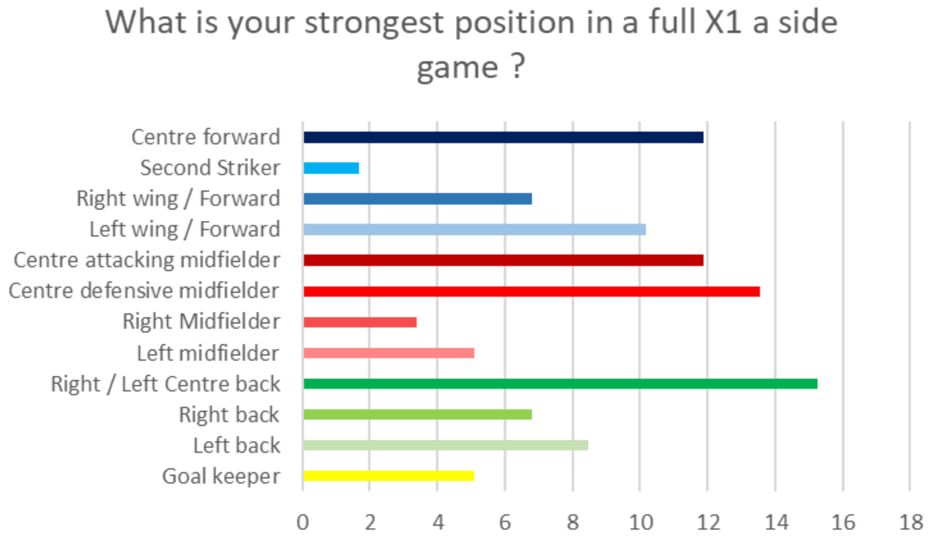


Figure 8.1.9: Position of players that participated in the survey

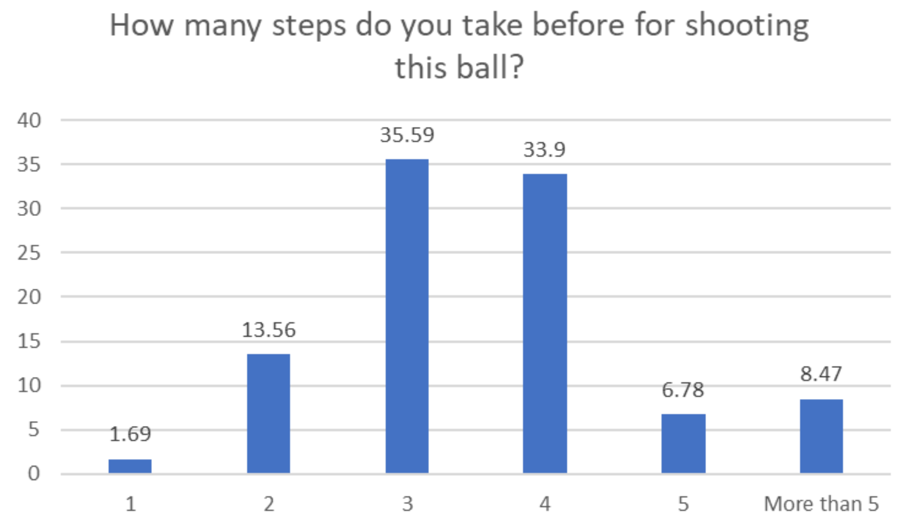


Figure 8.1.10: The steps taken before penalty kick

The results summary shows how most participants were right footed players. The position of the players was diverse, which showed positive forecast in wanting to link player position to the approach of penalty kicks. The key outcome was how most of the players ranged 3-4 steps before taking a penalty kick. These results have factors that will influence research areas for this study, and future possible testing with WT.

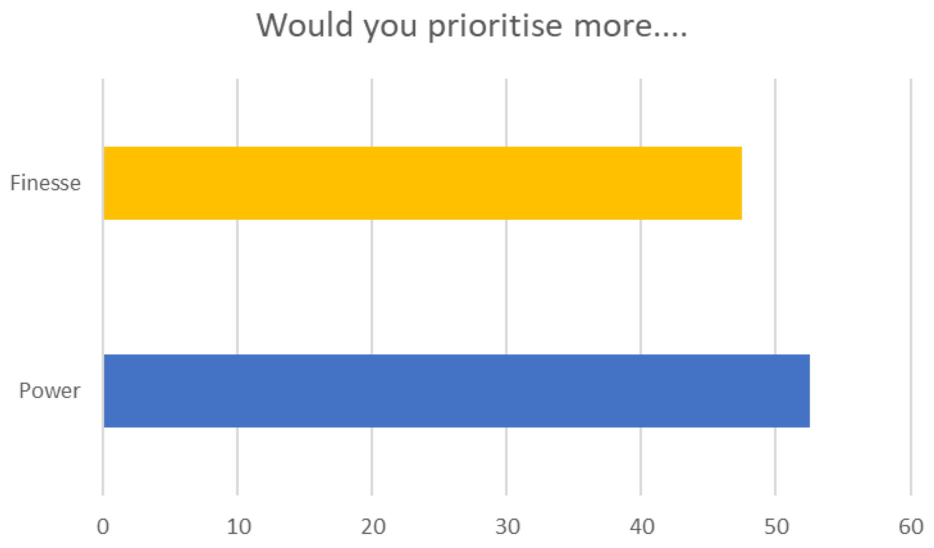


Figure 8.1.11: Which kick attribute did participants prioritise

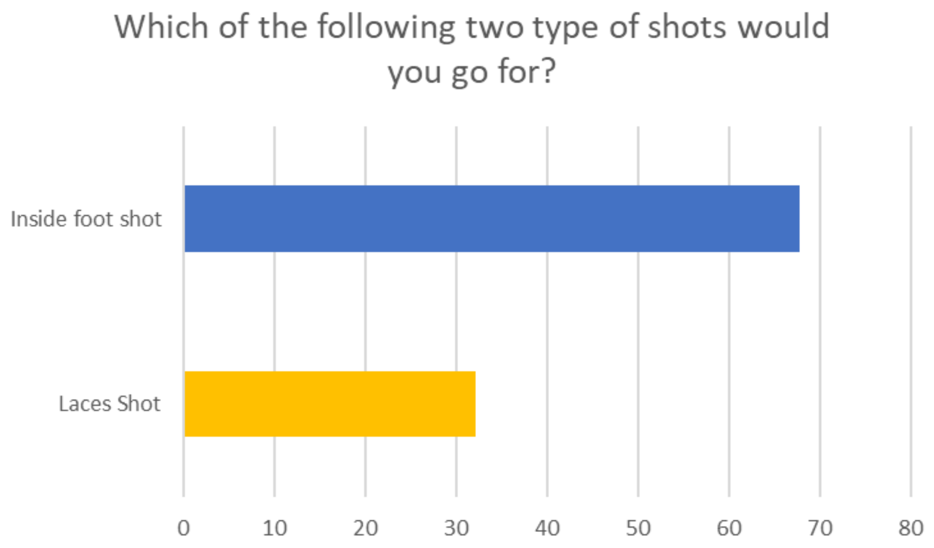


Figure 8.1.12: the type of shot users chose more

Whilst reviewing the progress of survey responses, the Finesse and Power attributes were initially trading leads. The percentage difference between the two were very close and this showed how participants may have struggled to pick out of these 2 properties. This shows they can be related with a bigger weighing factor in decision making for penalty kicks. The type of shot being favoured more for inside, could relate to how they prefer to go with a safer option. Laces shots are risky with the power to accuracy trade off being very fine, and the chance of error is higher than that of inside shots. This could mean that WT could "rate" laces shots with more leniency, as it is a harder shot to perfect.

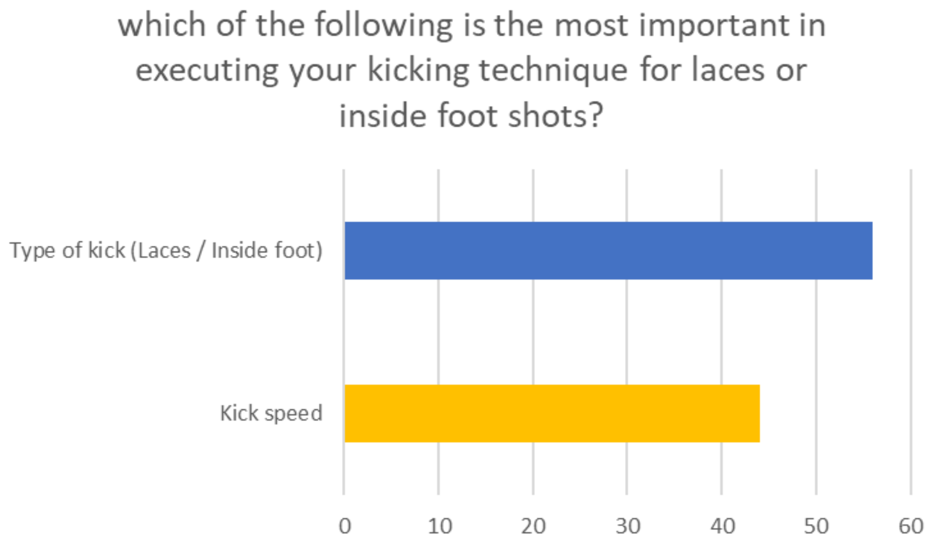


Figure 8.1.13: Which of these kicking attributes did footballers choose more

Why the type of kick is being "rivalled" with kick speed, is to understand if the users who picked finesse would also pick the type of kick, because Power and Kick speed have more similar traits under Laces shot properties, hence this analysis would grant greater insights to where amateur footballer's knowledge lies. This was strategically placed to confirm if the gaps are there for WT to "educate" about football shots to amateur footballers. Further analysis viewing the survey individual responses, would produce key findings between the number of players choosing both.

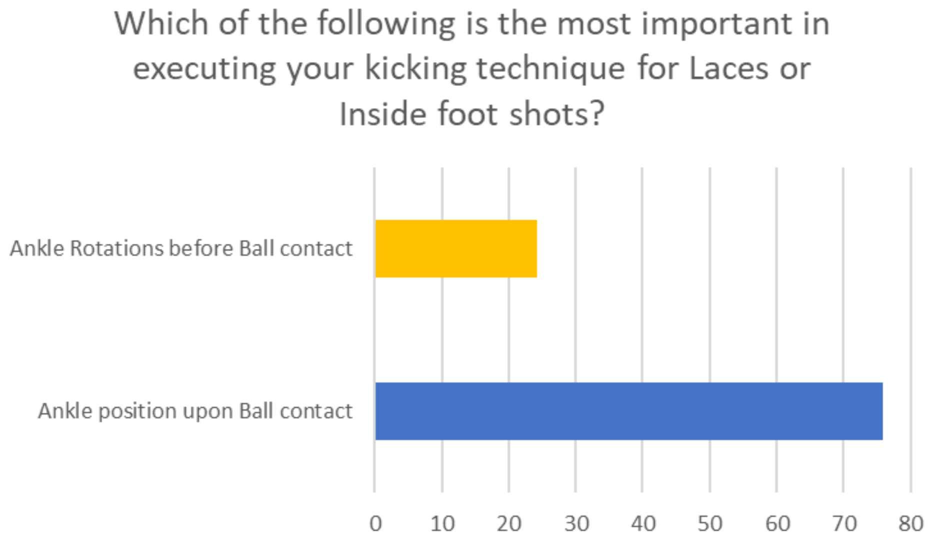


Figure 8.1.14: which ankle biomechanics do they feel is more important

Ankle position was more popular than Ankle rotation before ball contact. This was not surprising as it proves how players don't understand how vital the ankle stance at beginning of backswing can affect at the end, i.e., ball contact. These questions confirmed that WT has a big role to educate players on their shot technique and inform about factors that were not common before.

Individual response analysis

The survey outcomes were imported as CSV files. This file sorted every response into rows with headings as columns. Once this sheet was decluttered, filters were applied on all the question topics to understand which chosen answers came from the type of participant. These showed some significant outcomes that WT in amateur level football can impact, as well as educate key biomechanics involving ankle movement regarding shooting.

Finesse attribute selectors all chose Inside foot shots, but for power even though most chose laces, there were some who chose inside foot shots. All but 1, were Defensive minded players in Central defensive midfielder, Central defenders, and Goalkeepers. This shows how defensive players hone on their inside foot technique more due to their role in the team which include inside foot short passes, and power to clear the ball away. They aren't the usual penalty kicking personnel hence this also shows their lack of knowledge in executing good shots. There was also a mixed response, when finesse selectors did not choose type of kick, but also power. This shows how they want to exert an accurate kick, which inside foot shots have heavier influence in, yet want the capability to physically strike with higher velocity. This reconfirms the gap WT can penetrate to educate these users on their shooting techniques, to build the attributes they want consistently, i.e. physicality to increase kick power.

In terms of target choices, all Bottom left and Top right selectors were Right footed players. Players that would take 5 or more steps to execute kicks also stated that they will not change their choice from training, when they are under a penalty shootout situation. However, a mix of finesse and power responses show how user centred solutions are still required to meet multiple needs.

Central midfielders can be considered one of the most diverse positional roles in football. They have an influence in both attack and defence gameplay. These respondents chose not to change any of their options had they been involved in a game defining penalty kick. This shows how confident they are with the skills they possess and can believe they'll deliver this kick in a time of need. Consistency can be something the sensors can monitor and distinguish, hence the transfer of kicking abilities in a different situation being graded by WT, is a very possible capability.

With Question 9, 24 out of 34 respondents who would not change their kick options under penalty environment were attackers (midfielder/forwards). This showed that there is a strong belief with the choices of confident shooters, as these are the type of players who are accustomed to more frequent shots on goal. Players that chose to alter the power or finesse option, all chose Ankle contact upon ball contact, where all but 1 chose Inside shots. This showed how players stick to a safer option in inside foot shots, which encourages accuracy over shot power, where they also chose Ankle Position upon Ball contact, the exact finishing point in boot to ball energy transfer. This attitude showed what the "safest options" are in terms of when pressure is applied to the kick scenario. All players were from different position, exhibiting that this issue is inclusive.

Unsurprisingly defenders (Right/Left/central) had the most mixed combination of results when comparing "not change anything" feature in a game defining penalty kick. The ones who chose to change something, chose more than one option which could signal indecisiveness when they were in a position of penalty kick situation, even though most chose inside foot shots as preference. The changes were broadly spread throughout the attributes given, and there were no strong trends in terms of definitive kick properties. This is where WT User Experience is fundamental in outlining what a defender wants in shot tracking with the diverse range of power to finesse options, linking to their shot preference.

3 goalkeepers (referred to as A/B/C) answered the survey, with choosing Inside foot shot as preferred type. Goalkeepers B and C, selected Top left target, Power, Type of Kick and Ankle Position upon ball contact as their choices. The difference between them was their decision matrix weighting score, where the ranking of each attribute scored less than 1 per respective kick property. This shows how 1 goalkeeper thinks about their penalty striking whilst the other is not interested. Goalkeeper A and B gave the same scoring in ranking the attributes they prioritise. This shows how Goalkeeper B, is almost a mix of Goalkeeper C and A, further justifying why a user experience flowchart is crucial for WT in amateur level sport application.

By viewing the steps taken to take a penalty kick response, most have a range of 3-4 steps. This result could influence studies looking into landing feet of the footballers, and the loads that the experience, to why this is such a popular range. Comparing this to players who took 1-2 steps and more than 5, can build data set in player behaviour and study its effectiveness regarding Landing foot loads.

Making the players rank kicking properties was to give an overall projection of what WT could program regarding the attributes it tracks. When WT is implemented, it is used to track certain features, i.e. inside and laces foot shots. For WT to judge the importance of certain attributes over others, it needs to have some sort of priority rank. The players were tasked to rank what they personally feel would benefit them, and some of the results were predictable. Ankle motion related kick properties were forecasted to be the low scoring, as this study is trying to use WT to educate the importance of this biomechanical movement in kicking. Figure 8.1.15 displays the rating distribution of participants per each attribute. Shot technique was the attribute that scored the highest amount of 5(very important). This shows that the contact upon ball contact is something that the end user prioritises. Kick efficiency was 2nd highest, confirming COR being an important aspect within WT calculations. Ankle rotations before ball contact having highest 1 score, shows the gap in research.

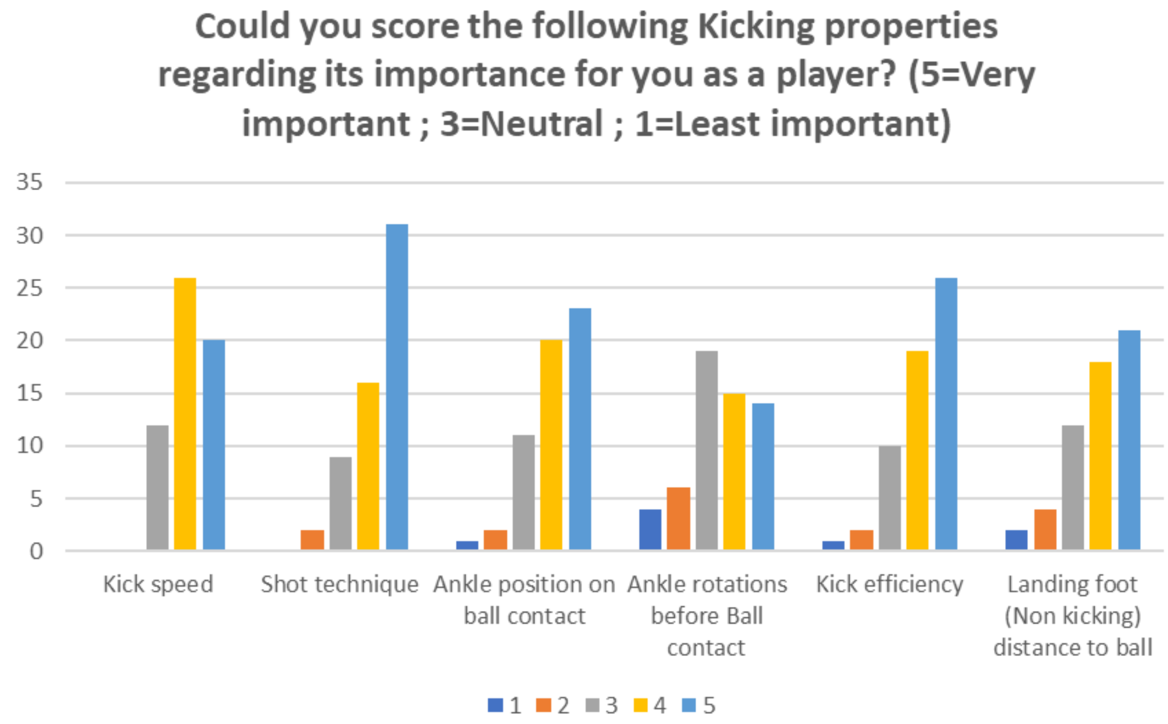


Figure 8.1.15: Kicking properties ranking score graph

Kicking Properties Ranking	1	2	3	4	5	Total	Weighted Average
Kick speed	0	0	12	26	20	58	**4.14**
Shot technique	0	2	9	16	31	58	**4.31**
Ankle position on ball contact	1	2	11	20	23	57	**4.09**
Ankle rotations before Ball contact	4	6	19	15	14	58	**3.5**
Kick efficiency	1	2	10	19	26	58	**4.16**
Landing foot (Non kicking) distance to ball	2	4	12	18	21	57	**3.91**

Table 8.1.A: Kicking Properties ranking score table

Predicted Kicking properties Rank	User Kicking properties Rank	
Shot technique	1	-
Kick speed	3	-1
Kick efficiency	2	+1
Landing foot distance	5	-1
Ankle position on ball contact	4	+1
Ankle rotations before ball contact	6	-

Table 8.1.B: Kicking Properties ranking prediction against final weighing

From the kick properties ranking Table 8.1.A, the main attribute in Shot technique remained the popular choice of priority. Kick speed was ranked 3rd overall by players, where kick efficiency became more important. Choosing kick efficiency over kick speed, means the general players participated want endurance ability more than physical. These are averages against 58 players who come from diverse range of needs; hence this table ranking cannot be something that WT should use to define attributes.

If WT was to use the full data set of respondents and create a decision matrix rank from the results of Table 8.1.A, it would be an injustice weighing score, because WT is a user centric application. The average results are not user specific, and the weighing would mean that WT will by default, rank the importance of these properties within its algorithm program, and output feedback data based on these results. To demonstrate how user flow should change, the following flowcharts are created for what WT should implement so that the experience is more personal to the player.

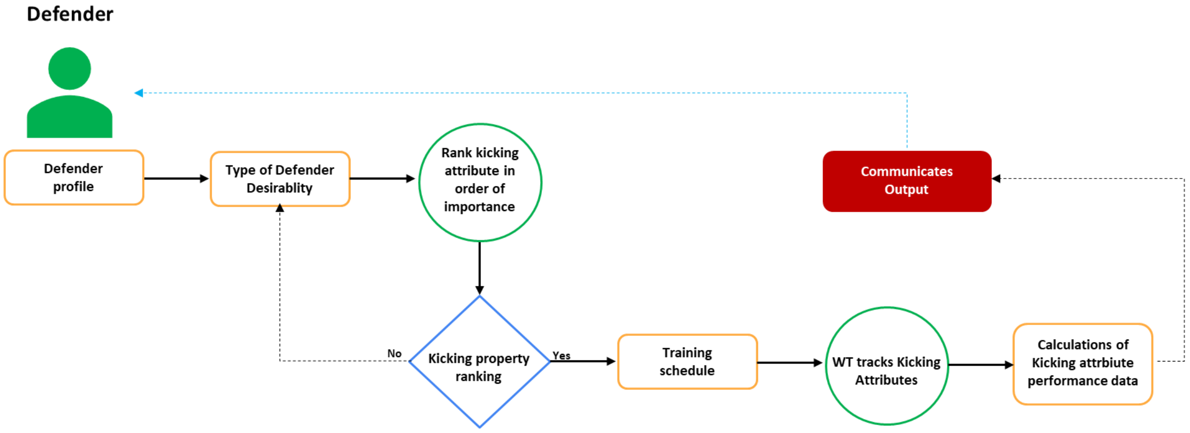


Figure 8.1.16: User Flowchart for a Defender

Post Survey discussion focus group

During post launch survey, a selected focus group was involved in discussions to explain how sensor readings would have taken place. This is done to discuss how the survey first made the player think about penalty kick approaches, how each question followed a talk about the importance of the listed kicking attributes, and how WT integrates in all this.

2 midfielders stated that the type of midfielder they are will also affect what kick priorities they choose. As 1 participant stated that they are a Box-to-Box midfielder, someone who tends to bring the ball from the opposition half to their own, generally being known as hard workers, may not choose to go for power when in a game defining penalty scenario because of their fatigue. This also showed how they think other midfielders such as Centre attacking, are better suited because they are generally better goal scorers. They also mentioned that sometimes position does not relate to being a better kicker, although every player should know how to strike a penalty kick, the psychological impact weighs heavier on someone who is an attacker because there's higher expectations of them, compared to a defensive minded player. When these points were made, a decision matrix formation that ranks attributes was shown, which they responded, that any future WT system should consider players who want to improve on shots, in mind with the expectations from them. Everyone wants to score a penalty, but the requirements of learning a kicking method should not affect the player's gameplay, as some won't prioritise learning shooting compared to passing.

With 3 defenders (2 central / 1 left back), discussing penalty shots was not the main theme. They wanted to know how to strike the ball well between the 2 techniques in laces and inside, which they believe can help them in game situations. This is because as defenders they are required more to obtain possession and pass to players with greater capability of creative gameplays. The discussion highlighted that this process of scoring kicking attributes should be done for long passing, as defenders want this technique to be something they're better at than shooting. When mentioning this method will be applied to other kicking attributes, there was a strong sense of encouragement that the way this survey was designed, a WT device should also ask these questions before it tracks the player. This could give greater understanding of the player's mindset or situation on the day they are training, which could be before a game, further building a profile of the player.

When discussing if this is "too much" monitoring, the focus group participants encouraged that if it improves them, and the affordability of WT has good value for investment, this should not be an issue. More User testing would need to occur with what WT can output and if it can be smart enough to adjust to various End user needs (greater "disruption"). Participants were anticipating more technology to be available for this kind of monitoring and a gaming function to add a social element of the experience was also encouraged. There is a strong indication that WT will play a bigger role in amateur footballers, and that there would be more investment if the added smart value tracks well.

The positive feedback from users were that they enjoyed a survey that made them realise important factors they never considered before. A left wing forward immediately said how they wanted to know more about the ankle movement upon kicking and highlighted how their heels always were sore when they performed incorrect form. This signified the initial problems that motivated this project, and when discussing the model framework, there was optimism in viewing the working model. They said that the actual device must be modular, and if their form was wrong, it should teach them what to do.

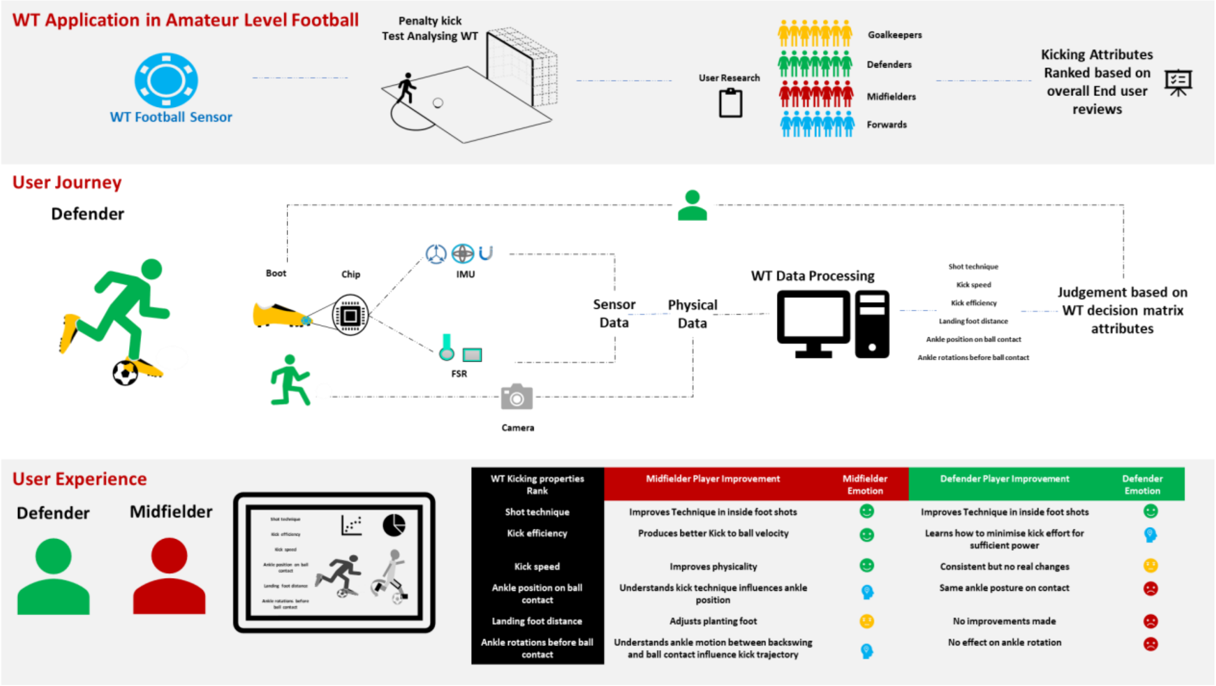
The use of camera was encouraged, as they feel this will not only benefit themselves viewing, but they would also like to show others, to "peer review" together. More than 1 subjective opinion is encouraged amongst the End users, hence if the feedback experience has a social element, then it can be helpful to know what their teammates have also prioritised. If they are going to face different opponents on a game week, then coaches inputting which attribute they their players to prioritise can help WT track these features closely, to judge how well they're being done. This can help the coach systematically identify which players are working towards the aim they set, where their "subjective opinion" influenced what the WT output data showed.

During the discussion, showing work of designing new data (Chapter 6) in how kick efficiency, strain, ankle angular velocity range and Ball contact consistency was monitored, were very well received. WT drafting new data that were not considered before, showed how there is always a desire to know more about it. Players said that when discussing their gameplay, having some scales to measure as performance indicators can encourage further analysis between players, to help them grow together. This grants them more elements to discuss about, and if they know how the numbers that output from WT link to a specific part of their gameplay, then they can program their training to improve these parts, as Footballers already have inside knowledge to further help WT. There were also mentions that if the user can pick which components to have greater scrutiny from WT, then it would make the experience much greater for the player themselves.

User experience can research the decision-making cognition of players when they are in a penalty kick scenario, as a psychological study. When players were put in a penalty kick scenario with a goalkeeper and having a game situation which could impact their mentality, data can be built around the approach to set pieces in football that differ based on consequences. This idea has great potential to further develop WT application, to build a system that can train player mentality. UX can be ground-breaking and motivating if it gamifies the experience. An example can be WT producing a gaming feature where different scenarios are placed for the user to shoot penalty kicks whilst tracking results. A model like will be very clever but will still require user test, to gauge its effectiveness and sustainability.

The most significant question was the ranking of the attributes. This is to formulate what a decision matrix would be, for the user to assign their important traits. This allows WT to adapt the experience to match what the footballer's needs are. Having a football ranking decision matrix allows the user element to be involved in the WT application of making it a "smarter" feedback system. The elements involved in a player picking the kick properties they believe are important to them, would show how the physical monitored data, will classify the performance calculated data, into something the user can work upon.

Figure 8.1.17 shows how the framework for Data application in WT is, when the research is done for all amateur players. This shows how the different needs are not personalised and how potentially two different positional players would feel with the outcome of their data.



WT Kicking properties Rank	Midfielder Player Improvement	Midfielder Emotion	Defender Player Improvement	Defender Emotion
Shot technique	Improves Technique in inside foot shots	🙂	Improves Technique in inside foot shots	🙂
Kick efficiency	Produces better Kick to ball velocity	🙂	Learns how to minimise kick effort for sufficient power	💭
Kick speed	Improves physicality	🙂	Consistent but no real changes	😐
Ankle position on ball contact	Understands kick technique influences ankle position	💭	Same ankle posture on contact	☹
Landing foot distance	Adjusts planting foot	😐	No improvements made	☹
Ankle rotations before ball contact	Understands ankle motion between backswing and ball contact influence kick trajectory	💭	No effect on ankle rotation	☹

Figure 8.1.17: Framework of WT application on football with current Kicking Properties Score

A user flowchart shows how the player's choice of ranking physical data, will influence them to grow in the way they want. This is increasing the perception where the output data, is fully controlled by the user input. When discussing this with focus group, (reiterative process), players mentioned that in a football scenario, some may want coach to input this data, as they want to be part of their team, and this means that WT must allow this feature. The new User flowchart is designed to show how the application of WT affects the new User journey, which increases the impact of User experience. This increases the inclusivity depth, by personalising the experience of feedback data.

Any human centred design involvement must use key user experience research pillars, which empathize, problem solves, unite, and rationalise in decision making. Therefore, a coach input allows the rational feature, where the researcher tackles empathy and pragmatism. Uniting the stakeholders involved, now completes all the key pillars of user experience research, that will come from WT application in amateur level football. This proves how the technical elements of this thesis, now implements design consideration, thus completing the Double Diamond methodology which structured this study. The different User experiences and modifications that refined this User flowchart model, displays how the user reiterative process from double diamond was followed.

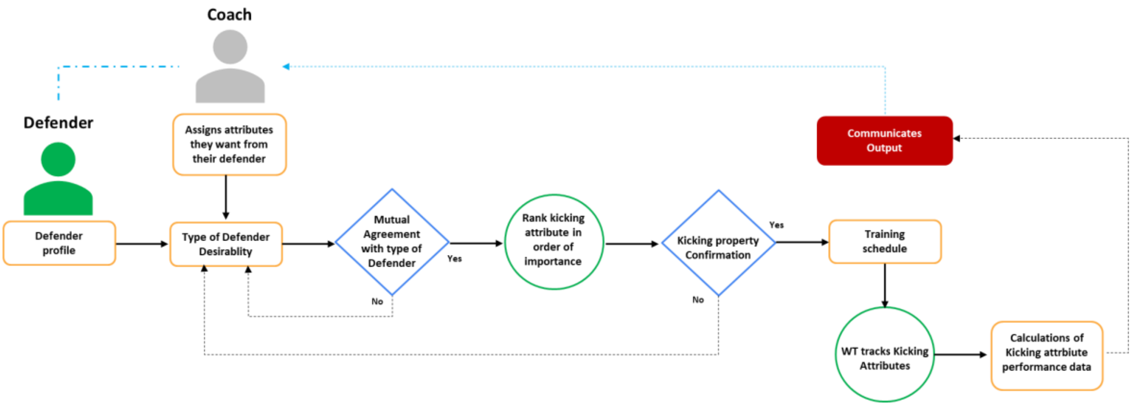
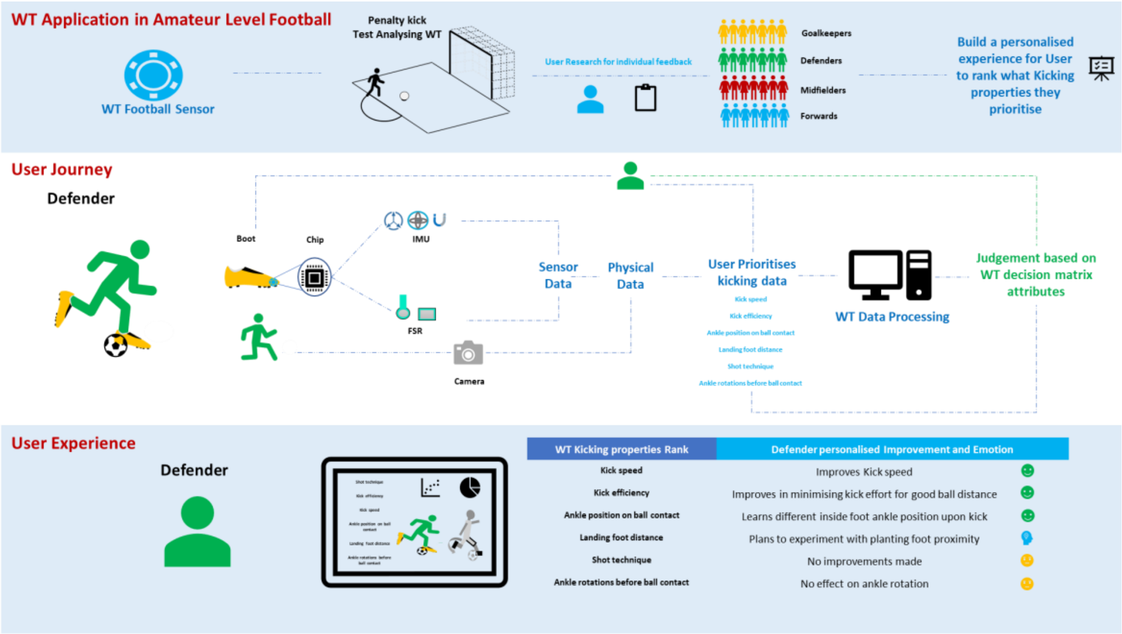


Figure 8.1.18: User Flowchart reiterated after Focus group discussion for Defender.

With User, there is a sense of emotion involved that displays how the experience is felt. A user centric project that WT application possess, is fundamental in making the User's feelings influence decisions. When comparing Figure 8.1.17 to 8.1.21, there is a more personalised experience, making the impact of WT more sentimental, and the user would feel a lot of trust and reliance in WT. When WT implements User research and delves into assigning Data, the feedback in User experience will be average. This is because WT would have been programmed to accommodate needs overall, where it helps everyone, more than specific user. To improve this segment, there needs to be greater consideration of the user input, this is so that the output data can be more meaningful. Viewing it as a way of inclusivity, the influence of WT in improving the player's kicking ability the way they want, becomes more apparent.

The survey design has outputted results that can be taken forward to analyse further in other aspects of biomechanics. The multiple insights obtained regarding just penalty shots, also asked questions that links to Force on landing foot. The post analysis of the survey outcomes can be transferred to monitoring different biomechanics involved in football kicking, including a different setting. For further research in this area, this has made it very useful to take a good sample data and use it to conduct another usability test.



WT Kicking properties Rank	Defender personalised Improvement and Emotion
Kick speed	Improves Kick speed
Kick efficiency	Improves in minimising kick effort for good ball distance
Ankle position on ball contact	Learns different inside foot ankle position upon kick
Landing foot distance	Plans to experiment with planting foot proximity
Shot technique	No improvements made
Ankle rotations before ball contact	No effect on ankle rotation

Figure 8.1.19: Framework of Personalised WT application on football Kicking data

8.2 Framework models to compute physical to performance data transformation via implementing sensors for football shots

8.2.1 IMU & FSR sensor Analysis

The two tested sensors in this study, looked at how the ankle motion can become an integral part of Football kicking biomechanics. IMU sensor looked at how the Linear velocity and Rotational acceleration can link ball contact to ankle stance. FSR sensor evaluated how the distribution of boot regions being in contact with the ball, showed its relevance to a good ball launch velocity, with efficient kick velocity. These two sensors can define what a good kick would be, but there is a dependency on how the ball travelled. User review discussions supported that there is always a greater use of video recording, which means that any use of camera capture, grants the opportunity to help reliability of linking sensor data to the outcome of the kick.

To create a framework illustrating the process of how performance data is designed within ankle biomechanics monitoring, needed an evaluation of monitoring methods. Research had limitations, however the tests conducted showed importance in linking a new biomechanical feature for football kicking. How this system works in real time and what each component of the sensor data influences the performance indicating data, is shown with flowcharts. This represents the overview of how the research in WT, can progress in implementing new findings regarding football shots and linking it to different body movements. To visualise what this research has done, in terms of shot analysis, and the tracking features it possessed, the following flow diagram communicates the essential components that produced intended results. Figure 8.2.1 displays how this study works with obtaining data, which through the User test and Pendulum experiments for their respective sensors, allowed learning of what can be monitored to relate football inside and lances shots, in producing relevant performance quantities.

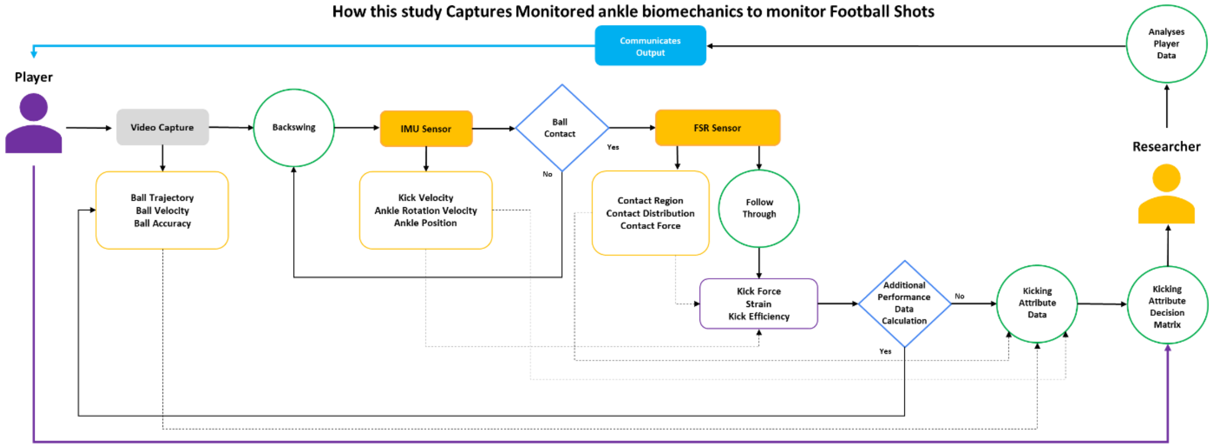


Figure 8.2.1: Flowchart of how this Study captured ankle biomechanics with IMU and FSR Sensors

WT in its authentic environment, needs to work with a feedback medium, such as the wearable display, a smartphone, PC or Tablet, with the provider's application being the source of communicating the processed data. Figure 8.2.2 displays the flowchart of how this research into ankle monitoring biomechanics for football shots, would have integrated in a "real world Wearable device." Like the previous flowchart, the Kicking attributes Decision matrix remains imperative in having the user input before the analysing of sensor data. This clarifies the Design synthesis within WT, to have this feature so the User experience felt by the footballer is sustainable. This is central to informing the player about how their body movement's affect improvement of their kicking techniques.

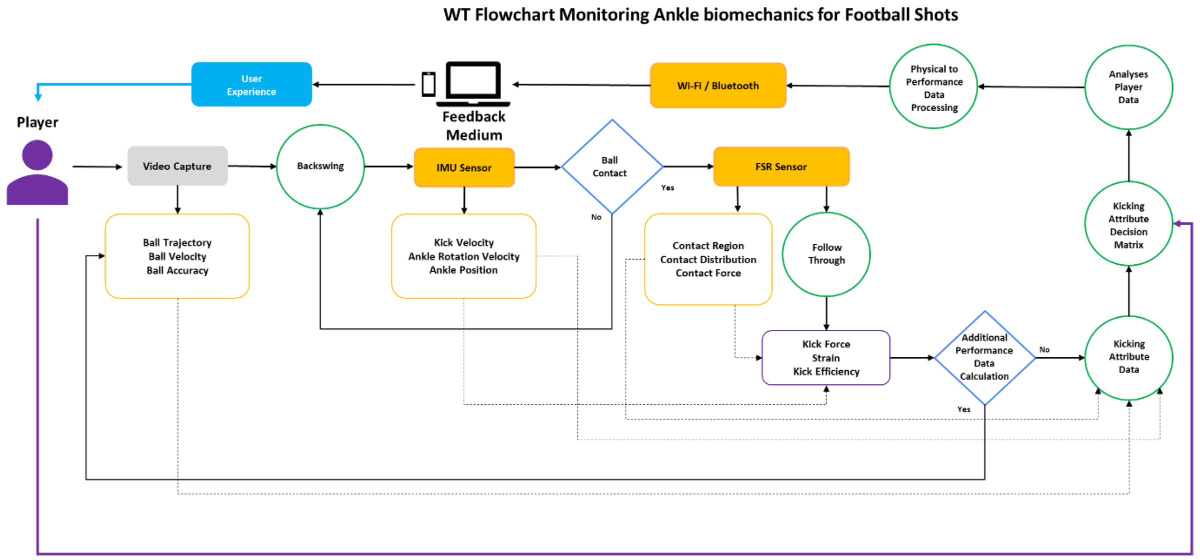


Figure 8.2.2: Flowchart of how IMU and FSR Sensors can work in a fully integrated WT system

Flowchart showing video capture using camera accessory allows observed attributes to be computed. Vernier video physics is a good example where one scale assigned in the video frame, automatically calculates tracked features with user input. First the pixel of the monitoring device needs to be defined, then an object within the camera view needs to be inputted with original size so that the rest of items can be quantified accurately. For this study, the ball was a common object to choose as the reference size, and this method can be applied for future use in this application, as all training happens with an actual size 5 ball (22mm in diameter). Goal sizes vary on the environment, and the boot or players body can be dependent camera angle view. Therefore, the ball used is the ideal measuring reference object, for any Camera integrated Football WT application.

Camera usage is supported by amateur footballers, where a great craving in viewing their style of play, makes them more aware of their movement. With early observations (Chapter 4), there were players who do not use camera accessory when training as they are more focussed on traditional methods of following existing protocols in improving their kicking. This could be influenced by continuous training from an early age, gaming, watching online videos etc, where the adaptation process of video recording is not desired.

Flowchart 8.2.3 shows how IMU and FSR sensor can be worked to monitor the quantities from this study, without a camera. The processing would be more difficult, however for both IMU and FSR can work by defining their parameters to quantify certain biomechanics. The program can achieve this by splitting the role of sensors to monitor certain segments of the movement, which are defined by the sensing of the axis for IMU, and the contact surface of FSR. Sensor tracking the split between backswing, ball contact and follow through components of football biomechanics, allows performance data to be calculated. This manufactures the desired quantities without a need of camera, where the system solely relies on the sensor “identifying” when those axial changes are occurring. This may not be as reliable in the current phase of wearables, because the programming and algorithms involved with the System on chip, must differentiate when it’s a kick, compared to other football activities within the environment. These will require extensive coding of the filters to calculate the different properties. The user will still need to input onto a potential application (smartphone/tablet) to setup the tracking to start, to help the wearable “prepare” for calculations.

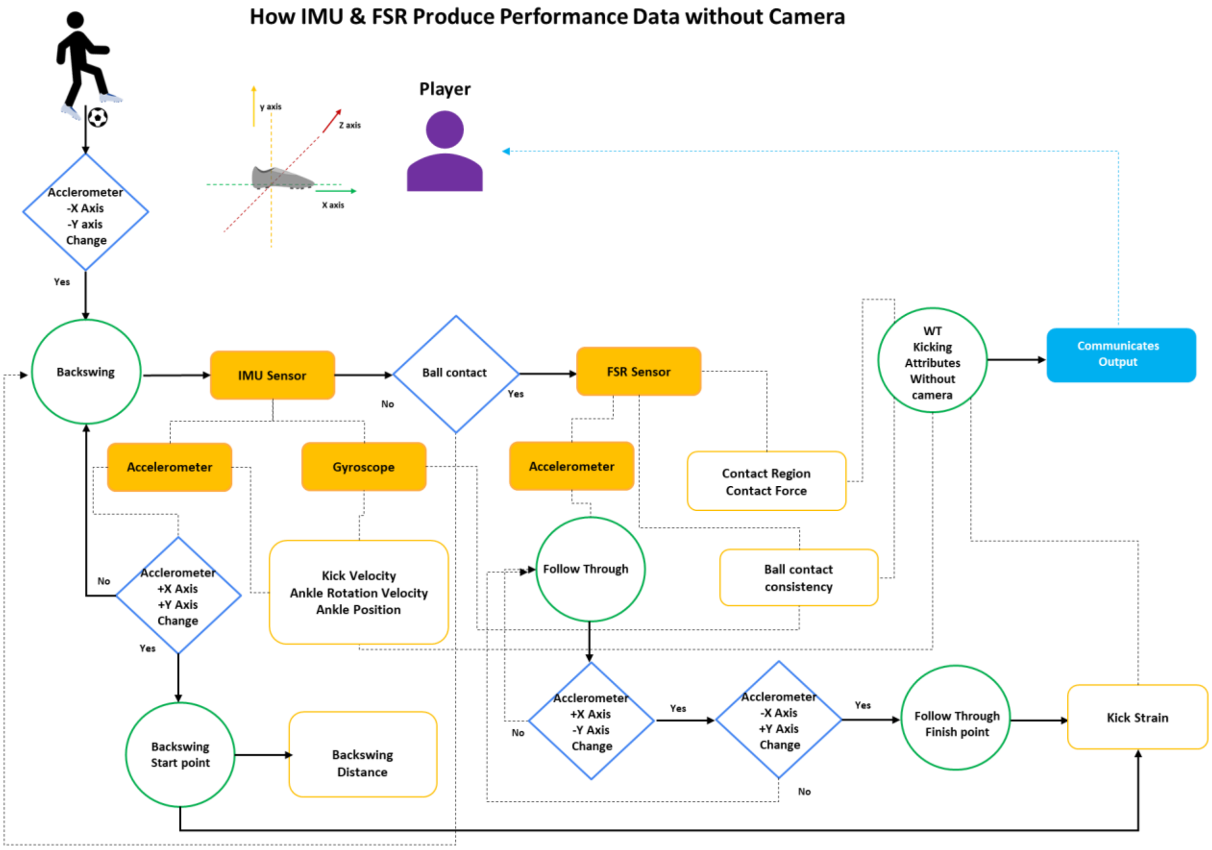


Figure 8.2.3: Flowchart of how IMU and FSR Sensors compute Performance data without a camera

8.2.2 Physical data to Performance data Framework

The aim of this research was to create a framework to display how physical monitored data can be converted into performance meaningful data using sensors. The following framework illustrates the precise components that extract relevant information about ankle, it's movement, relevancy to football kicking, how sensor placement defines the quantities it tracks, and the process of converting monitored data into meaningful data.

The frameworks intention is for it to be used as a tool, to further enhance WT influence for amateur level football. This is to promote greater analysis of footballers, to educate more about themselves. The framework lists out the methods needed and what information needs to be studied for WT to become "smarter" in specific sport application.

The full framework model Figure 8.2.4 displays how sensor placed for monitoring ankle motion, produces relevant data. This is also impacted by the choice of equipment and observed data, which all feed into physical data. This data along with the computed performance data is now fed into the decision matrix, which reiterated the input from the End user, before performance analysis. This is to demonstrate the importance of User's input in the ranking of the performance data attributes which personalises the performance analysis to build the desired player profile.

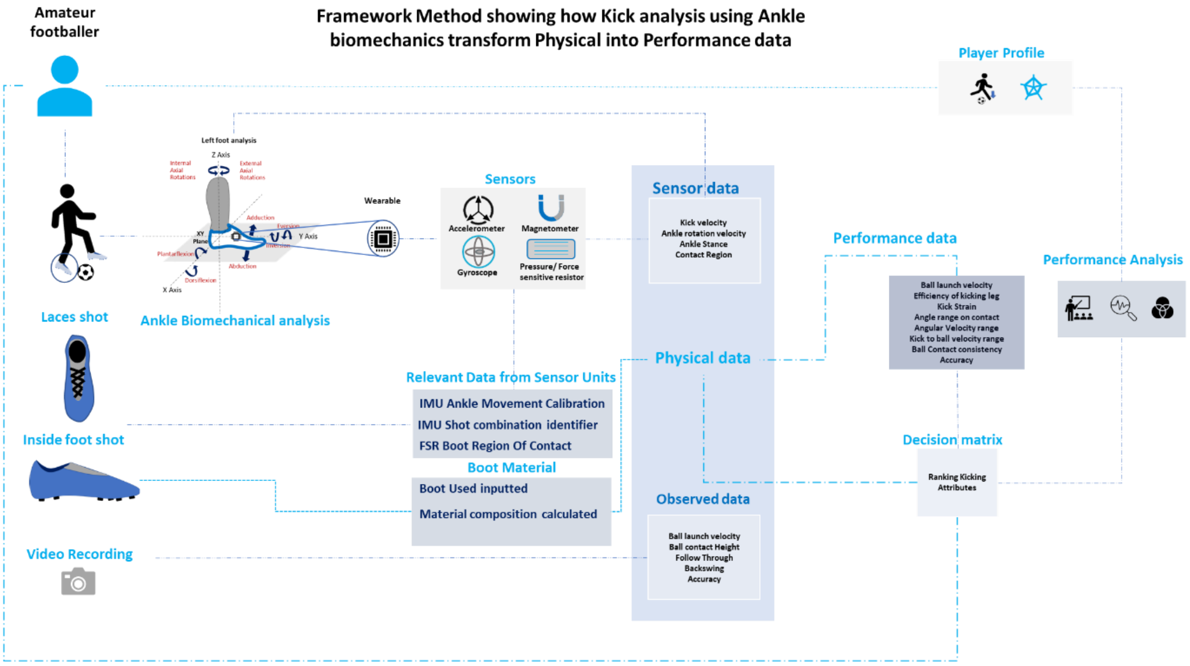
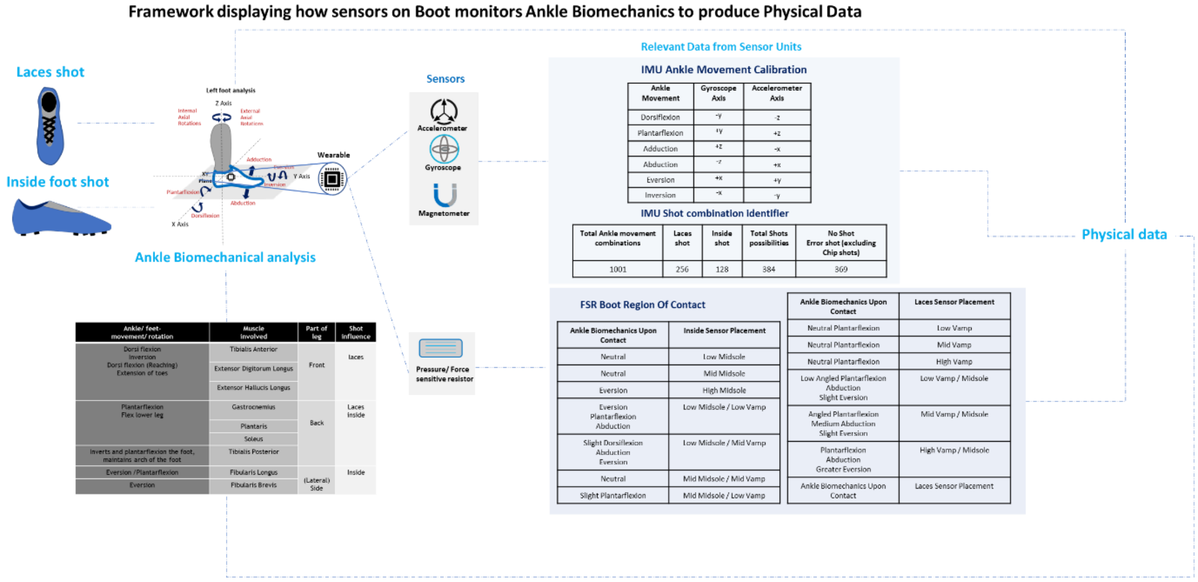


Figure 8.2.4: Full Framework Model displaying how WT tracks Ankle biomechanics for Shot monitoring

To compute physical data, WT need sensors in designated areas to quantify relevant features. For this study, the ankle motions pose the greatest significance of body movement for research. This sub-framework of Physical Data displays the Ankle movement calibration, shot identifier from IMU sensor and Boot region of contact relying on FSR sensor. This all links to the bones and muscles composing the ankle, which influence the type of kick. This section associates the laces and inside shot types, with the required muscle, which controlled sensor location. This process can be repeated for another chosen body region, where its body composition must be studied to link it to sensor parameters. It is essential that physical data is defined before any processing stages are involved in WT.



Ankle/ feet-movement/ rotation	Muscle involved	Part of leg	Shot influence
Dorsi flexion Inversion Dorsi flexion (Reaching) Extension of toes	Tibialis Anterior	Front	laces
	Extensor Digitorum Longus		
	Extensor Hallucis Longus		
Plantarflexion Flex lower leg	Gastrocnemius	Back	Laces inside
	Plantaris		
	Soleus		
Inverts and plantarflexion the foot, maintains arch of the foot	Tibialis Posterior		
Eversion /Plantarflexion	Fibularis Longus	(Lateral) Side	Inside
Eversion	Fibularis Brevis		

IMU Ankle Movement Calibration

Ankle Movement	Gyroscope Axis	Accelerometer Axis
Dorsiflexion	-y	-z
Plantarflexion	+y	+z
Adduction	+z	-x
Abduction	-z	+x
Eversion	+x	+y
Inversion	-x	-y

IMU Shot combination Identifier

Total Ankle movement combinations	Laces shot	Inside shot	Total Shots possibilities	No Shot Error shot (excluding Chip shots)
1001	256	128	384	369

FSR Boot Region Of Contact

Ankle Biomechanics Upon Contact	Inside Sensor Placement
Neutral	Low Midsole
Neutral	Mid Midsole
Eversion	High Midsole
Eversion Plantarflexion Abduction	Low Midsole / Low Vamp
Slight Dorsiflexion Abduction Eversion	Low Midsole / Mid Vamp
Neutral	Mid Midsole / Mid Vamp
Slight Plantarflexion	Mid Midsole / Low Vamp

Ankle Biomechanics Upon Contact	Laces Sensor Placement
Neutral Plantarflexion	Low Vamp
Neutral Plantarflexion	Mid Vamp
Neutral Plantarflexion	High Vamp
Low Angled Plantarflexion Abduction Slight Eversion	Low Vamp / Midsole
Angled Plantarflexion Medium Abduction Slight Eversion	Mid Vamp / Midsole
Plantarflexion Abduction Greater Eversion	High Vamp / Midsole
Ankle Biomechanics Upon Contact	Laces Sensor Placement

Figure 8.2.5: Framework displaying how Sensor tracks Ankle biomechanics for Physical Data

Good ankle rotation between backswing point and ball contact, adequate speed of kick, and not too much follow through all link to a good shot. The method of obtaining these quantities is shown on the framework below, linking to the source of tracking, and what it means to the overall framework of converting physical data. This purpose is for improvement indicators to aid the creation of performance stats. The key links between the sensor and observed data that feeds the Physical data, are worked together to create new Performance data for shot monitoring. This illustration is one of the key objectives in this study, which demonstrates how sensors can deduce relevant factors to prove the importance of ankle biomechanics for Laces and Inside foot shots.

Framework Method showing how Physical Ankle biomechanics data transform into Performance data with Camera

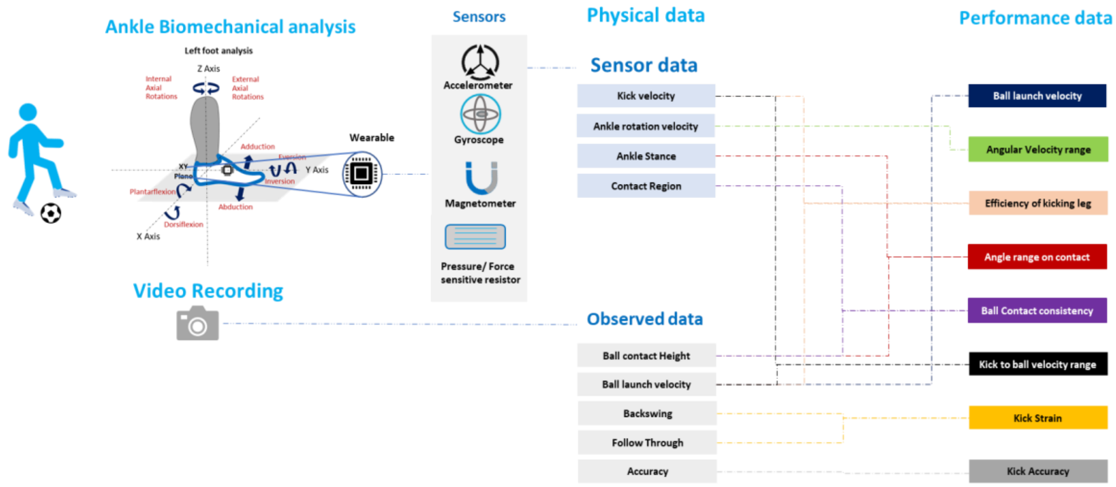


Figure 8.2.6: Framework displaying how Ankle Physical Data converts into Shooting Performance data

Summary

User experience of WT is decisive for its sustainability. Expert interviews specified that making sense of data is integral for WT, and further research justified why this is important Design process for WT application to be smart. This chapter highlights how the adaption required for amateur footballers to involve with WT can learn more about their kicking motion. The value of the survey is important to understand user behaviour and what different positional players may prioritise in terms of WT data. This adds the smart value of WT and can be something that helps further enhance sensors used in future considerations. The survey granted more opportunities to showcase how WT ankle monitoring is essential in defining shooting techniques. The results showed there is a gap for amateur footballers to realise the importance of ankle rotations, and when further discussions took place, there is now greater understanding of varied factors that were not considered before, being of importance now. Another key outcome is that there needs to be greater control from the User to manipulate what the WT can process for a personalised experience. This step means that the Decision Matrix formed in Chapter 6, could have considered some influence from the player, even though a coach was consulted in creating that ranking of attributes. To make it more meaningful, the User must grant where they are in control of the outcomes, to give them a more valuable experience from WT, to build their designated player profile, which will resonate on their performance in gameplay. The framework illustrates the necessary steps to compute the relevant performance data, which proved principal factors in monitoring ankle motion quantity, and relating it to football kicking.

9.Research review

9.1 Analysing research outcomes and the impact of wearable technology for amateur level footballers

9.1.1 Project Analysis

To analyse the research conducted thoroughly, each section is reviewed to understand how it has contributed to the overall aim and objectives of this study. Consideration must also be applied to know how the findings affect any future possible testing using the methods of this research. A NOISES evaluation tool is used to review the research, weighing in on factors that could also change if the study was repeated under different circumstances [Four Week MBA, 2022]. The letters define analysis tool structure, where the needs(N) that were required within this research, followed by the opportunities(O), what improvements(I) could be made, the strengths(S) in the findings, the exceptional(E) circumstances and summary(S).

The study that commenced from a master's dissertation gave this research key insights to build a foundation to increase the depth of monitoring through WT. This required a selection of body part to be explored, and with primary research indicating that football boots have great investment amongst the selected end users, there was a requirement to investigate the anatomies involved with this equipment. Researching what exists in relation to ankle movement to determine it as a key biomechanical component of kicking, a fundamental skill in football, gave this research the drive to examine these properties.

The literature review was indispensable in defining what is involved in WT. This gave the overall outlook to the WT system and displayed what should be more focussed for this research. The gathering of important literature aided to conducting the next stages of this research. Sensor role, and precise body definition involved in football kicking showed what was necessary to go onto the next stage of Design process. The findings resonate throughout the rest of the thesis, which show how important it was across the whole research to validate solutions.

The methodology gave the outline of how this project needed to be conducted. The research conducted over 4 years, and to follow a guide is imperative so that the findings are matching the initial outcomes of the study. As the process went through, key reiterative stage, in where user reviewed the kicking properties after survey, showed how their input validated a better framework design for this study. This showed how the Double Diamond was the best methodology for this research.

Primary research observation and expert interviews linked both the Technology and Design elements for this project. WT needs human factors input, and consulting with the relevant stakeholders gave more opportunities for this research to become impactful. In terms of contributing to knowledge, this step of the research helped guide where the study can be most relevant, and its purpose in making greater sense of the monitored data. These discussions resulted in a need to quantify subjective opinions when grading the quality of the kick. Along with literature review, the experts in industry consulting showed how there is attention for injury monitoring in WT. This is something future WT studies can investigate, and even relating to this study, when incorrect form of kicks that could be dangerous resulting in overuse injuries, can be something that can be analysed further.

Theoretical development was the most important chapter that defined the working parameters for this research. This is because the key mechanical terms, formulas and how data is derived, heightened the technicality of this study to prove how scrutinised the research must be. COR is an example of this to distinguish kick efficiency, and in the right testing condition, Reynolds number can relate to higher ball velocities, depending on its design, with drag and lift coefficients used to judge different ball projectiles. This completed the technological elements into what design could feed off, and it stimulated how the experiments that followed will be conducted to make more reliable results. This enabled greater relations to be built in the design of performance data.

Key material study and what players prioritise in boot design consideration, displayed how it can affect a player's kick. This is because the user would choose their boot depending on how much feel they want upon contact, and the design elements that affect the experience will impact their selection. Hence for pendulum test (Chapter 7), it was important to place the sensors on the outer soles, rather than inside, where socks could also be a good equipment to have sensors embedded. The material of the boot did not affect this, as sensors were placed outside, however when forming a final decision matrix that relies upon the Data Framework, there will be some factors to consider regarding boot material, where the user can input the design they're using and the material composition, which can be provided for WT to make adjustments in calculations, as prototype testing can show some differences (e.g. a boot will have higher KTB for same region of contact). The result is however that more of data output would be on the user side, which is fed by IMU and FSR data.

IMU sensor test proved how ankle rotations prior to ball contact were a performance indicator that influences shot outcomes. This also showed how players who were highly rated before any tracking was done, showed consistent degree of ankle motion of the shots taken. This was linked to their gameplay style and validated the IMU has a big role in monitoring ankle motions to confirm it being an integral part of biomechanics in kicking. WT tracking a good kicker ability, does not automatically mean a poor kicker should follow the exact form because learning about their own biomechanics and consistency can lead to greater refinement in delivering good shots for themselves.

By forming the COR calculation, Kick efficiency was created as a kicking performance statistic. This was done by analysing the kick velocity of the player, and how much the ball travelled, resulting in less effort being applied. This theoretically links to the balance of hip rotation and relaxation of the kicking phase, which shows how the calculation made via COR, links to greater biomechanical features. This implementation is very important for the future as it showed how a simple ankle motion study, can be taken forward in monitoring the new performance data in kick efficiency [I. Anderson, D. and Sidaway, 2013] [Kellis and Katis, 2007]. Kick Strain was also derived from the backswing and follow through distances, before and after ball contact, further cementing this study designing more relevant data the links to shooting, both in performance and possible injury monitoring.

The decision matrix element of ranking the attributes were influenced by consulting with a coach, which swapped the top 2 players who were the best shooters of the ball. The design of the decision matrix ranked Laces shot with a higher score weighing, to accommodate its difficulty, however when consulting with focus groups during post survey, this could have been modified by what the user thinks is important. This makes the research consider the design solutions of WT application in applying meaningful data to footballers. The outcome of this reflects on the data framework design.

With FSR pendulum setup being a small-scale version of what could have been with participants, there was still a need to demonstrate how the results can have football relevancy. An attribute ranking table was created as if they were assumptions that envisioned a player striking the ball using the pendulum results. A potential fourth circle FSR could have been placed on upper sole region to get more distribution split between higher vamp and mid sole, however the percentage of contact region helped identify where it can educate the amateur footballer more about their ball contact phase. With actual user testing, this may have provided greater impact, where an IMU sensor working alongside FSR to give the kick velocity, angular rotation prior to kick, and the angle of contact upon kick, to build a more solid tracking data of the ankle motions for shooting. This is something that was illustrated on flowchart Figure 8.2.2.

Table 7.3.A and 7.3.B showed how laces and inside shots, and subsequent ankle movement can depend on sensor placement. This would incur some axial rotations around the malleolus bones and quadrus plantae muscle. These were not considered, even though they are more influential in the trajectory angle of the ball launch. The sensors which were not placed around those regions can be implemented for a future test rig, which allow more rotation measures within this area, to advance greater sensory findings linking lower foot movement and ball contact.

The test of repeatability was very important to strongly claim that sensors should be placed in love/mid vamp and midsole contact areas of the boot. This repeated experiment highlighted even greater importance within the lower-midsole area for inside foot shots, and the use of accuracy filter helped distinguish where wrong part of the boot is contacted. The repeated experiment validates the suggestions made from the preliminary test regarding sweet spot regions of the boot.

There were instances where the ankle posture was not correct for the sensors to track. Even when good kicks were executed by the pendulum test, there were no readings, and even with sensor readings, some were not close to intended target. This shows how the IMU sensors are vital in monitoring ankle angle stance, and along with FSR to be implemented, to know the exact contact region. Circle FSR’s produced the better readings, and these are the best option to place on the midsole and vamp sections of the outer sole. The circle FSR can be distributed along them to give a better reading of precise ball contact, and IMU can show where the ankle stances have been at point of contact using the signal reading from FSR. Together these can produce smart output data together to increase the value of WT in amateur level sport, where the methods applied in this experiment can be transferred onto other biomechanical elements in terms of kicking, and more set piece environment.

Kicking techniques will impact how well a shot is taken. Isshi & Maruyama conducted a study of how the Foot angle of laces kicking affects the power and accuracy of the football. The key conclusion that was made from their test was that the “foot angle upon contact had no influence on the ball velocity/power, but only for ball rotation”. This could be interpreted as, the angle at which the ball relays onto the boot, will affect the trajectory of the ball, if the player intends to execute greater curve as the ball elevates in different heights (high or low). Inside foot shots have priority in accuracy as opposed to laces. Inside foot kicking techniques was also more used during their researched study, in both men and women, where the reasoning for that particular kick (e.g. long passes) varied between the genders. When shooting on goal, laces were more dominant. It could be more preferred due to the trade-off between accuracy and shot power, increasing the average of what the football can achieve. This is purely dependant on the player’s technique, as one player may have a greater inside foot shot power, whereby the accuracy is perceived to be greater for this type of shot, can be graded with similar success to someone who exclusively shoots laces shots.

The research conducted for this thesis, agrees with those statements, as the kicking power generally is generated from the legs and hips, however the ankle posture upon ball contact can affect the velocity of ball travelled depending on the region of contact. Although this is backed up only by IMU and FSR sensor test from this study, there is enough data to show that the ankle stance and where the ball connects with the boot (i.e. midsole/mid vamp) can alter kick to ball velocity difference (kick efficiency). Another agreement is that the contact region and ankle stance does affect the balls direction, which further shows why sensor on outer soles will generate more data and understanding of ball behaviour upon different kicking styles. Inside foot accommodates accuracy, as the survey showed how finesse options selectors all chose Inside shot as to be their shot type.

Whilst the survey was being completed, the Chapter 7 Pendulum Test was being drafted. When the discussions were taking place, the feedback given by users in how some would prioritise different aspects of how they want to kick, is what inspired the attribute table ranking for FSR data, linking it to how accuracy or power would have had the priority. Post discussing survey showed that some players may feel they can strike the ball with a hybrid of inside and laces, which will cause their ankle to be experiencing plantarflexion, abduction and eversion properties, and the ball contact being in between the midsole and upper vamp region. This is still technically the laces shot because the striking zone, is in front of the laces of the boot, hence it cannot be considered inside, even if the motion is in between them. An inside foot shot can be defined when there is greater midsole than vamp region of connection. This means that this study has defined these shot types even further by selecting which part of the boot is in most contact with the ball. In relation to data, some players said that what if they don't know which attributes they want to prioritise, just the way they want to play, which means that WT could be able to advise them on what training is required for them to become the type of player they desire. So, the design can implement flexibility in ranking the attributes, or how to rank them, for the player to have the choice to be in control of what they are learning and what WT is guiding them on. The balance between user input and WT feedback primarily lies with the user experience design of data outputs.

9.1.2 Impact of study

Figure 1.2.5 showed the journey of how monitored data aims to tackle ankle motions to compute performance related kicking data. With the research being conducted with the outcomes, the full data journey results are present in Figure 9.1.1. This specifies more relevancy to what data has been designed due to sensor monitoring around the ankle motions. A WT research project revolves around design and technology themes. To creating new football related sport data, for this case grading a successful kick, meant the method of obtaining and applying the right sensors to produce a creative yet applicable solution, must have a balance of design and technology. These are paramount to linking the user to current wearable trends. Established and made wearable phases are present in this study where the sensors used to compute new performance data are primarily for this WT application. FSR was provided by a wearable manufacturer, however their true application in football has not been materialised yet. Future phase where new sensors are manufactured for WT will be incorporated into any new studies. Even during these phases, UX still has the bigger role in making sense of the data, where the user must have a choice element of what to do with it.

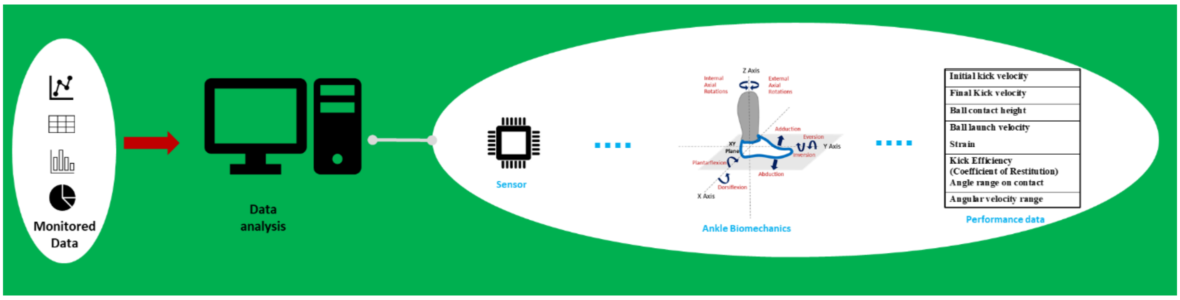


Figure 9.1.1: Full Data Journey of computing ankle biomechanics as kicking performance parameters

The intended impact of this study was to use the research findings to move forward with other biomechanical analysis and set piece scenarios. This cements the approach for this research being a tool of guiding future investigations that can generate even more performance data. Figure 9.1.2 shows an example framework that could use this method to calculate strain on quadriceps and hamstrings for shot purposes. This is something that tracks both performance and injury.

The Physical data would be different as sensors would be placed on the relevant body part, and it would work with camera recordings to feed more data to calculate performance stats. This study's impact can be seen with the way it defines the physical data quantities, so the framework that is shown on Figure 8.2.4 is followed in what to do next to get more relevant data. With such example, there still needs to be a study in the biological elements of hamstrings and quadriceps, so this would require a human factors study.

When a researcher decides to analyse a new body region, the steps needed to tackle the choice of monitored elements are displayed on Figure 9.1.3. The example shows how shoulder blade movement is tracked in relation to football shots, human factors and equipment studies are needed to identify the role of sensors used. This can then help know what physical data needs to be computed and the necessary calculations that would help build performance data. The end user will always affect the experience of the attribute ranking, which tells WT what to do with the performance data.

Long resistance sensor alongside FSR data, can help identify if incorrect motions that cause an injury, can signal abnormal biomechanics, with sensor placement on different body parts. Even within ankle motion analysis, using IMU sensors, testing can allow calibration to identify how drastic changes may have occurred, in ankle rotation velocities with minimal backswing or follow through, as an indicator that a dangerous movement of the ankle has been experienced by the player. This can be an example of how it links to identifying ankle injury and possibly different grades of sprain. The same application of injury monitoring can be transferred to different biomechanical studies within WT tracking. Long resistance sensor covering the shoulder, triceps, elbows and forearms can monitor precise follow through strains experienced by the hand, which can identify different stresses associated with kinetic linkage.

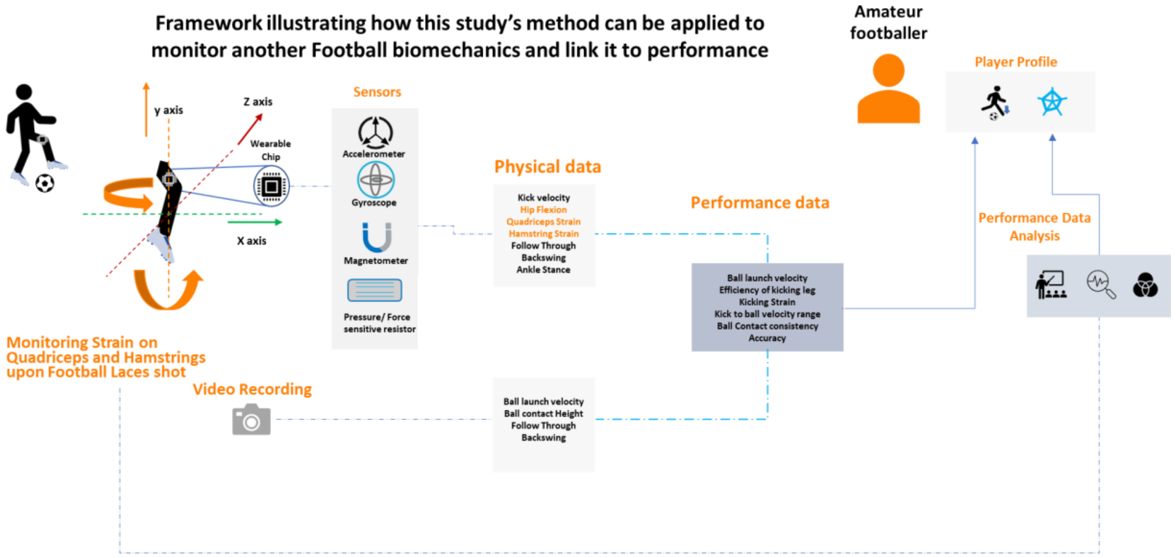


Figure 9.1.2: Framework applied for another biomechanical element with this Study's method

Self-improvement comes in the form of obtaining benchmarks of a player's current performance in certain attributes, then applying the next steps needed to improve on those aspects. This metric must be derived from physical data that's been transformed into performance data. This study relies upon penalty kick analysis to improve the player's shooting ability, and the required metrics relate to kick and ball velocities. COR has been derived as another metric in the form of showing kick efficiency, which can be transferred to different kicking types within football. The framework shown on Figure 8.2.4 can be reconstructed for additional capture and advance different levels of various football attributes. This is something that must be done via monitoring certain biomechanics, understanding the needs within sport terms and what equipment effects there are, before identifying the type of data that will form a performance metric. Figure 9.1.3 displays how these methods can be applied to track other football biomechanics and link them into performance.

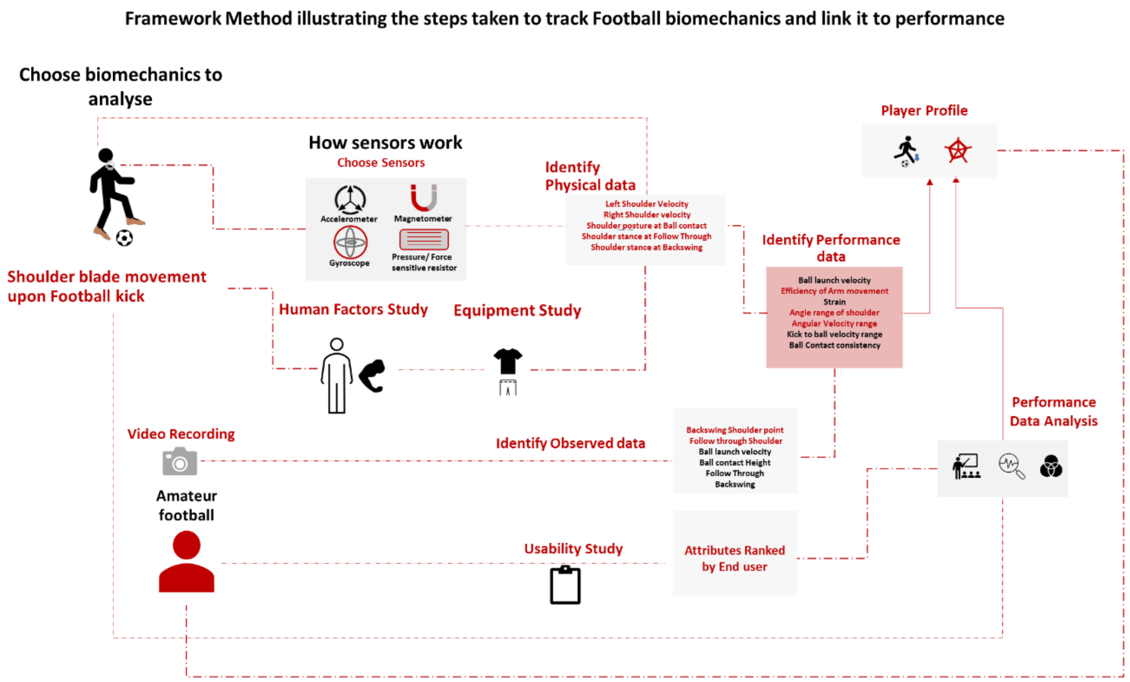


Figure 9.1.3: Framework for steps taken to Study Biomechanical Feature to apply in Performance

A full body analysis network can be created to show how sensor integration across the anatomy, computes the specific attributes of choice. WT can then build on the specific body regions so that the end user garners more data on themselves, which allows them to pick the sections that they want to improve on. WT will need to have input data of the correct form of kicking. This is because without pre-set data, WT will not have anything to rely upon to tell it what a good kick is. So, for the testing phase, there needs to be substantial data that show where it will be inputted to give more knowledge to WT, and an example of how this can be done, is shown on Figure 9.1.4.

WT can output data depending on task completion. The quantification of this can be something that's inspired from video games. The scoring method to build a benchmark could be how consistent penalty kicks have hit the target and if their Kick to ball speed has improved. This generates a learning mechanism which the player can refine to keep improving. The UX must keep the user motivated, as Personas from primary research mentioned that a game and social element, can help sustain its usage.

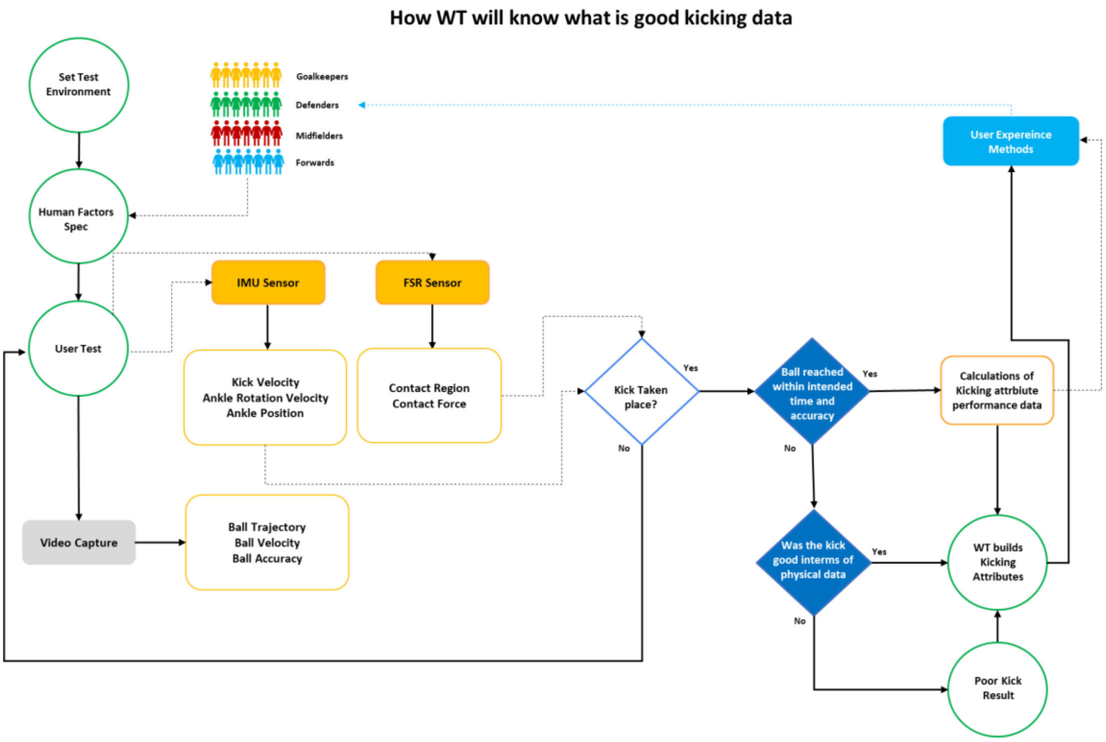


Figure 9.1.4: Flowchart of how to identify good kicking to build a data set for WT information

9.2 Conclusion of wearable technology research through penalty kick analysis and how future studies can be conducted to increase sensor applications with amateur level sport.

9.2.1 Future

Figure 9.1.2 – 9.1.3 briefly shows how the future of tracking biomechanical features with this study's method can be implemented. Future experiments can rely on the framework design and make smart modifications to implement for real world scenarios, where the end user will always be part of reiterating any design elements across the process.

The initial OpenSim test was to understand how key biomechanical features of ankle rotation affects kick speed with altering hip flexion and knee angle. Experimenting with the software built many results, and identified which muscles are worked when striking a ball. The muscles total fibre force was analysed for Hip flexion, that refined various behaviour of them during the kick phase, involving bicep femoris long head, psoas, rectus femoris and gluteus maximus muscles. This shows that for a hip flexion study, sensor placements can be made within these regions. This is something for future consideration outside of the ankle region placement, to further increase the parameters of sensor embedding for WT.

Some players (based on observation) would change boots for training and match, hence if the boot has sensors, and is used for training only, can the new behaviour of the player adjusting to a new kicking technique be transferred when they change boots. If the application of the WT is modular and is a device that can be taken off and put on the player's choice of boot, this would make it easier for them to adapt to WT whilst still choosing their choice of equipment. However, this could also contribute to error as the sensors have a chance to be misaligned and would also need to be recalibrated every time you move them to a different boot. FSR sensors can be worked around by sleeves to be placed around the regions of contact, and IMU sensor can be applied in a similar manner.

This way both sensors can be integrated onto the boot region so the player can still perform kicking in a set piece situation, whilst quantifying their body movements.

An important consideration for the future would be to place more FSR sensors on outer sole, because when the Kick to ball velocity was high, the FSR readings still managed to give higher analogue readings compared to ones where Kick to ball velocity were low, which proves why sensor placement is fundamental in WT. This shows that there could have been more sensors on the different outer sole regions to calculate better distribution of the ball contact and link it to the force that's transferred onto the ball. If a pressure mat sensor was placed throughout all outer sole regions, then there could be results that show different regions of the boot being sweet spot. However, having precise spots has its unique advantage as different parts of the foot fill the volume inside of the boot differently depending on player. This can pinpoint precise locations that are being "felt" more. The human factors research behind the boot design for a player, needs to consider different bone structures that behaves differently depending on the contacts. This could mean that future boot designs that are mass manufactured for amateur players easily, could help shape the boot with precise anthropometrics.

To build a standalone sensor integrated environment, where more sensors are placed throughout all equipment, can also track without a need of camera. With sensors now on the landing foot, the force felt upon planting, can be monitored with FSR and IR sensor to detect different distances from ball. This can link the proximity of foot plant upon striking the ball just with the use of sensors on boot and ball. This way there is an overall analysis of the kick which has sensors embedded, to give a whole representation of the shot. Having GPS on the ball can help monitor the trajectory where the IR sensor on goal will confirm it's accuracy. Even with this implementation, there may still be a need to use cameras as players will want to see their motions, as they can view themselves in "third person". This is something that has been influenced by gaming, where this view shows the clear overview of the movement considering the environment. Figure 9.2.1 – 9.2.2 display how this could work.

UX regarding how gaming could be implemented within WT feedback is also a future study. Conducting a psychological test, in how a player changes their kick properties depending on different penalty kick situations, can further help build a unique experience that motivates the user to keep investing in WT. This research will work more with the user and the precise experience which can lead to further tests, gauging how users fare in different set piece scenarios.

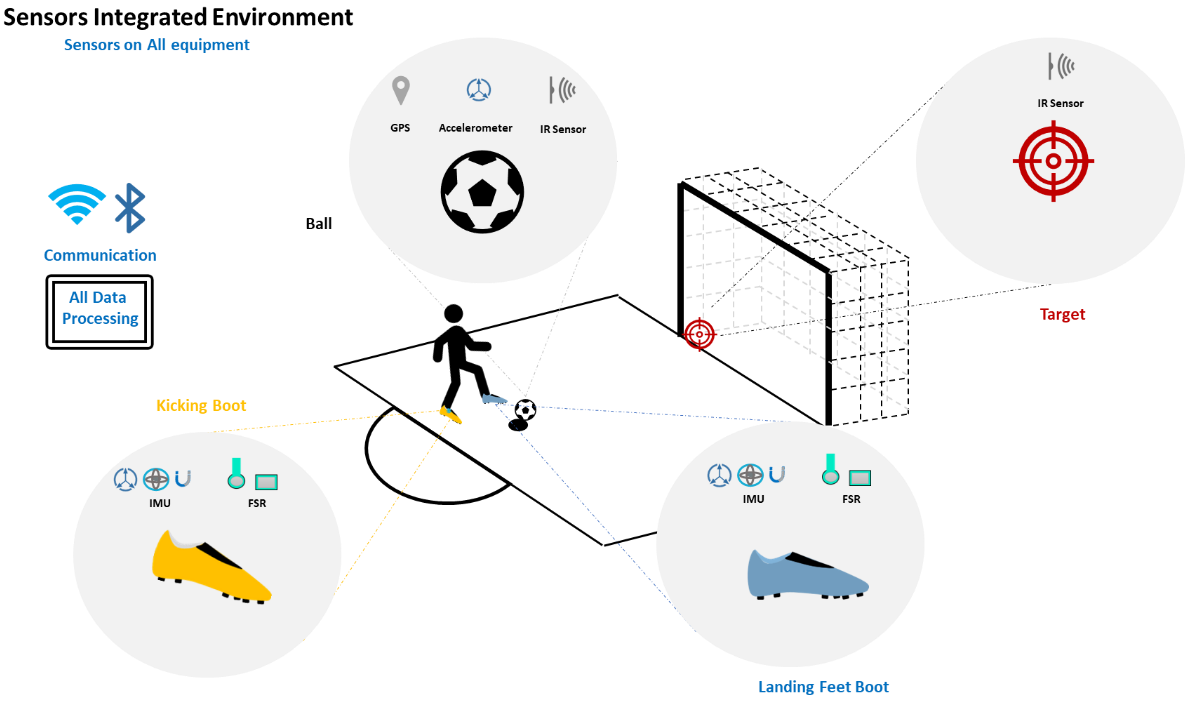


Figure 9.2.1: Full Sensor Integrated Setup for Penalty kick analysis

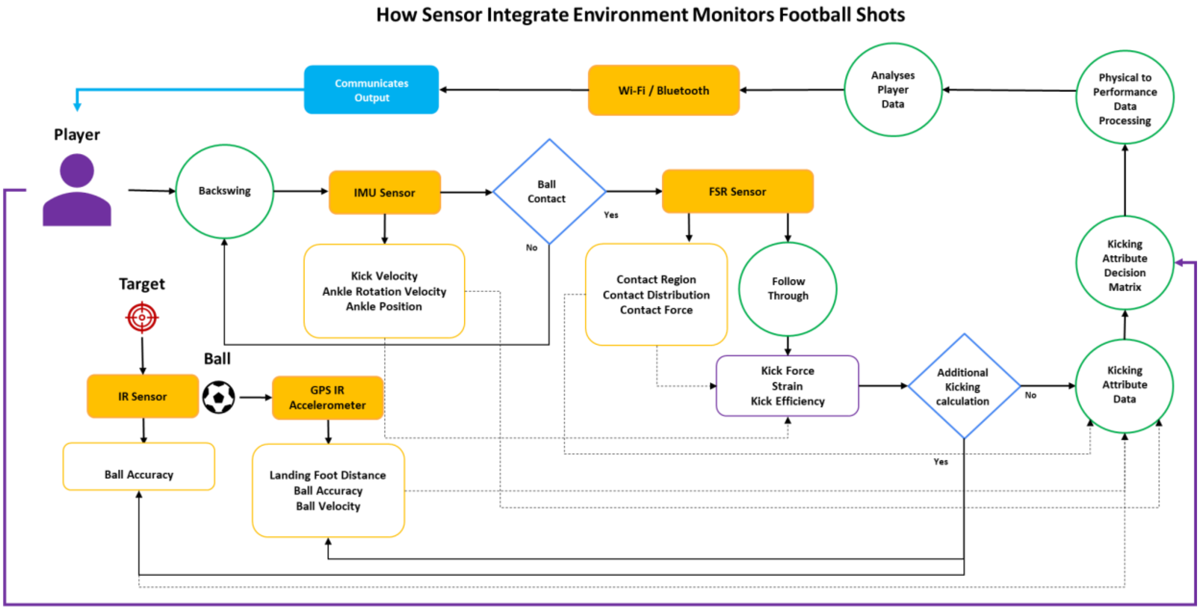


Figure 9.2.2: Full Sensor Integrated Setup Flowchart

Another future study possibility is changing the environment. This study was conducted under penalty kicking set piece condition. Figures 9.2.3 – 9.2.4 display how this model can be now applied to any dead ball situations such as corners and free kicks, and the studies that would entail from it. This exhibits evidence of the impact this study wanted to have and transfer the knowledge as a researcher, to tackle technical and design elements within football monitoring WT integration.

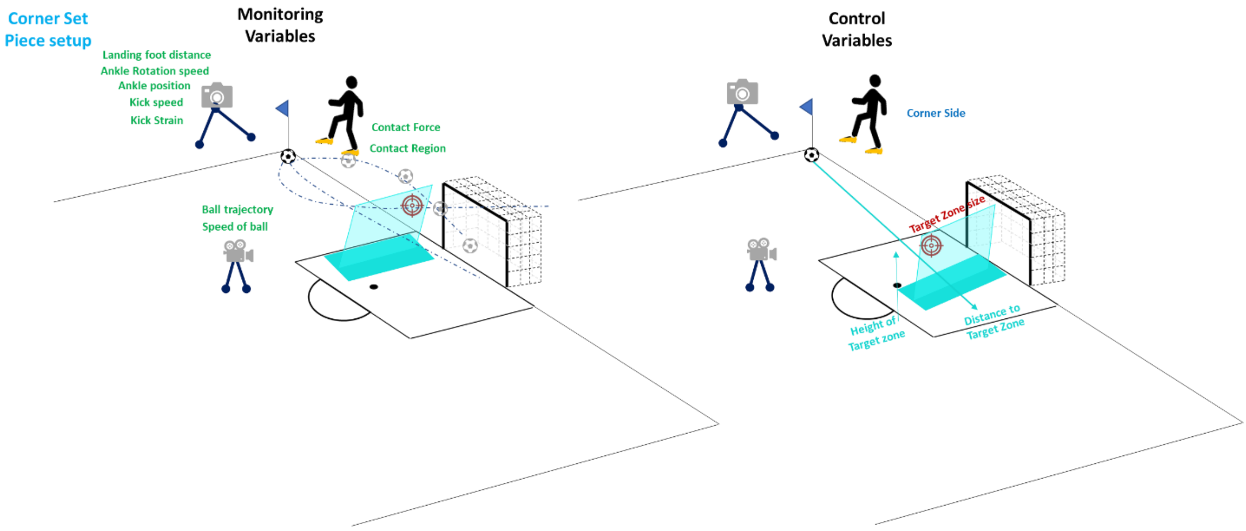


Figure 9.2.3: Future Set piece Corner Setup Monitoring and Control Variables

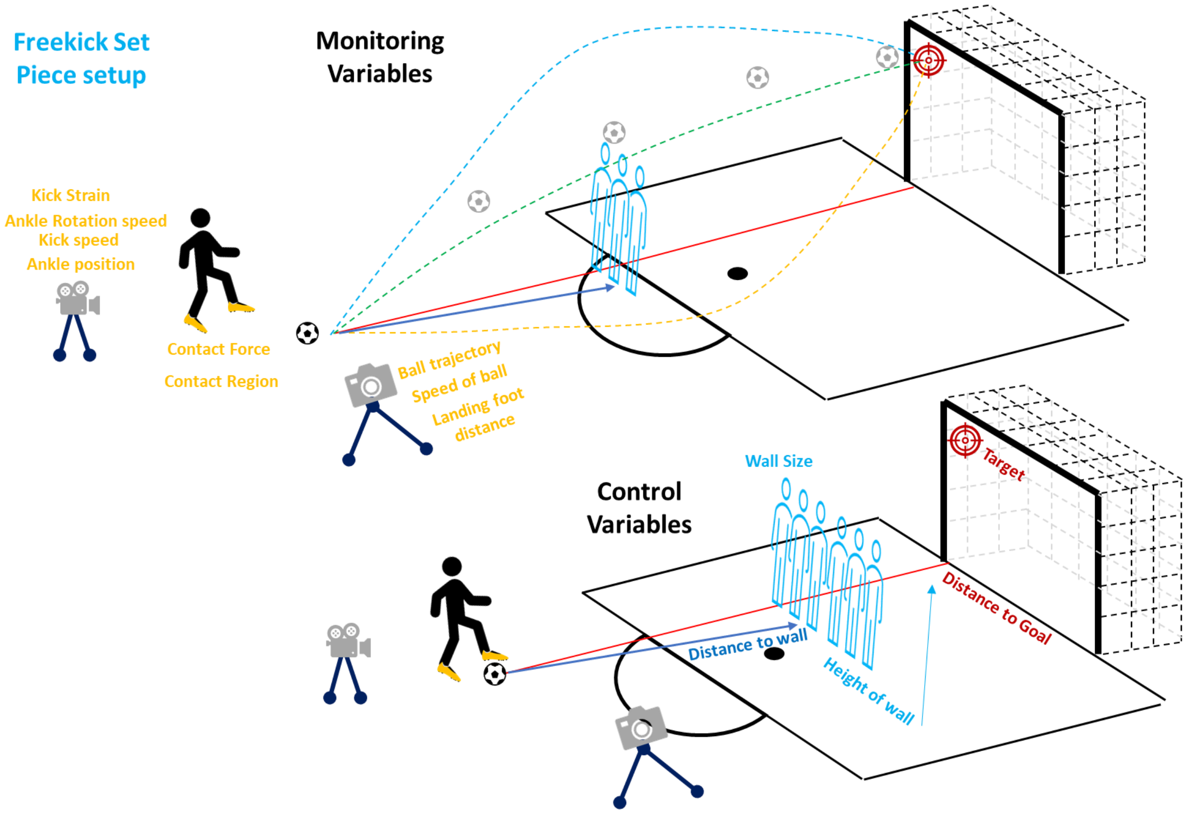


Figure 9.2.4: Future Set piece Freekick Setup Monitoring and Control Variables

The IMU sensors used in the usability study with Brunel university's football team has sensitivity ranges adequate for ankle monitoring purposes within penalty kick scenarios. This can be applied to other set pieces as shown on Figure 9.2.4. However, when ankle motion is restricted in sport, such as ice hockey, where the skate's manoeuvre in different angles but within a set range, the sensor would require knowing precise ankle mobility options for different movements. This means that before any research is set, there needs to be a control study that calibrates what the correct ankle motions could be. This is where the precision of the sensors is required to be filtered, to eliminate any errors that arise during research tests.

In the IMU experiments, gyroscope and accelerometer data is used, but not magnetometer. Magnetometers don't directly link to any motion analysis within this research, but as it helps with coordination, this could be something that's applied to the ball. With the addition of optic sensors such as infra-red, the proximity of ball accuracies on targets can be monitored. Such example of this potential setup is shown on Figure 9.2.1.

Sensors can be attached to the boot via manufacturing the conductive ink and threads within it's material. If upon user research, the end user would want to use a specific boot, then WT may not be desired to be embedded. Instead, the end user may want a detachable device around the ankle, with sensors that can track their kick attributes. Upon user observation (Table 4.2.A), players decided to change boots when training and playing competitive matches. This entails the opportunity to have something that could be worn and replaced giving user freedom of equipment choice.

The results of this work can be used to assist future software and computer game applications by adding greater parameters in their simulation. As video games design very realistic stadiums, that are set in virtual representation of a precise geographical location, they could have different ball behaviour characteristics within them, depending on their environment. Ball designs also vary, and depending on the panels, they could also behave differently inside the game environment, where the mechanics of ball characteristics will affect how the game simulates different kick scenarios. The end user who may use video games to learn more about the sport, would also learn how the ball and environment play a part in how certain kicks could deter. Game mechanics that reflect realistic behaviours provide greater immersion, which would improve the simulations to be more realistic.

Placing sensors on the ball can have even greater benefits for WT, as the flowchart on Figure 9.2.2 display this for IMU sensor. Obtaining ball characteristics from wind tunnel experiments, and inputting these onto WT database could help processing physical data of player to be more accurate and grade their kicks more fairly. Different shot types require different ankle movements on the ball (Chapter 2.2.3). There is non-linearity in transfer of momentum, hence there needs to be sensors on the ankle and ball to enable capturing this. Ankle motion before ball contact and ankle stance upon ball contact are good indicators of defining the shot type. This is important because the projections will also alter depending on where on the ball the shot is applied, hence sensors across the body and ball are vital for obtaining key data, such as understanding different postures.

The distribution of sensors across the panel design of the balls will differ based on the stitching, as circle FSR can show the regions of contact, whereas flex and long resistance sensors could also determine contact based on miniscule resistant changes. Embedding them onto the balloon and covering it with the leather panels could be used, however testing would require multiple trials to determine how to calibrate these sensors. Experimenting with optic fibre yarns within ball surfaces can also increase the smart element of understanding ball behaviour upon different kick techniques [Textile-blog., 2022]. The same application can also be used for boot material to monitor different changes of feet movement at a small scale and increase precision of biomechanical tracking. It can grant more data to be formed into performance metrics, with the aid of using robotic rigs, that applies greater control measures.

An electronic rig would also help improve the test setup where distributing the sensors across the boot, grants greater opportunities to modify ankle biomechanics upon these kicks using motors that can manoeuvre within the backswing phase before ball contact. This would allow tests to focus on specific areas of interest, where more control parameters can be applied, to improve any future WT designs considerations. An electronic rig would also decrease many human errors and will need diagnostic settings applied, to reduce potential systematic errors. An electronic rig could also consistently kick with the same force, and monitor different ball movements over much more repetition, which will increase the reliability of WT in knowing what kick a player has executed well.

The cumulative data through scientific tests for WT applications has huge potential within artificial intelligence [Singh,2022][Bocas, 2022]. This can be used in learning the data processing that researchers apply within methods of transforming physical into performance data. Artificial intelligence could quickly develop WT, as a lot of the automation can increase the levels of understanding of biomechanical tracking, quick and efficiently. To increase a footballer's technique, artificial intelligence could also influence the progression overload of what the next stage could be for an amateur level footballer to become semi-pro and professional. This also benefits coaches who want to train higher level players. Identifying self-improvement levels of a player can automate and process physical data into meaningful performance data. This would require precision tracking of training data to be formed at different playing levels. The progression can then be used as historical data to further enhance this technology and aid any wearable manufacturers in embedding the sensors with precise body coverage.

Providing greater inside knowledge to WT, will increase the precision and reliability of users learning multiple kicking techniques. This requires greater research being done on the UX, where input data would be more varied, and end user feedback can relay to artificial intelligence on data priorities. Artificial intelligence could also help advance embedding sensor technologies within the equipment, where more inside data feeds into how experiments are setup within a sport environment for biomechanical data monitoring. These testing advances can help boot manufactures in designing equipment fit for purpose. Robot games can also learn how realistic biomechanical movements affects ball trajectory, which can use statistics-based models to determine how well it kicks. The more data artificial intelligence can learn and apply, the faster the growth of WT can be for multiple industries.

For different sport considerations, the same methodological approach in research can be used as it links the biomechanics to the sensor placement and user input. Certain sport has greater physical data influence, hence WT for this kind will be easier to test from and deduce performance parameters. Framework design showing what raw physical data can be dissected to compute football performance data based on boot and ankle position on contact and the steps taken – can easily be applied to a different sport looking to monitor kicks.

Sound can also be a new way of monitoring how well sweet spot regions are connected. This idea is allowing a new sense test which could link to ball trajectory and kick efficiency. This can also be used to view if the motion has been executed correctly, forming new data in linking sound to energy transfer as a way of judging how well the ball has been struck. Microphone to pick up ball contact sounds of different connections from boot can output various signal waves that determines striking zones around the chosen ball. Monitoring the temperature of the ball upon different striking can also use the sense of feel, linking how this energy that's dissipated from the kick onto ball, can be monitored. This could be an important analysis to lead increasing sensor applications within the set environment for sport which provide even more data WT to work around.

Double diamond methodology allows a continuous process of research into more biomechanical movements in football as well as other sports. As this research ends, and how future studies are very much possible with the same structure, a redesign of the double diamond methodology is created, to display infinite process methods using reiterative design principles that tackles WT application in sport. Figure 9.2.5 shows how the continuous development of sensor tracking in football, which can be considered for any sport, and applied to any biomechanical study in design.

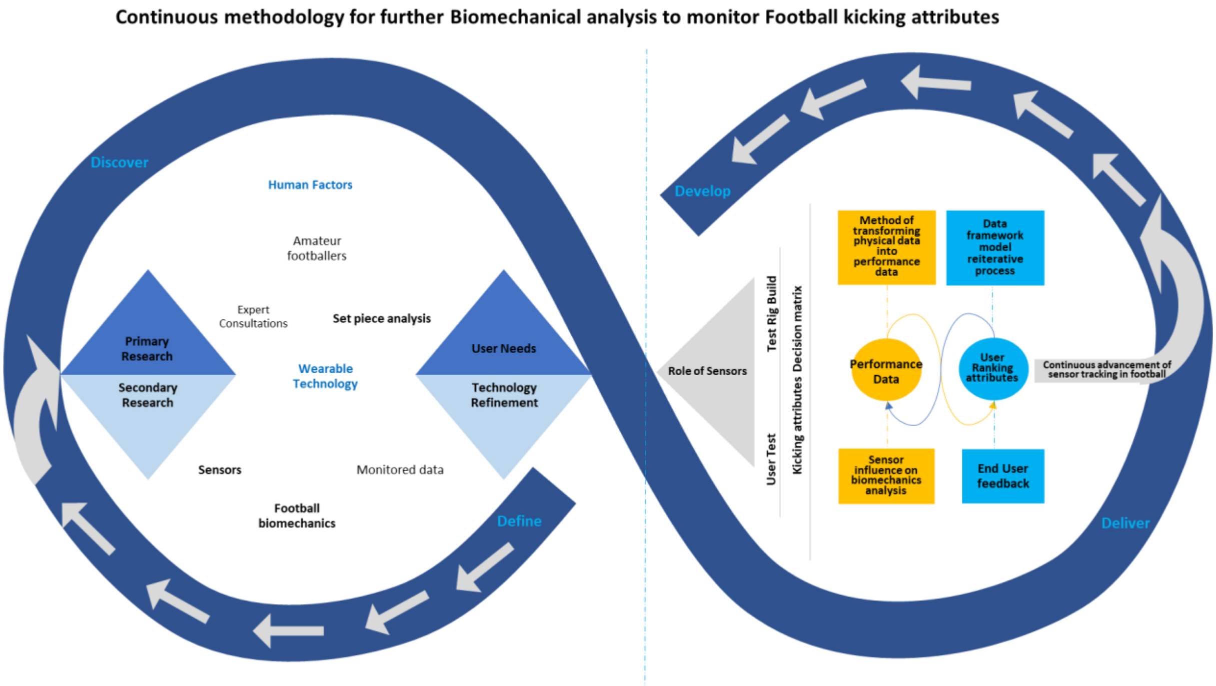


Figure 9.2.5: Methodology design for continuous development of Sensor tracking Football attributes

9.2.2 Contribution to Knowledge

Research limitations due to the global COVID-19 pandemic meant a full study involving both sensors being worked together on the user, could not be tested. If more time was allowed then perhaps another usability study would have shown the true impact of both sensors within UX, and possible build of a robotic pendulum powered by a motor to reduce variance and increase control parameters for specific ankle motion analysis within penalty shots. This would have ideally allowed the whole system to work within the flowchart diagrams that were created from Figure 8.2.1-8.2.6. The Survey and User discussion justified the flowchart design, and future study processes ar (Bocas, 2022)e listed from Figure 9.1.2 – 9.2.4.

An important question WT will have to answer is what factors a good kick can be defined by. This study examines the ankle and boot region, so within this projected WT application, good ankle stance upon kick, efficiency of kick, less strain in relation to backswing and follow through, ball contact consistency and ball accuracy, all influence what a good shot it. The mentioned qualities are not a singular biomechanical feature. This shows that when grading a good kick, even when sensors are primarily monitoring ankle motions, the significance of its results prove other elements of body biomechanics are also performing well. The primary example from this is Kick efficiency relating to good hip rotation and flexion, with strain linking to knee extension, 2 different biomechanics, where this study's tracked experiments, also showed results relating to these quantities. WT study looking into ankle movement in football shots has created new performance data, with a greater overall influence in further defining the existing biomechanics, validating the research methods to be taken forward for future experiments. Systematically computing and designing of new data, by analysing mechanical features such as COR, shows that more statistics can be derived with monitoring greater body parts to increase the user experience value of WT.

This thesis used IMU and FSR sensors monitoring ankle motions upon football kicking that created new kicking attributes from mechanical quantities. These impact the user experience of amateur footballers who get the opportunity to analyse further about themselves through WT integration. One of the key contributors to knowledge linking ankle movement and placement of sensors on the boot can influence other studies to in monitoring biomechanical elements of football using WT. With user participants, their biological data, such as leg length, feet size, weight and feet width can all help increase the depths of finding which biological element effects the quality of football shots. Different attributes can also be tested, where such as long and short passing with the same methodology.

There are 6 biomechanical known features of kicking, this research has shown outcomes that prove how ankle motions in between backswing and ball contact phase is equally important relating to how well laces or inside foot shots are struck. Framework diagrams 8.2.4 – 8.2.6 display the process needed for raw physical data consisting of sensor and observed data, to create new performance data. These were the key contribution to knowledge, however during the research, another key find was the way subjective opinion being quantified with user inputting what is relevant to them (Figure 8.1.20), showed how the design sector of this study proved it also influenced the outcomes. This created the attribute ranking decision matrix, which will give scores to grade kicks based on how important it was for the user. In conclusion, with the overall research conducted through its limitations, still produced findings that contribute to design and technology, and how vital it is for the advancement of WT in amateur level sport.

A NOISES analysis reviews the outcome of the thesis, giving a rational view of this research [Four Week MBA, 2022]. Outlining what the initial needs were, how the opportunity arose, what went well, what could be done better, the exceptional circumstances that impacted the study during the 4 years of research, and summary of the outcomes. Thesis review table 9.2.2 of the study confirms that the aims, objective, and contribution to knowledge are obtained through this research.

Needs

There was a need to implement WT in Amateur level football. Amateur footballers want to learn more about themselves, and want a quantification of their abilities

Opportunities

Ankle biomechanics are not prioritised enough, even when they're a significant part of how well a shot has been taken. This Study gave an opportunity for amateur footballers, to learn more about the importance of Ankle motion upon Laces/Inside shots.

Improvements

Greater use of sensors and placement around the lower feet could have identified more contact regions. Different boots and balls can be tested for building a bigger data set. Wireless testing can also be done to compare if there are any data latencies compared to wired.

Strengths

This study has shown enough Evidence to support how important Ankle motions influence Inside and Laces shot. New performance data have been formed whilst conducting this biomechanical study, and Amateur footballers have learnt even more about the factors that link to a good shot

Exceptions

COVID 19 pandemic made it harder to do further usability testing with the IMU and FSR sensors integrated.

The data is strong enough to support the study Aim and Objectives

Summary

WT implemented in this study has allowed the conversion of monitored physical ankle biomechanics data, and through usability refinement, personalised meaningful performance data, with influencing the Decision Matrix attribute scoring.
This is exhibited on the Data Framework model

Figure 9.2.6: NOISES Analysis of Thesis

Aim	Objectives	Contribution to knowledge
Create a **framework** that displays how Physical **Ankle movement** data converts into **Meaningful Performance Data** using **wearable sensors**, illustrating the importance of **ankle biomechanics** upon **Penalty kick ball striking,** for amateur level footballers	Conduct Biomechanical research analysis during a football kicking phase	There are 6 key biomechanics involved in football kicking (Section 2.4.1), can this study add another fundamental biomechanical feature; **Ankle motions prior to ball contact**; through the use of Wearable sensors
	Locate where wearable sensors can be relevant to provide Laces and Inside foot shot monitoring	
	Identify the role of IMU and FSR sensors that provides ankle movement data to form performance data	
	Define how User conditions the Decision Matrix Attribute Ranking that alters the perception of Quantified Performance Data depending on their priority	To illustrate the steps taken in how **raw biomechanical sensor data** produces **sport specific performance data**
	Design a Framework, that's shows the method of capturing raw biomechanical physical data and the steps needed to convert it into performance data	
✓	✓	✓

Table 9.2.A: Thesis Review Table

10. Appendix

10.1 Bibliography

10.1.1 References

Adafruit. (2021). *Adafruit Learning System*. Retrieved April 24, 2021, from <https://learn.adafruit.com/force-sensitive-resistor-fsr>

Adafruit. (2021). *Adafruit Learning System - Force Sensetive Resistor*. Retrieved Apr 24, 2021, from <https://learn.adafruit.com/force-sensitive-resistor-fsr>

Adidas. (2022). *Adidas*. Retrieved 12 12, 2022, from https://www.adidas.co.uk/

Adidas. (2022). *Adidas*. Retrieved Dec 12, 2022, from https://www.adidas.co.uk/

An, B.; Shin, J.; Kim, S.; Kim, J.; Ji, S.; Park, J.; Lee, Y.; Jang, J.; Park, Y.; Cho, E.; et al. . (2017). Smart Sensr systems for wearable electronic devices. *Polymers, 9*(303).

Anatomy-zone. (2012). *Inversion of the Foot - Musculoskeletal*. Retrieved Oct 12, 2019, from http://anatomyzone.com/anatomy-feed/inversion-foot/

Ansys. (2022). *Engineering Simultion Software*. Retrieved Nov 15, 2022, from https://www.ansys.com/en-gb

Anuva. (2018). *A resource guide to wearable device sensors*. Retrieved Oct 12, 2018, from https://anuva.com/blog/a-resource-guide-to-wearable-device-sensors/

Arduino. (2022). *Arduino - Home*. Retrieved Dec 15, 2022, from https://www.arduino.cc/

Arduino-docs. (2022). *Arduino Docuementation* . Retrieved Dec 10, 2022, from https://docs.arduino.cc/

Aris, T. &. (2013). The influence of football boot construction on ball velocity and deformation. *IOP Conference Series: Materials Science and Engineering, 50*(10.1088). Retrieved 2018

Armstrong. (2019). *Blooms taxonomy*. Retrieved May 25, 2019, from https://cft.vanderbilt.edu/guides-sub-pages/blooms-taxonomy/

Aroganam G, Manivannan N, Harrison D, Garaj V. (2021). Building subjective opinion on amateur football player 1 step kicks by analysing ankle biomechanics. *Annals Sports Medecine , 8*(1174).

Asai, T. &. (2016). Flow visualisation of downhill skiers using the lattice Boltzmann method. *European Journal of Physics., 38* (024002).

Aughey, R. F. (2010). Real-time versus post-game GPS data in team sports. *J. Sci. Med. Sport, 13*(1), 348-349.

Badoe, William & Opoku-Asare, Nana Afia & Ansah, Ross. (2014). A Multiple Colour Bobbin Winder: An Enhanced Accessory for Transforming Indigenous On-Loom Weaving. 21. . *IISTE, 21*(1).

Baptiste, Darbois, Texier. (2016). Physics of knuckle ball. *New J. Physics., 18*(073027).

Beecham-Research. (2018). *Wearable Technology Application Chart: Beecham Research.* . Retrieved October 24 , 2018, from http://www.beechamresearch.com/article.aspx?id=20

Blessing L., a. C. (2009). Comparison with Other Methodologies, DRM, Design Research Methodology. *Springer Verlag London Limited, Section 2.7*, 39.

Bousfield. (2015). *Football Kick Biomechanics*. Retrieved Mar 16, 2019, from https://footballkickbiomechanics.wordpress.com/

Broadbent, D. (2017). Performance Analysis in Football . London: Department of Life Sciences, Brunel University London, Sport Psychology.

Brockett, C. a. (2016). Biomechanics of the ankle. . *Orthopaedics and Trauma, 30*(3), 232-238.

Brunner, T.; Lauffenburger, J.; Changey, S.; Basset, M. . (2015). Magnetometer-augmented IMU simulator: In-depth elaboration. *Sensors , 15*, 5293–5310.

Business-Wire. (2019). *Global Industrial Wearable Devices Market - Increasing Demand for IoT to Drive Growth*. Retrieved May 14, 2019, from https://www.businesswire.com/news/home/20180209005498/en/Global-Industrial-Wearable-Devices-Market---Increasing

Castaneda, D.; Ghamari, M.; Esparza, A.; Soltanpur, C.; Nazeran, H. (2018). A review on wearable photoplethysmography sensors and their potential future applications in health care. *Int. J. Biosens. Bioelectron., 4*(195).

Catapult. (2018). Immersive Technologies in Manufacturing . London: Catapult .

CDG. (2019). *Circular Design Guide*. Retrieved May 24 , 2019, from https://www.ellenmacarthurfoundation.org/assets/design/User_Centred_Reseach%20Guide_FINAL.pdf

Charmant, J. (2022, 11 08). *Kinovea*. Retrieved from Kinovea: https://www.kinovea.org/

Chu VW, Fong DT, Chan YY, Yung PS, Fung KY, Chan KM. (2022). Differentiation of ankle sprain motion and common sport. Hong Kong: The Chinese University of Hong Kong,.

Cleveland-Clinic. (2021). *Achilles tendon: Function, anatomy and common conditions* . Retrieved May 24, 2021, from https://my.clevelandclinic.org/health/body/21927-achilles-tendon

Conductive-transfers. (2019). *conductive-transfers*. Retrieved Apr 14, 2019, from https://www.conductivetransfers.com/

Creasey, S. (2018). *Wearable Technology Will Up The Game For Sports Data Analytics*. Retrieved October 20, 2018, from https://www.computerweekly.com/feature/Wearable-technology-will-up-the-game-for-sports-data-analytics

Davis, F. D., Bagozzi, R. P., & Warshaw, P. R. (1989). User acceptance of computer technology: a comparison of two theoretical models. . *Management science, , 35*(8), 982-1003.

De Arriba-Pérez, F.; Caeiro-Rodríguez, M.; Santos-Gago, J.M. . (2016). Collection and processing of data from wrist wearable devices in heterogeneous and multiple-user scenarios. *Sensors , 16*(1538).

Decathlon.co.uk. (2021). *Rip-Tab Football Boots Agility 140 TF*. Retrieved Jul 8, 2021, from https://www.decathlon.co.uk/p/rip-tab-football-boots-agility-140-tf/_/R-p-309496

Deros, B.M. & Mahamad Ali, Mohd Firdaus & Ismail, Ahmad Rasdan. (2012). Bio-mechanics analysis of instep kicking among Malaysian football players. *SEANES, 1-5*.

Design-Council. (2018.). *What Is The Framework For Innovation? Design Council's Evolved Double Diamond.* Retrieved Jun 8, 2019, from https://www.designcouncil.org.uk/news-opinion/what-framework-innovation-design-councils-evolved-double-diamond

Design-Council. (2005). *The Design Process: What is the Double Diamond?* Retrieved Jun 7, 2019, from https://www.designcouncil.org.uk/news-opinion/design-process-what-double-diamond

Design-methodologies. (2012). *Design methodologies* . Retrieved Aug 25, 2019, from http://www.nwlink.com/~donclark/design/design_models.html

Dimension-Engineering. (2018). *A Beginner’s Guide to Accelerometers.* . Retrieved November 15 , 2018, from https://www.dimensionengineering.com/info/accelerometers

Drew, M.K.; Purdam, C. . (2016). Time to bin the term ‘overuse’ injury: Is ‘training load error’ a more accurate term? *Br. J. Sports Med. , 50*, 1423–1424.

EA-Frostbite. (2022). *The most adopted platform for game development - EA - frostbite.* Retrieved Oct 25, 2022, from https://www.ea.com/frostbite

Early-Game. (2021). *FIFA Ratings Explained: How Is The Overall Rating Created?* Retrieved Oct 21, 2021, from https://earlygame.com/fifa/fifa-ratings-explained-overall-rating

EA-Sports. (2022). *EA Sports publisher of FIFA, Madden NFL, NHL, UFC, PGA Tour, and F1.* . Retrieved Dec 16, 2022, from https://www.ea.com/sports

Ebling, M. R. (2016). IoT: From sports to fashion and everything in-between. *IEEE Pervasive Comput. , 15*(2–4).

Edvocate. (2019). *What You Need to Know as an Educator: Understanding the 4 Main Branches of Philosophy* . Retrieved Aug 2, 2019, from https://www.theedadvocate.org/need-know-education-understanding-4-main-branches-philosophy/

El-Amrawy, F.; Nounou, M.I. . (2015). Are Currently Available Wearable Devices for Activity Tracking and Heart Rate Monitoring Accurate, Precise, and Medically Beneficial? . *Healthc. Inform. Res., 21*, 315–320.

Elisa-Vaselli. (2015). *What are the optimal biomechanics of a soccer in-step kick?* Retrieved Feb 28 , 2019, from http://biomechanicsforinstepkickinsoccerblog.blogspot.co.uk/

Endeavour-Partners. (2014, Jul 2). *Inside Wearables—Part 2.* Retrieved Oct 6, 2018, from https://digitalwellbeing.org/wp-content/uploads/2015/11/2014-Inside-Wearables-Part-2-July-2014.pdf

Epson-Device. (2017). *Gyro sensors, How they work and what's ahead*. Retrieved Oct 4, 2018, from http://www5.epsondevice.com/en/information/technical_info/gyro/

Esposito, E. (2018). *4 types of research methods all designers should know | Inside Design Blog.* Retrieved May 24 , 2019, from https://www.invisionapp.com/inside-design/research-methods-designers/

Ferguson, A. (2018). *How Accurate Are Wearables?* . Retrieved Feb 28, 2019, from https://www.athleticbusiness.com/equipment/how-accurate-are-wearables.html

Ferraro, V. (2015). Smart Textiles and Wearable Technologies for Sportswear: A Design Approach. Basel, Switzerland: MPDI Sensors and Applications.

Ferraz, Ricardo & Tillaar, Roland & Marques, Mário. . (2012). The Effect of Fatigue on Kicking Velocity in Soccer Players. . *Journal of human kinetics, 35*, 97-107.

Fitbit. (2018). *Fitbit. Our Technology. Available online: (accessed on).* Retrieved Oct 20 , 2018, from https://www.fitbit.com/uk/technology

Fitzpatrick, John & Linsley, Andy & Musham, Craig. (2019). Running the curve: a preliminary investigation into curved sprinting during football match-play.

Forrest, F. and Syrenis. (2022). *Wearables: Managing complexities in data privacy and consent in Healthcare Tech, Pharmaceutical Technology*. Retrieved Nov 5, 2022, from https://www.pharmaceutical-technology.com/sponsored/wearables-managing-complexities-data-privacy-conse

Fritz, T.; Huang, E.M.; Murphy, G.C.; Zimmermann, T. (2014). Persuasive Technology in the Real World: A Study of Long-Term Use of Activity Sensing Devices for Fitness. Toronto, ON, Can: SIGCHI Conference on Human Factors in Computing Systems.

Gobinath. (2017). Wearable Technology: Studying how wearables that monitor body movements, can increase performance, and reduce frequency of injuries for amateur level football players. . London: Brunel University, Design MSc Dissertation.

Gobinath A ; Nadarajah M and David H. (2019). Review on Wearable Technology Sensors used in Consumer Sport Applications. . Basel: Sensors MDPI.

Gómez-Espinosa, A., Espinosa-Castillo, N. and Valdés-Aguirre, B. . (2018). Foot-Mounted Inertial Measurement Units-Based Device for Ankle Rehabilitation. *Applied Sciences, 8*(11), 2032.

Grand-ViewResearch. (2016). *Wearable Medical Device Market Growth, Research, Size And Forecasts*. Retrieved Nov 12, 2018, from https://grandviewresearchinc.blogspot.com/2016/02/wearable-medical-device-market-growth.html

Grandviewresearch. (2018). *Wearable sensors market size, share & trend analysis report 2018-2025*. Retrieved Oct 24, 2018, from https://www.grandviewresearch.com/industry-analysis/global-wearable-sensor-market

Group, N. N. (2019). *Iterative Design of User Interfaces.* . Retrieved May 26, 2019, from https://www.nngroup.com/articles/iterative-design/

Hatton, L. (2019). *Industry Analysis: Wearable Technology.* Retrieved Jan 12, 2019, from https://www.csus.edu/indiv/h/hattonl/documents/WearableIndustry.docx

Hildeman, A. (2018). *Classification of Epileptic Seizuresusing Accelerometers*. Retrieved Nov 5, 2018, from http://publications.lib.chalmers.se/records/fulltext/145997.pdf

Hinch, W. (2017). *8 Technology Trends Driving the Sports Industry*. Retrieved Oct 1, 2018, from https://blog.pitchero.com/8-technology-trends-driving-the-sports-industry

Hong & Asai. (2014, Feb 19). *Effect of panel shape of soccer ball on its flight characteristics.* Retrieved May 10, 2020, from https://www.nature.com/articles/srep05068.pdf

Hong Sungchan, Takeshi Asai,. (2017). Aerodynamic effects of dimples on soccer ball surfaces. *Heliyon, 3*(10).

Hong, Sungchan & Asai, Takeshi & Seo, Kazuya. . (2015). Visualization of air flow around soccer ball using a particle image velocimetry. *Scientific Reports. , 5*(10).

HP1T. (2019). *HP1 Technologies | Impact Sensor Systems*. Retrieved Apr 14, 2019, from https://www.hp1t.com/

Hulin, B.T., Gabbett, T.J., Lawson, D.W., Caputi, P. & Sampson, J.A. (2016). The acute: Chronic workload ratio predicts injury: High chronic workload may decrease injury risk in elite rugby league players. *British journal of sports medicine, 50*(4), 231-236.

Human-Body. (2020). *Human Body Part Weights*. Retrieved May 1, 2021, from http://robslink.com/SAS/democd79/body_part_weights.htm

Hussein, Al & Abbas Fadhil, Rashad. (2019). VIDEO QUALITATIVE ANALYSIS OF SOCCER PLACE-KICK.

I Anderson, D. and Sidaway, B. . (2013). *Kicking biomechanics: Importance of balance | Lower Extremity Review Magazine.* Retrieved Mar 7, 2019, from https://lermagazine.com/article/kicking-biomechanics-importance-of-balance

Iactive-Design. (2018). *Class Workshop - The Design Methodology.* Retrieved Jun 14, 2019, from http://khairunysarts.blogspot.com/2015/03/class-workshop-about-design-methodology.html

IDTech. (2018). *Wearable Sensors 2018–2028: Technologies, Markets & Players*. Retrieved Oct 24, 2018, from https://www.idtechex.com/research/reports/wearable-sensors-2018-2028-technologies-markets-and-players-000555.asp

Inclusivedesigntoolkit. (2019). *What is inclusive design?* Retrieved Apr 14, 2019, from http://www.inclusivedesigntoolkit.com/whatis/whatis.html

Institute., F. (2018). *What's the Difference Between AR, VR, and MR?* Retrieved Dec 6, 2018, from https://www.fi.edu/difference-between-ar-vr-and-mr

Ismail, Ahmad Rasdan & Mansor, Mohd Radzi Abu & Mahamad Ali, Mohd Firdaus & Jaafar, Sharipah & Johar, M.S.N. (2010). Biomechanics Analysis for Right Leg Instep Kick. *Journal of Applied Sciences. , 10*.

James, D.A.; Petrone, N. . (2016). Sensors and Wearable Technologies in Sport: Technologies, Trends and Approaches for Implementation. *Springer: Berlin/Heidelberg*(9789811009914.), 1–49.

Jens-Bangsbo. (2014). PHYSIOLOGICAL DEMANDS OF FOOTBALL. *Sports Science Exchange, 27*(125), 1-6.

Jovanov, E.; Milenkovic, A.; Otto, C.; De Groen, P.C. . (2005). A wireless body area network of intelligent motion sensors for computer assisted physical rehabilitation. *J. Neuroeng. Rehabil., 2*(6).

Kalantari, M. (2017). Consumers' adoption of wearable technologies: Literature review, synthesis, and future research agenda. *Int. J. Technol. Mark., 12*, 274–307.

Kamisalic, A.; Fister, I.; Turkanovic, M.; Karakatic, S. (2018). Sensors and Functionalities of Non-Invasive Wrist-Wearable Devices: A Review. . *Sensors , 18*(1714).

Karim. (2014). Wearable Technology KARIM Foresight Report. Brussels: European Union.

Katis & Kellis. (2007). Biomechanical characteristics and determinants of instep soccer kick. *JSSM, 6*, 154-165. Retrieved Feb 24, 2019, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3786235/pdf/jssm-06-154.pdf

Konami. (2022). *Efootball PES 2020 KONAMI DIGITAL ENTERTAINMENT B.V*. Retrieved Dec 10, 2022, from https://www.konami.com/games/eu/en/products/pes2020/

Kuruganti, T. (2014). Low-cost Wireless Sensors for Building Monitoring Applications. Washington, DC, USA, : Oak Ridge National Laboratory, U.S. Department of Energy.

Lakna-Pedia. (2017). *Difference Between Dorsiflexion and Plantar Flexion | Definition, Type of Motion, Example.* Retrieved Oct 4, 2018, from https://pediaa.com/difference-between-dorsiflexion-and-plantar-flexion/#Dorsiflexion

Lee, J.; Kim, D.; Ryoo, H.; Shin, B. . (2016). Sustainable wearables: Wearable technology for enhancing the quality of human life. . *Sustainability , 8*(466).

Lees. (2020). *Lift/Drag Ratio, Forces Interaction and Use.* Retrieved May 19, 2020, from https://skybrary.aero/tutorials/liftdrag-ratio-forces-interaction-and-use/

Lees, A. , Asai, T. , Andersen, T. B. , Nunome, H. and Sterzing. (2010). The biomechanics of kicking in soccer: A review . *Journal of Sports Sciences, 28*(8), 805-817.

LIVESTRONG. (2020). *The Muscles & Body Parts Needed To Kick A Football* . Retrieved May 5, 2020, from https://www.livestrong.com/article/354537-the-muscles-body-parts-needed-to-kick-a-football/

Lou, C.; Wang, S.; Liang, T.; Pang, C.; Huang, L.; Run, M.; Liu, X. . (2017). A Graphene-Based Flexible Pressure Sensor with Applications to Plantar Pressure Measurement and Gait Analysis. *Materials , 10*(1068).

Lumen. (2020). *Muscles Of The Lower Leg And Foot | Human Anatomy And Physiology Lab* . Retrieved May 8, 2020, from https://courses.lumenlearning.com/ap1x94x1/chapter/muscles-of-the-lower-leg-and-foot/

Madehow. (2021). *How soccer ball is made - material, making, history, used, industry, machine.* . Retrieved Nov 9, 2021, from http://www.madehow.com/Volume-5/Soccer-Ball.html

Marco L Calderon. (2010). The Design Research Methodology As A Framework For The Development Of A Tool For Engineering Design Education. Technical University Of Catalonia: Department Of Engineering Projects.

Maxim-Integrated. (2019). *Wearable Weight Loss—Slim Down Wellness Devices with Better Energy Efficiency.* Retrieved Jan 10, 2019, from https://www.maximintegrated.com/en/app-notes/index.mvp/id/5949

McNulty, N. (2019). *Bloom’s Digital Taxonomy* . Retrieved May 25, 2019, from https://www.niallmcnulty.com/2017/11/blooms-digital-taxonomy/

Medline. (2020). *Leg Skeletal Anatomy: Medlineplus Medical Encyclopedia Image.* Retrieved Jun 6, 2020, from <https://medlineplus.gov/ency/imagepages/8844.htm>

Merholz, P. (2013). *The Double Diamond Model of Product Definition and Execution*. Retrieved May 24, 2019, from https://www.slideshare.net/peterme/doublediamond-stage

Microsoft. (2022). *Experience the power of Windows 11 OS, Computers & Apps, Windows*. Retrieved 11 28, 2022, from https://www.microsoft.com/en-gb/windows?r=1

Moschini, A. and Neal Smith. (2012). EFFECT OF SHOE MASS ON SOCCER KICKING VELOCITY.

Murakami, H.; Kawakami, R.; Nakae, S.; Nakata, Y.; Ishikawa-Takata, K.; Tanaka, S.; Miyachi, M. . (2016). Accuracy of Wearable Devices for Estimating Total Energy Expenditure: Comparison with Metabolic Chamber and Doubly Labeled Water Method. *JAMA Intern. Med. , 176*, 702-703.

MySmart-Bottle. (2019). *My Smart Bottle Site*. Retrieved Mar 31, 2019, from https://www.mysmartbottle.com/

Nagano, H.; Begg, R. (2018). Shoe-Insole Technology for Injury Prevention in Walking. *Sensors , 18*(1468).

NAITO, Kiyoshi & Hong, Sungchan & KOIDO, Masaaki & NAKAYAMA, Masao & SAKAMOTO, Keiko & Asai, Takeshi. (2018). Effect of seam characteristics on critical Reynolds number in footballs. . *Mechanical Engineering Journal., 5*(1), 17.

NASA. (2012). *Drag on a Soccer Ball*. Retrieved Jun 10, 2021, from <https://www.grc.nasa.gov/WWW/K-12/airplane/socdrag.html>

National-Archives. (2012). *Provisional Monthly HES Topic of Interest: A&E Sports Injury Attendances.* Retrieved Oct 5, 2018, from http://content.digital.nhs.uk/catalogue/PUB06857/prov-mont-hes-admi-outp-ae-apr-feb-12-toi-rep.pdf

NetWorld-sport. (2022). *Football pitch sizes for 5, 7, 9 & 11-a-side*. Retrieved Dec 17, 2022, from https://www.networldsports.co.uk/buyers-guides/football-pitch-size-guide

Newlearningonline. (2019). *Pedagogy | Learning by Design | New Learning*. Retrieved Jul 4, 2019, from http://newlearningonline.com/learning-by-design/pedagogy

Nhs.uk. (2017). *Sports injuries - Conditions:* . Retrieved Oct 1, 2018, from http://www.nhs.uk/Conditions/Sports-injuries/Pages/Symptoms.aspx

Nike. (2022). *Nike*. Retrieved Dec 4, 2022, from https://www.nike.com/gb/

NSMI. (2017). *Football Injuries | Sports Medicine Information :* . Retrieved Oct 3, 2018, from http://www.nsmi.org.uk/articles/football-injuries.html

NTU. (2019). *The research process National Taiwan University of Sport* . Retrieved May 24, 2019, from http://sportpsy.camel.ntupes.edu.tw/ezcatfiles/t012/img/img/171/theresearchprocesses.pdf

Nunome, H., Asai, T., Ikegami, Y., & Sakurai, S. . (2002). Three-dimensional kinetic analysis of sidefoot and instep soccer kicks. . *Medicine and Science in Sports and Exercise, 34*(12), 2028-2036.

O'Reilly, N. (2019). *Sport Injury Classification*. Retrieved Mar 3, 2019, from https://www.physio-pedia.com/Sport_Injury_Classification

Ovrebekk, T. (2020). *The Importance of Average Power Consumption to Battery Life. Available online:*. Retrieved Jan 4, 2020, from https://blog.nordicsemi.com/getconnected/the-importance-of-average-power-consumption-to-battery-life

Papi, E.; Koh, W.S.; McGregor, A.H. . (2017). Wearable technology for spine movement assessment: A systematic review. . *J. Biomech., 64*, 186–197.

Passaro, V.; Cuccovillo, A.; Vaiani, L.; De Carlo, M.; Campanella, C. (2017). Gyroscope Technology and Applications: A Review in the Industrial Perspective. . *Sensors , 17*, 2284.

Patel, S., Park, H., Bonato, P., Chan, L., & Rodgers, M. (2012). A review of wearable sensors and systems with application in rehabilitation. . *J. Neuroeng. Rehabil., 9*(21), 21.

PDHPE. (2021). *Objective And Subjective Performance Measures.* Retrieved Dec 22, 2021, from <https://www.pdhpe.net/factors-affecting-performance/how-does-the-acquisition-of-skill-affect-performance/assessment-of-skill-and-performance/objective-and-subjective-performance-measures/#:~:text=In%20contrast%20subjective%20performance%20measures,than%2

Pete B Shull , Jirattigalachote W, Hunt MA, Cutkosky MR, Delp SL. (2014). Gait & posture: Quantified self and human movement: A review on the clinical impact of wearable sensing and feedback for gait analysis and intervention. *Gait Posture, 40*(1), 11.

Physics HKU. (2016). *Revealing the Magic in Everyday Life* . Retrieved May 15, 2020, from https://www.physics.hku.hk/~phys0607/lectures/chap05.html#:~:text=The%20coefficient%20of%20restitution%20would,by%2020%25%20after%2

Physics Of Soccer . (2020). *Real World Physics Problems.* Retrieved Apr 6, 2020, from https://www.real-world-physics-problems.com/physics-of-soccer.html

Physics-Tutor . (2016). *Electricity - detailed contents*. Retrieved Jun 8, 2020, from https://www.a-levelphysicstutor.com/m-momimp-coeffrest.php

Physioworks.com.au. (2017). *Football - Soccer Injuries* . Retrieved Sep 28, 2018, from http://physioworks.com.au/Injuries-Conditions/Activities/soccer-injuries

Pires, V.M.R.C. (2017). Impact of Internet of Everything Technologies in Sports—Football. Lisboa: Ph.D. Thesis, Nova Informational Management School.

Pueo, Basilio. (2016). High speed cameras for motion analysis in sports science. *Journal of Human Sport and Exercise, 11*(10), 53-73.

Reyes, J.de L. . (2016). *Four easy exercises to improve your kick, Kombat Arts Training Academy*. Retrieved May 7, 2020, from https://kombatarts.com/four-easy-exercises-improve-kick/#:~:text=Strengthening%20the%20calves%20is%20a,or%20other%20attack%20very%20swiftly.

Robslink.com. (2021). *Human Body Part Weights*. Retrieved Dec 12, 2021, from http://robslink.com/SAS/democd79/body_part_weights.htm

Sakamoto, Keiko & Numazu, Naoki & Hong, Sungchan & Asai, Takeshi. . (2016). Kinetic Analysis of Instep and Side-foot Kick in Female and Male Soccer Players. . *Procedia Engineering., 147*, 214-219.

Salazar, A.J.; Silva, A.S.; Borges, C.M.; Correia, M.V. (2010). An initial experience in wearable monitoring sport systems. Corfu, Greece, 3–5 Nove: IEEE International Conference on Information Technology and Applications in Biomedicine,.

Science ABC. (2021). *Why People At The Edge Of A Merry Go Round Fly Off At Greater Speeds Than The Ones Inside?* Retrieved Apr 15, 2021, from https://www.scienceabc.com/nature/universe/what-is-tangential-velocity.html

Science Buddies. (2019). *Comparing the Engineering Design Process and the Scientific Method*. Retrieved May 26, 2019, from https://www.sciencebuddies.org/science-fair-projects/engineering-design-process/engineering-design-compare-scientific-method

Sciencing. (2017). *Types of Gyroscopes*. Retrieved Nov 30, 2018, from https://sciencing.com/types-gyroscopes-7329313.html

Sherman, W.R.; Craig, A.B. (2003). Understanding Virtual Reality:.

Shin, G.; Jarrahi, M.H.; Fei, Y.; Karami, A.; Gafinowitz, N.; Byun, A.; Lu, X. . (2016). Wearable Activity Trackers, Accuracy, Adoption, Acceptance and Health Impact:. *J. Biomed. Inform. , 93*(103153).

shodhganga, S. P. (2010). *Design simulation and fabrication of micromachined acceleration sensor*. Retrieved Nov 18, 2018, from http://shodhganga.inflibnet.ac.in/bitstream/10603/2272/8/08_chapter%202.pdf

Soccerballworld.com. (2019). *Soccer Ball Design*. Retrieved Nov 18, 2021, from https://soccerballworld.com/soccer-ball-construction-and-design/

Solidworks. (2022). *Dassault Systems, 3D CAD Design Software Solidworks.* Retrieved Dec 15, 2022, from https://www.solidworks.com/

SportsRec. (2019). *Types of Kicking in Soccer*. Retrieved Nov 22, 2019, from https://www.sportsrec.com/7772870/types-of-kicking-in-soccer

St.com. (2017). *LSM6DSL iNEMO inertial module: always-on 3D accelerometer and 3D gyroscope*. Retrieved Mar 5, 2020, from https://www.st.com/resource/en/datasheet/lsm6dsl.pdf

Statista-plot. (2018). *Wearable-Technologies. The Most Successful Wearables for Consumers.* . Retrieved Oct 28, 2018, from https://www.wearable-technologies.com/2016/01/the-most-successful-wearables-for-consumers/

Stealth-Optional. (2021). *FIFA vs PES sales: Which football sim game has sold the most units?* . Retrieved May 5, 2021, from https://stealthoptional.com/feature/retro/fifa-vs-pes-sales-which-football-sim-game-has-sold-the-most-units/

Sterzing, T., Müller, C., Wächtler, T., & Milani, T. L. (2011). Shoe influence on actual and perceived ball handling performance in soccer. *Footwear Science, 3*(2), 97-105.

Suphan Nasira, Yigit Yurdera, . (2015). Consumers’ and Physicians’ Perceptions about High Tech Wearable Health Products. *Procedia - Social and Behavioral Sciences, 195*, 1261-1267.

Taha, Zahari & Aris, Mohd & Hassan, Mohd Hasnun Arif. . (2013). The influence of football boot construction on ball velocity and deformation. Pahang, Malaysia: IOP Conference Series: Materials Science and Engineering.

TE Connectivity. (2018). *Accelerometer Types*. Retrieved Nov 18, 2018, from https://www.te.com/usa-en/industries/sensor-solutions/insights/types-of-accelerometers.html

Tekscan. (2021). *How Does a Force Sensing Resistor (FSR) Work?* Retrieved Nov 10, 2021, from https://www.tekscan.com/blog/flexiforce/how-does-force-sensing-resistor-fsr-work

Thompson, K. and WooCommerce, B. . (2019). *Positivism and Interpretivism in Social Research*. Retrieved May 24, 2019, from https://revisesociology.com/2015/05/18/positivism-interpretivism-sociology/

Torbjørn Soligard, Grethe Myklebust, Kathrin Steffen, Ingar Holme, Holly Silvers, Mario Bizzini, Astrid Junge, Jiri Dvorak, Roald Bahr, Thor Einar Andersen,. (2008). Comprehensive warm-up programme to prevent injuries in young female footballers: cluster randomised controlled trial. *BMJ, 377*, 2469.

Tuplin S, Passmore M, Rogers D, Harland AR, Lucas T, Holmes C. . (2012). The application of simulation to the understanding of football flight. . *Journal of Sports Engineering and Technology., 226*(2).

Vandrico. (2018). *Wearable Technology Database*. Retrieved Dec 6, 2018, from https://vandrico.com/wearables/

VariantMarketResearch. (2019). *Global Wearable Technology Market | Size & Share | Industry Analysis & Growth | Forecast & Global Scenario*. Retrieved Apr 14, 2019, from https://www.variantmarketresearch.com/report-categories/consumer-electronics/wearable-technology-market

VCU. (2019). *Virginia Commonwealth University, Course Notes, The Foot and Ankle*. Retrieved Mar 24, 2019, from https://courses.vcu.edu/DANC291-003/unit_8.htm

Vectors. (2020). *Lower Leg Bone Anatomy Vector Image On Vectorstock.* Retrieved Oct 22, 2020, from https://www.vectorstock.com/royalty-free-vector/lower-leg-bone-anatomy-vector-19255914

Verle, M. (2009). *What Are Microcontrollers and What Are They Used for? In Architecture and Programming of 8051 MCUs*. Retrieved Nov 1, 2018, from https://learn.mikroe.com/ebooks/8051programming/chapter/what-are-microcontrollers-and-what-are-they-used-for/

Vernier. (2019). *Video Physics*. Retrieved Dec 12, 2019, from https://www.vernier.com/products/software/video-physics/

Villiers, Rikus Ruben de, and Jacobus Paulus Fouché. (2015). Philosophical paradigms and other underpinnings of the qualitative and quantitative research methods. *Journal of Social Sciences, 43*(2), 125-142.

Wearable-Technologies. (2018). *The Most Successful Wearables for Consumers.* Retrieved Oct 28, 2018, from https://www.wearable-technologies.com/2016/01/the-most-successful-wearables-for-consumers/

Web-MD. (2019). *Ankle Sprain: Symptoms, Classification, and Treatment of Sprained Ankles.* Retrieved Jan 21, 2019, from https://www.webmd.com/fitness-exercise/what-is-an-ankle-sprain#2

Wiewiorski, Martin & Wurm, Markus & Barg, Alexej & Valderrabano, Victor. (2017). Football/Soccer. *Foot and Ankle Sports Orthopaedics-Springer*, 459-464.

Witgrip.org. (2018). *Home.* Retrieved Apr 14, 2019, from http://www.witgrip.org/

Writer, A.S. (2022). *How to increase kicking power - easy ways to improve, MMA Channel*. Retrieved Nov 10, 2022, from https://mmachannel.com/how-to-increase-kicking-power-easy-ways-to-improve/

Xie, J.; Wen, D.; Liang, L.; Jia, Y.; Gao, L.; Lei, J. . (2018). Evaluating the Validity of Current Mainstream Wearable Devices in Fitness Tracking Under Various Physical Activities. *JMIR Mhealth Uhealth, 6*(94).

Yard EE, Schroeder MJ, Fields SK, Collins CL, Comstock RD. . (2008). The epidemiology of United States high school soccer injuries. *Am J Sports Med., 36*(10).

Zepp. (2018). *Sensors to Take Your Game to the Next Level*. Retrieved Oct 24, 2018, from https://www.zepp.com/en-us/#

Zhou, B.; Koerger, H.; Wirth, M.; Zwick, C.; Martindale, C.; Cruz, H.; Eskofier, B.; Lukowicz, P. (2016). Smart soccer shoe: Monitoring foot-ball interaction with shoe integrated textile pressure sensor matrix. Heidelberg, Germany: ACM International Symposium.

Zhou, Bo & Koerger, Harald & Wirth, Markus & Zwick, Constantin & Martindale, Christine & Cruz, Heber & Eskofier, Bjoern & Lukowicz, Paul. (2016). Smart soccer shoe: monitoring foot-ball interaction with shoe integrated textile pressure sensor matrix. *64.* Kaiserslautern, Germany: ACM International Symposium on Wearable Computers.

Zinergy-power.com. (2019). *Provider of revolutionary flexible printed batteries.* Retrieved Nov 20, 2019, from https://www.zinergy-power.com/

10.1 Miscellaneous

10.2.1 Documents

Section 5

The following images display All the Solidworks FEA simulation results for the boot designs. These are split by the position, the stress application and direction on boot and the material (SBR / PVC). Each figure has a title that represents the specific boot used and result.

GK Outersole PVC Default stress

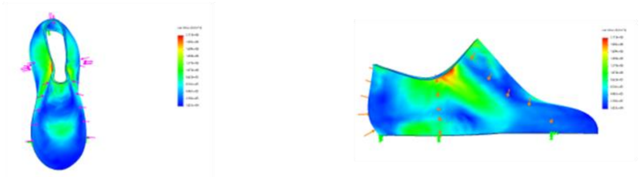


Figure 10.5.1

GK Outersole Vertical force stress

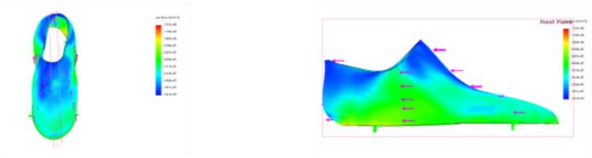


Figure 10.5.2

GK Outersole Vertical foward force stress

Figure 10.5.3

GK Outersole Inside force stress

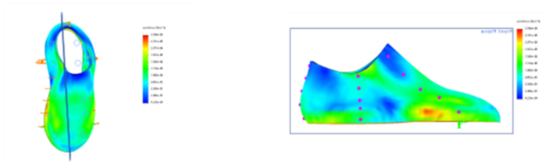


Figure 10.5.4

GK Outersole SBR stress

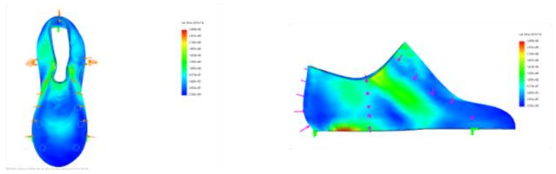


Figure 10.5.5

GK Outersole Vertical SBR force stress

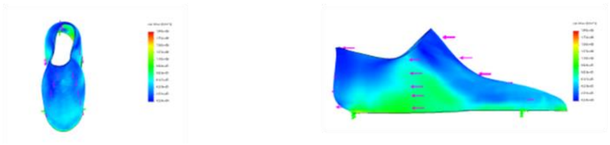


Figure 10.5.6

GK Outersole SBR Vertical foward force stress

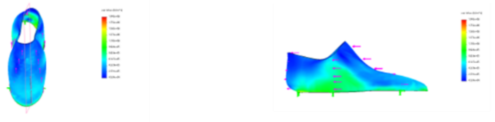


Figure 10.5.7

GK Outersole SBR Inside force stress

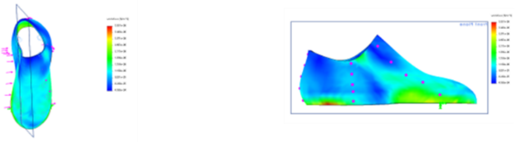


Figure 10.5.8

Defender Outersole PVC Default stress

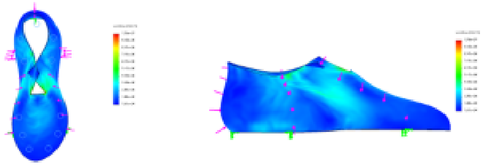


Figure 10.5.9

Defender Outersole Vertical force stress

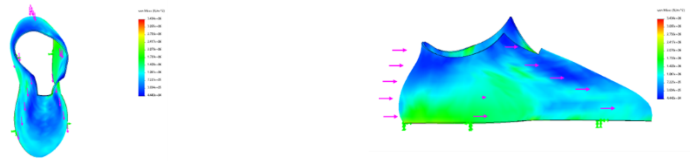


Figure 10.5.10

Defender Outersole Vertical foward force stress

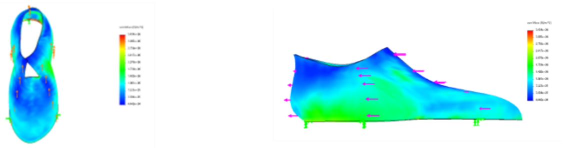


Figure 10.5.11

Defender Outersole Inside force stress

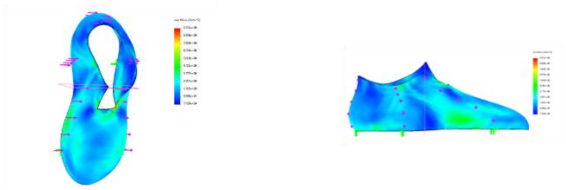


Figure 10.5.12

Defender Outersole SBR stress

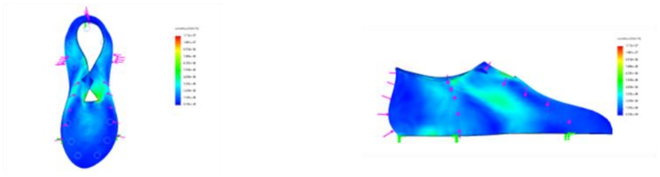


Figure 10.5.13

Defender Outersole Vertical SBR force stress

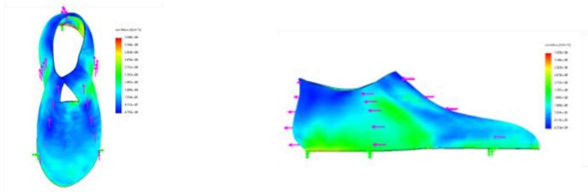


Figure 10.5.14

Defender Outersole SBR Vertical foward force stress

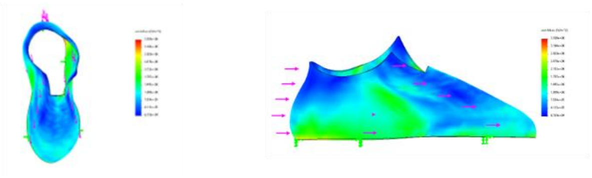


Figure 10.5.15

Midfielder Outersole PVC Default stress

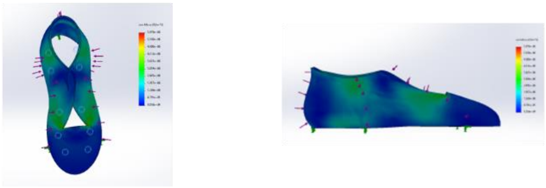


Figure 10.5.16

Midfielder Outersole PVC outer stress

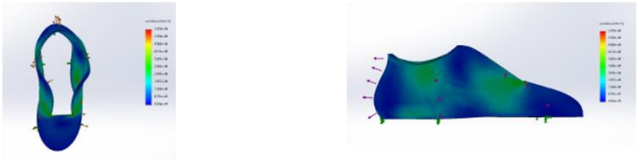


Figure 10.5.17

Midfielder Outersole Vertical force stress

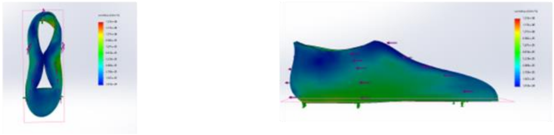


Figure 10.5.18

Midfielder Outersole Vertical foward force stress

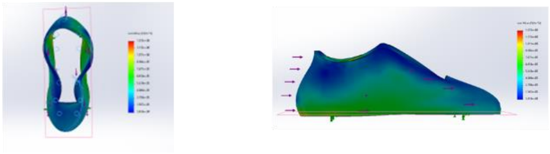


Figure 10.5.19

Midfielder Outersole Inside force stress

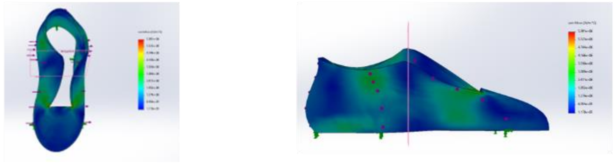


Figure 10.5.20

Midfielder Outersole SBR stress

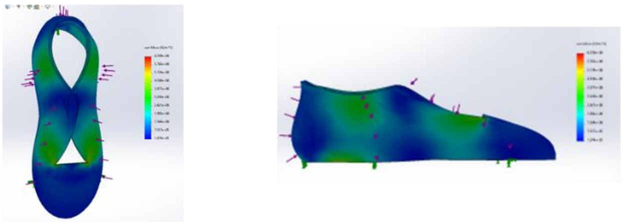


Figure 10.5.21

Midfielder Outersole PVC outer stress

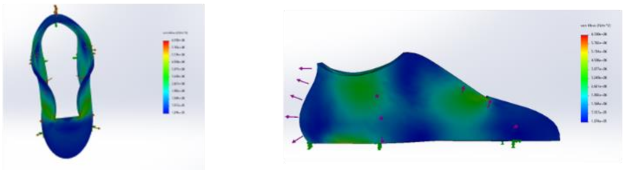


Figure 10.5.22

Midfielder Outersole Vertical SBR force stress

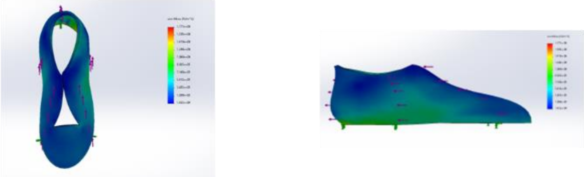


Figure 10.5.23

Midfielder Outersole SBR Vertical foward force stress

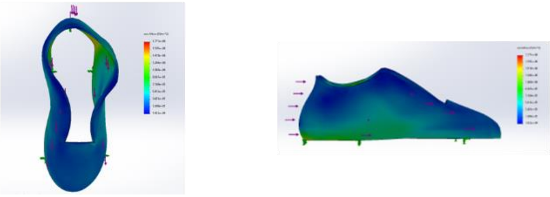


Figure 10.5.24

Midfielder Outersole SBR Inside force stress

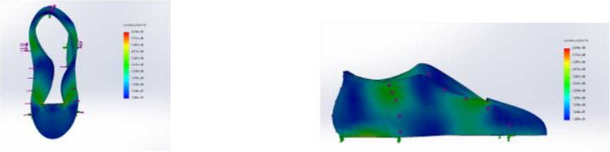


Figure 10.5.25

Striker Outersole PVC Default stress

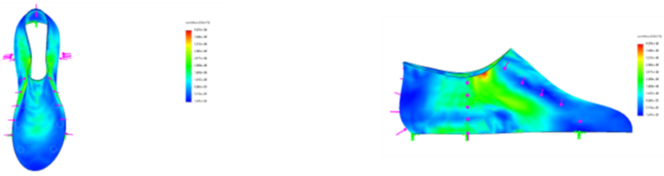


Figure 10.5.26

Striker Outersole Vertical force stress

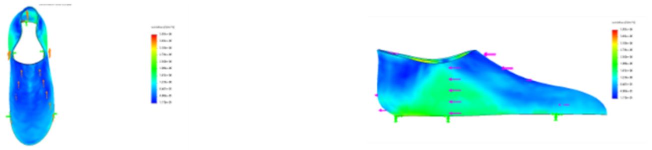


Figure 10.5.27

Striker Outersole Vertical forward force stress

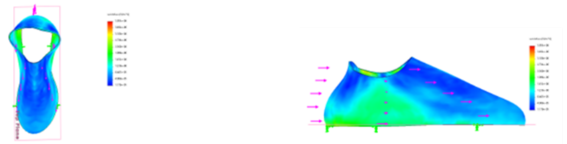


Figure 10.5.28

Striker Outersole Inside force stress

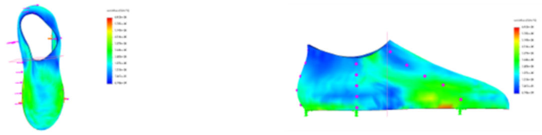


Figure 10.5.29

Striker Outersole SBR stress

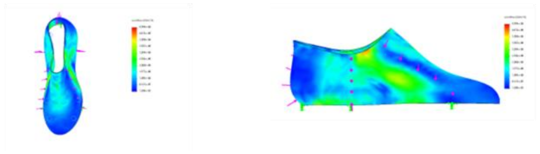


Figure 10.5.30

Striker Outersole Vertical SBR force stress

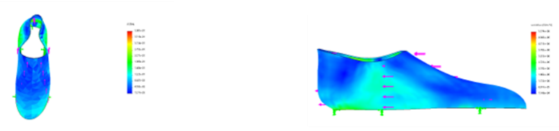


Figure 10.5.31

Striker Outersole SBR Vertical foward force stress

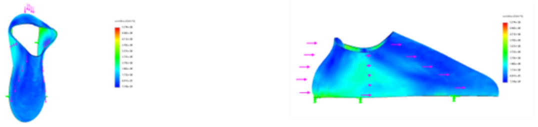


Figure 10.5.32

Striker Outersole SBR Inside force stress

Figure 10.5.33

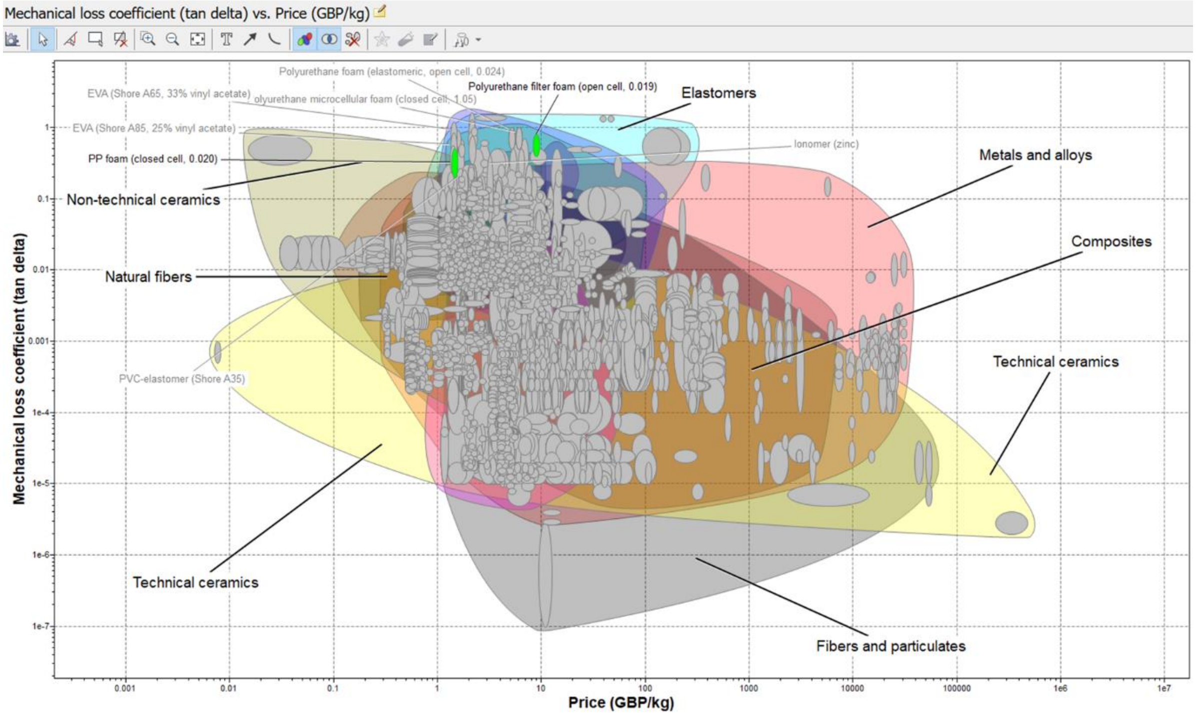


Figure 10.5.34: Ashby diagram of Mechanical Loss Coe. against Price for Insole material selection

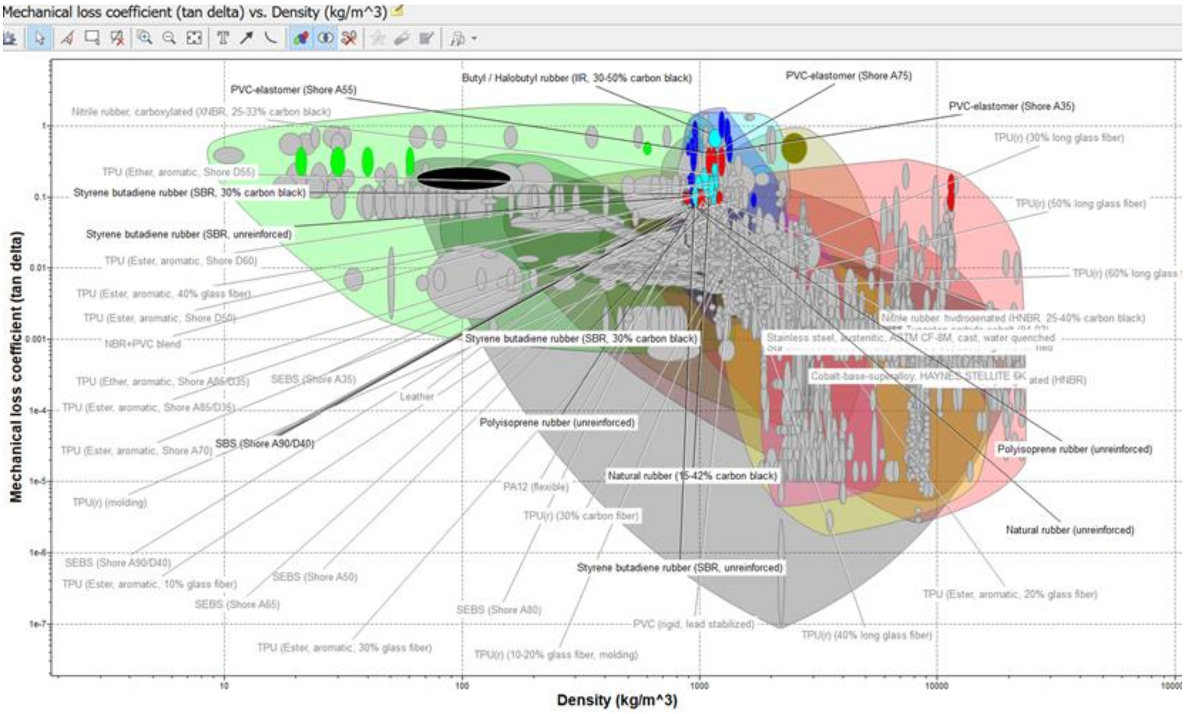


Figure 10.5.35: Ashby diagram of Mechanical Loss Coe. against Density for Outer Sole material selection

Section 6

Laces

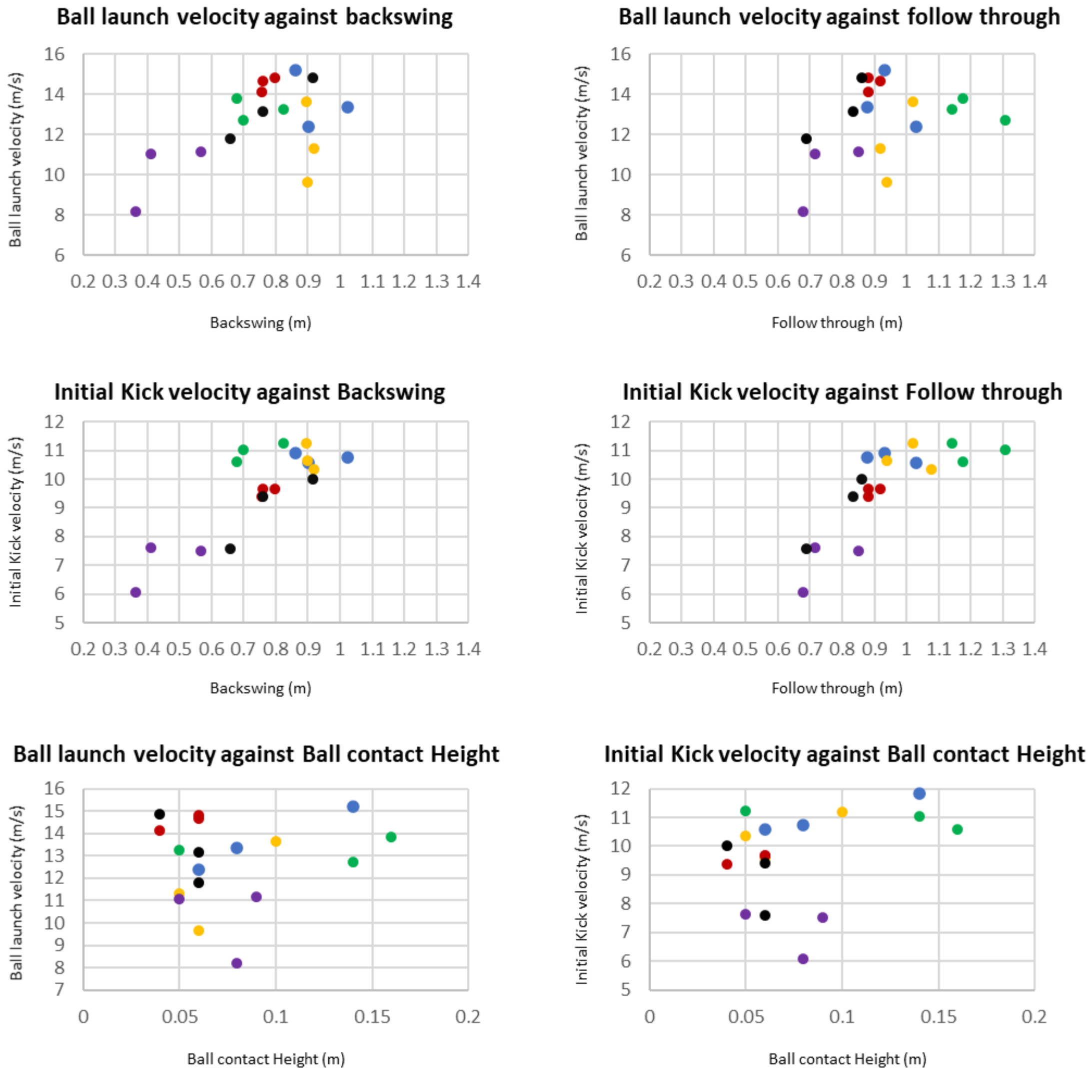


Figure 10.6.1: Laces shot graphs for Kick velocity, BLV, BC height against BS/FT

Inside

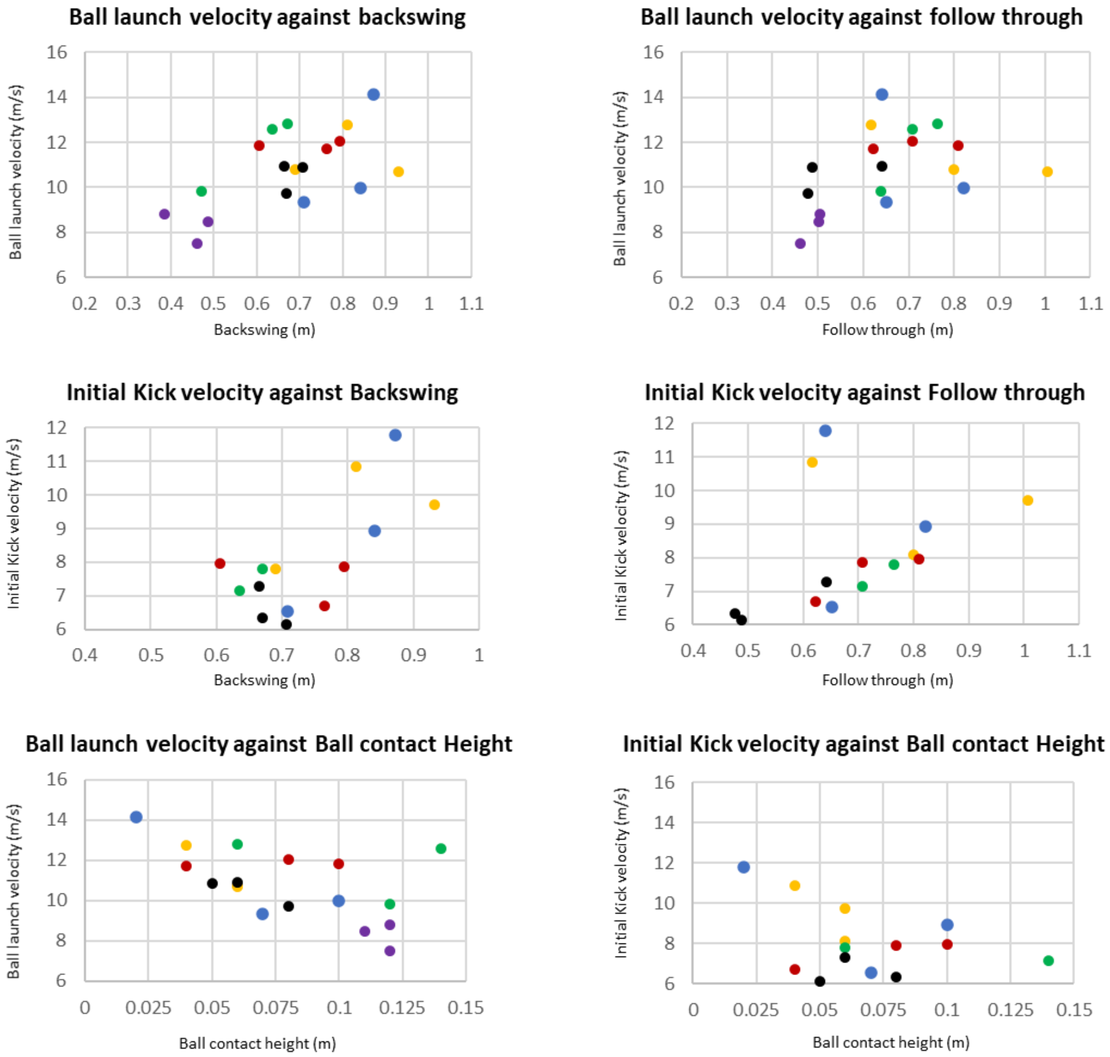
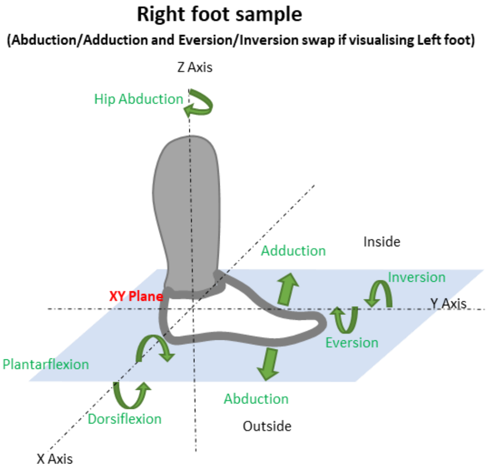


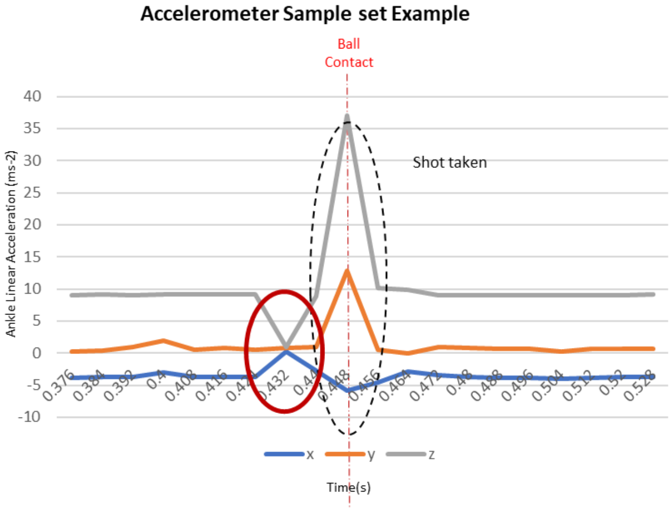
Figure 10.6.2: Inside shot graphs for Kick velocity, BLV and BC height against BS/FT

Analysis of graphs

Movement direction	Gyroscope Axis	Accelerometer Axis
Dorsiflexion	-y	-z
Plantarflexion	+y	+z
Adduction	+z	-x
Abduction	-z	+x
Eversion	+x	+y
Inversion	-x	-y



The IMU data is plotted onto a spreadsheet, and a shot sequence is cut for each player. Due to being 1 step shots, readings of just before "peak values" (Backswing/Follow through phase) shows how the ankle manoeuvred in trying to contact ball.



Accelerometer peak plots showed when the shots were taken, at the same time interval, Gyroscope values also showed their peak. Further analysing Gyroscope graph plots, there were another smaller set of peaks on graph showing some rotation, signifying the foot changes. These are the difference between the angular velocity changes around the ankle before the kick phase starts. Displaying the ankle stance at the start of the kick phase and how it manoeuvred, under their control, linking it to ankle contact projections and Launch ball velocity, an overall idea of the kick can be studied.

1 Step kicks, eliminates the chance of running up to the ball. This method of kicking allowed the sensor to obtain how the foot moved just before the kick starts (furthest backswing position), enabling the comparison to show how the "transfer of energy" upon backswing onto ball contact, has affected the quality of kick.

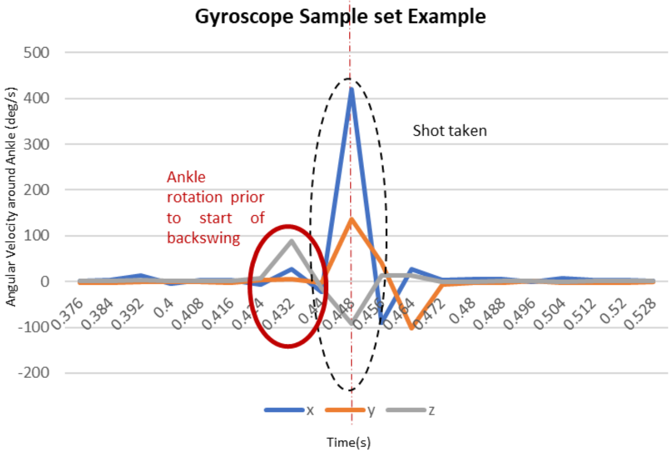


Figure 10.6.3: IMU graphs for Laces and Inside kicks with corresponding axis of Accelerometer/Gyroscope

Analysis of IMU graphs

The IMU graphs show how players have "directed" their ankle for their shots. The key focus in studying Gyroscope data, due to it producing the rotational velocity around the ankle which is influenced by the kicking leg. This rotation relates to hip flexion where greater rotation around the hip, could results in larger angular velocity. When the axis relates to the biomechanical ankle movement, this can show how much the player exerted their ankle rotation in that direction (e.g. Eversion/Abduction for inside foot shots). These are Laces shots which are sorted in their respective X Y Z axis.

Players either exerted more Eversion or Abduction around the ankle whilst under taking laces shots. is bigger for it's respective players (4/6), they resulted in not being abduction. This is also the same when the players experienced greater Abduction, their

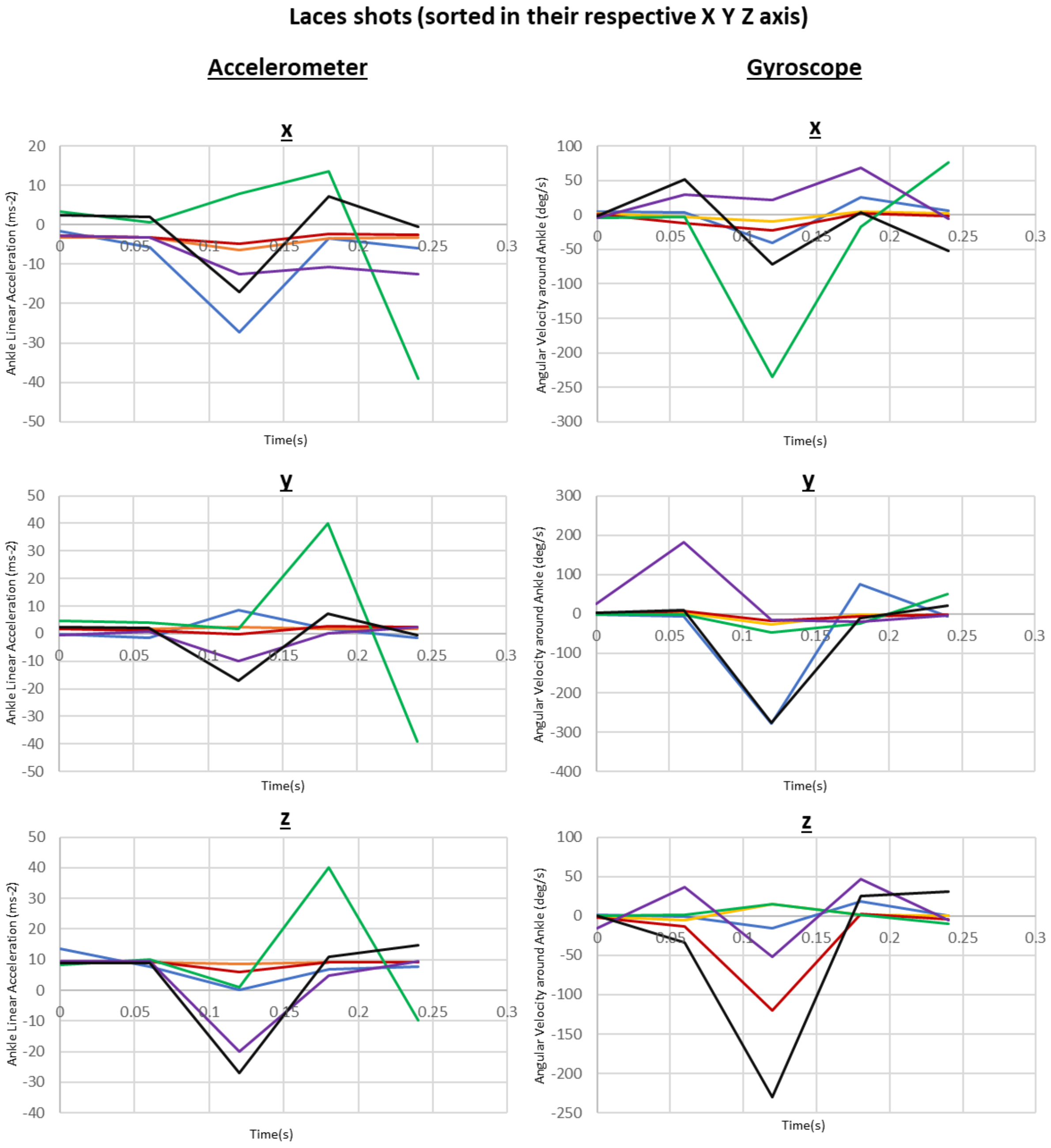


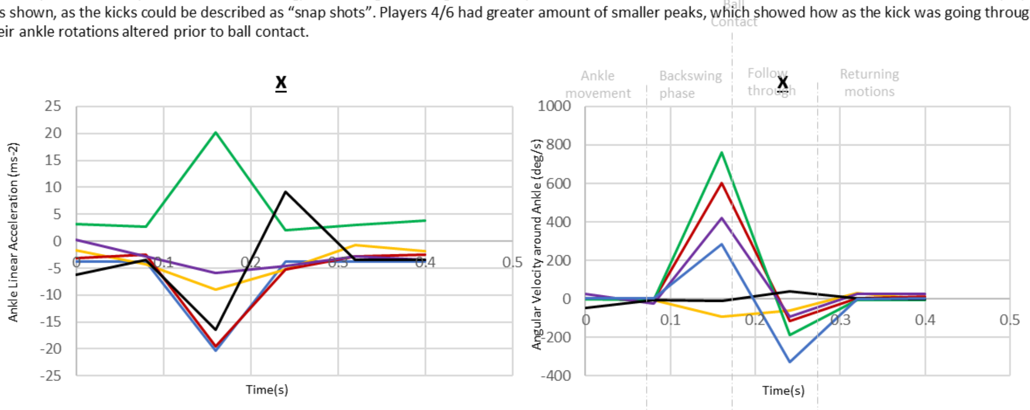
Figure 10.6.4: Accelerometer Gyroscope Laces shot identifier

Inside shots (sorted in their respective X Y Z axis)

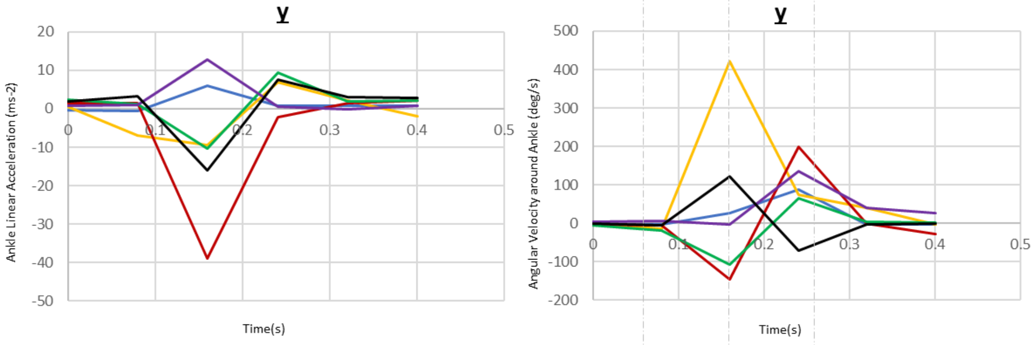
Accelerometer

Gyroscope

The “peak value”, is assigned after a certain number of seconds, to “emulate” how the shots would have looked, had they started their kick at the same time. This is to give direct comparison in how each player kicked. For this set of results, Players 1-3 maintained minimal rotation, as they went through their kick. Players 5 and 6, stressed more inwards, where inversion was more likely to have occurred at the start of the backswing. This particular axis shows the Eversion/Inversion. Player 5 had low backswing, but had a greater angular velocity around the ankle in order to connect the ball. The drastic motion of player 4 is shown, as the kicks could be described as “snap shots”. Players 4/6 had greater amount of smaller peaks, which showed how as the kick was going through, their ankle rotations altered prior to ball contact.

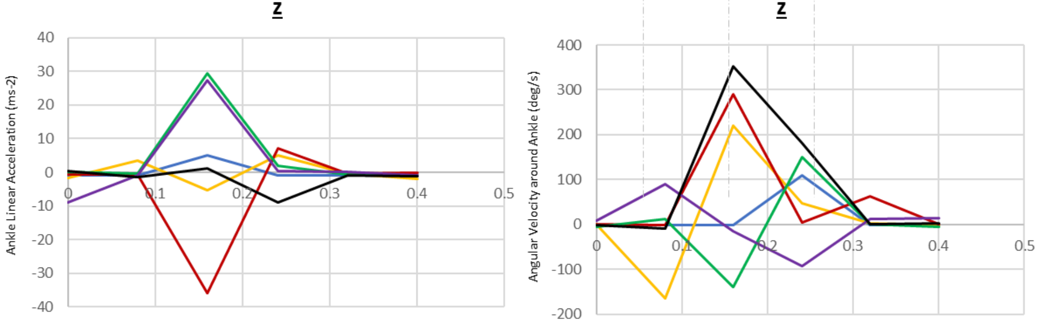


This shows the Eversion/Inversion. Player 5 had low backswing, but had a greater angular velocity around the ankle in order to connect the ball. The drastic motion of player 4 is shown, as the kicks could be described as “snap shots”.



Only player 5 took a big plantarflexion angle (axis moving positive direction) as the kick phase started. Player 5 did not kick with great speed or backswing distance, hence this shows the technique emphasizing the ankle stance they’re accustomed to. Player 2 showed one of the highest backswings for Inside shot, and it shows that the ankle experienced this, maintaining their position of Dorsiflexion upon kick, with low ball contact point.

Player 2 showed one of the highest backswings for Inside shot, and it shows that the ankle experienced this, maintaining her position of Dorsiflexion upon kick.



During the backswing phase, the Lateral rotation showed how some players “opened out” their foot, as the X axis going down showed abduction (Players 1,3,6). Player 5 stressed more inwards, where adduction was more likely to have occurred at the start of the backswing. This could suggest more stresses felt around the first metatarsal – phalange joint. Player 2 and 4 show that as the kick went through, they shot “inside-out”, meaning they applied effort on an inner angle upon contact before follow through brought their ankle back out.

Player 6 experienced greater rotation for abduction. Player 3 data shows how they angled out their body, as both Eversion (y) and Abduction rotations were higher, compared to plantarflexion.

Figure 10.6.5: Accelerometer Gyroscope Inside foot shot identifier

Section 7

The pendulum experiment equipment was either purchased online, or was a preowned item by the researcher. The following links are the bill of material that can be obtained, should this experiment be repeated with the same apparatus used. Items such as duct tape, Velcro, ball, and electronic kits, were either bought at a retailer in person, or was provided by Brunel University London, UK.

6kg Barbell (https://www.decathlon.co.uk/120m-domyos-weight-bar-chrome-id_8289897.html)

Dumbell Bars

(https://www.amazon.co.uk/Hardcastle-Spinlock-Dumbbell-Bars-Grips/dp/B00R50PK2G/ref=asc_df_B00R50PK2G/?tag=googshopuk-21&linkCode=df0&hvadid=222165639010&hvpos=&hvnetw=g&hvrand=9738701885529027021&hvpone=&hvptwo=&hvqmt=&hvdev=c&hvdvcmdl=&hvlocint=&hvlocphy=9044962&hvtargid=pla-467195174373&psc=1)

Weight discs (home)

Smart weight lock (https://www.decathlon.co.uk/smart-disc-collar-28-mm-id_8380690.html)

100kg Weight rack (https://www.decathlon.co.uk/100-weight-rack-id_8380450.html)

Long barbell (https://www.decathlon.co.uk/2m-domyos-weight-bar-chrome-id_8289900.html)

Retro fit clamp (https://www.themetalstore.co.uk/products/retro-fit-clamp-on-tee-inline?utm_source=google&utm_medium=product_feed&utm_campaign=products&gclid=EAIaIQobChMIk8vQ99O46wIV84BQBh28MATJEAQYAyABEgJnffD_BwE)

Dumbell Extender (https://www.ebay.co.uk/p/22035054820)

Size 9 boots (https://www.decathlon.co.uk/p/rip-tab-football-boots-agility-140-tf/_/R-p-309496)

Section 7 Graph results for preliminary test results showing all the shots taken. These graphs are linked to the first set of pendulum test, before the test of repeatability was constructed. Figure 10.7.8 – 10.7.31: display all square and circle FSR kick trial, with Flex sensor and long sensitive resistor result plots separated with their respective sensor placement.

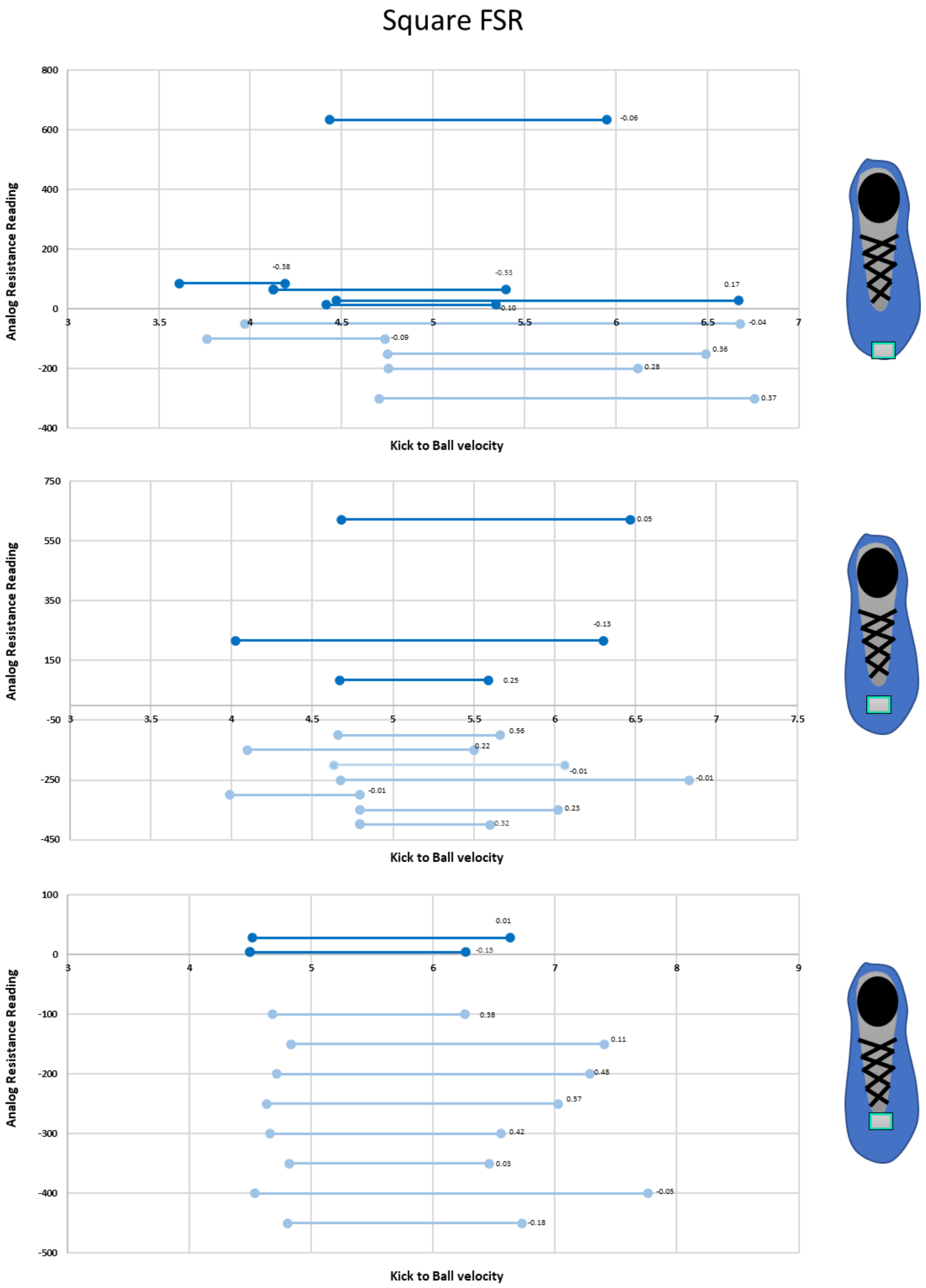


Figure 10.7.8

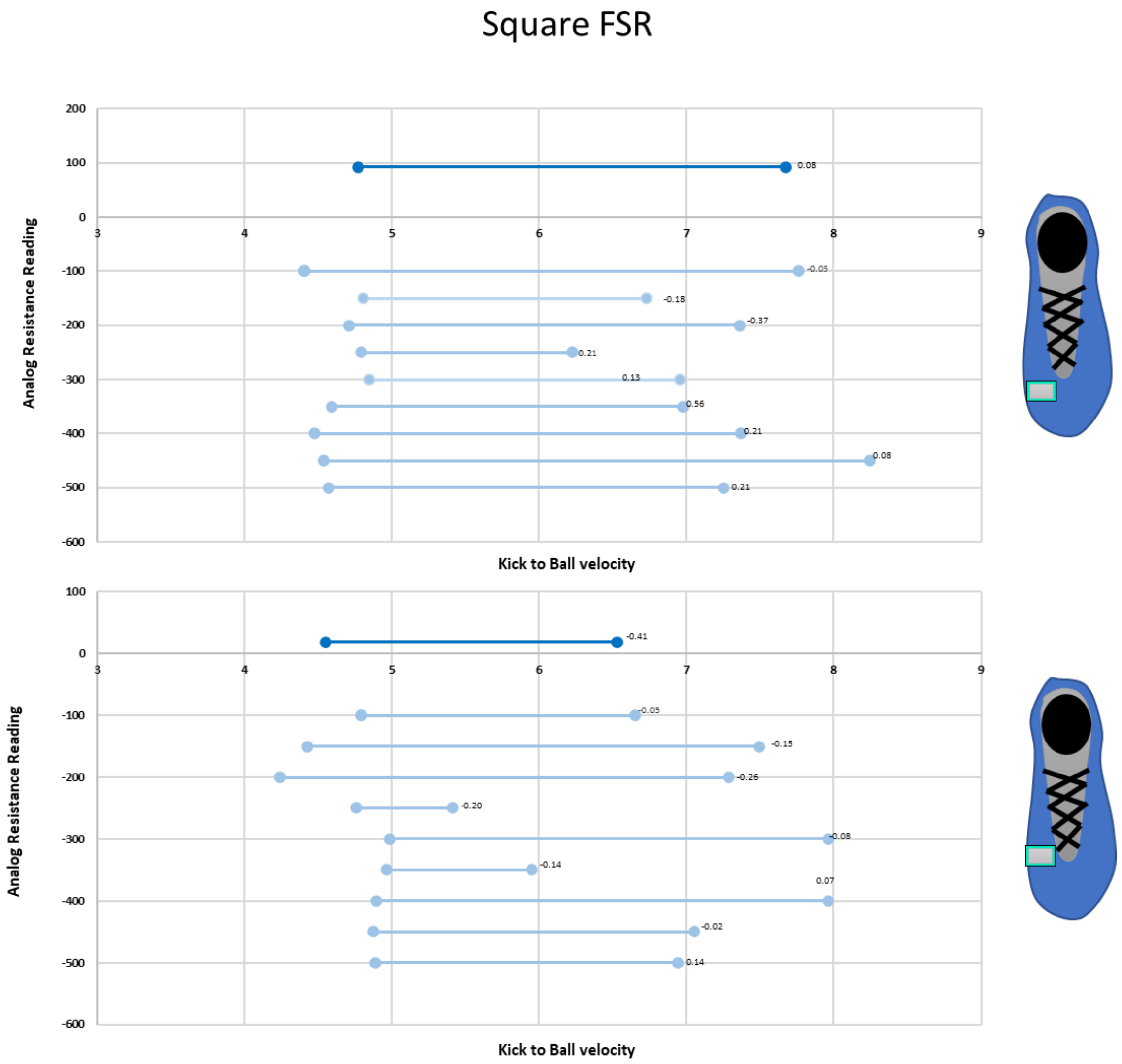

Square FSR
Analog Resistance Reading
200
100
0
-100
-200
-300
-400
-500
-600
3
4
5
6
7
8
9
0.08
-0.05
-0.18
-0.37
0.21
0.13
0.56
0.21
0.08
0.21
Kick to Ball velocity
Analog Resistance Reading
100
0
-100
-200
-300
-400
-500
-600
3
4
5
6
7
8
9
-0.41
-0.05
-0.15
-0.26
-0.20
-0.08
-0.14
0.07
-0.02
0.14
Kick to Ball velocity

Figure 10.7.9

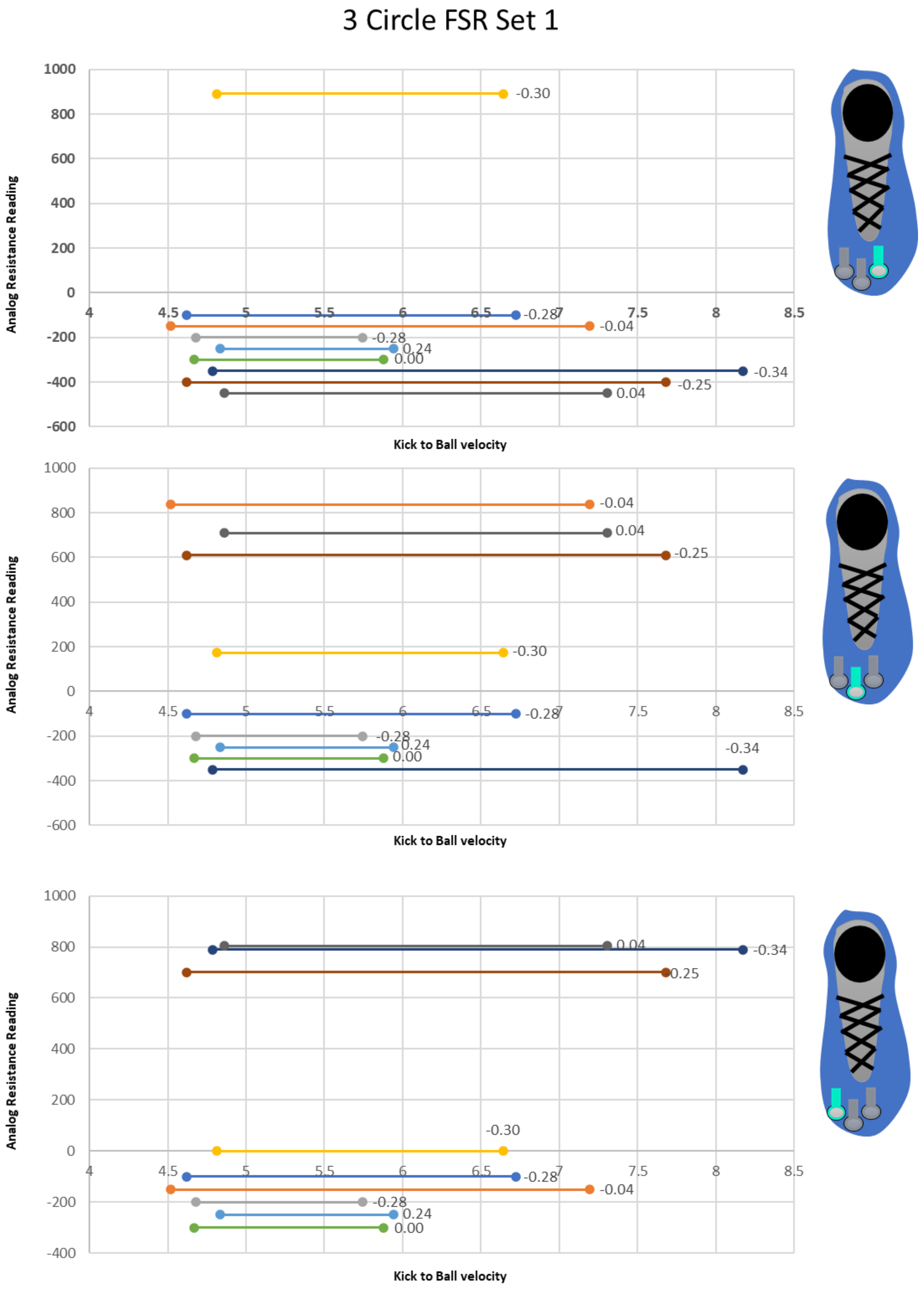

3 Circle FSR Set 1

Figure 10.7.10

3 Circle FSR Set 2

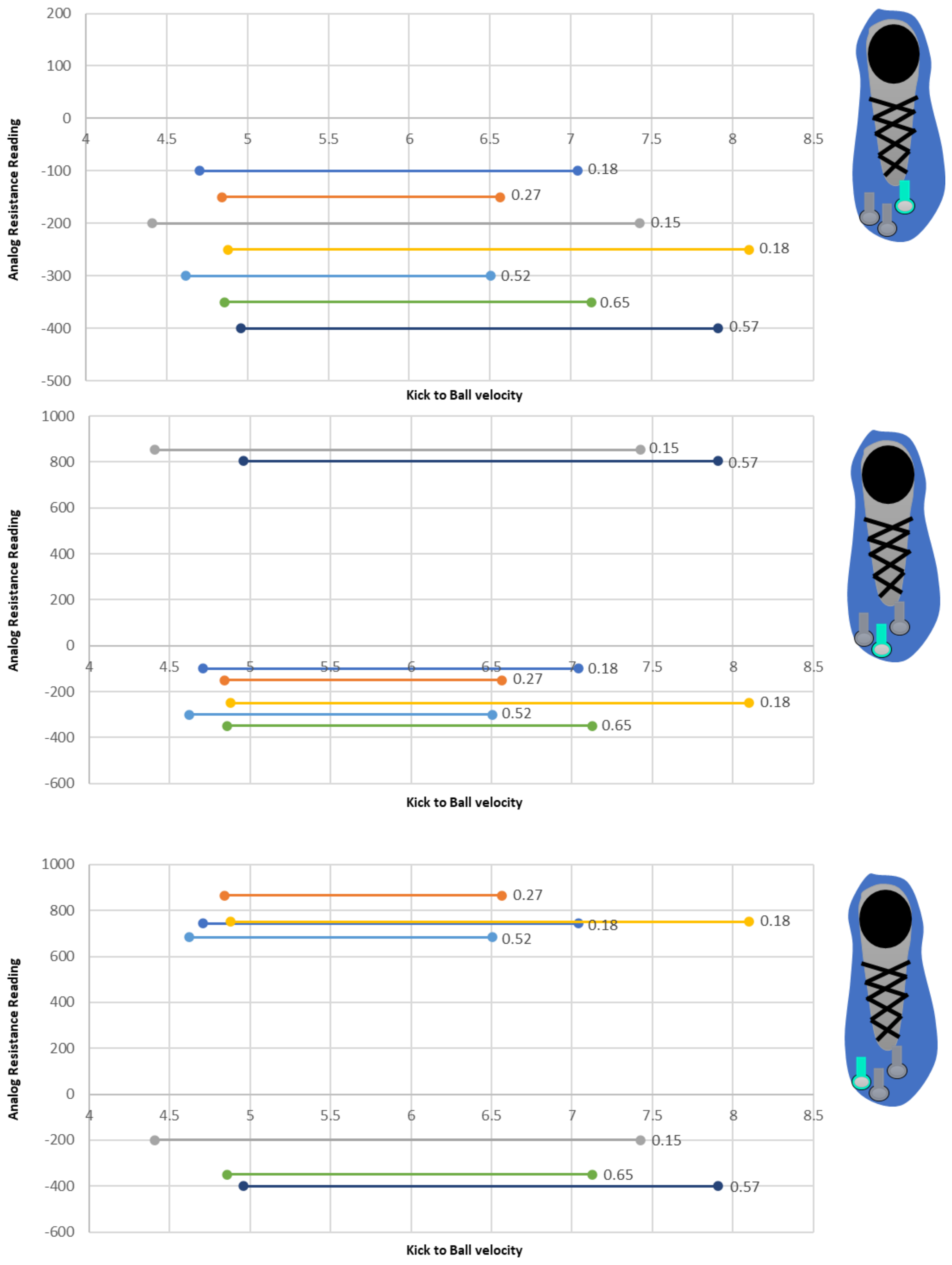


Figure 10.7.11

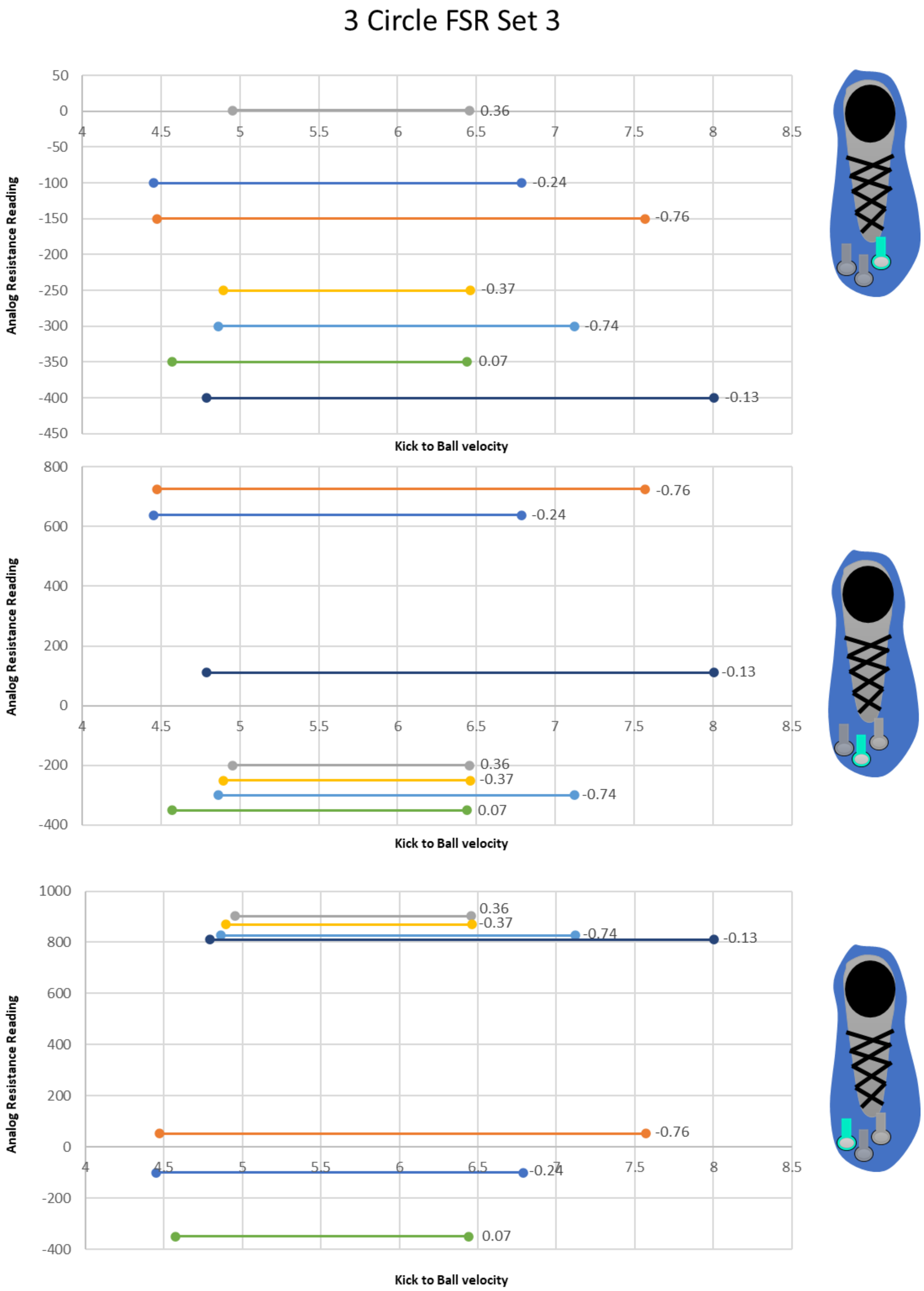


Figure 10.7.12

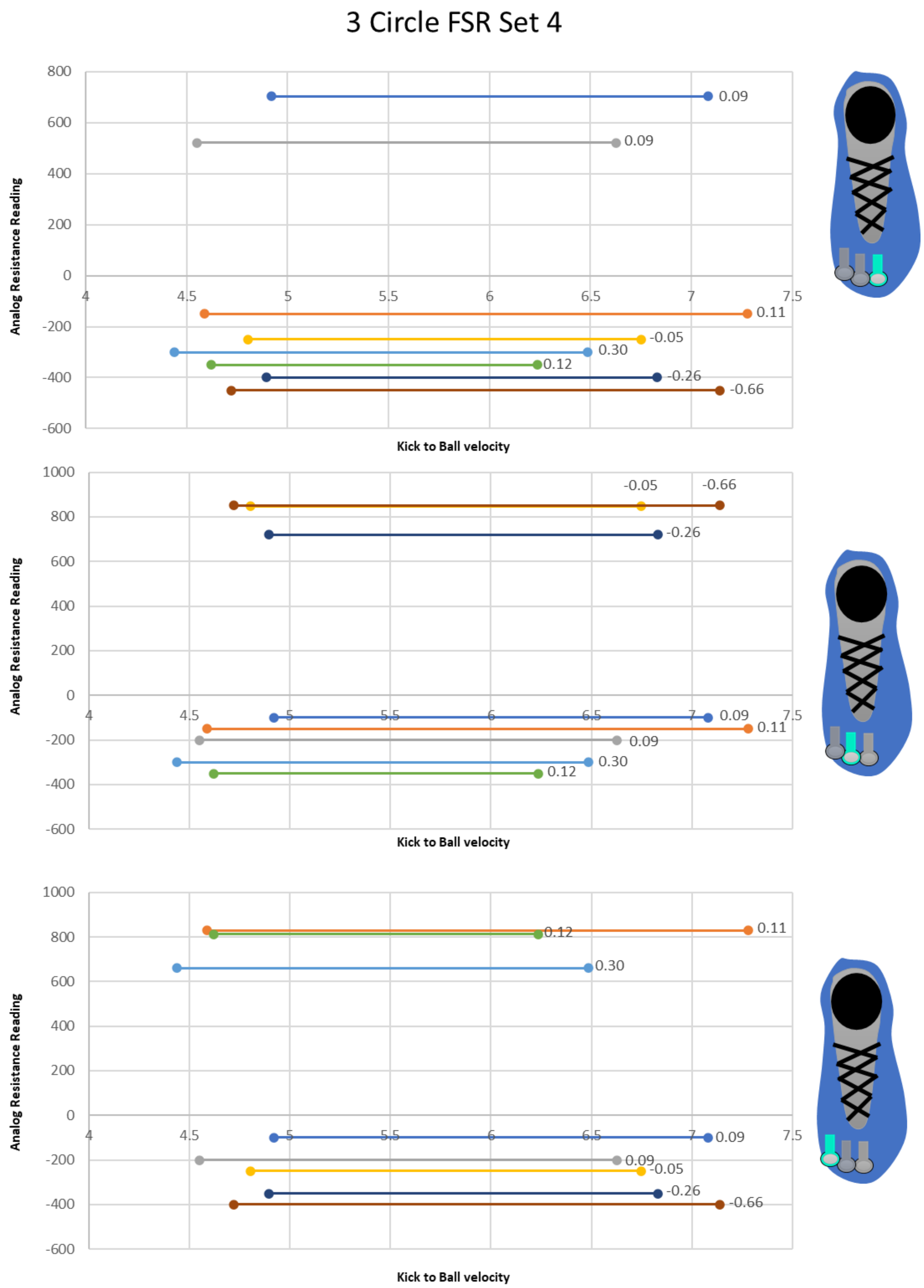

3 Circle FSR Set 4

Figure 10.7.13

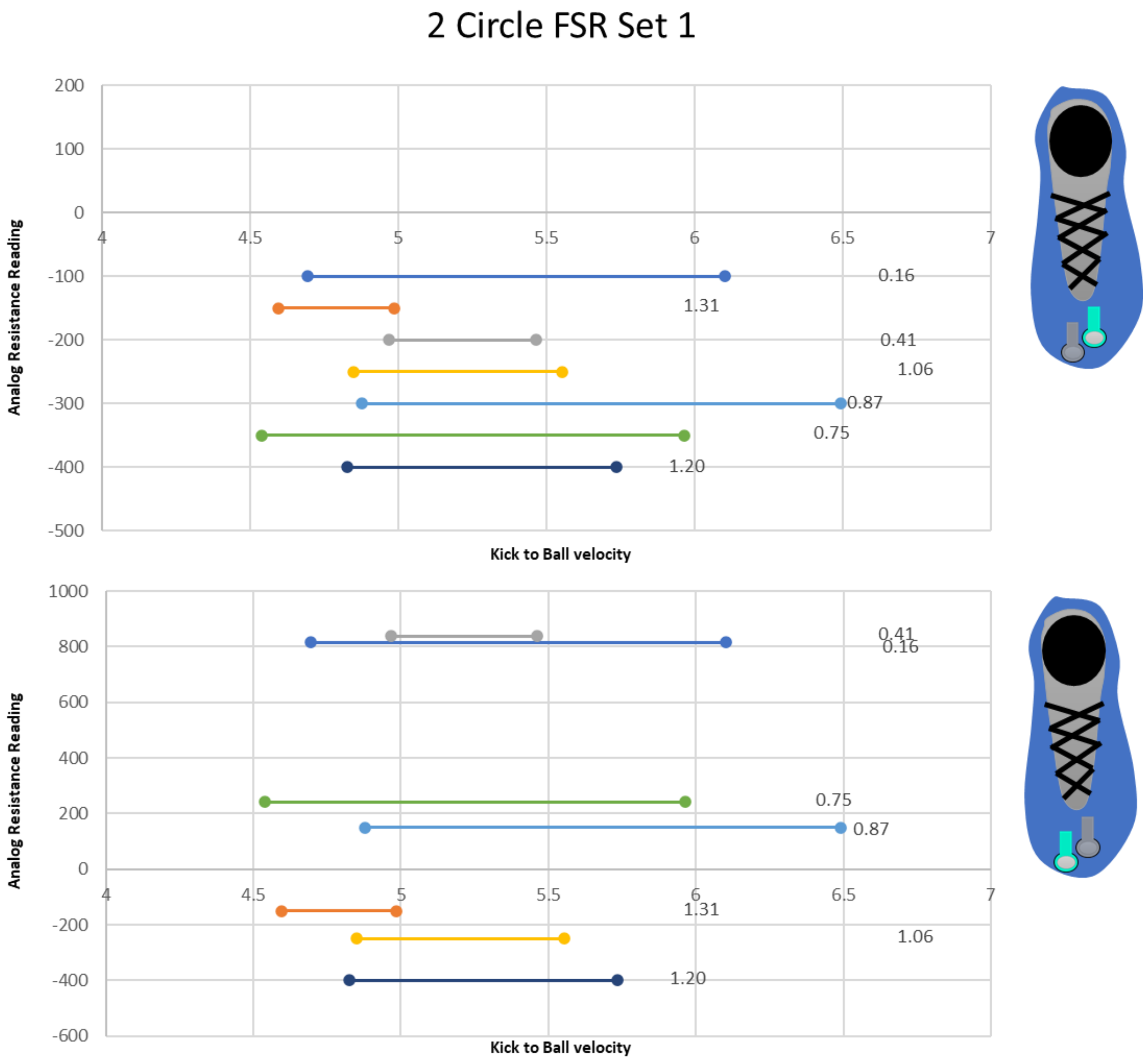


Figure 10.7.14

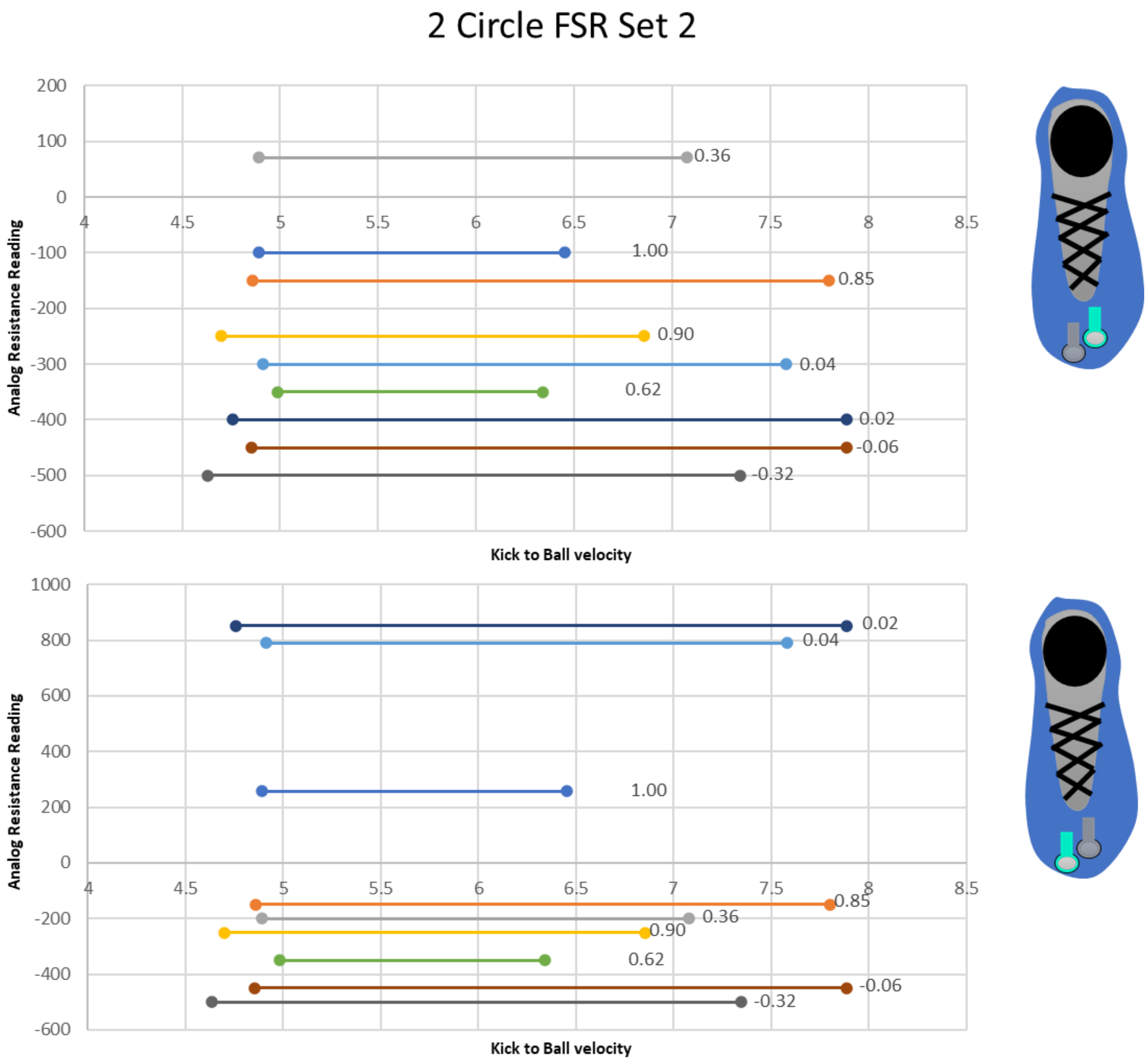


Figure 10.7.15

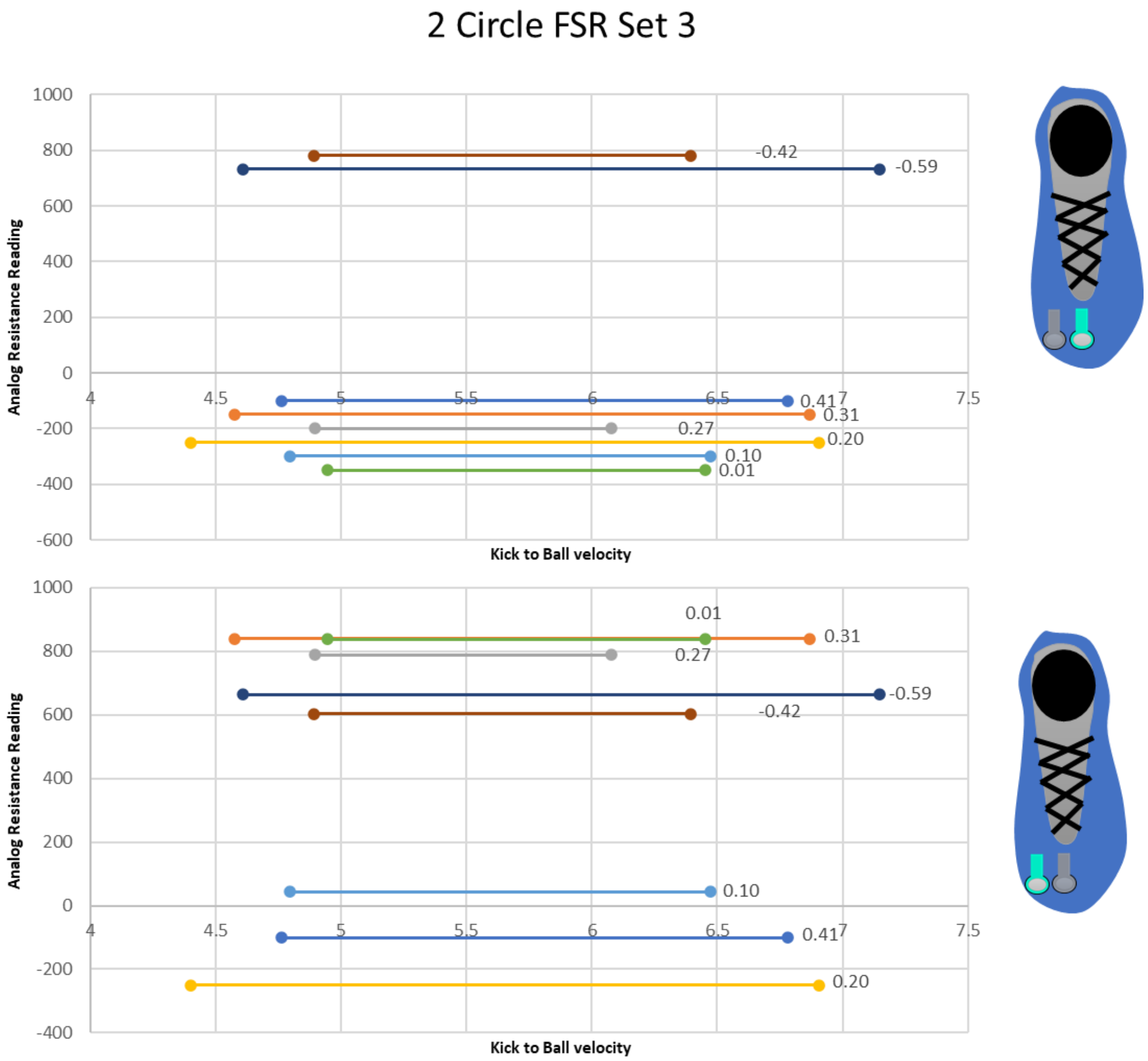


Figure 10.7.16

2 Circle FSR Set 4

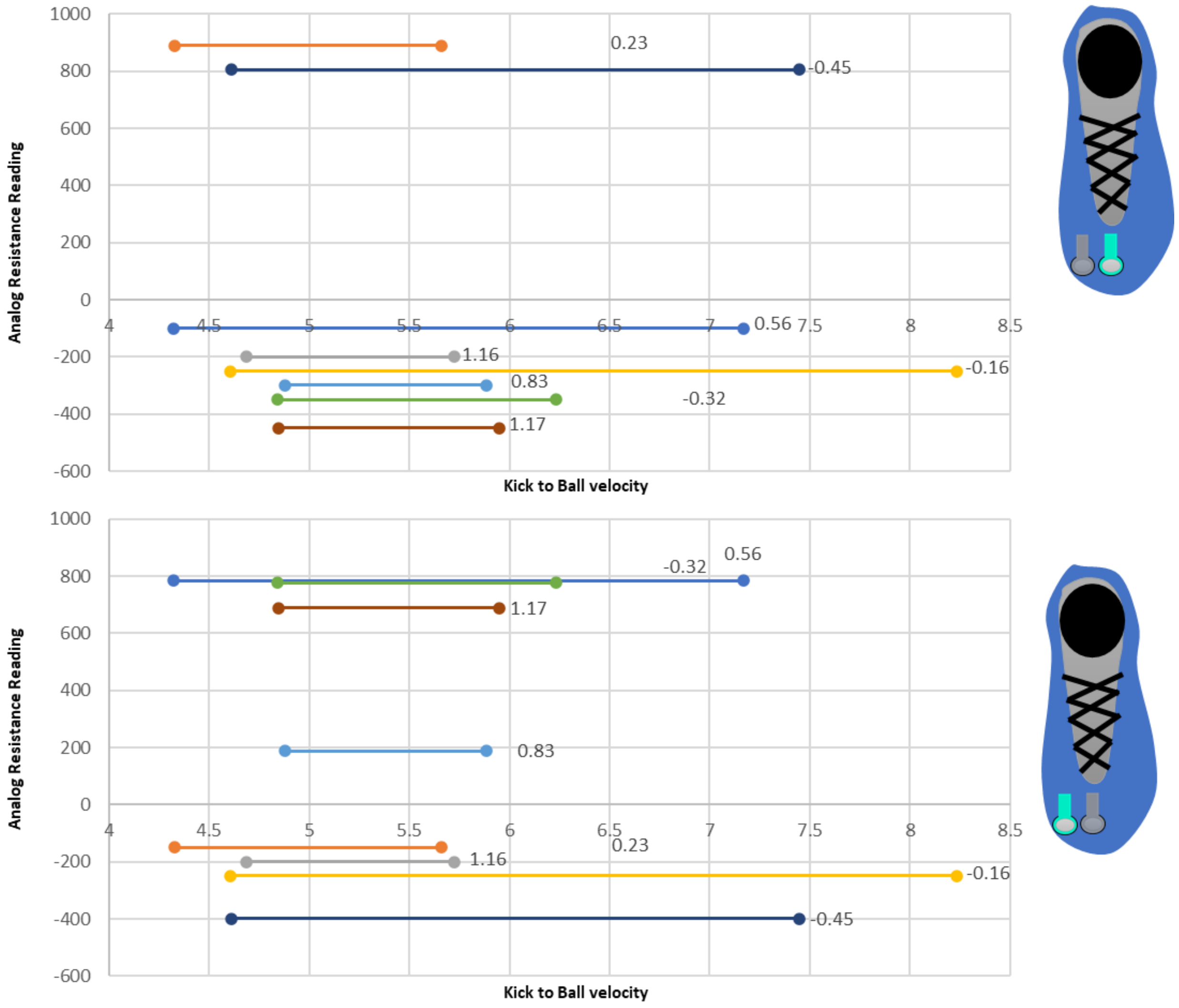


Figure 10.7.17

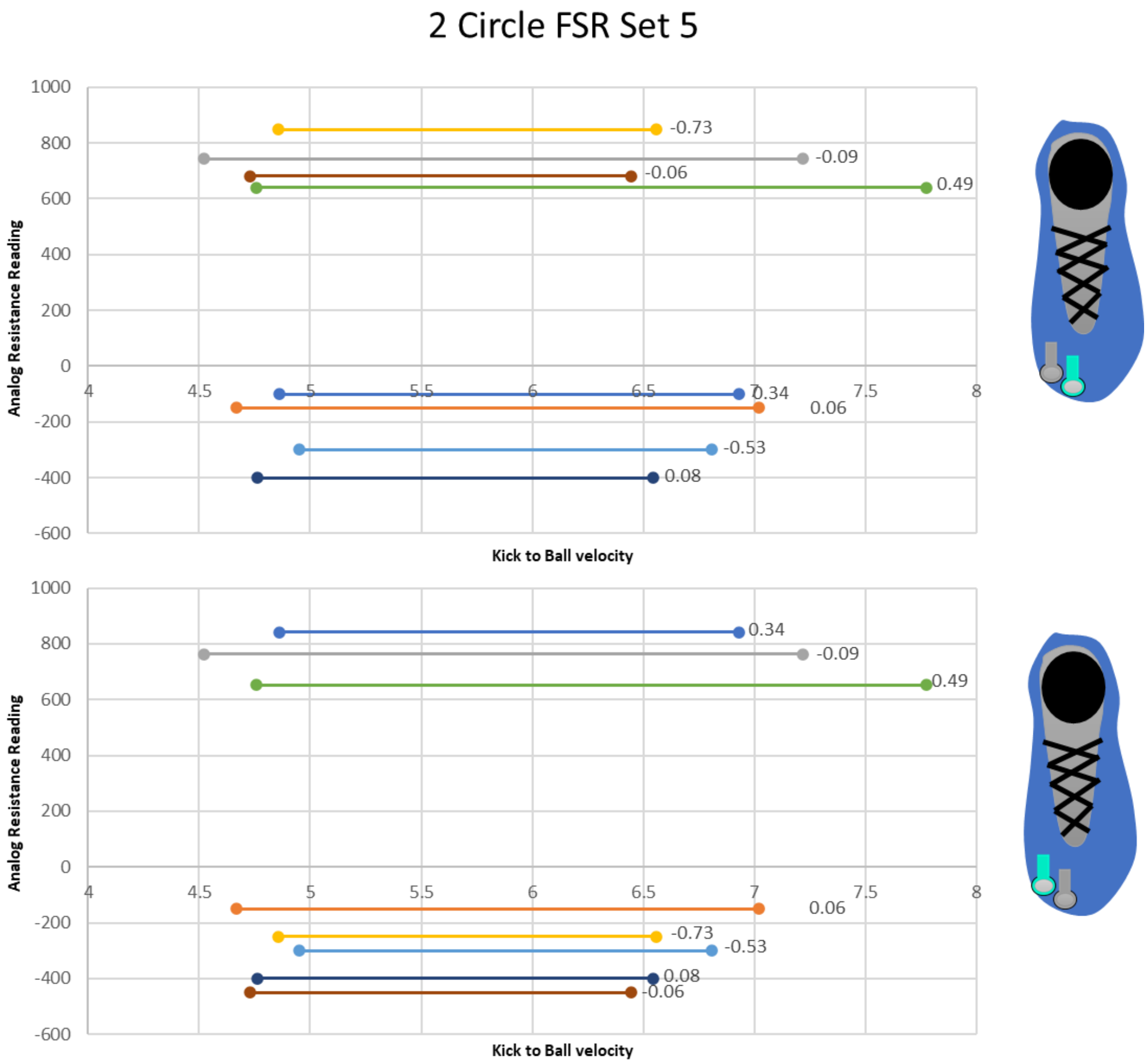


Figure 10.7.18

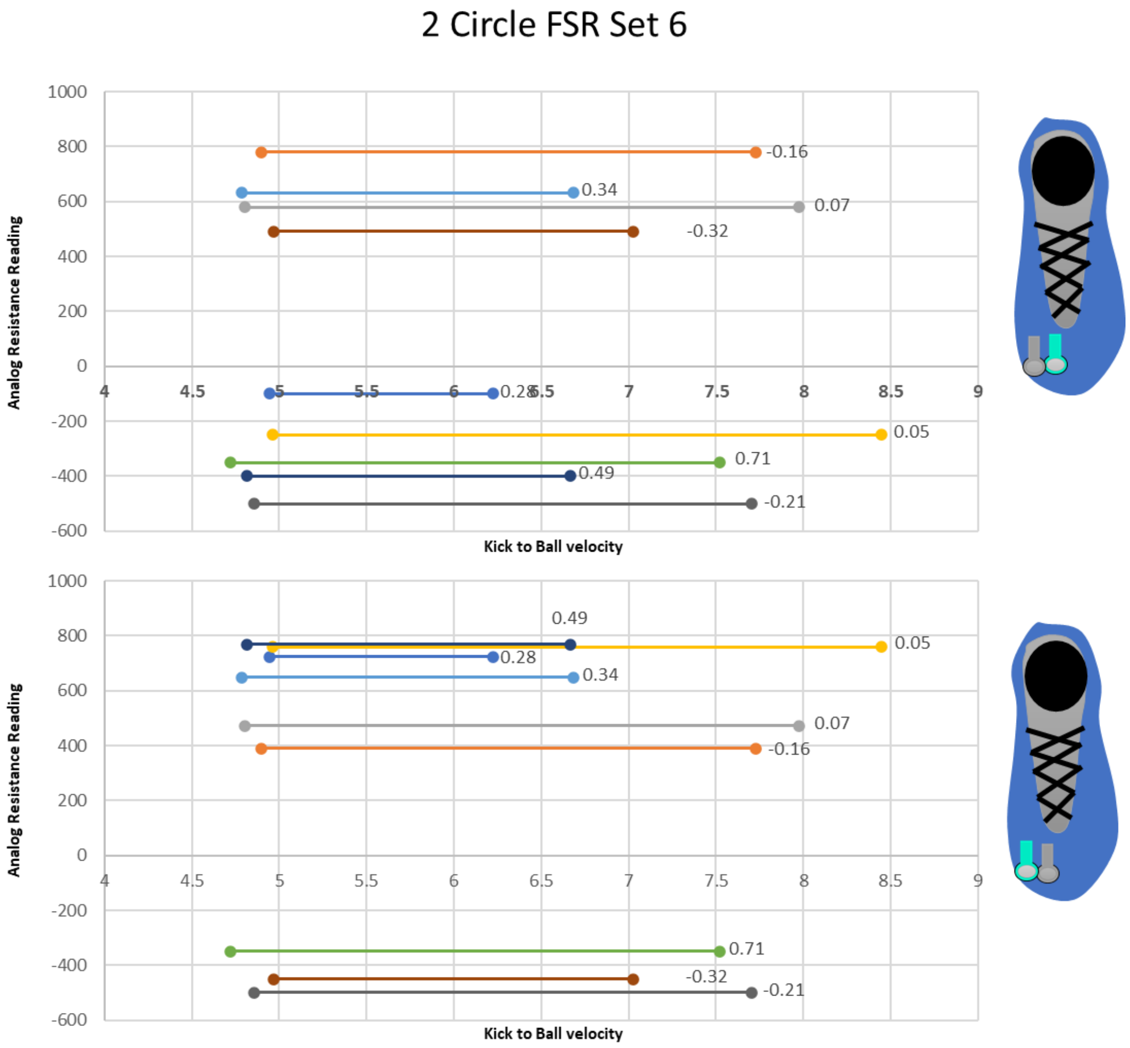


Figure 10.7.19

2 Circle FSR Set 7

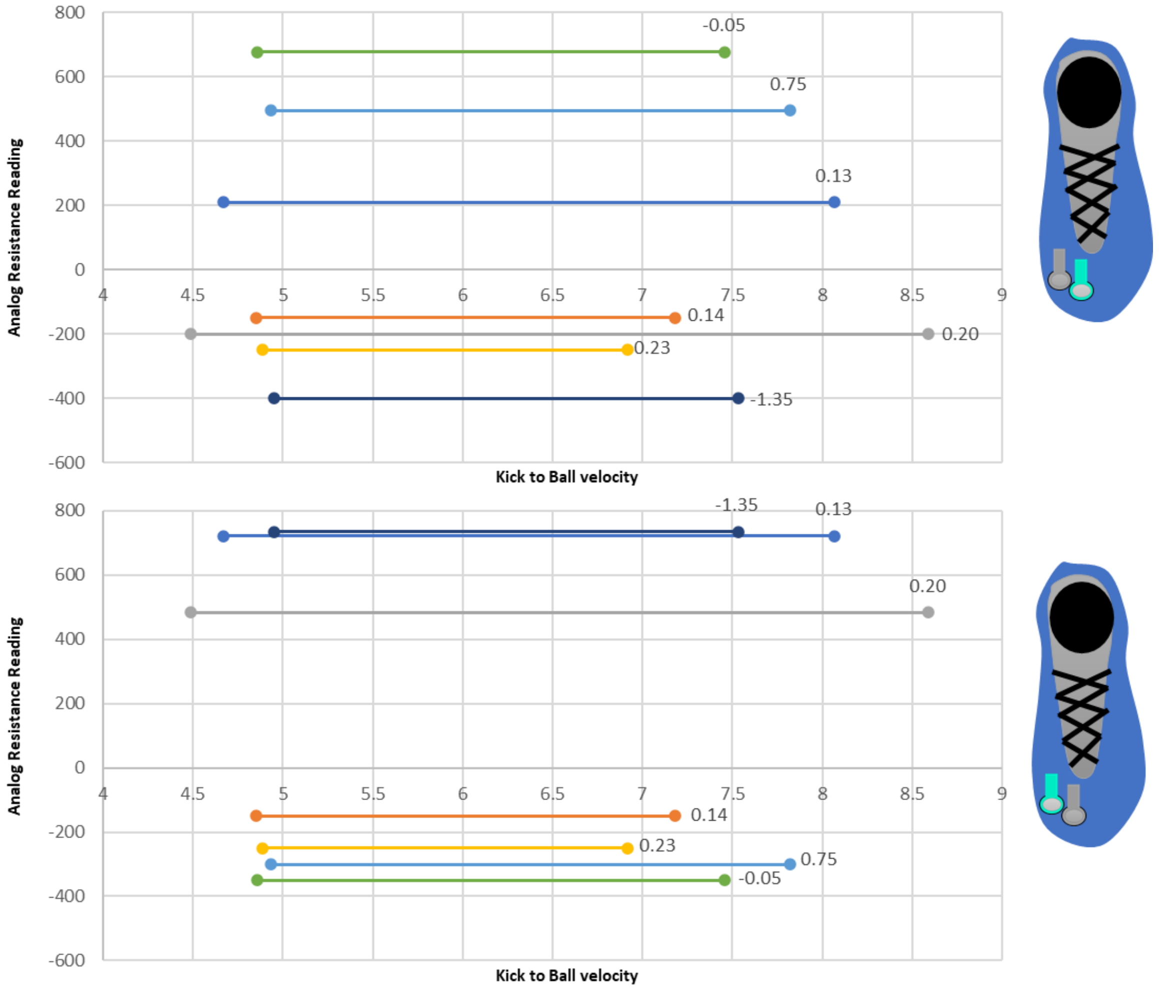


Figure 10.7.20

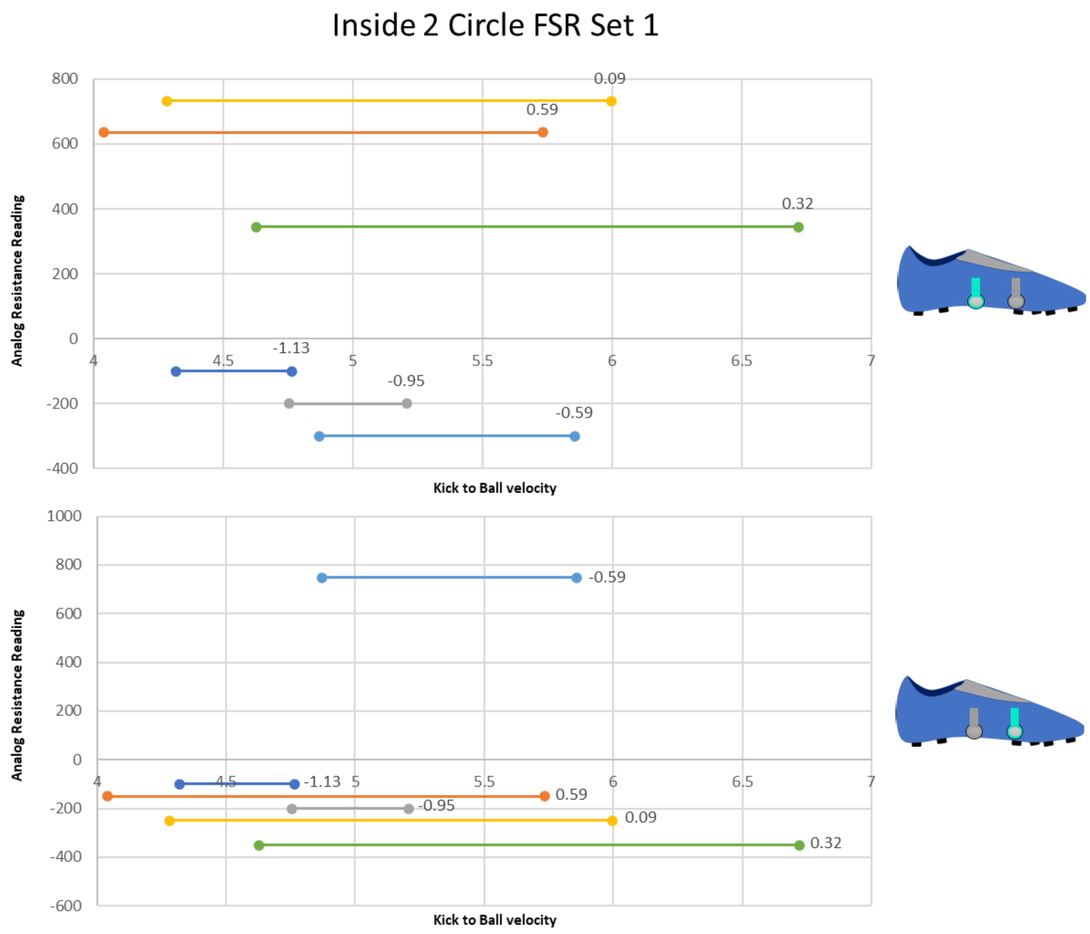


Figure 10.7.21

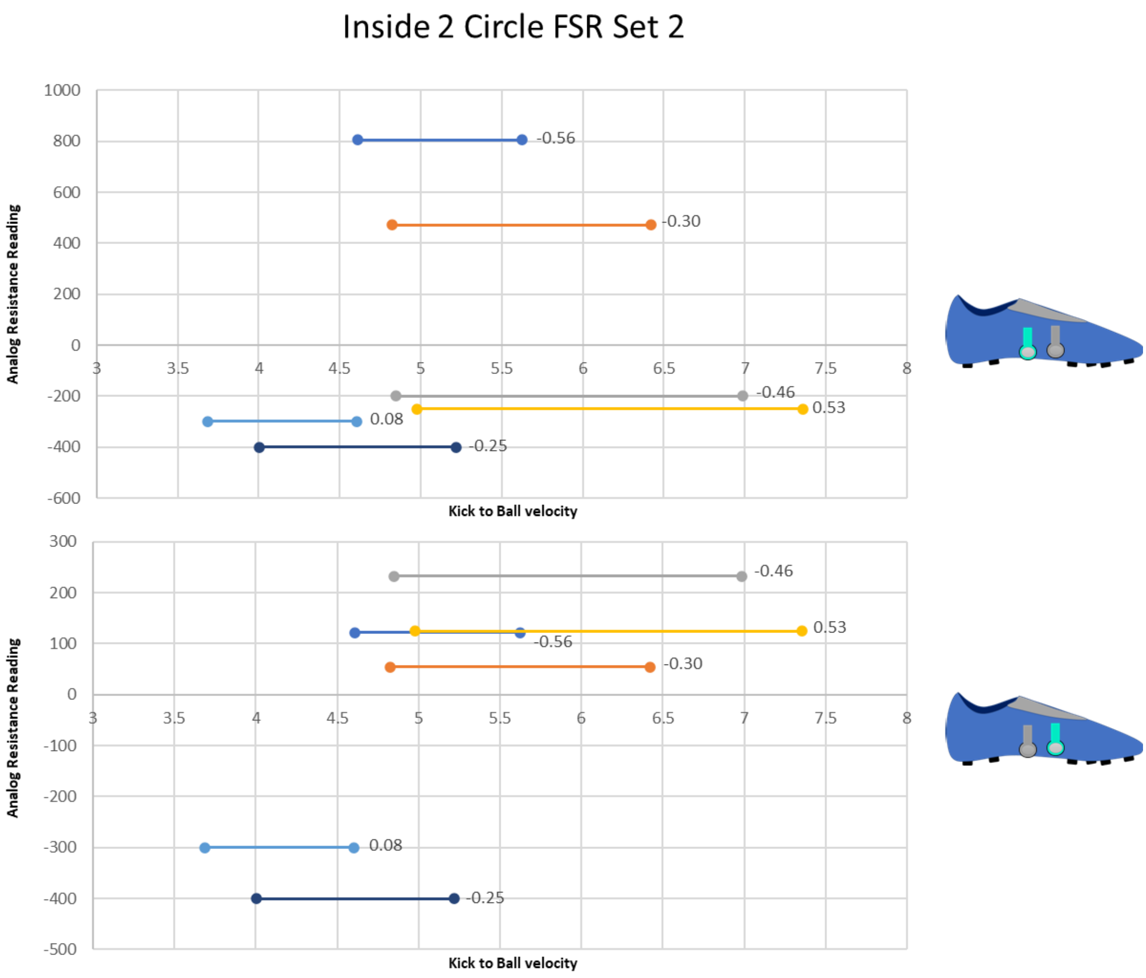


Figure 10.7.22

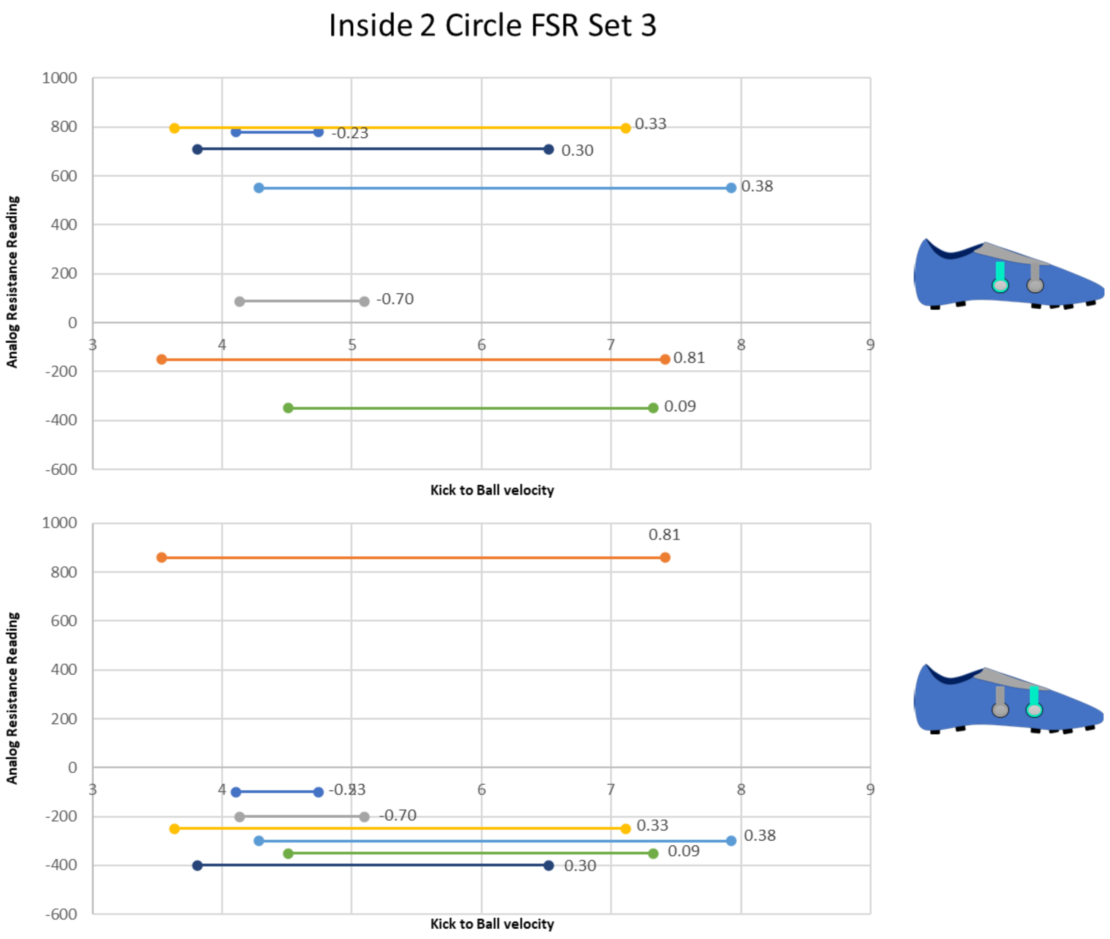


Figure 10.7.23

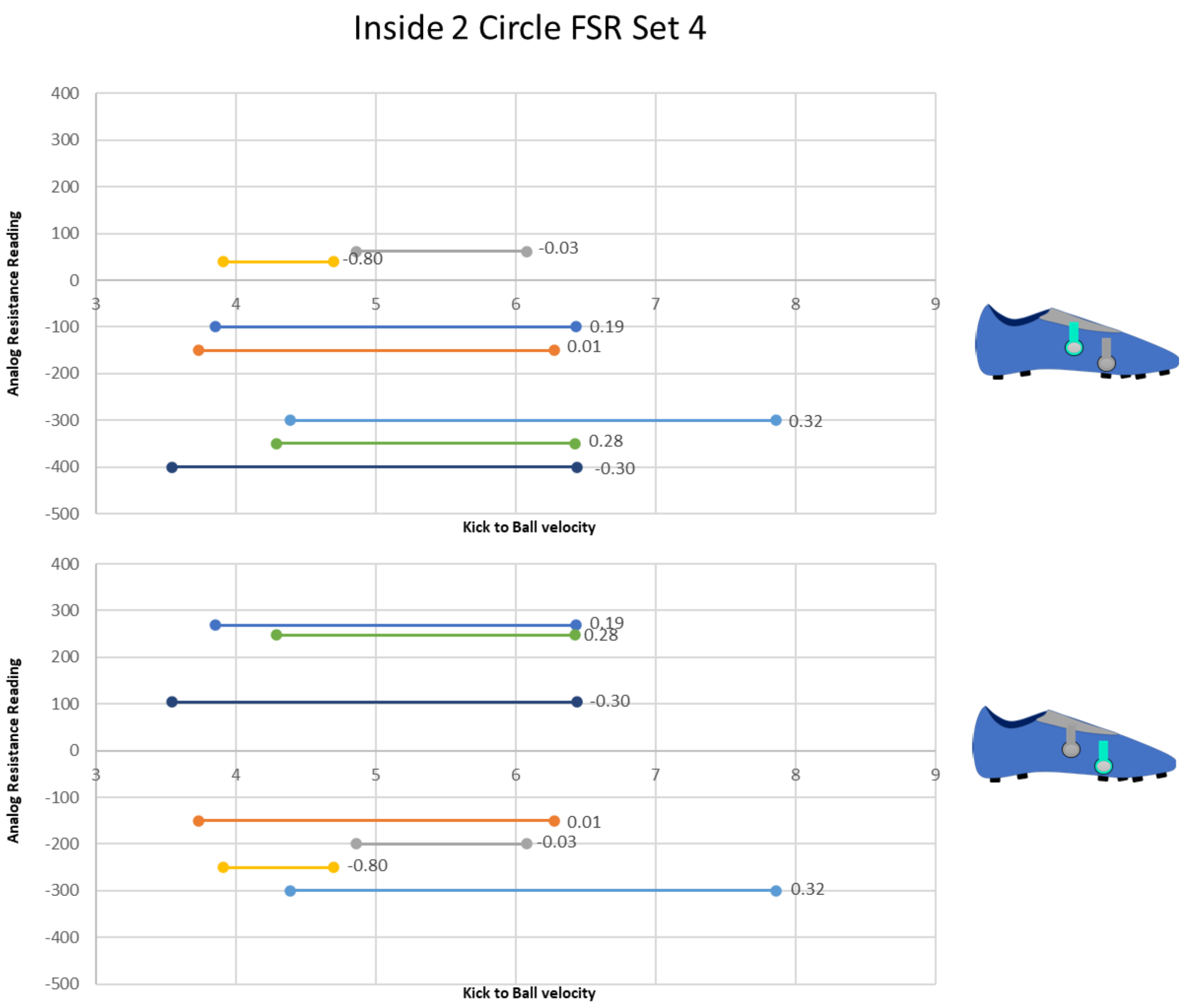


Figure 10.7.24

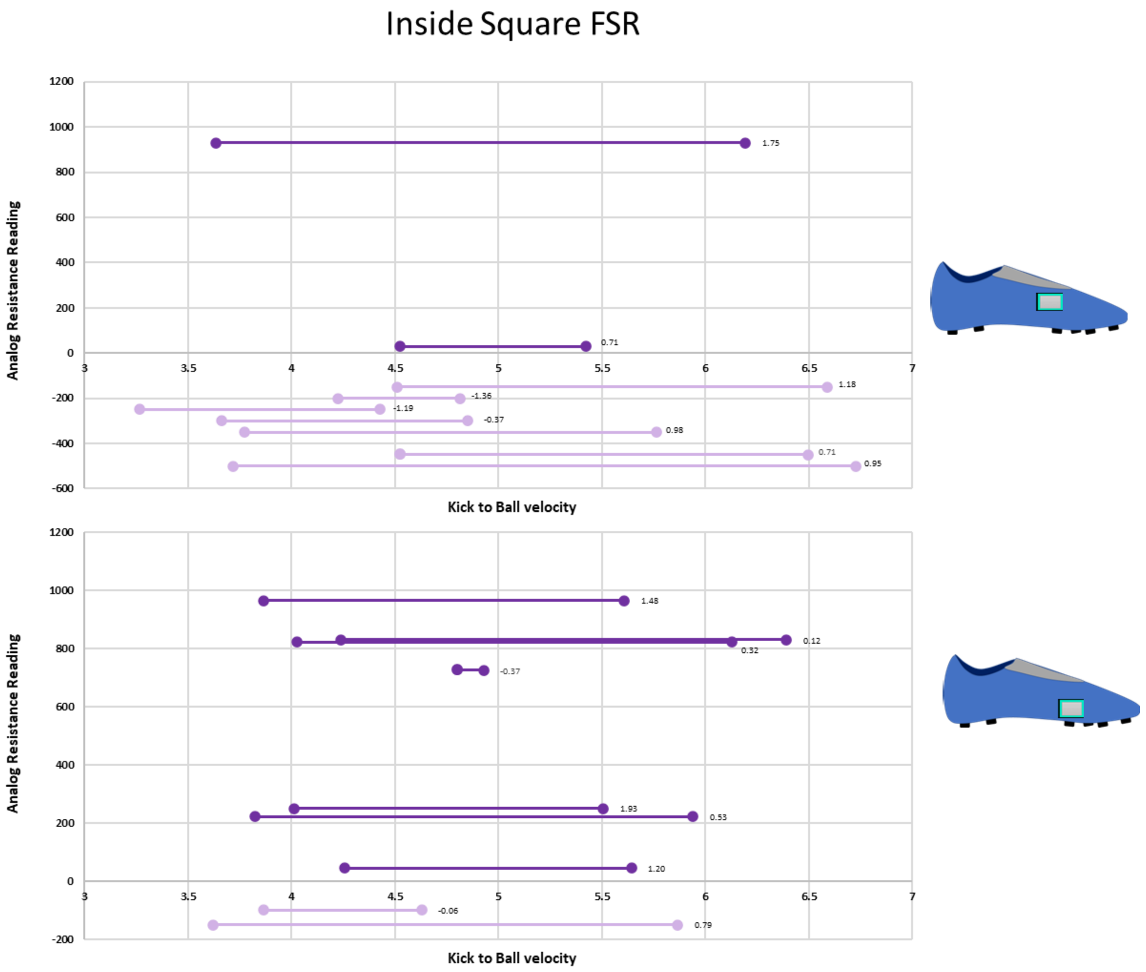
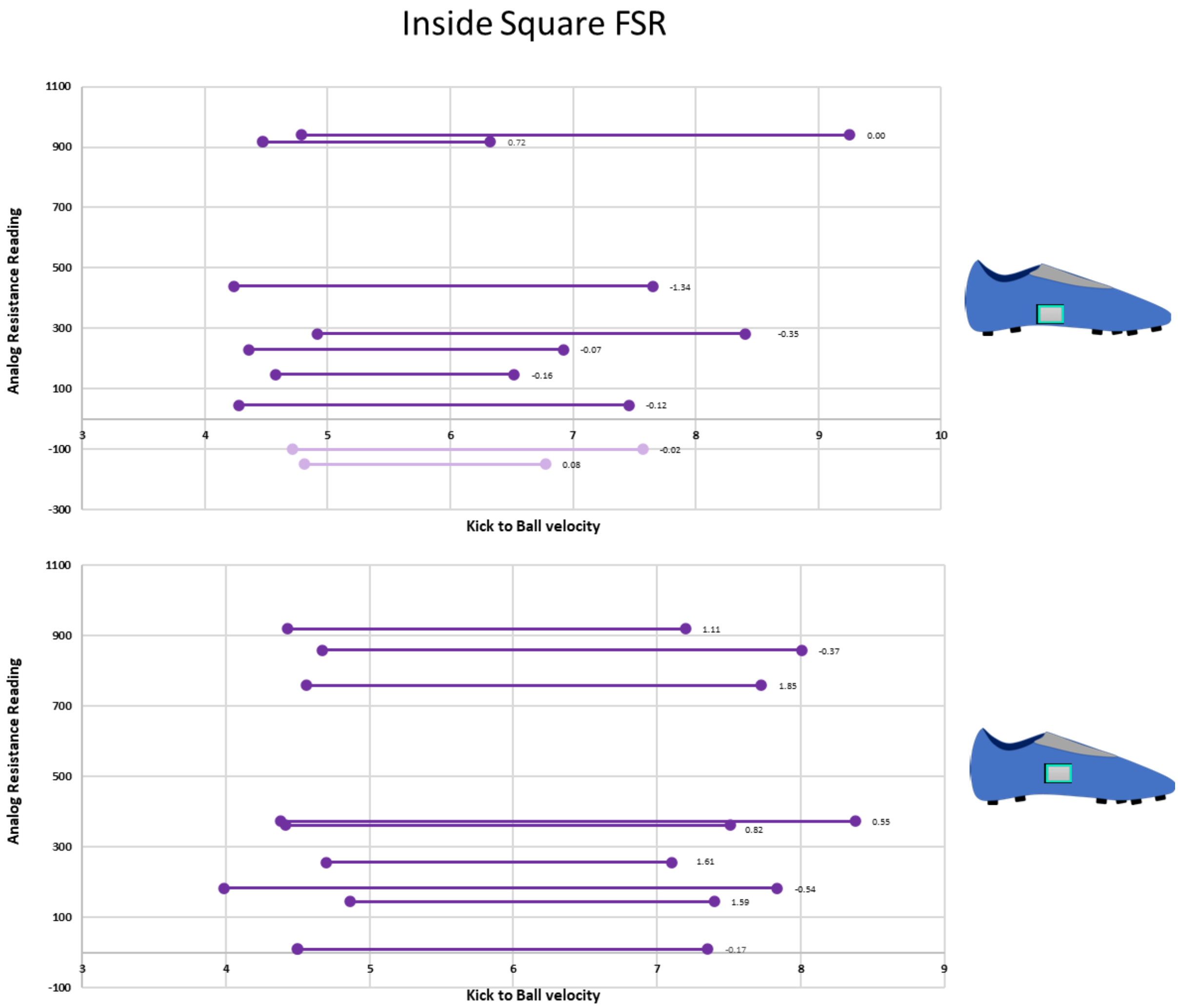


Figure 10.7.25



Inside Square FSR

Figure 10.7.26

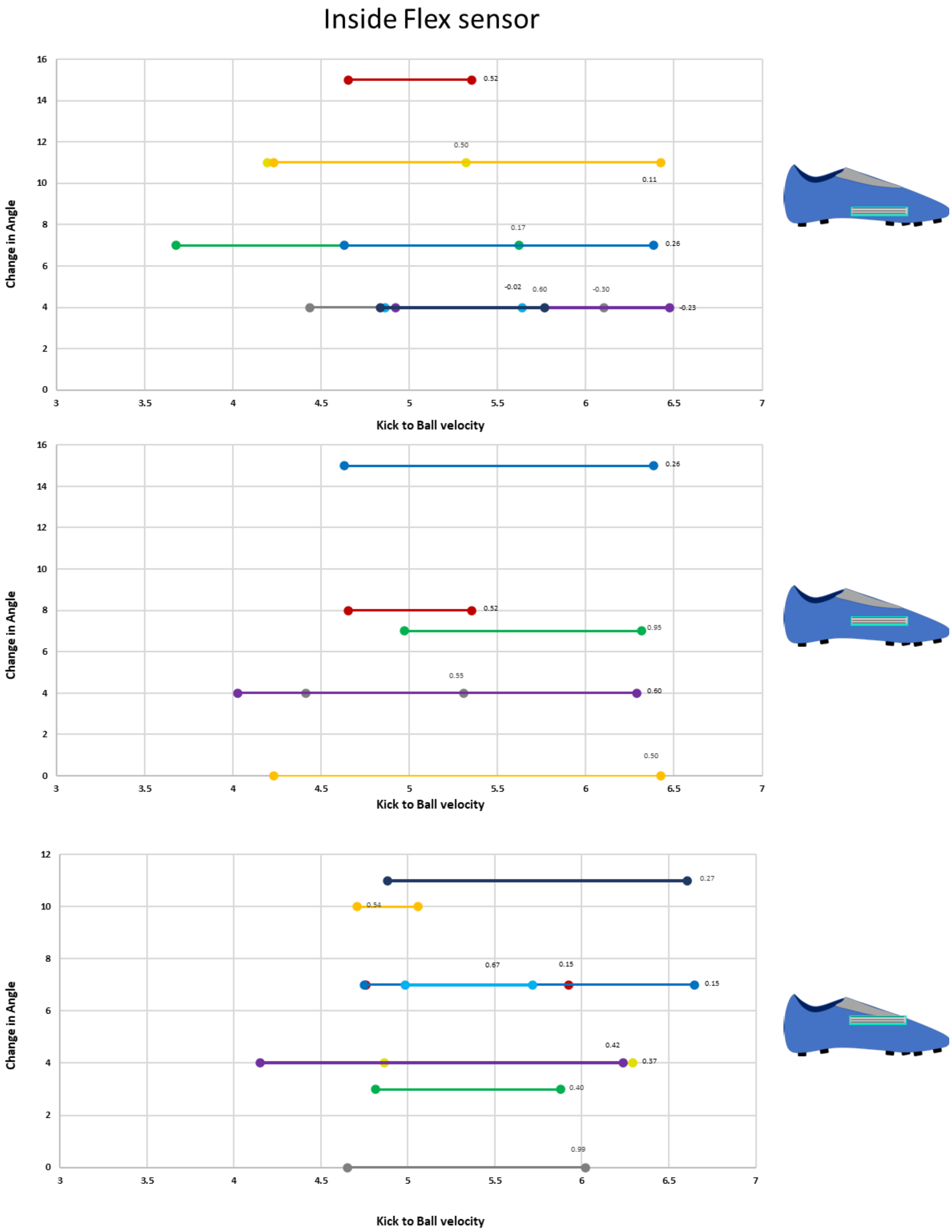


Figure 10.7.27

Inside Flex sensor

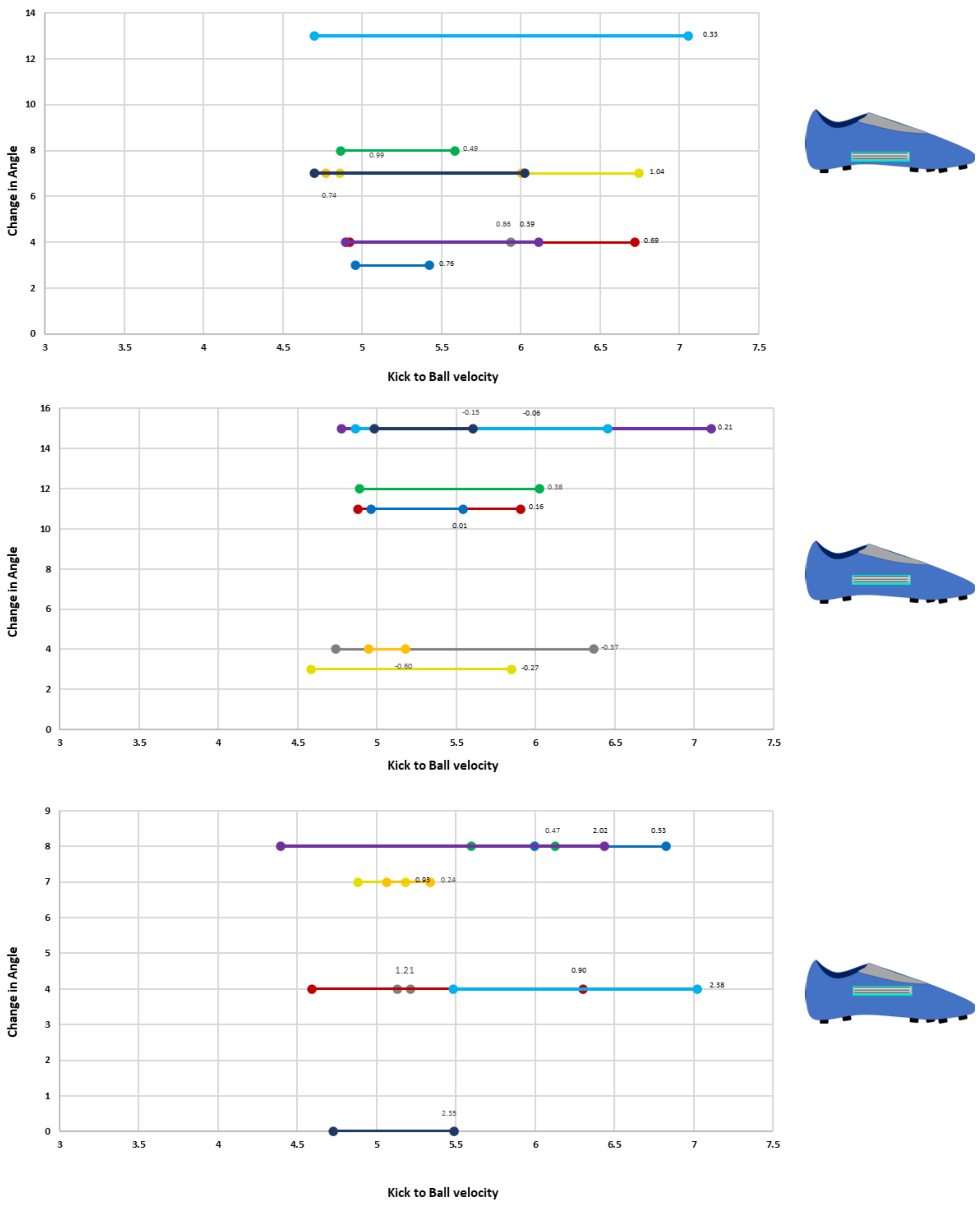


Figure 10.7.28

Inside Long sensitive resistance

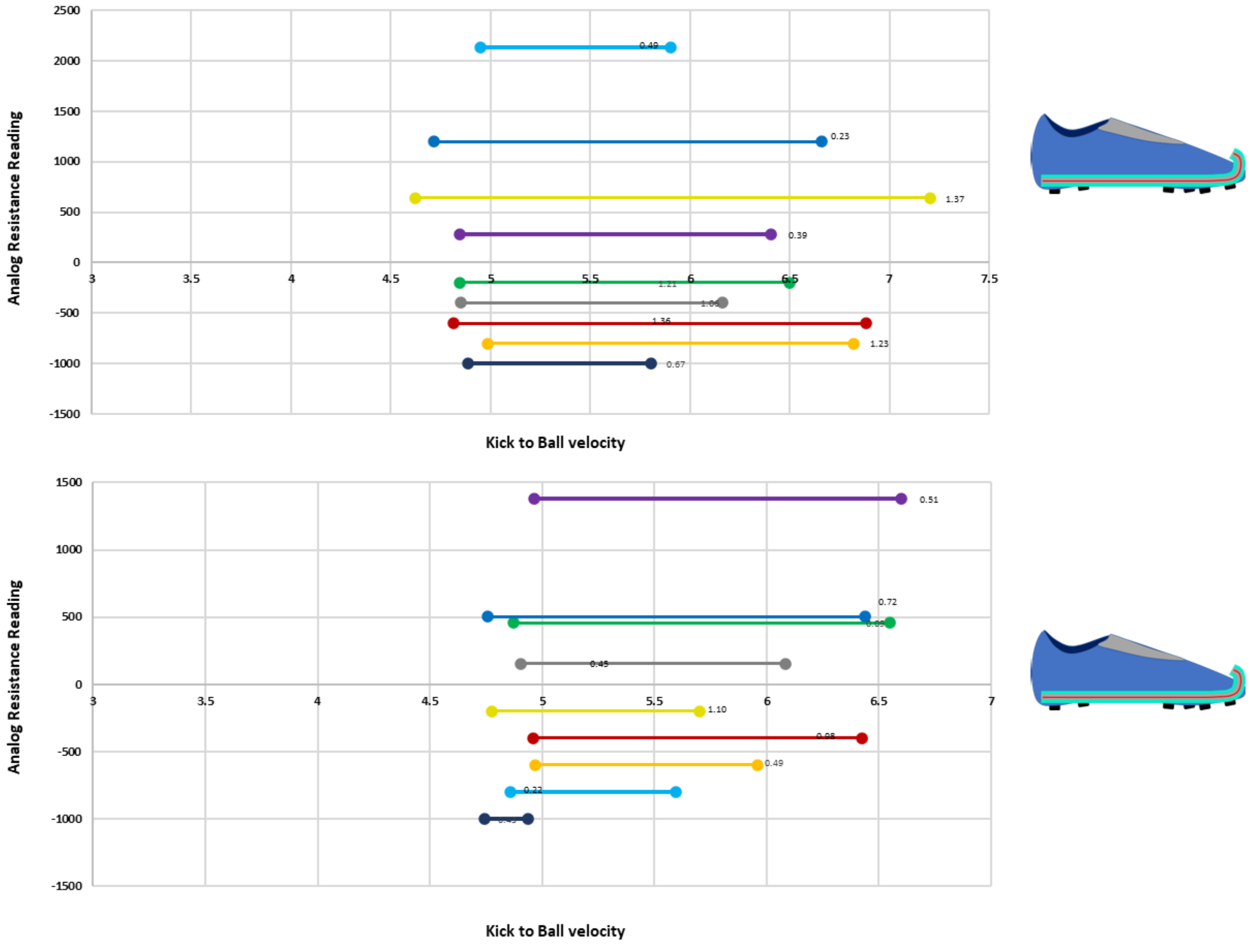


Figure 10.7.29

Inside Long sensitive resistance

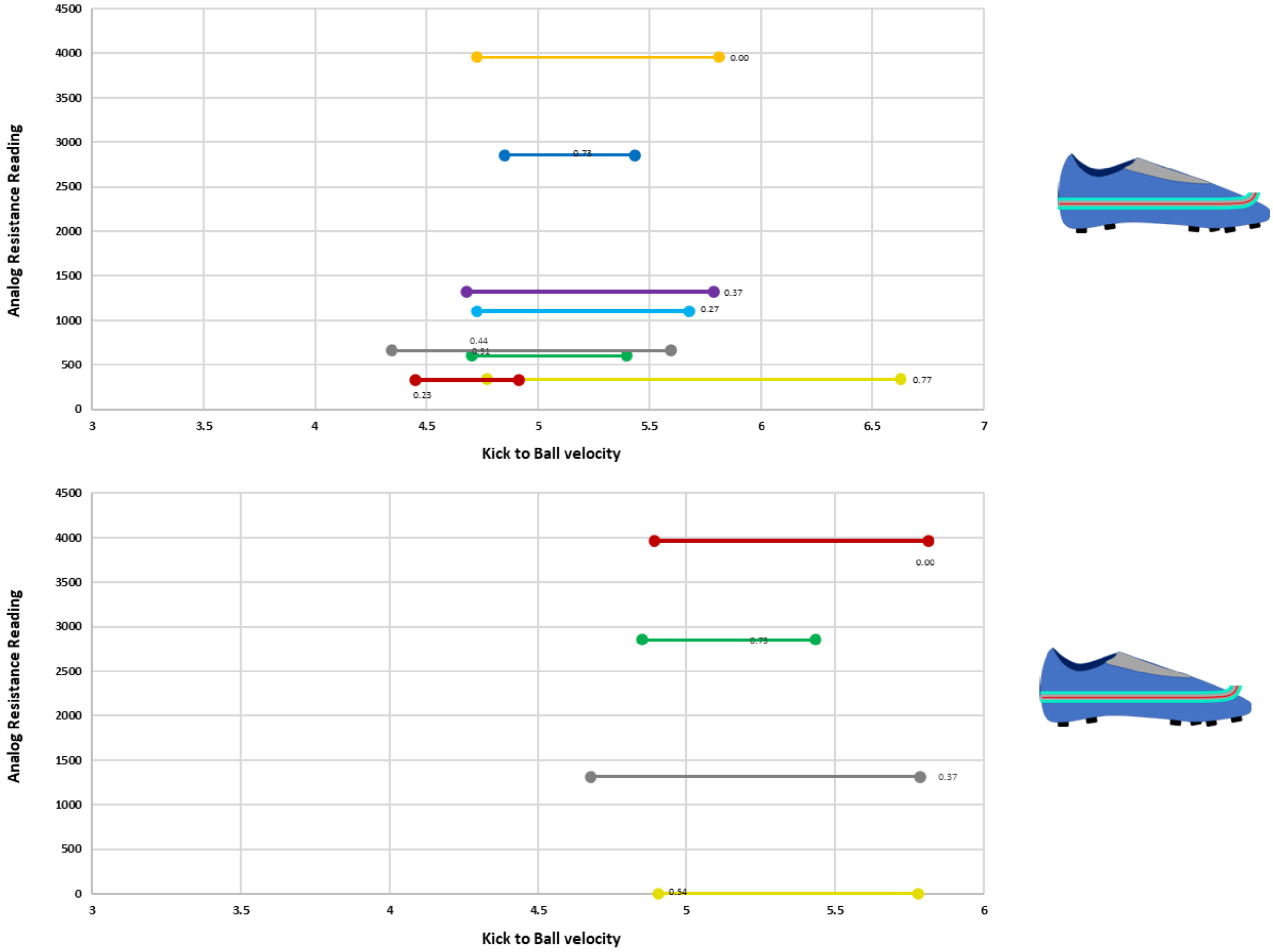


Figure 10.7.30

Inside Long sensitive resistance

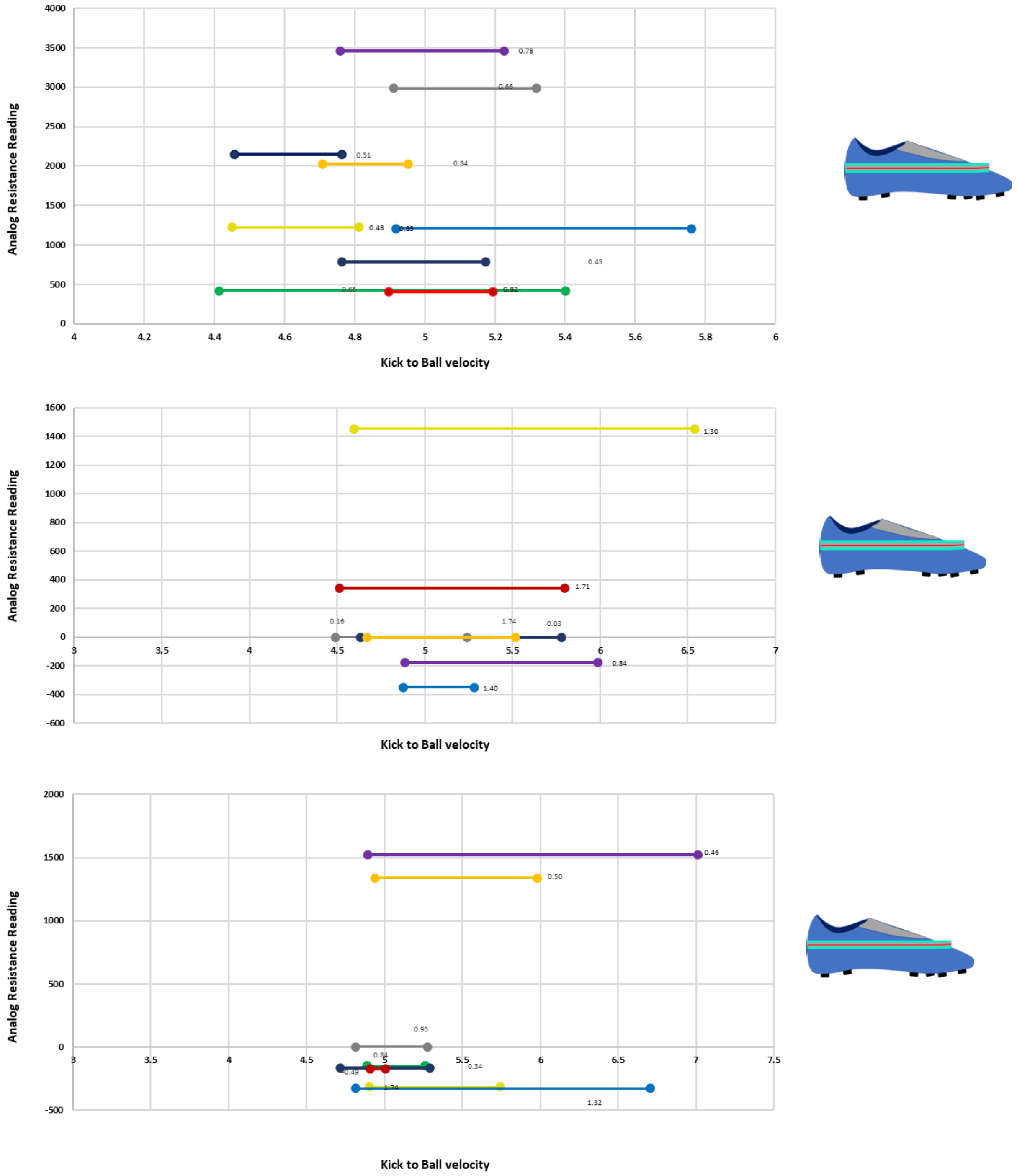


Figure 10.7.31

The following figures are the pendulum test of repeatability results for square and circle FSR sensor data. These are split into their laces and inside shot configuration where, the format displays a line graph of the full result, followed by the box and whisker plots displaying FSR contact distribution, before and after accuracy filter. The sensor configuration (treatments) schematics are also shown.

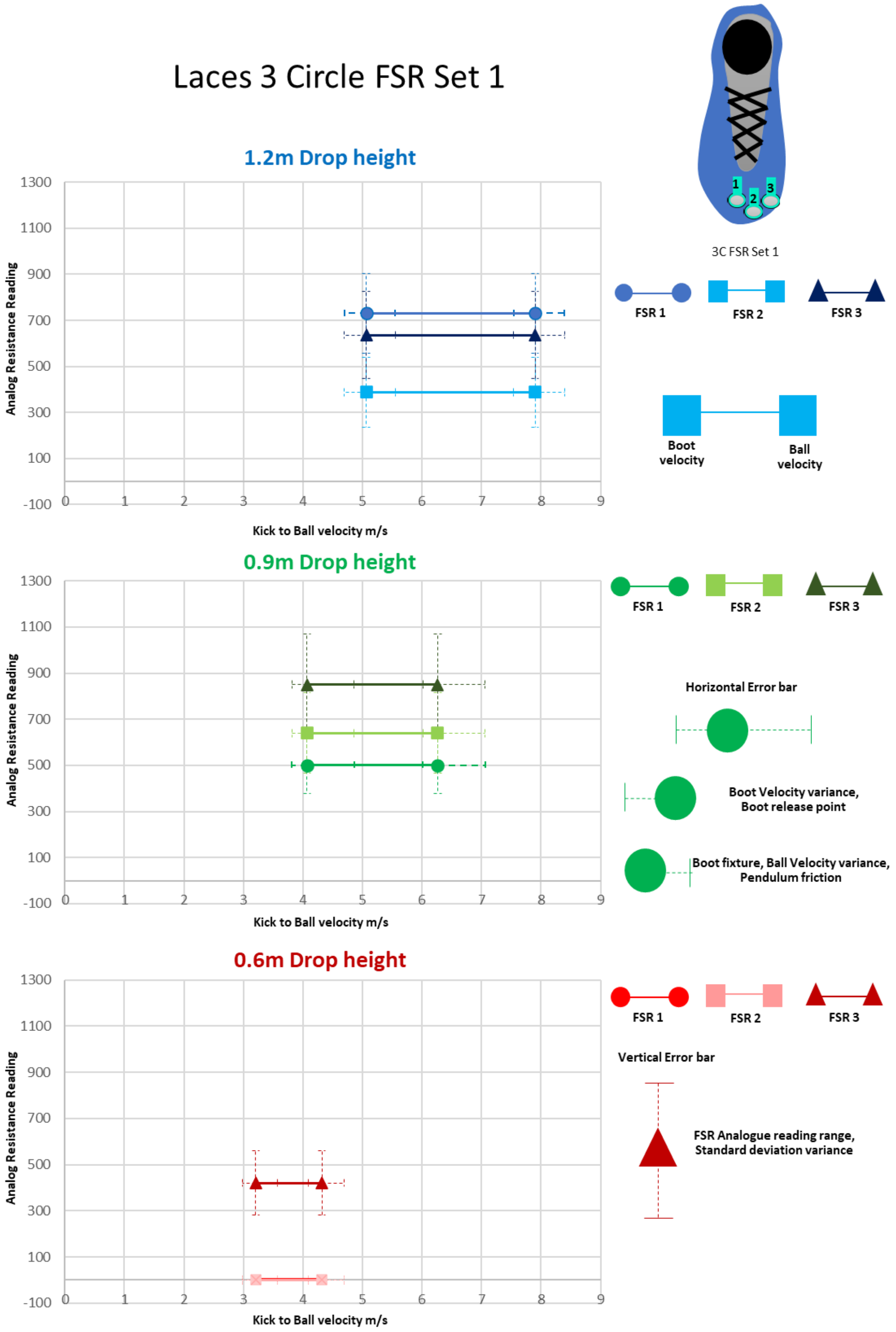


Figure 10.7.32

Laces 3 Circle FSR Set 1 with contact distribution : 1.2m Drop height

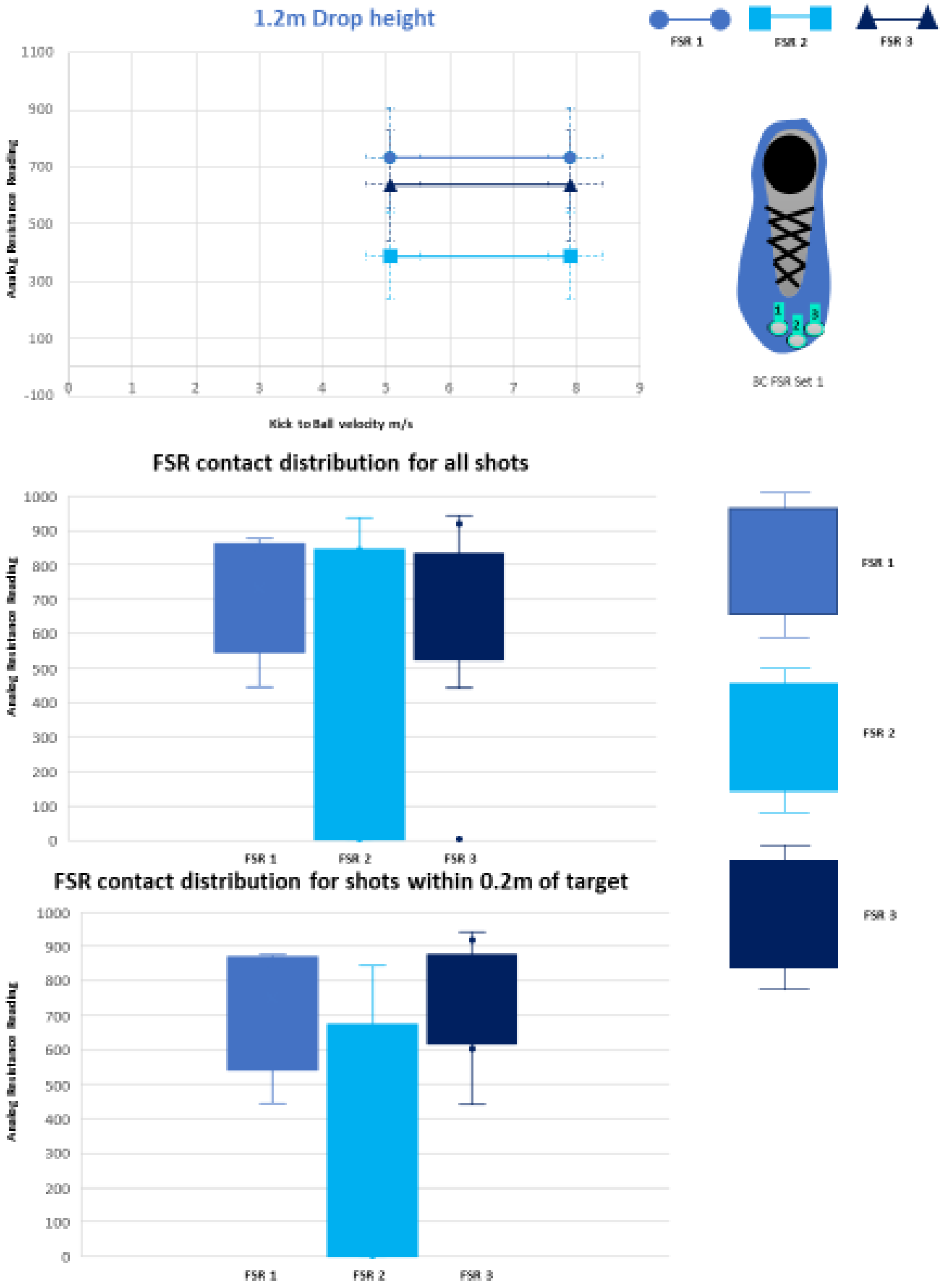


Figure 10.7.33

Laces 3 Circle FSR Set 1 with contact distribution : 0.9m Drop height

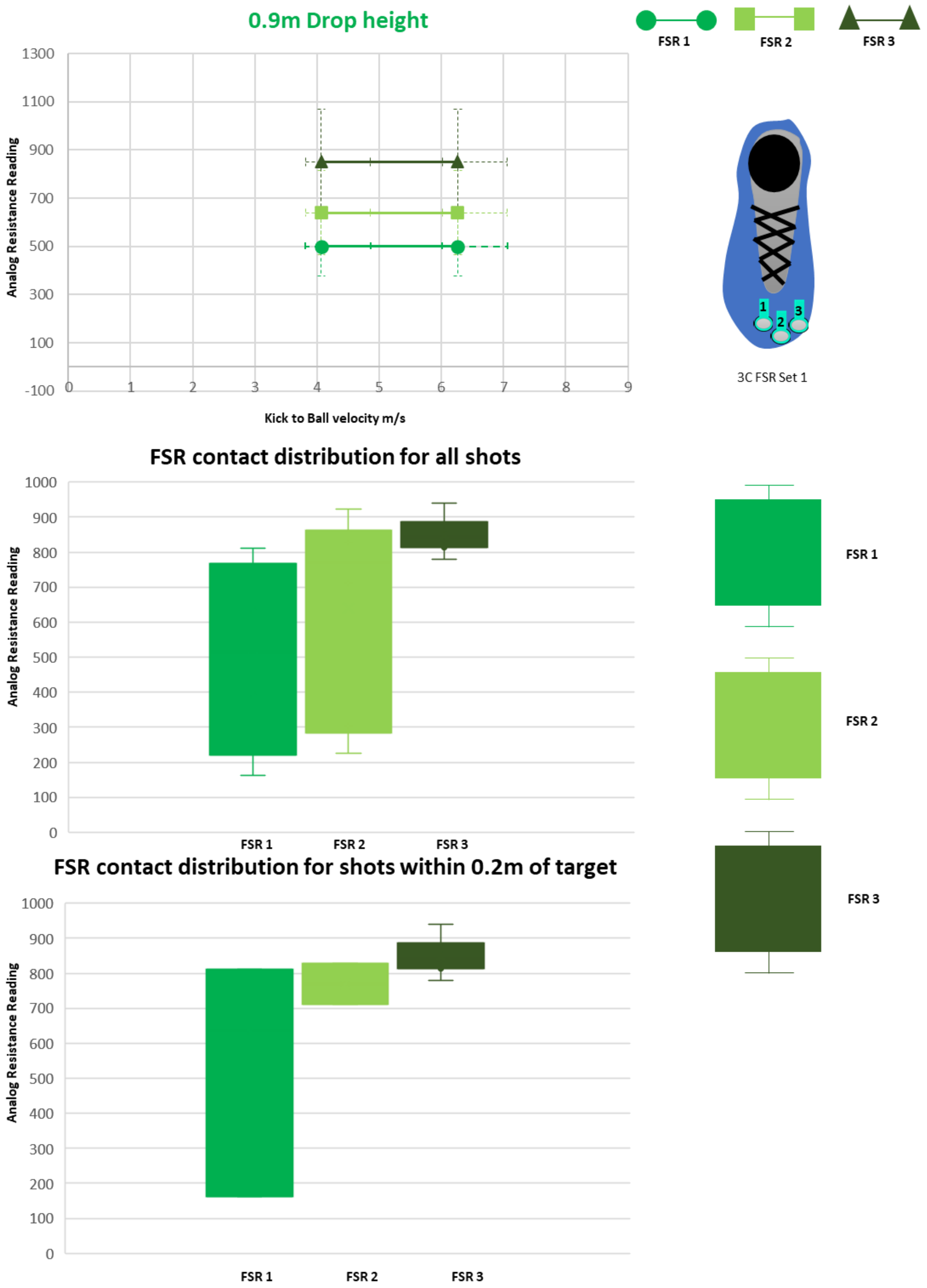


Figure 10.7.34

Laces 3 Circle FSR Set 1 with contact distribution : 0.6m Drop height

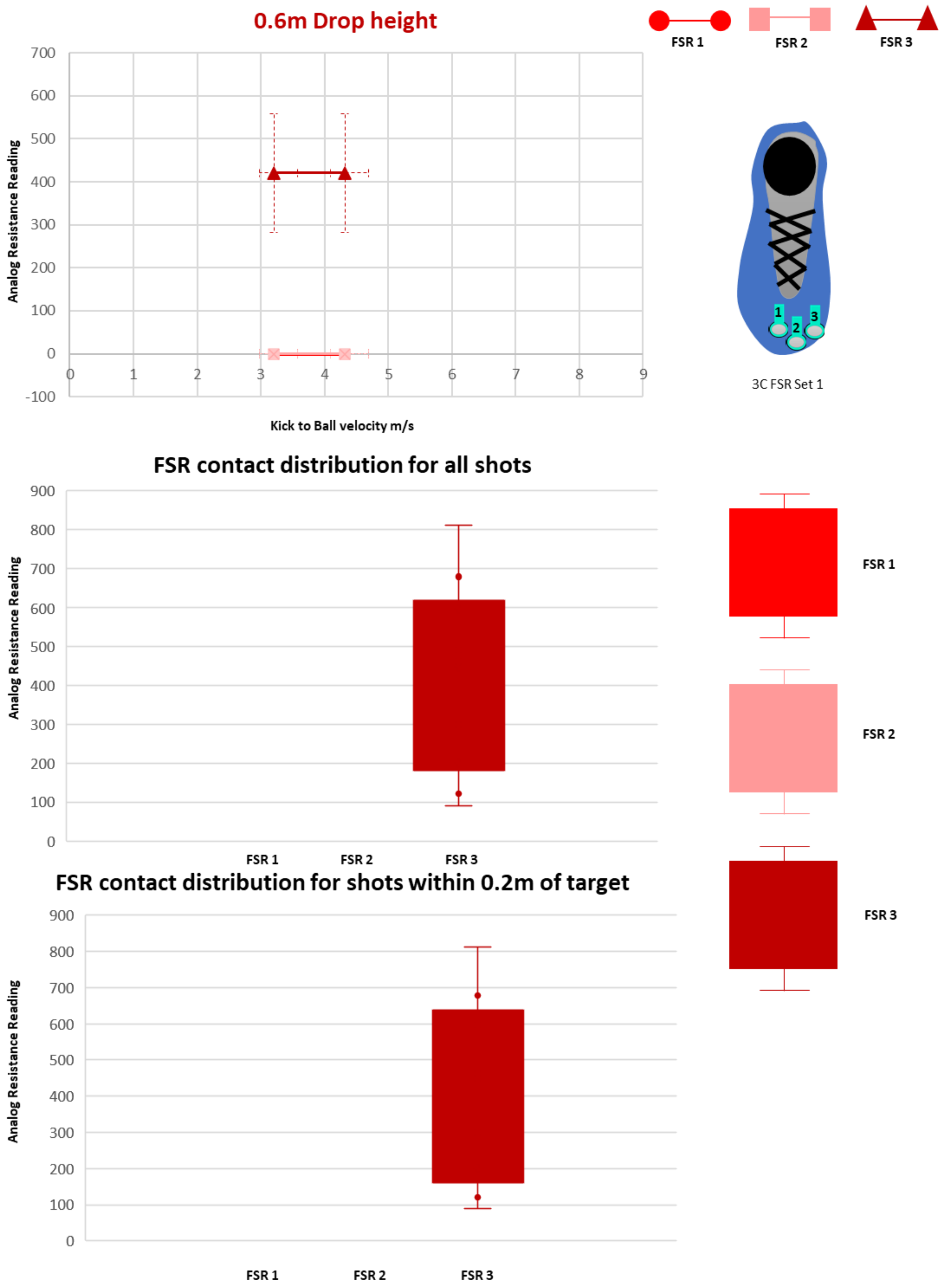


Figure 10.7.35

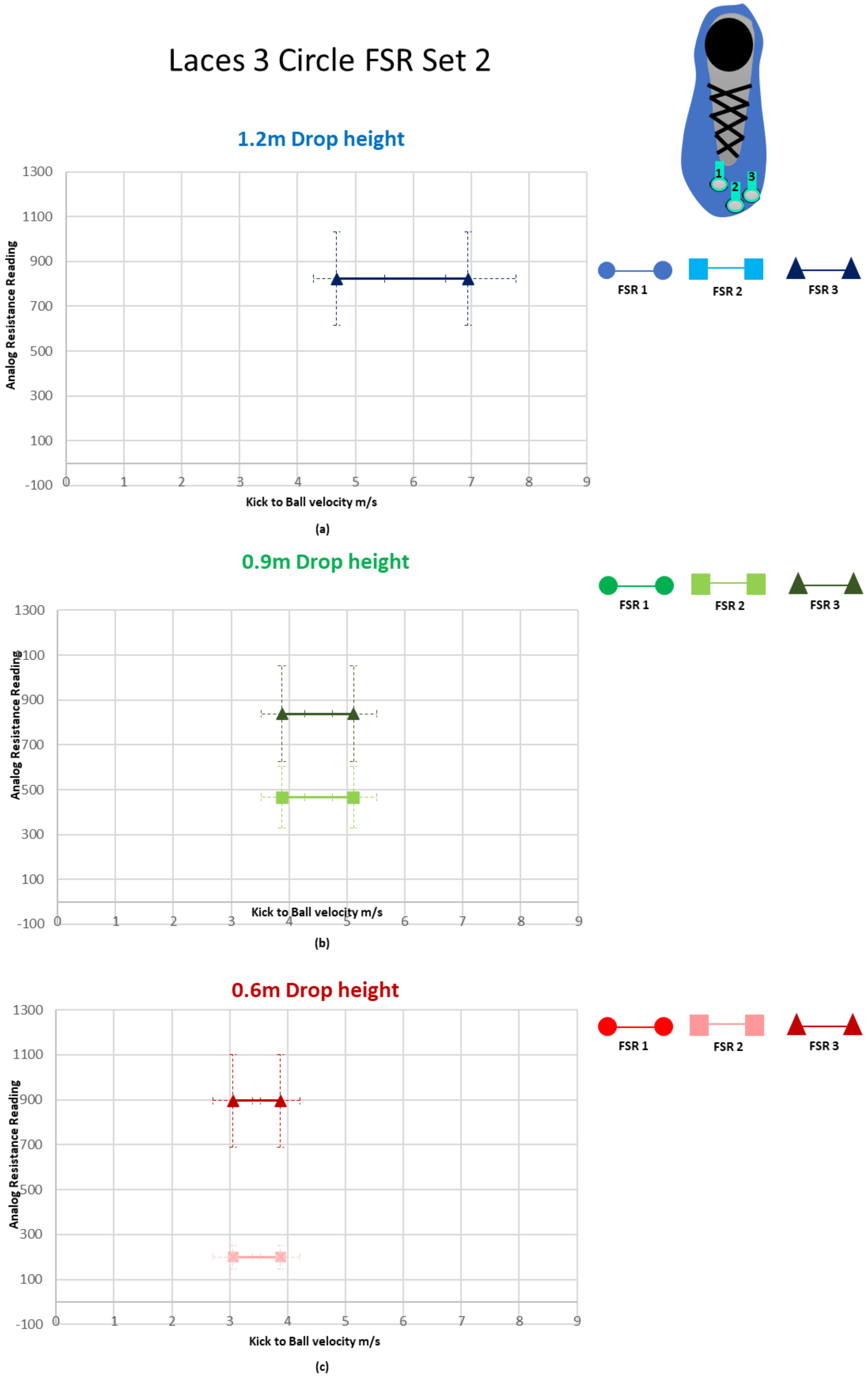
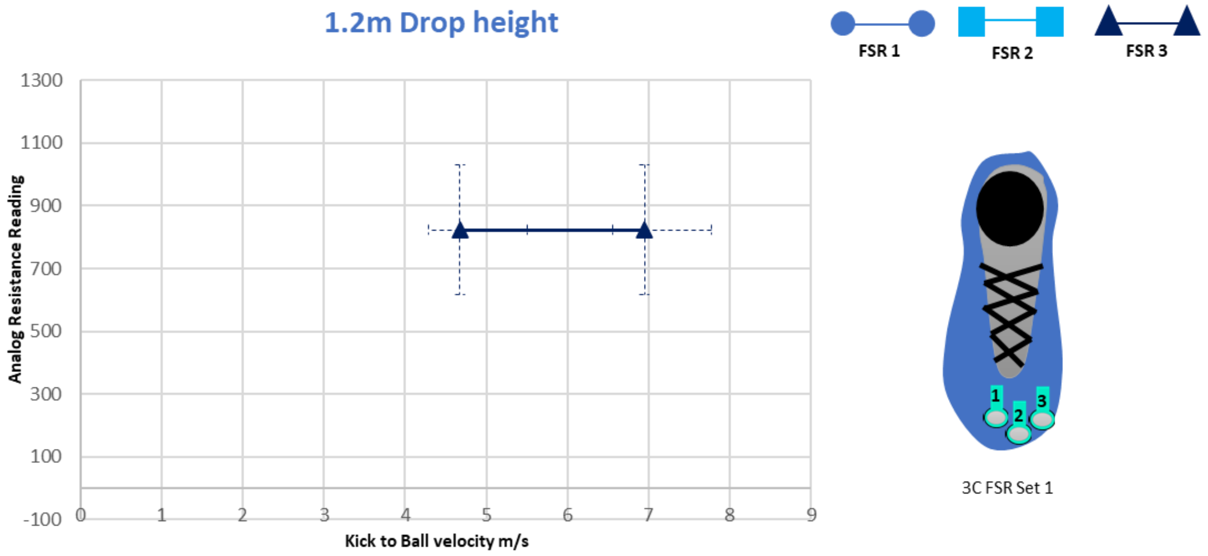
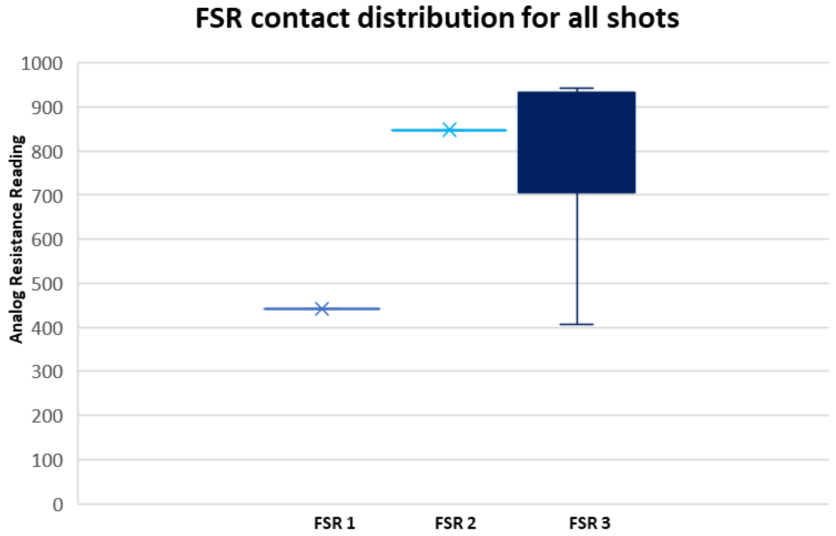
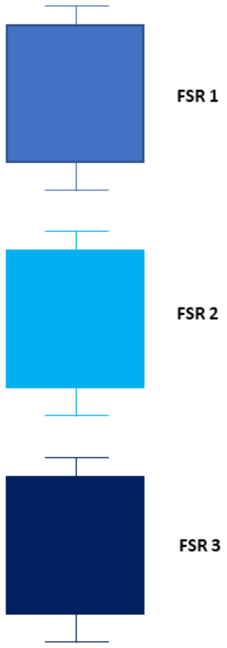


Figure 10.7.36

Laces 3 Circle FSR Set 2 with contact distribution : 1.2m Drop height







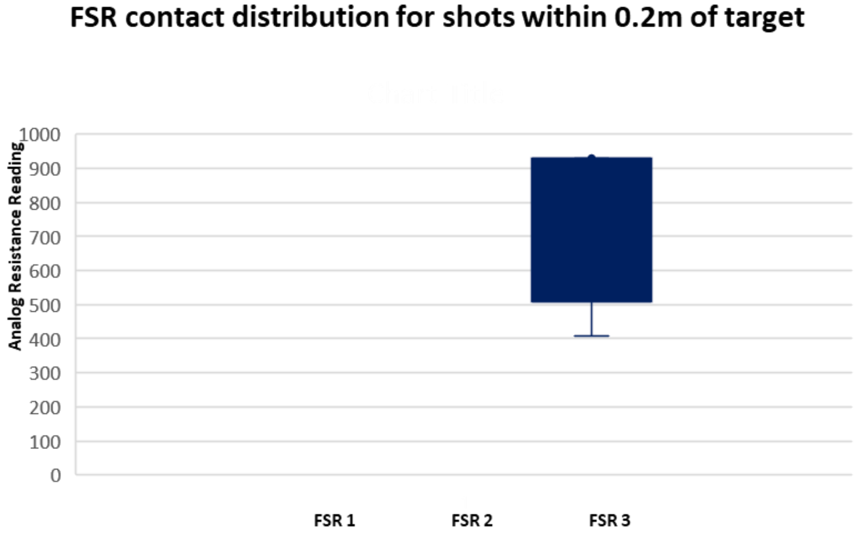


Figure 10.7.37

Laces 3 Circle FSR Set 2 with contact distribution : 0.9m Drop height

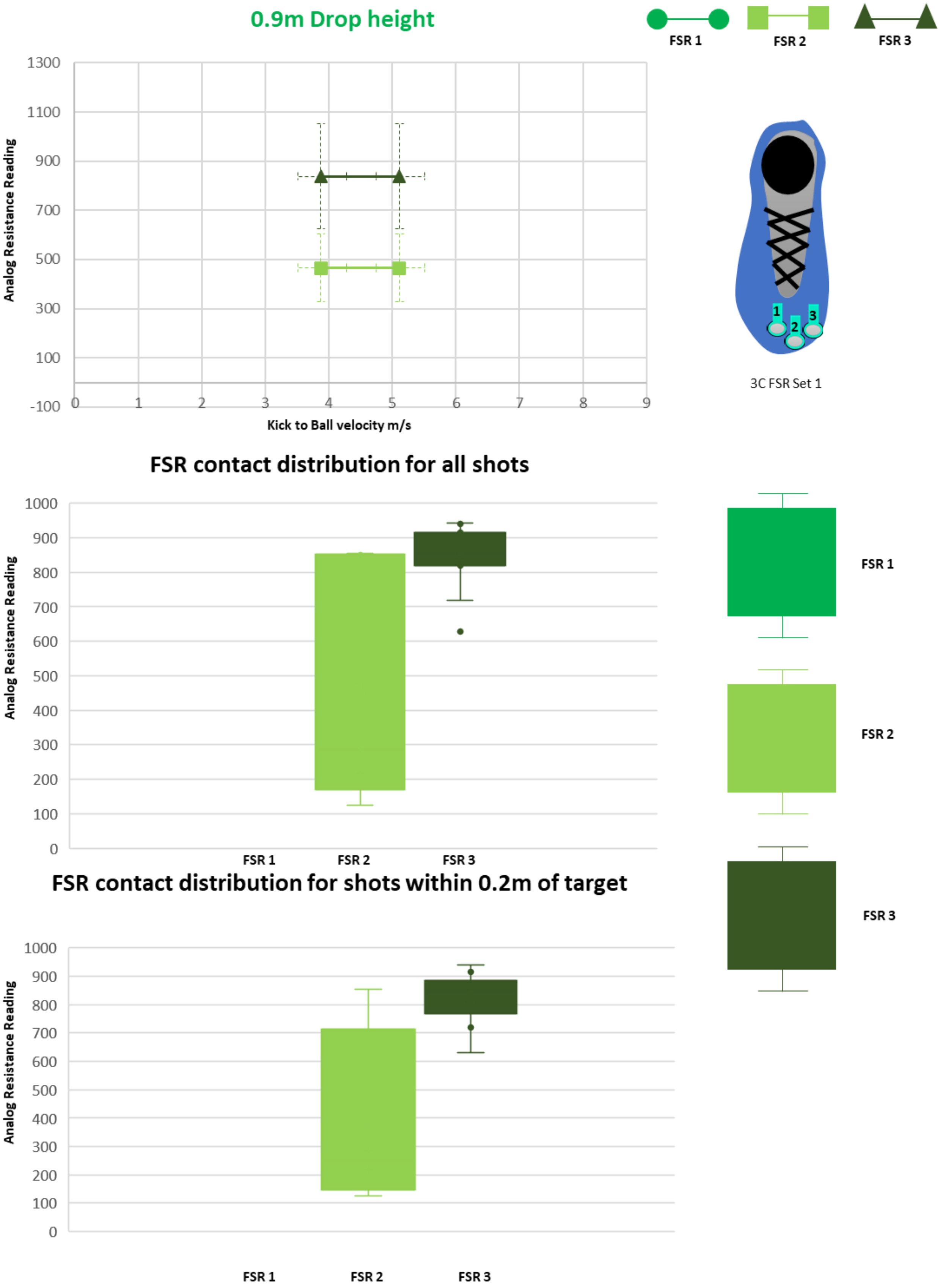
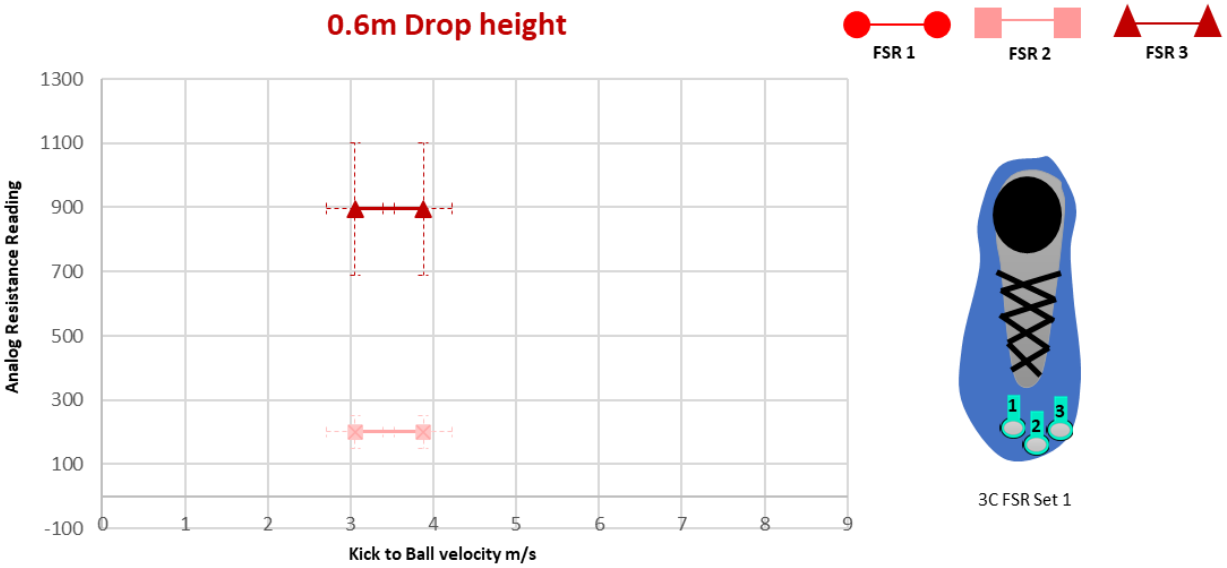
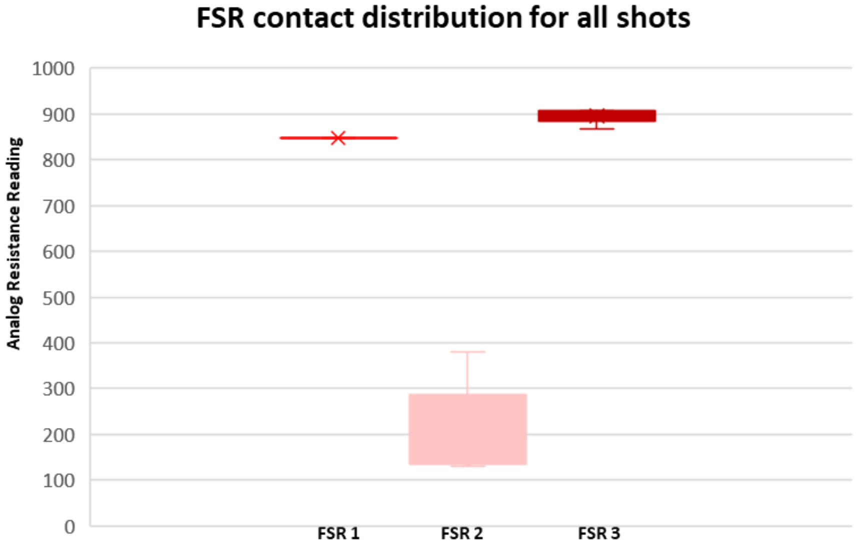


Figure 10.7.38

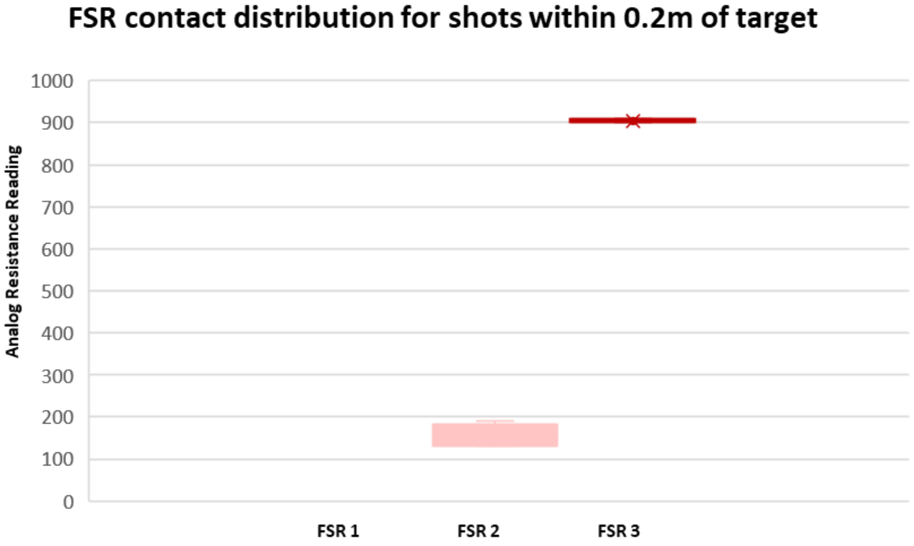
Laces 3 Circle FSR Set 2 with contact distribution : 0.6m Drop height



0.6m Drop height



FSR contact distribution for all shots



FSR contact distribution for shots within 0.2m of target

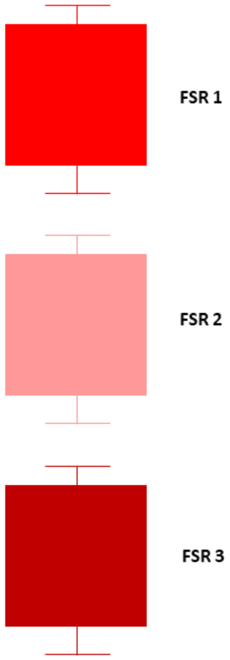
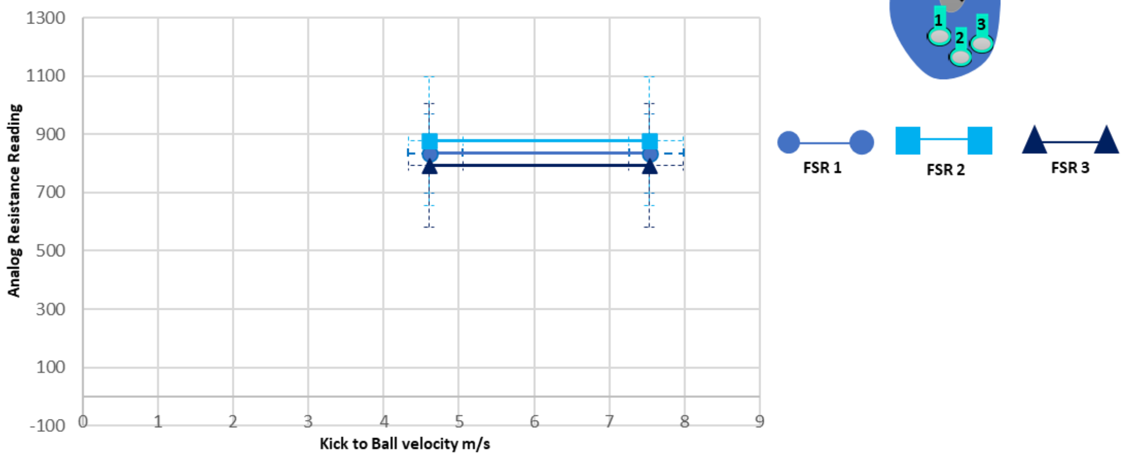


Figure 10.7.39

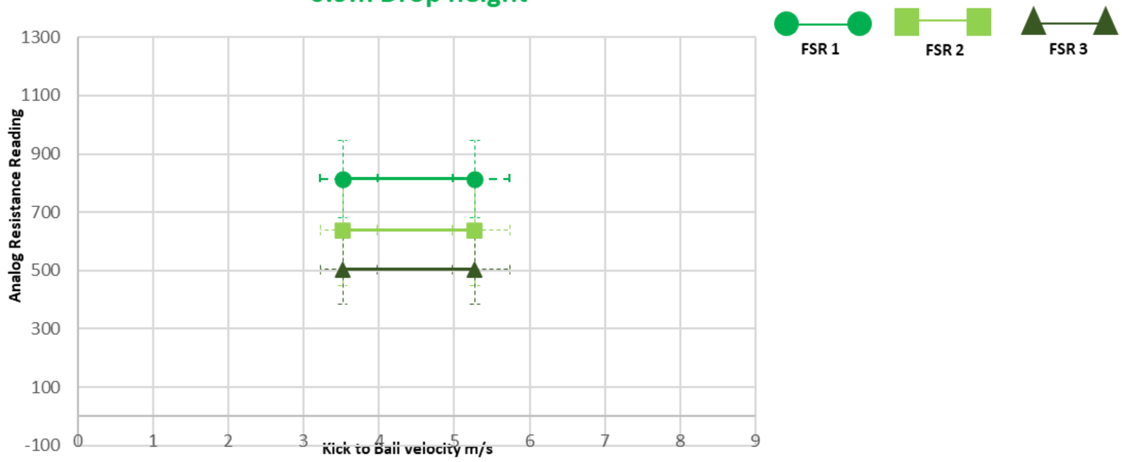
Laces 3 Circle FSR Set 3

1.2m Drop height



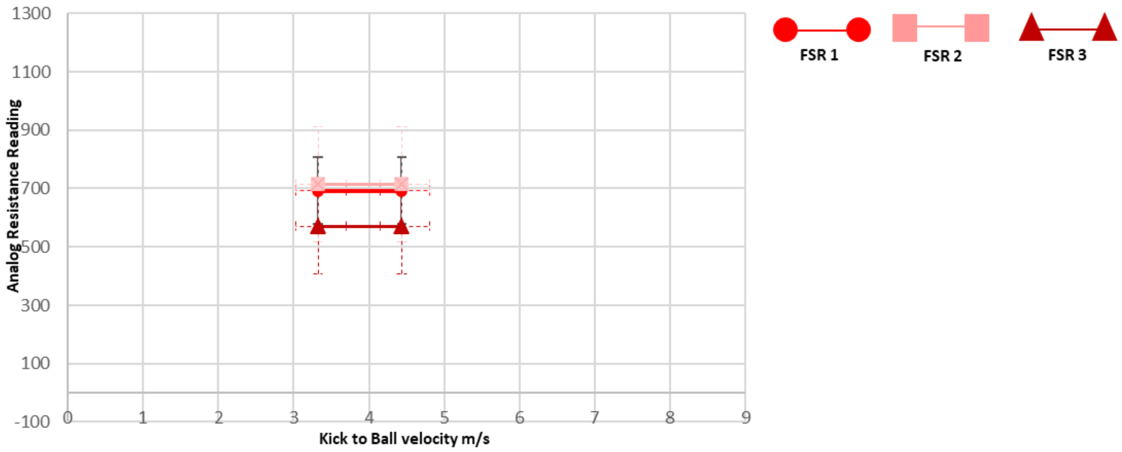
(a)

0.9m Drop height



(b)

0.6m Drop height



(c)

Figure 10.7.40

Laces 3 Circle FSR Set 3 with contact distribution : 1.2m Drop height

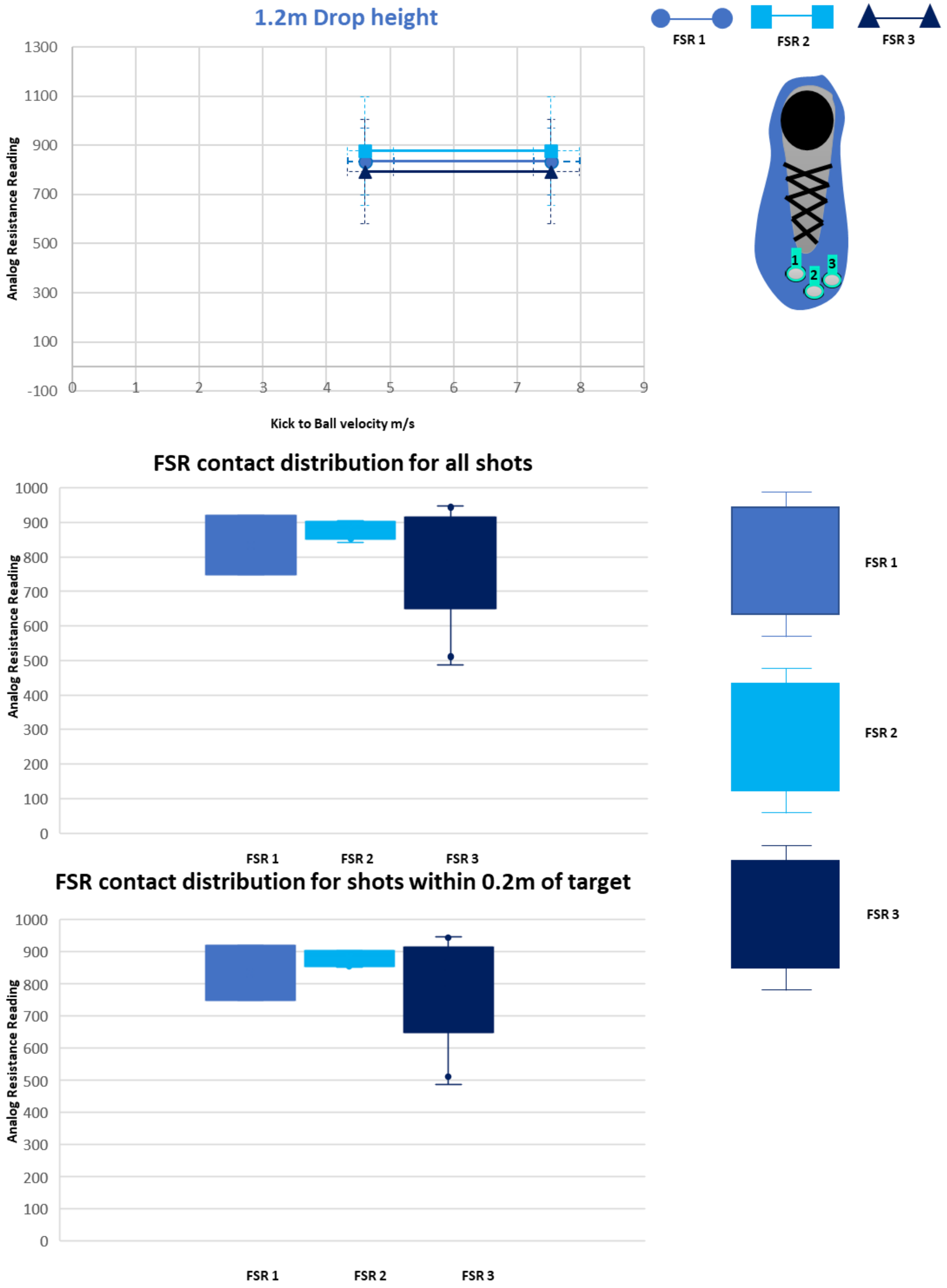
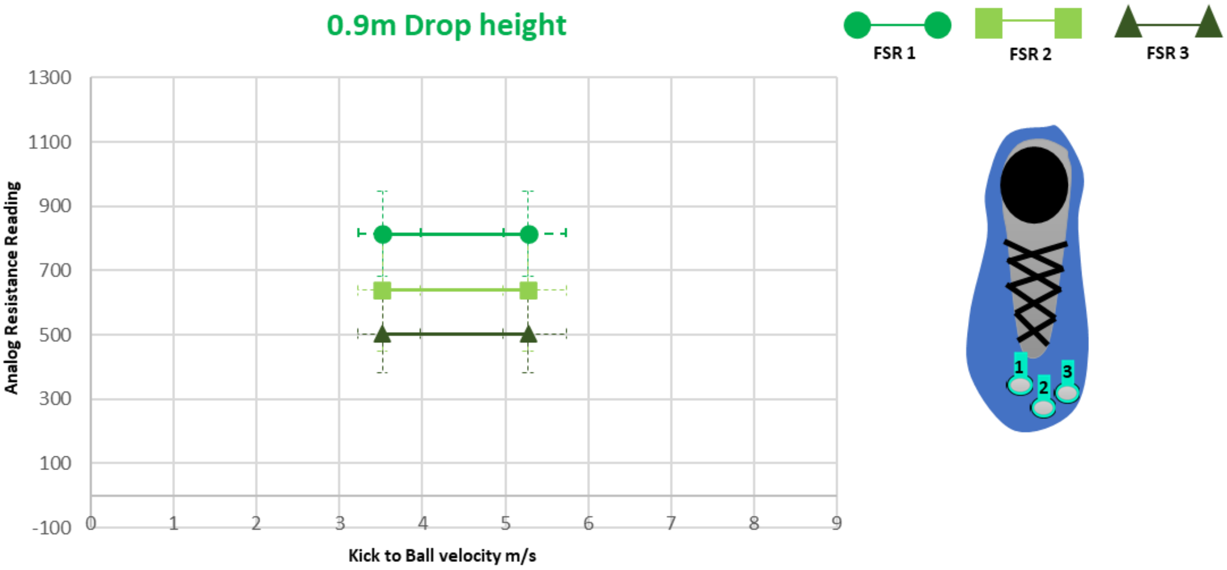
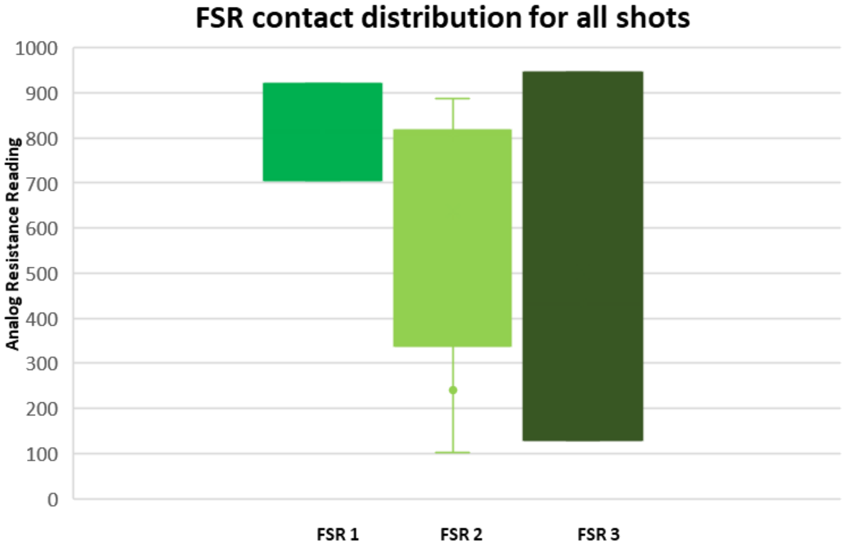


Figure 10.7.41

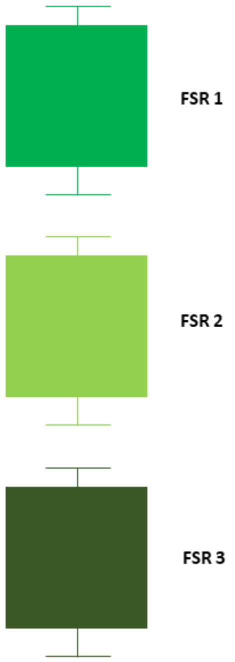
Laces 3 Circle FSR Set 3 with contact distribution : 0.9m Drop height



0.9m Drop height



FSR contact distribution for all shots



FSR contact distribution for shots within 0.2m of target

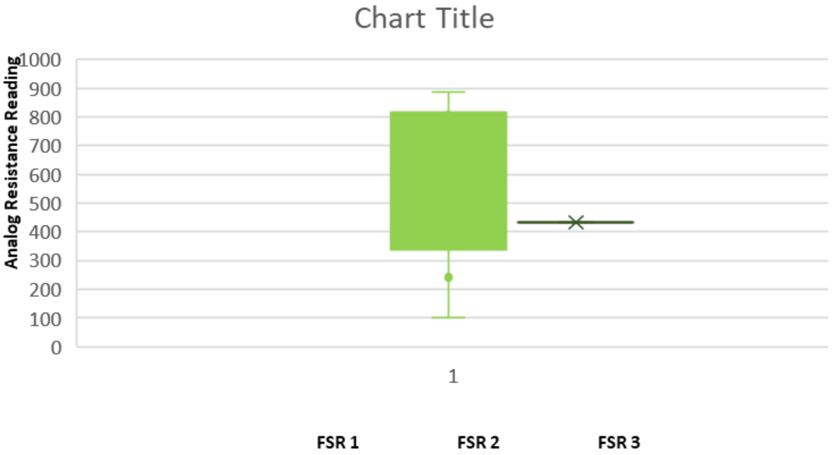


Figure 10.7.42

Laces 3 Circle FSR Set 3 with contact distribution : 0.6m Drop height

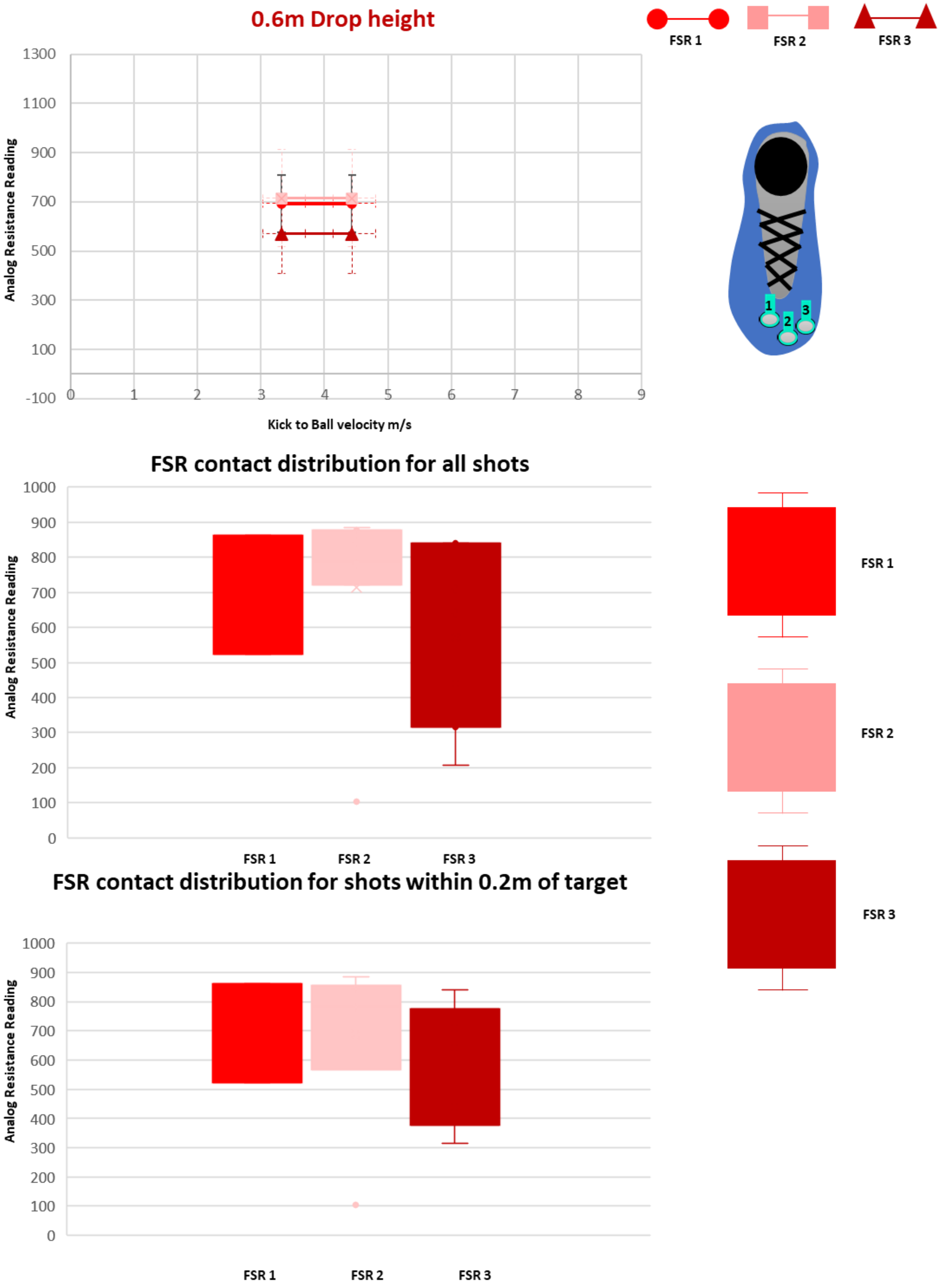
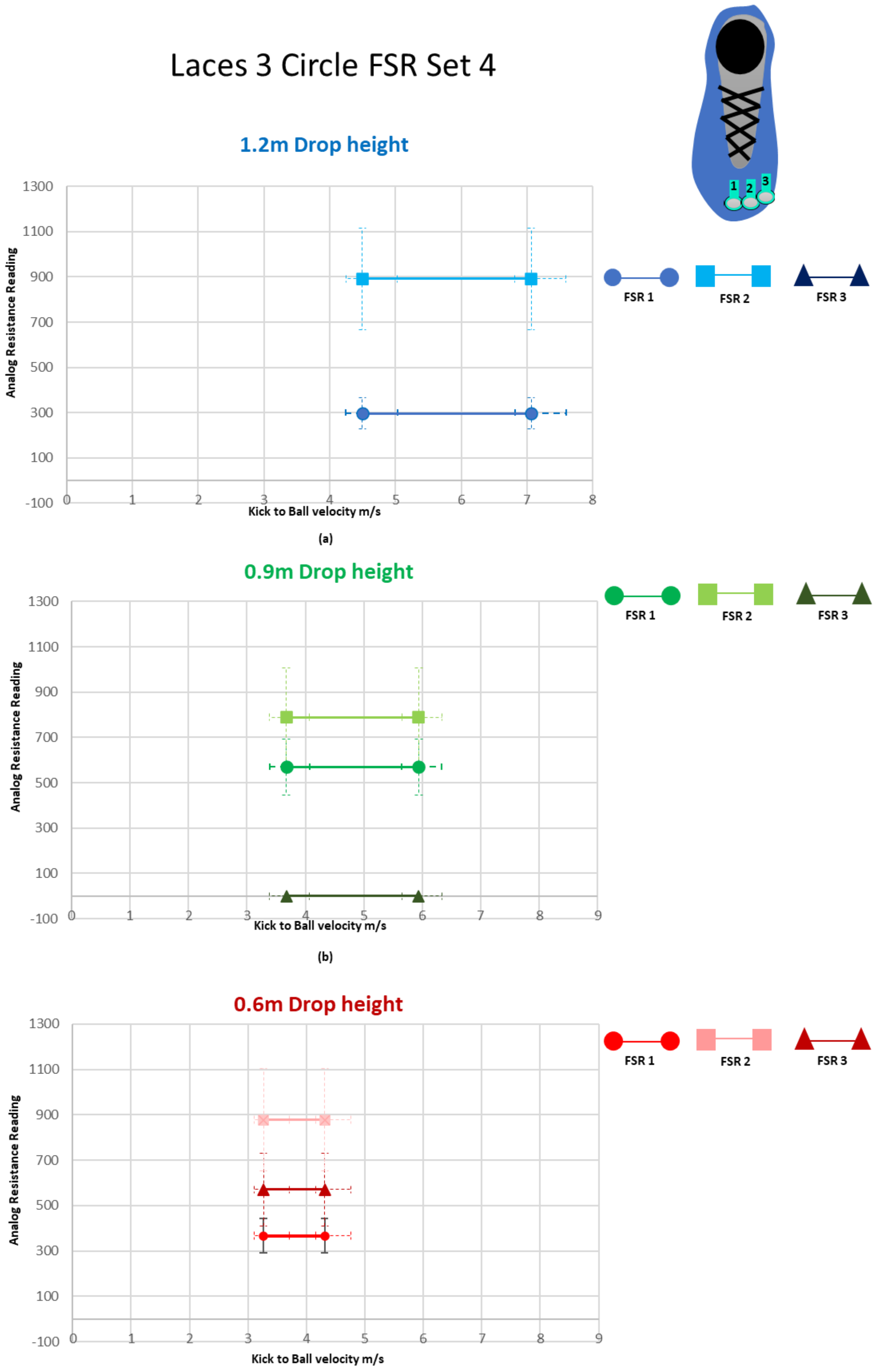


Figure 10.7.43

Laces 3 Circle FSR Set 4



(a)

(b)

(c)

Figure 10.7.44

Laces 3 Circle FSR Set 4 with contact distribution : 1.2m Drop height

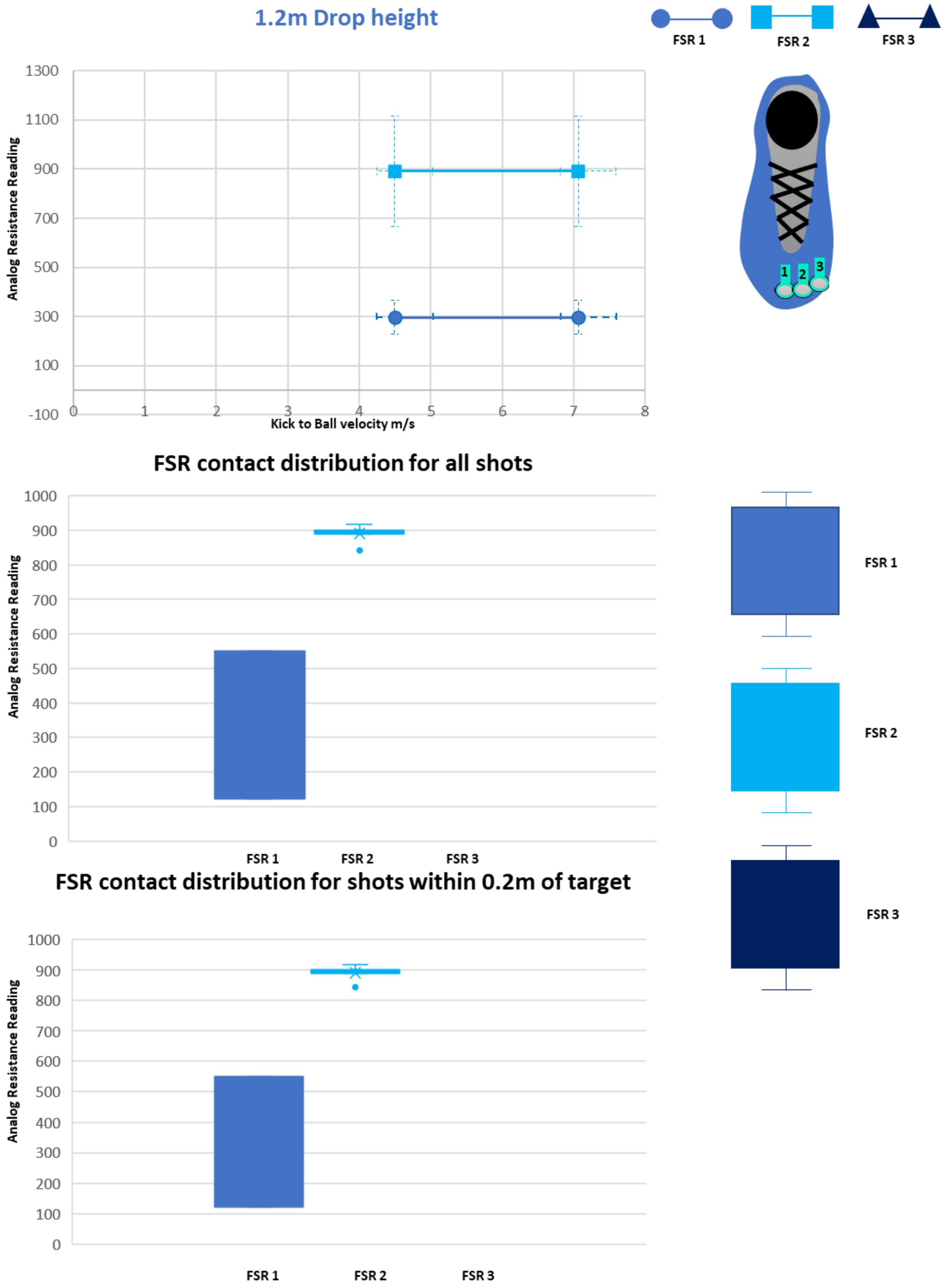


Figure 10.7.45

Laces 3 Circle FSR Set 4 with contact distribution : 0.9m Drop height

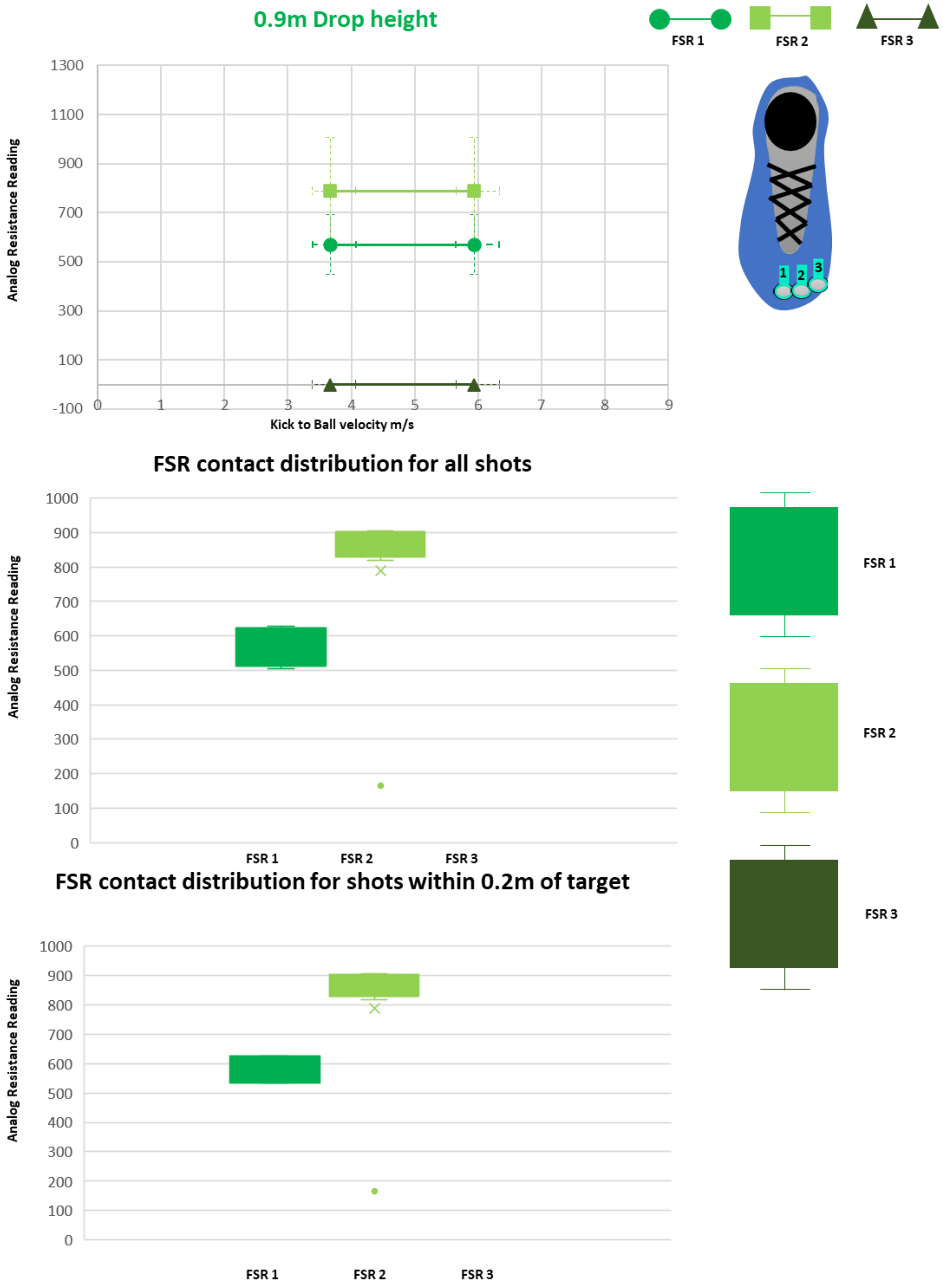
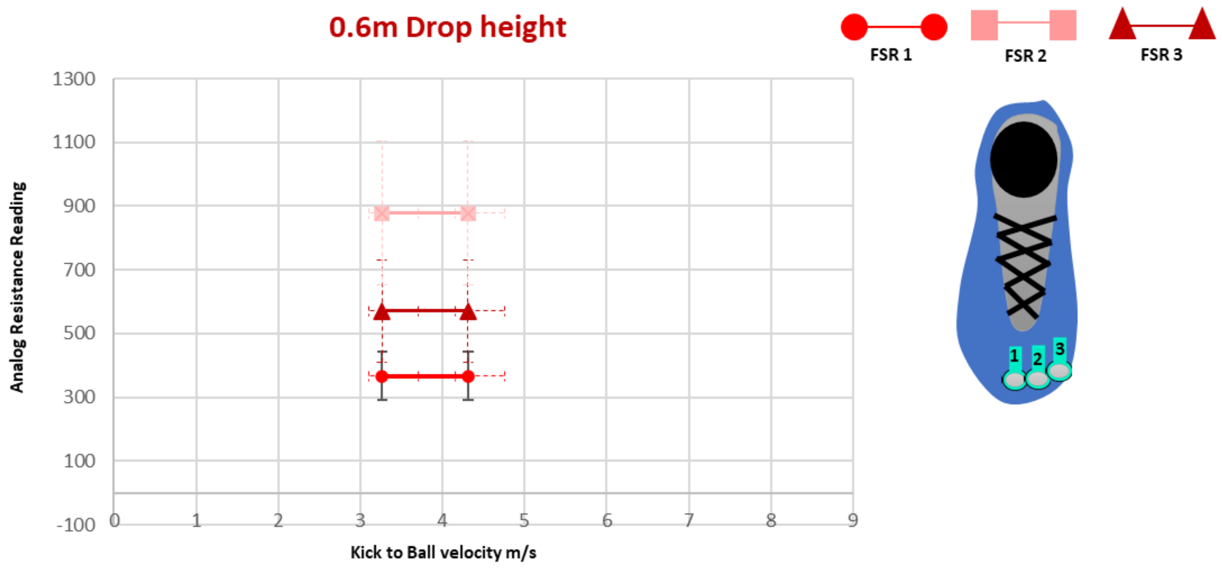


Figure 10.7.46

Laces 3 Circle FSR Set 4 with contact distribution : 0.6m Drop height



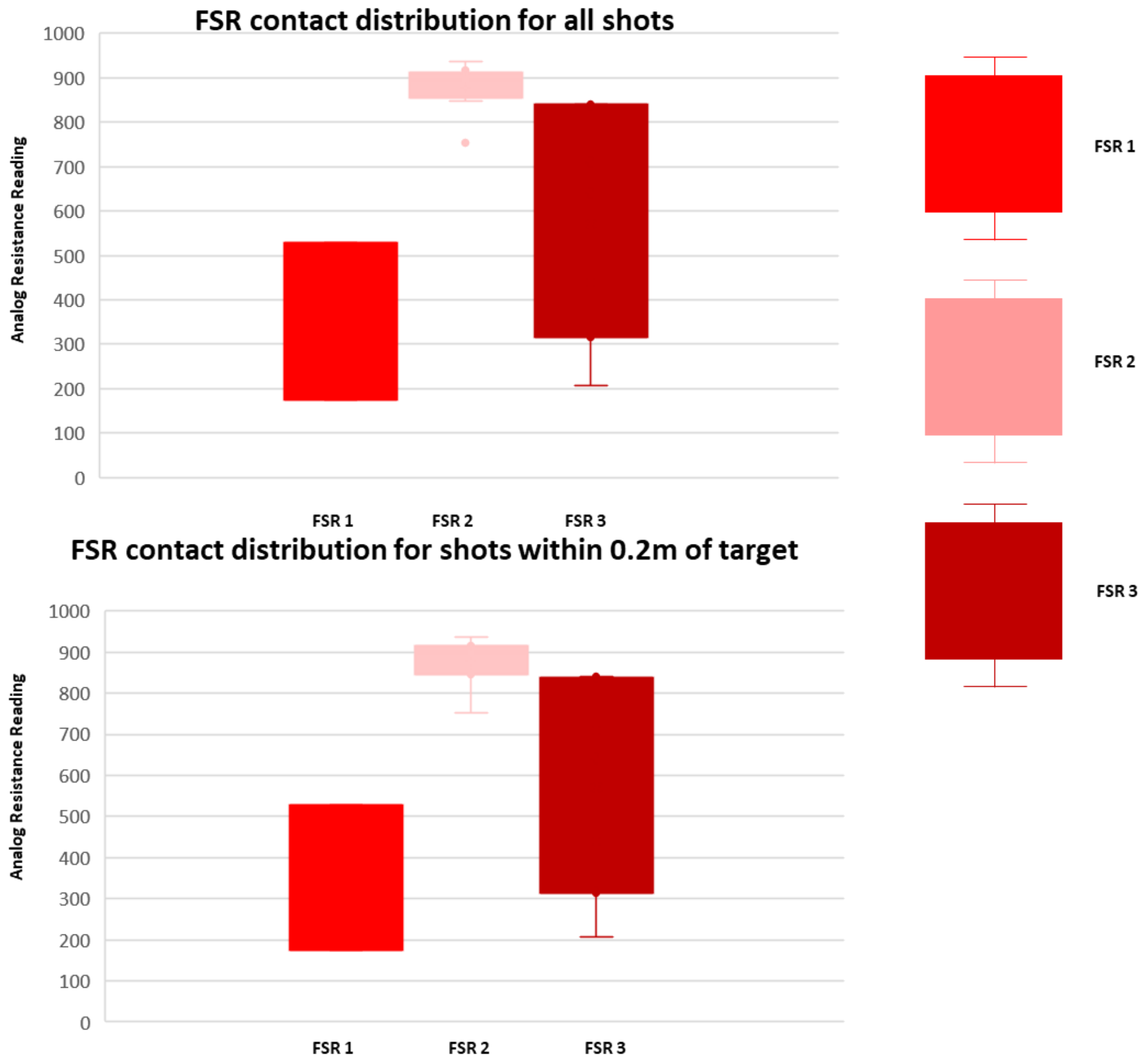


Figure 10.7.47

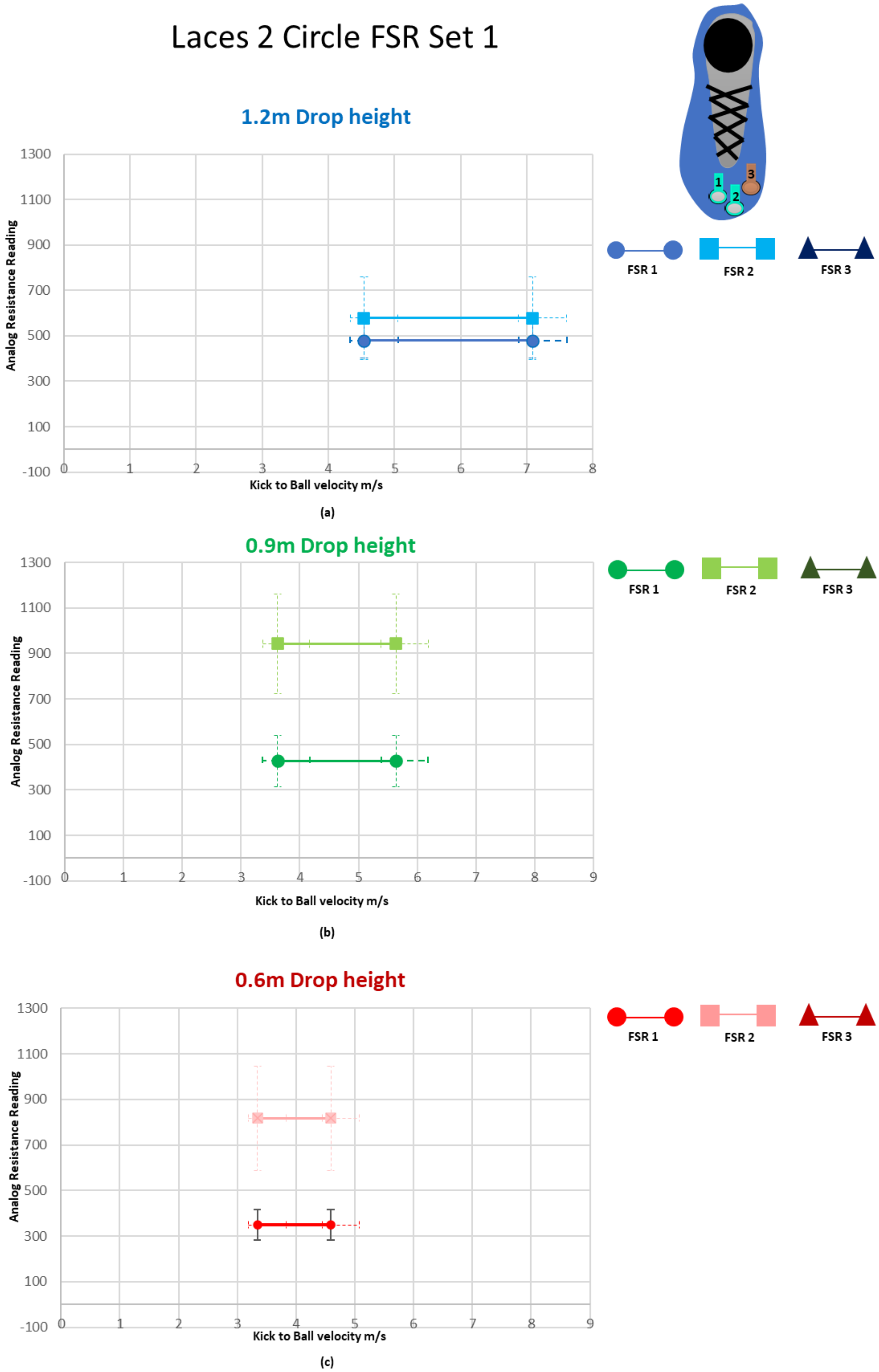


Figure 10.7.48

Laces 2 Circle FSR Set 1 with contact distribution : 1.2m Drop height

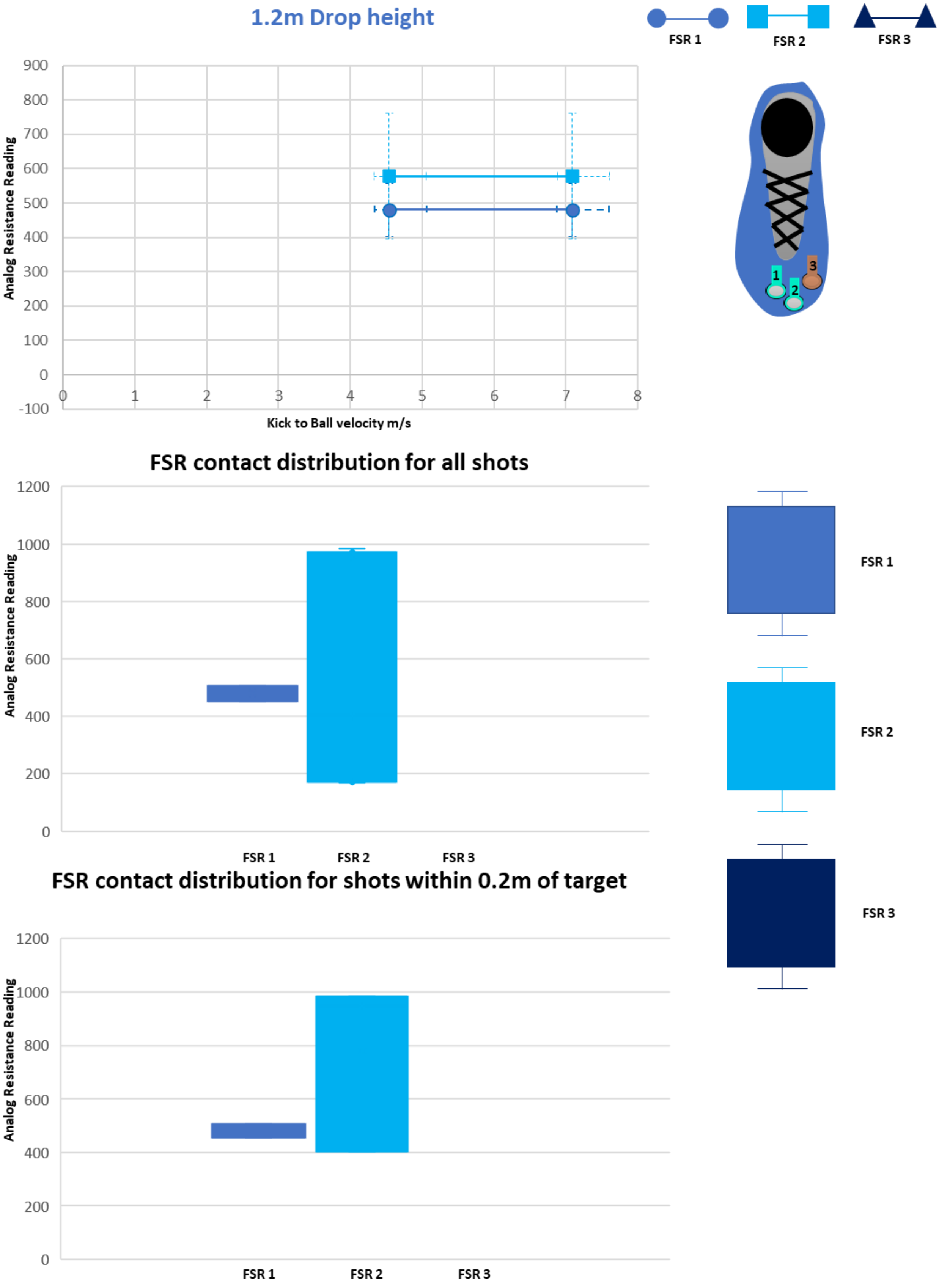


Figure 10.7.49

Laces 2 Circle FSR Set 1 with contact distribution : 0.9m Drop height

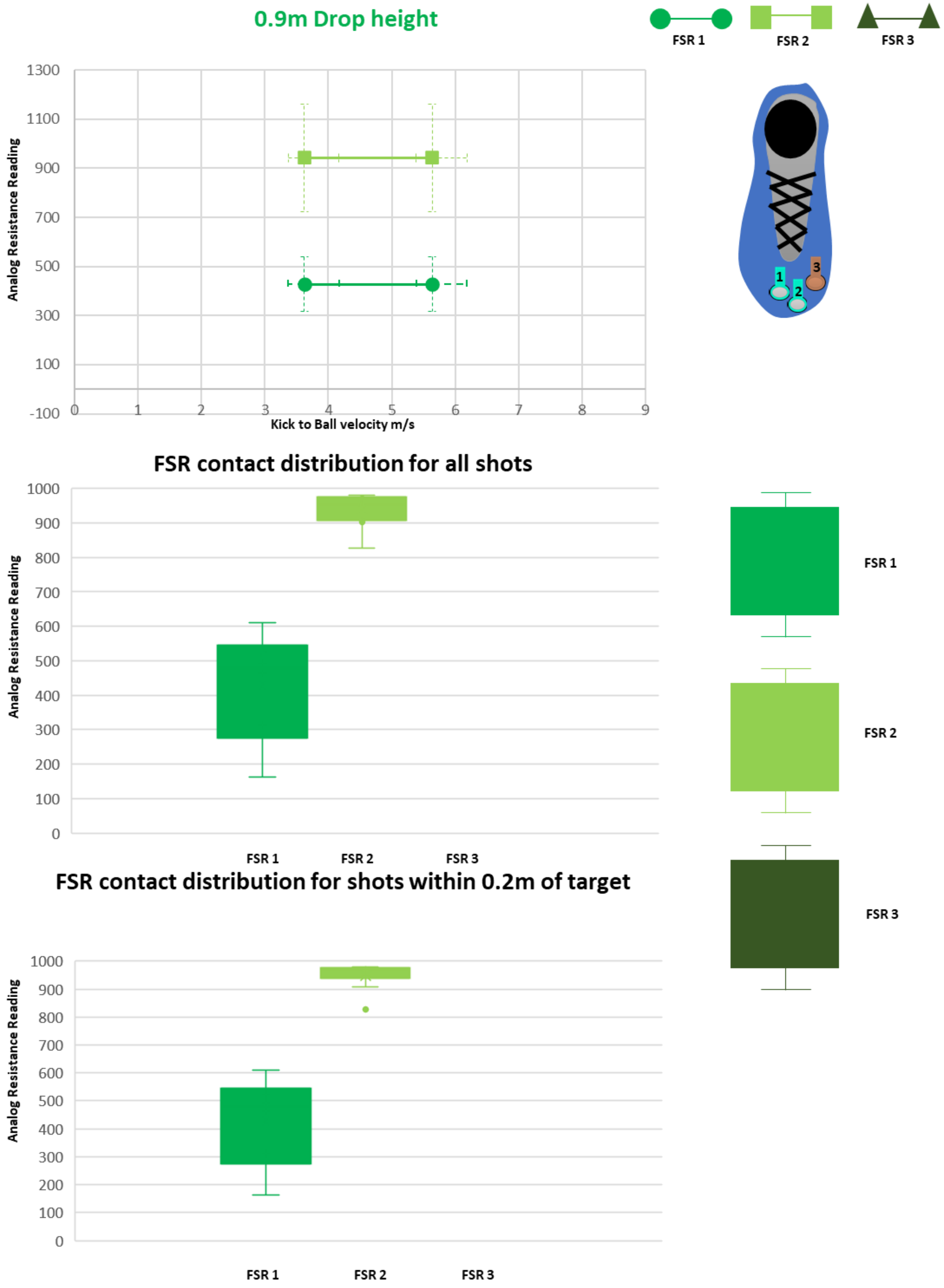


Figure 10.7.50

Laces 2 Circle FSR Set 1 with contact distribution : 0.6m Drop height

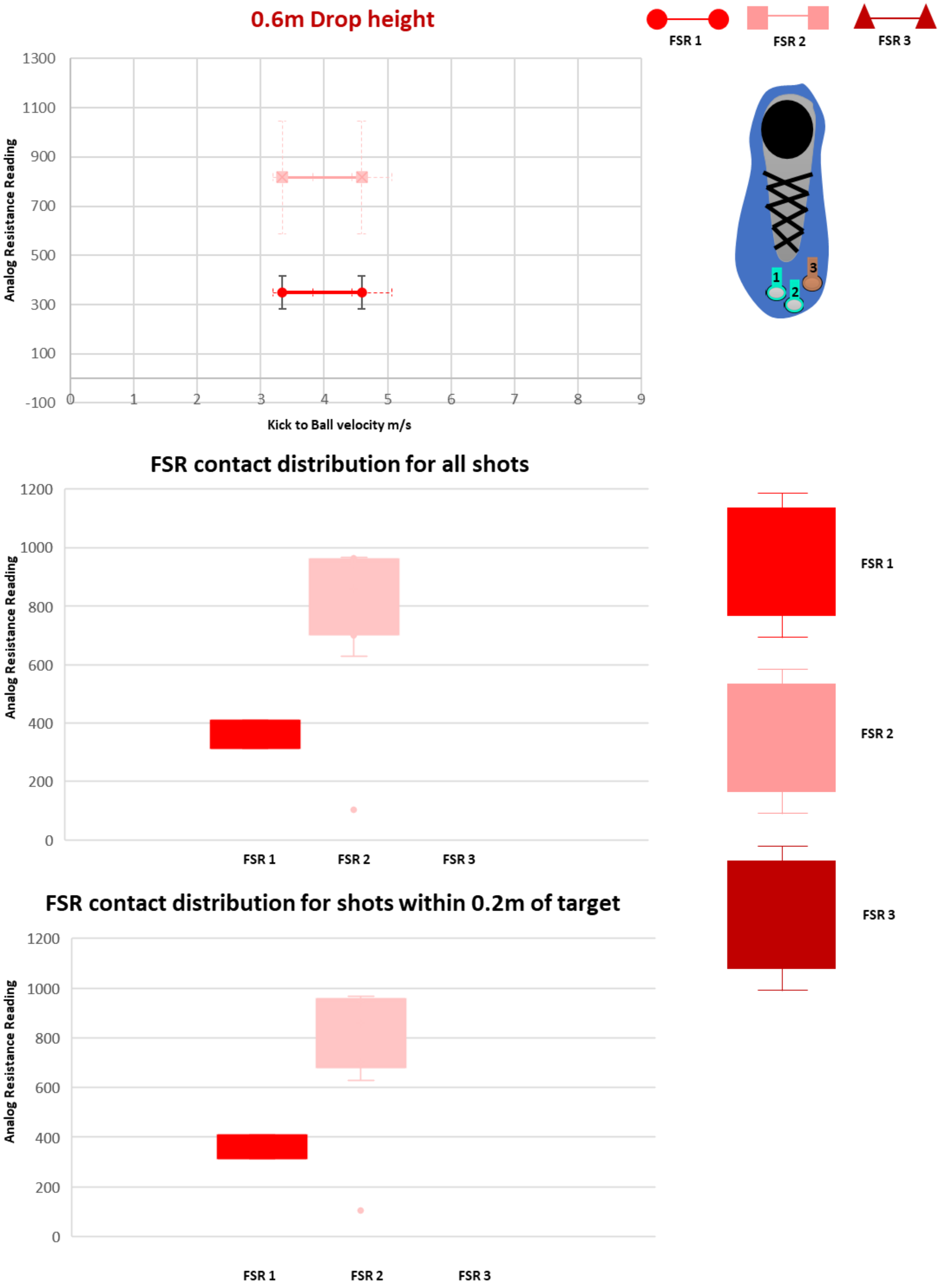


Figure 10.7.51

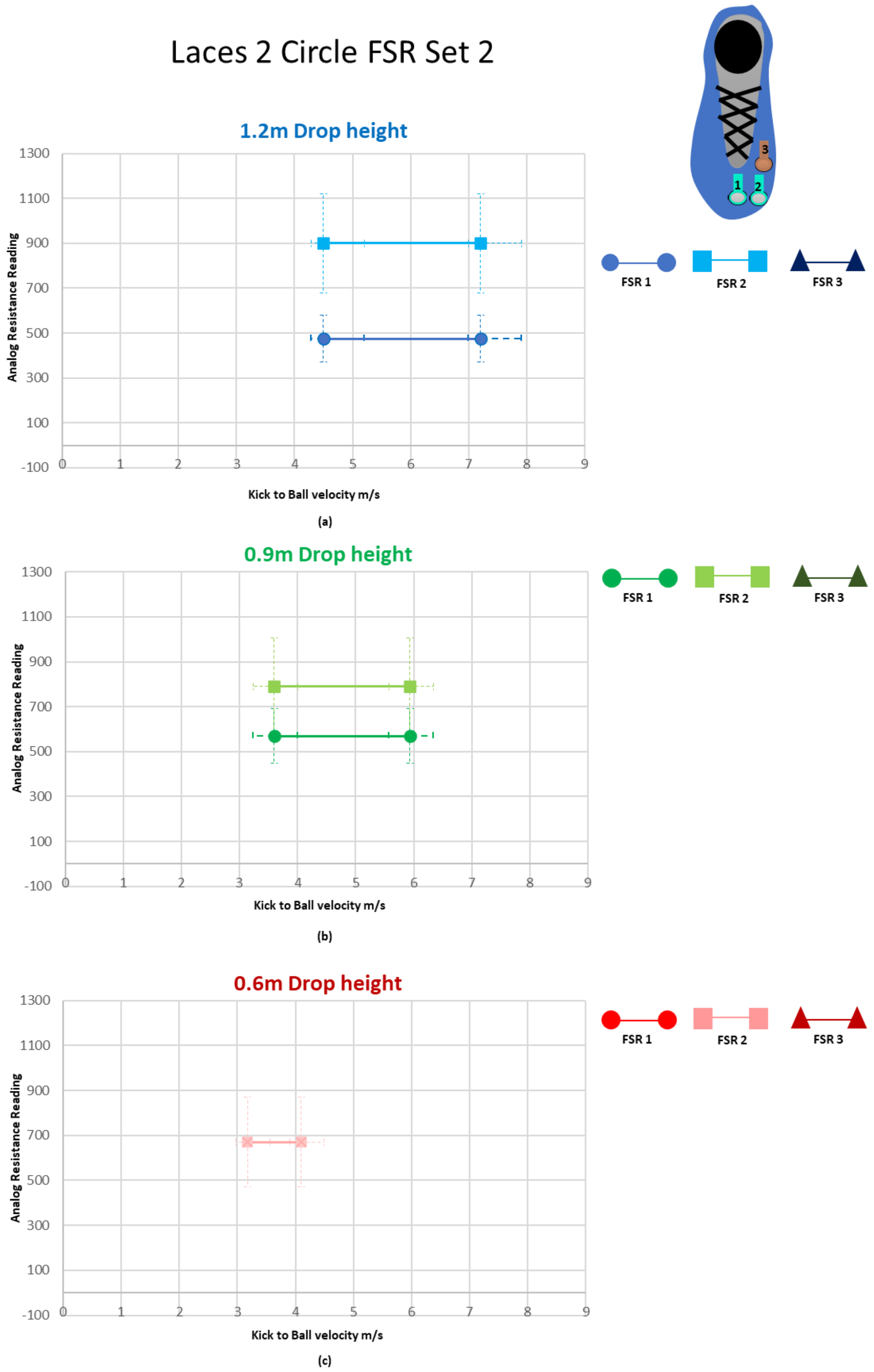


Figure 10.7.52

Laces 2 Circle FSR Set 2 with contact distribution : 1.2m Drop height

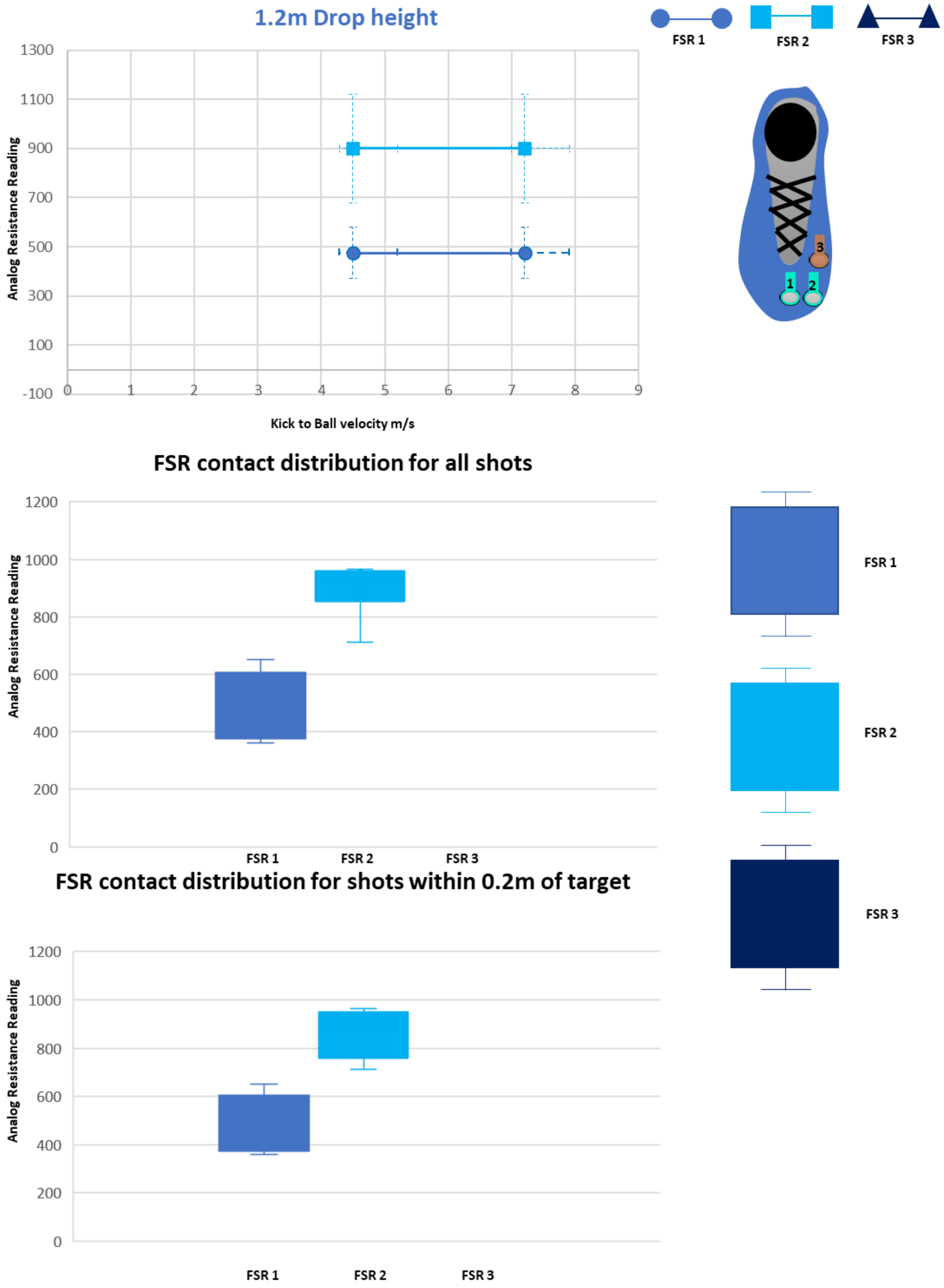


Figure 10.7.53

Laces 2 Circle FSR Set 2 with contact distribution : 0.9m Drop height

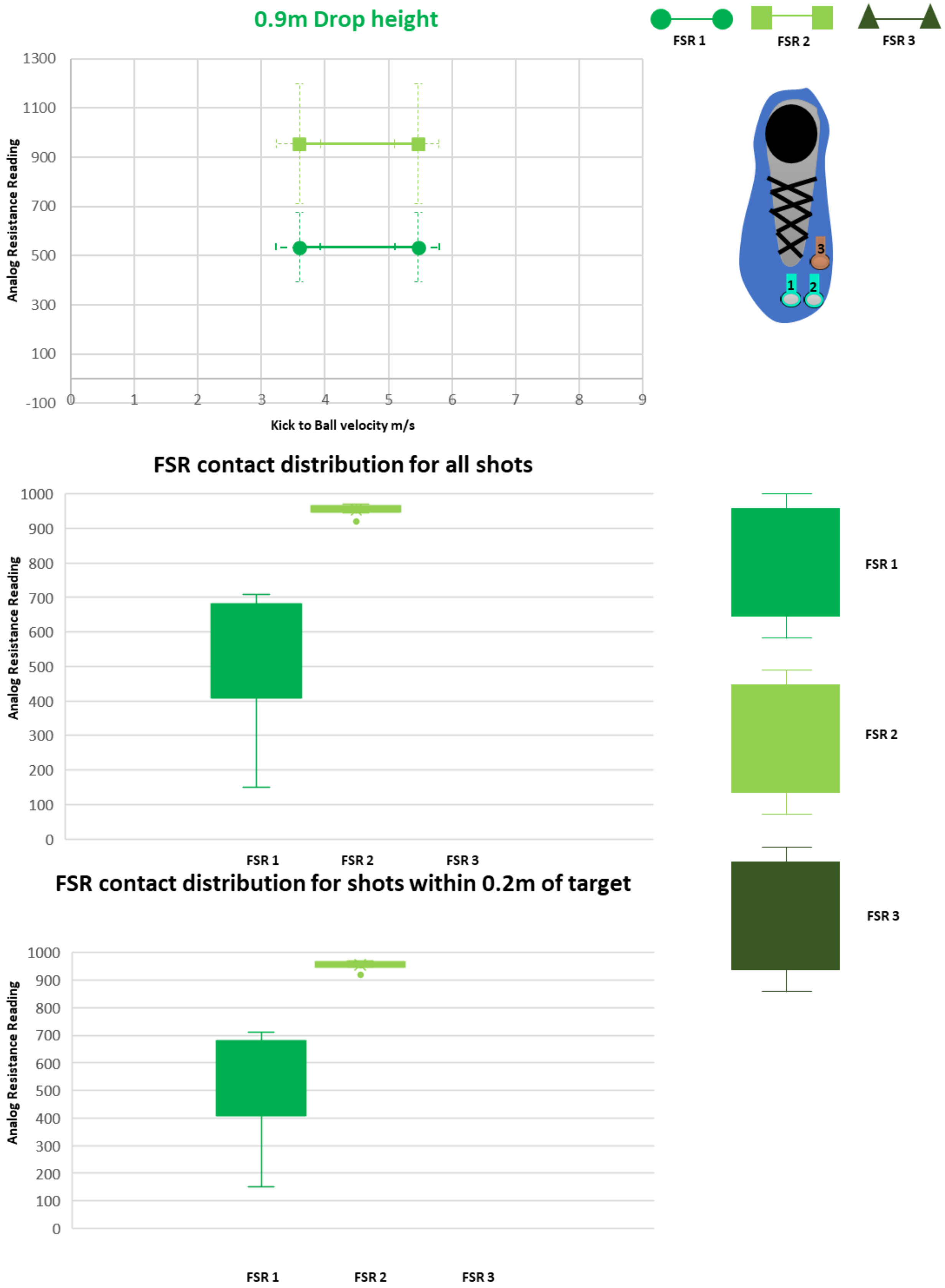


Figure 10.7.54

Laces 2 Circle FSR Set 2 with contact distribution : 0.6m Drop height

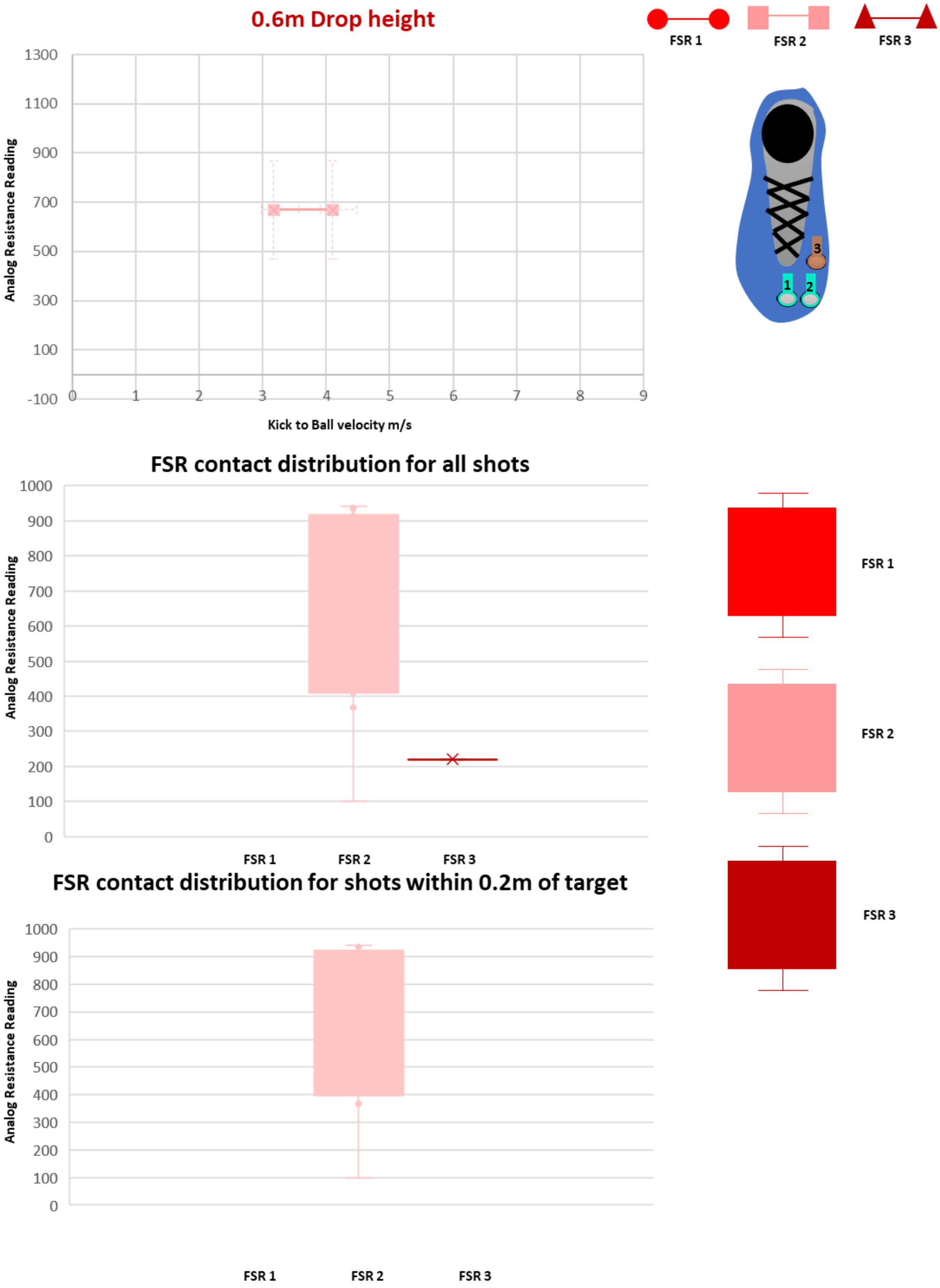


Figure 10.7.55

Laces 2 Circle FSR Set 3

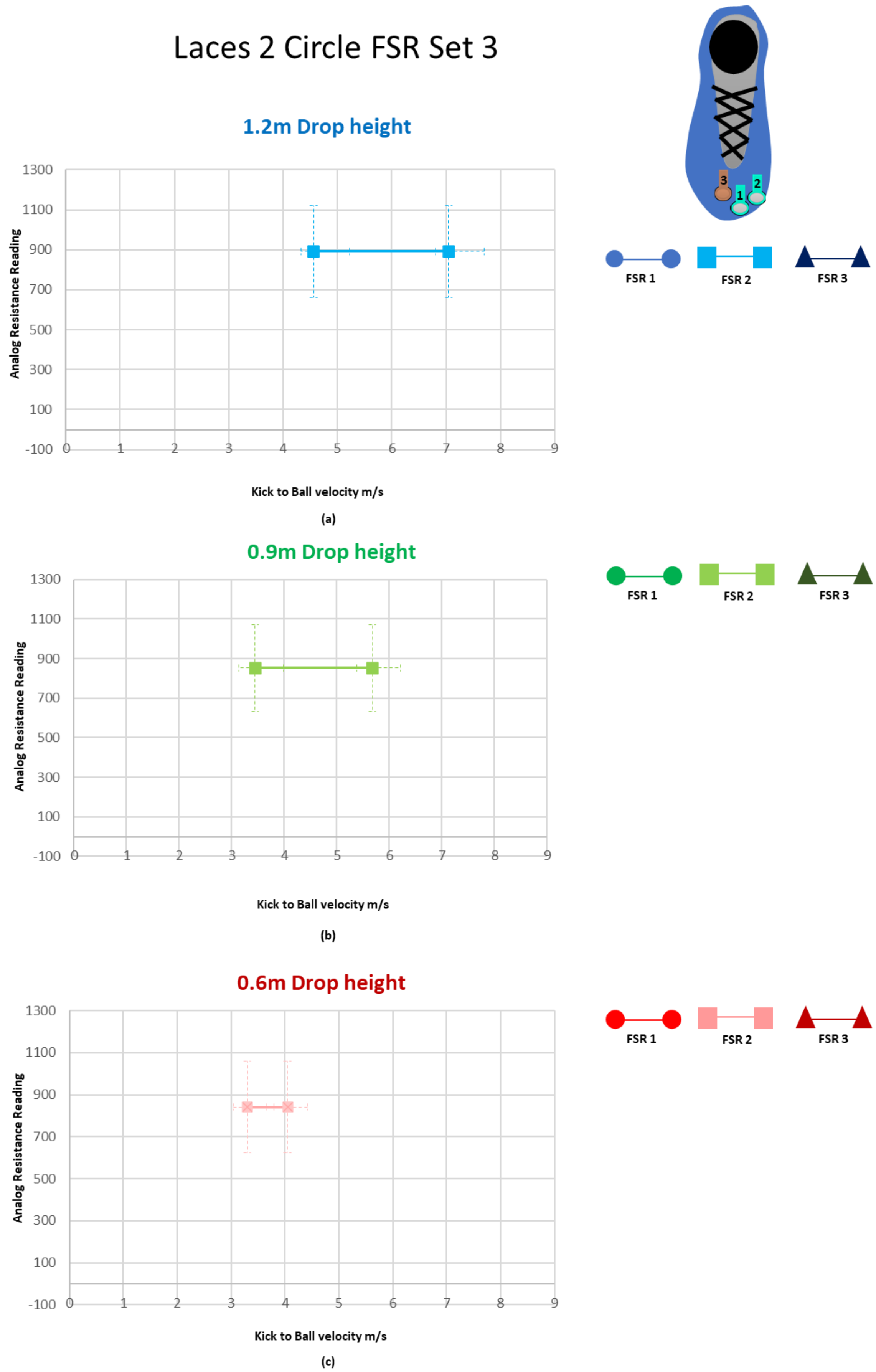


Figure 10.7.56

Laces 2 Circle FSR Set 3 with contact distribution : 1.2m Drop height

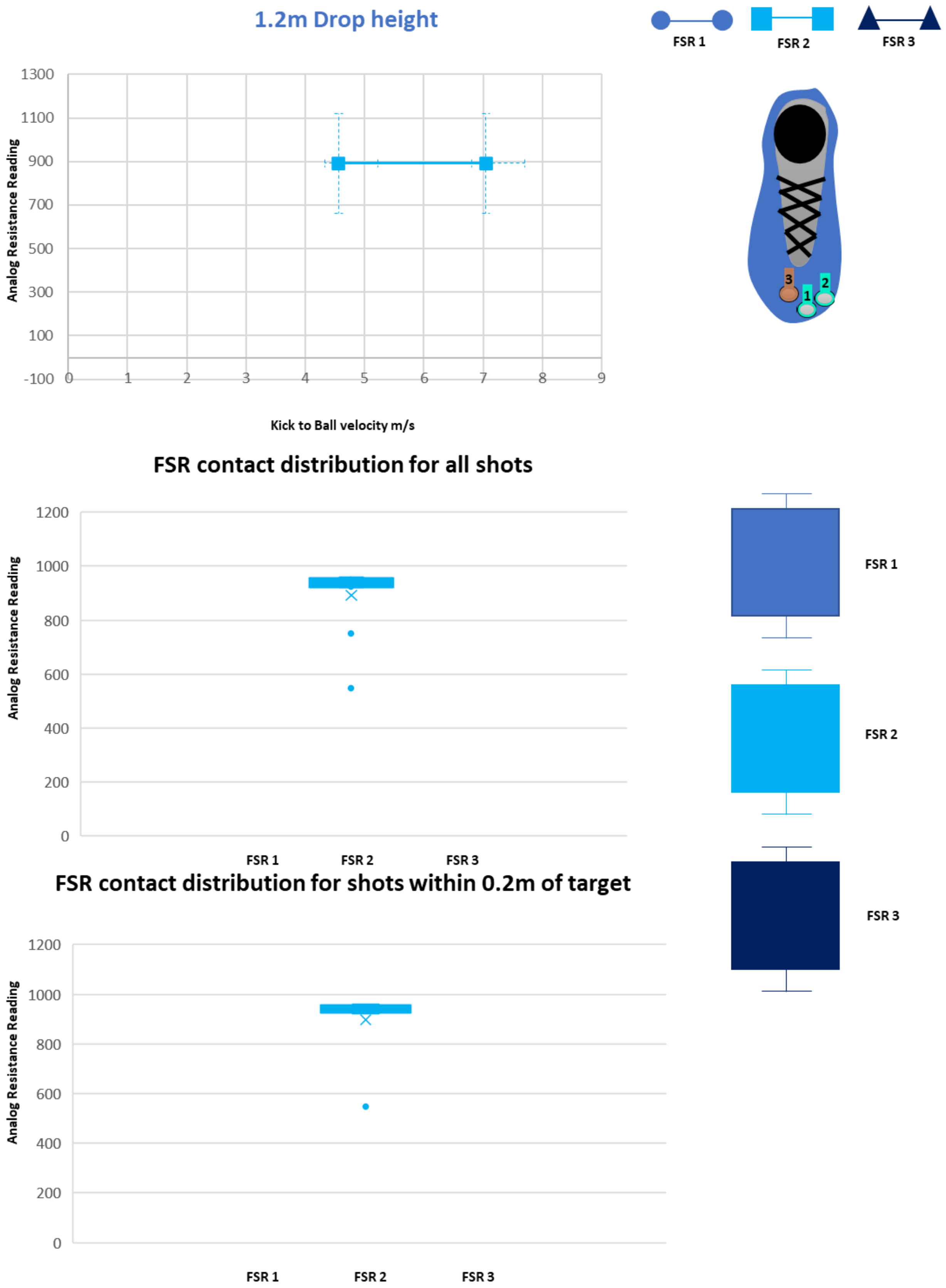
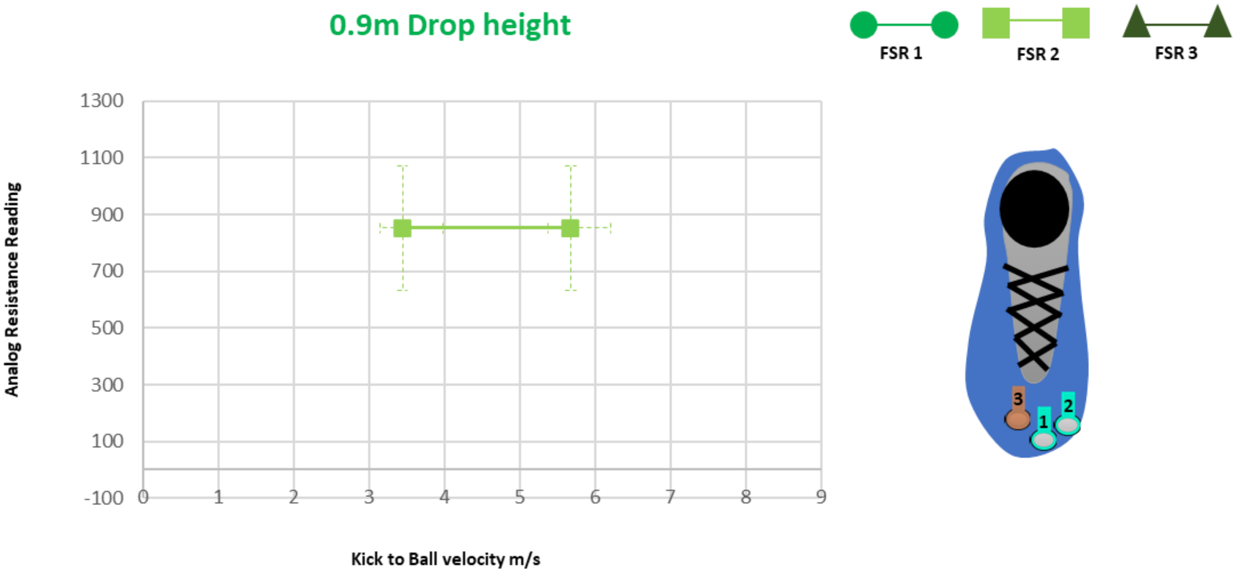
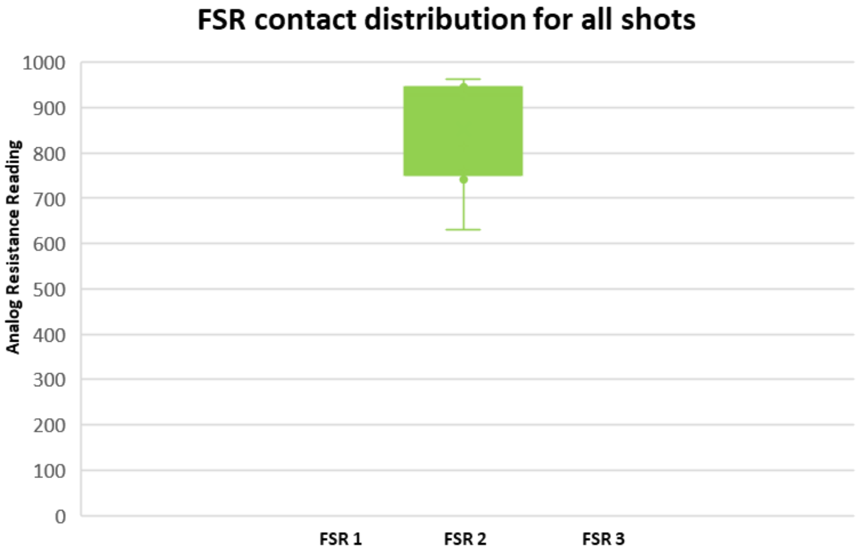
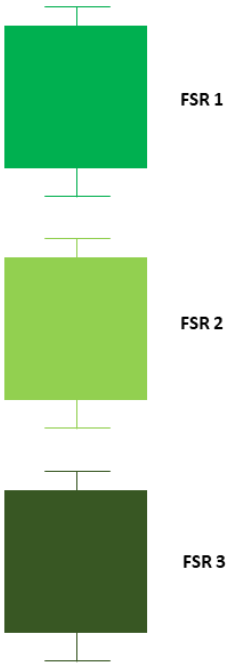


Figure 10.7.57

Laces 2 Circle FSR Set 3 with contact distribution : 0.9m Drop height







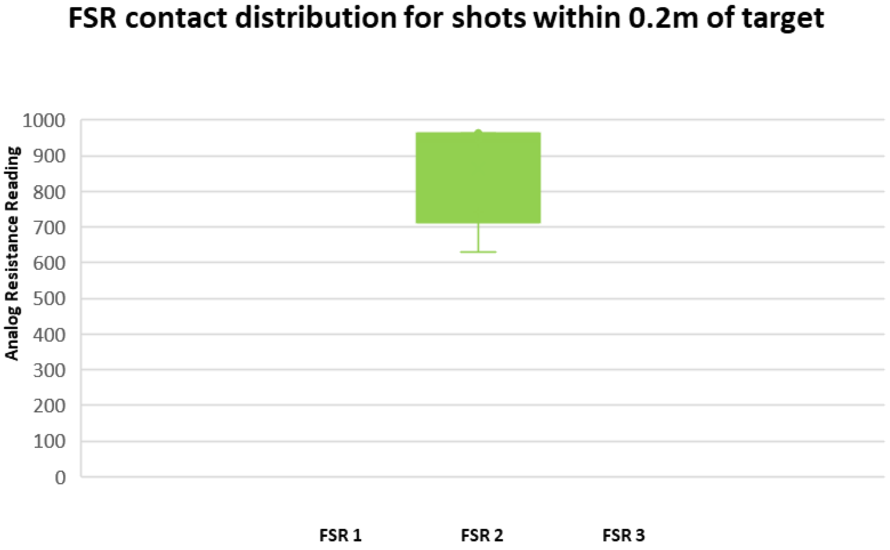


Figure 10.7.58

Laces 2 Circle FSR Set 3 with contact distribution : 0.6m Drop height

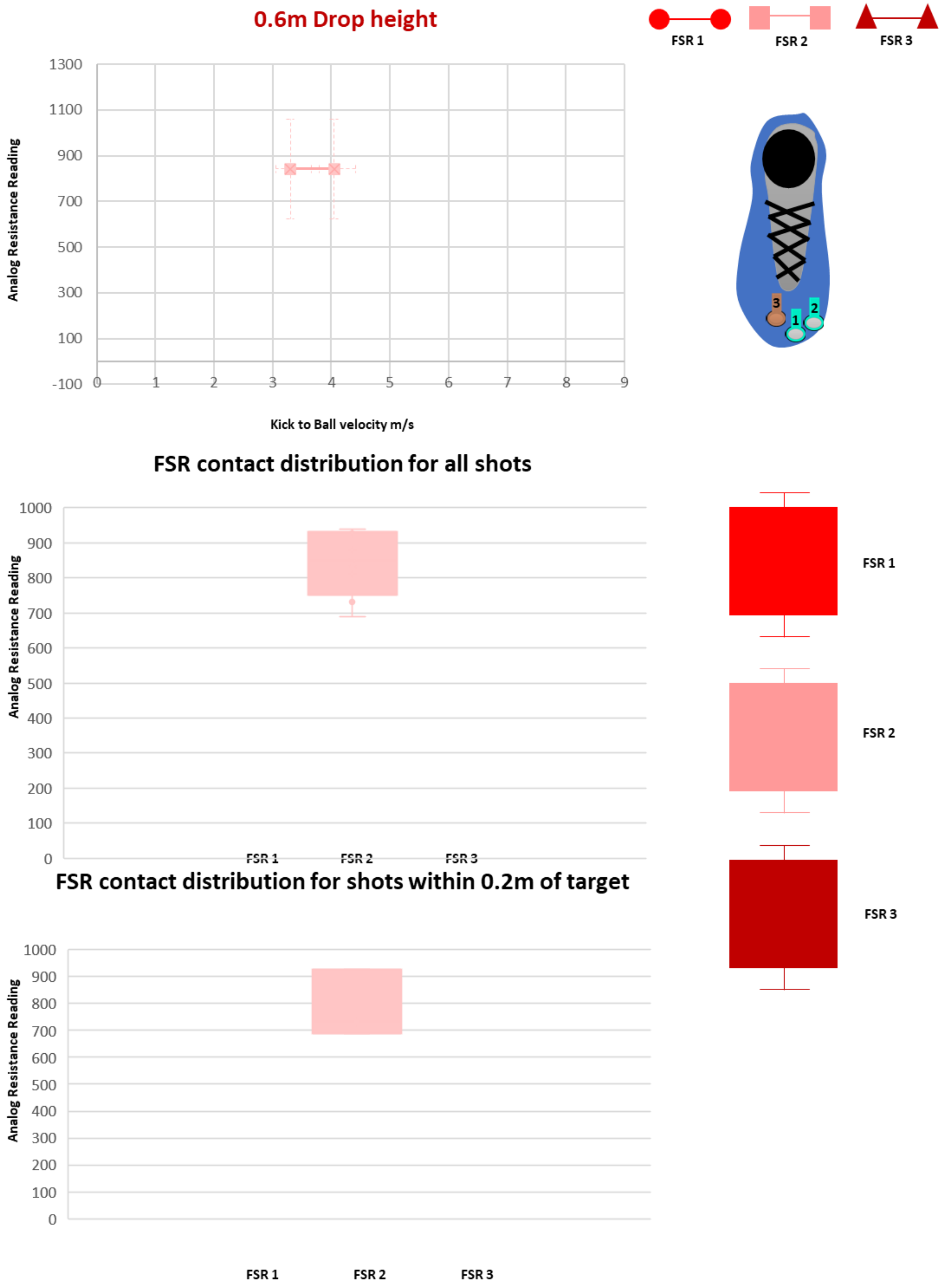
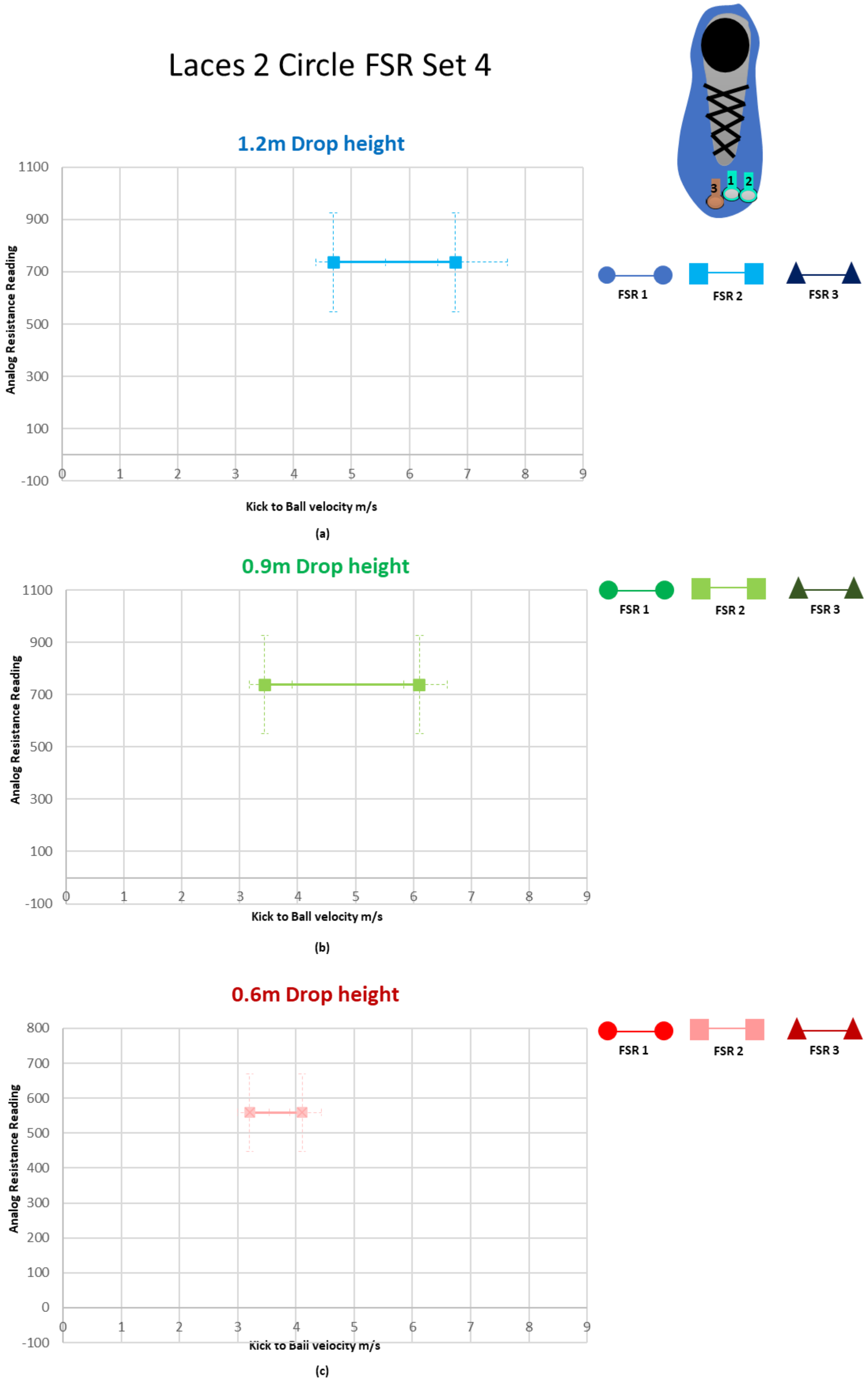


Figure 10.7.59

Laces 2 Circle FSR Set 4



(a)

(b)

(c)

Figure 10.7.60

Laces 2 Circle FSR Set 4 with contact distribution : 1.2m Drop height

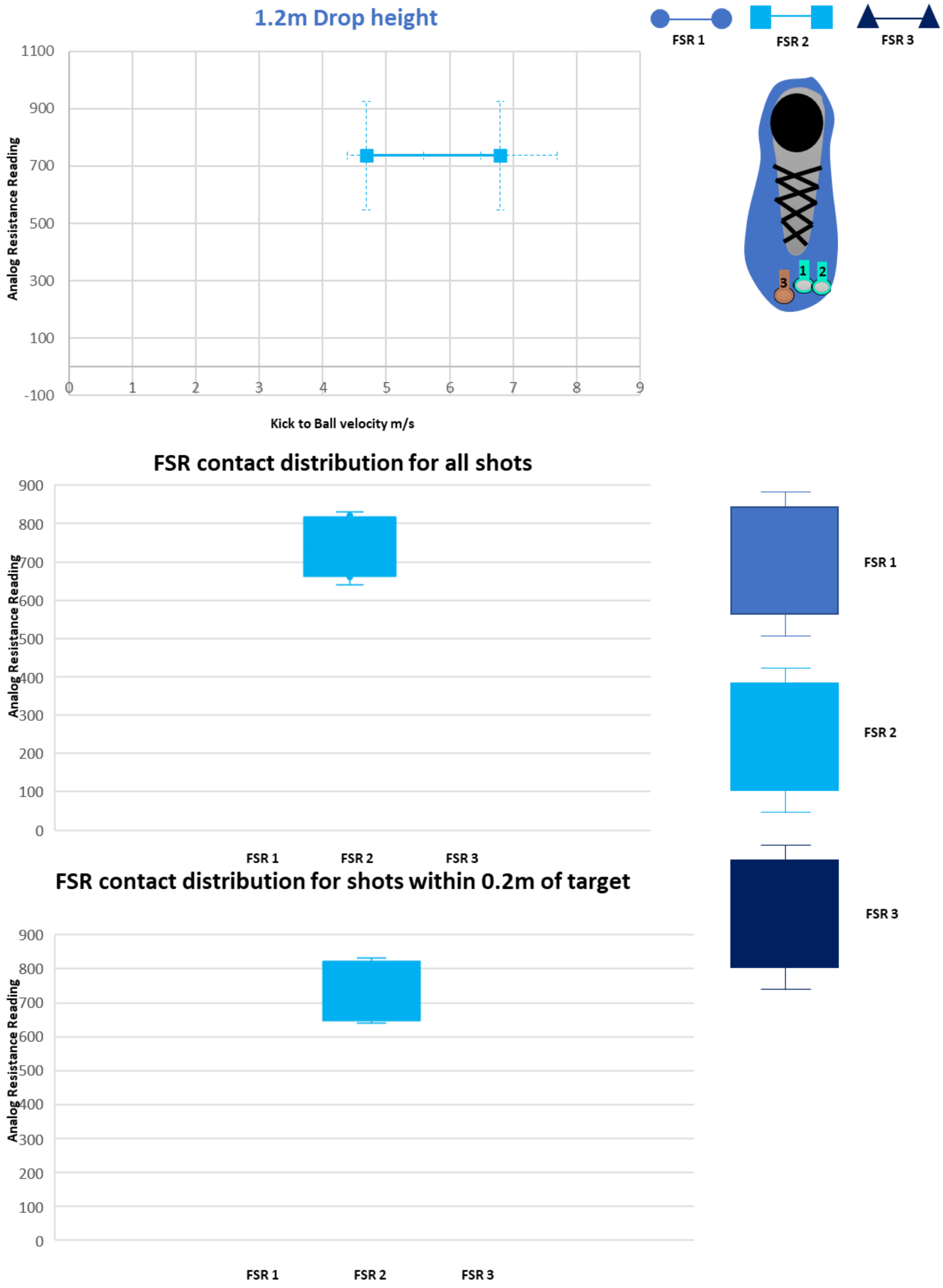


Figure 10.7.61

Laces 2 Circle FSR Set 4 with contact distribution : 0.9m Drop height

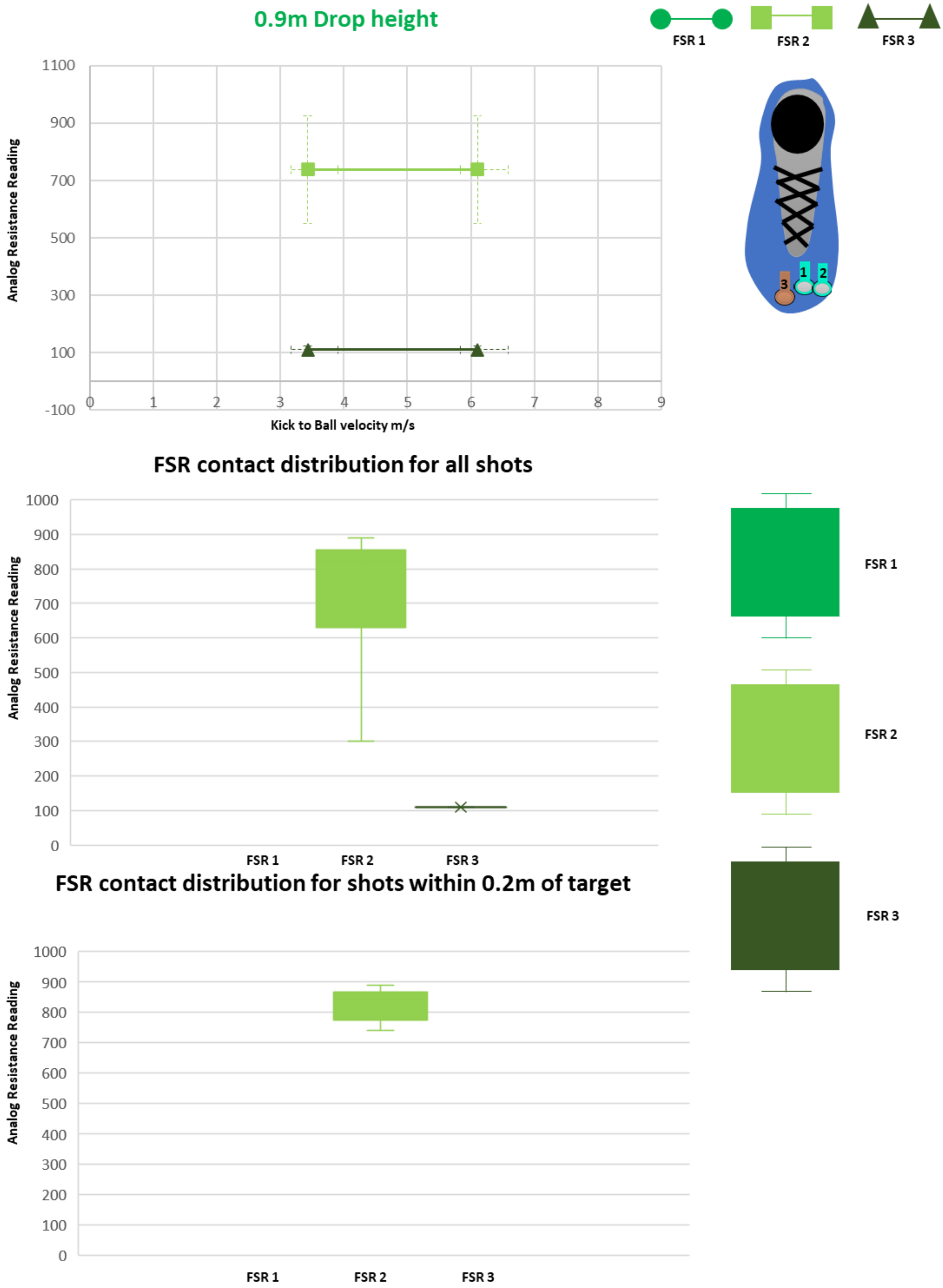


Figure 10.7.62

Laces 2 Circle FSR Set 4 with contact distribution : 0.6m Drop height

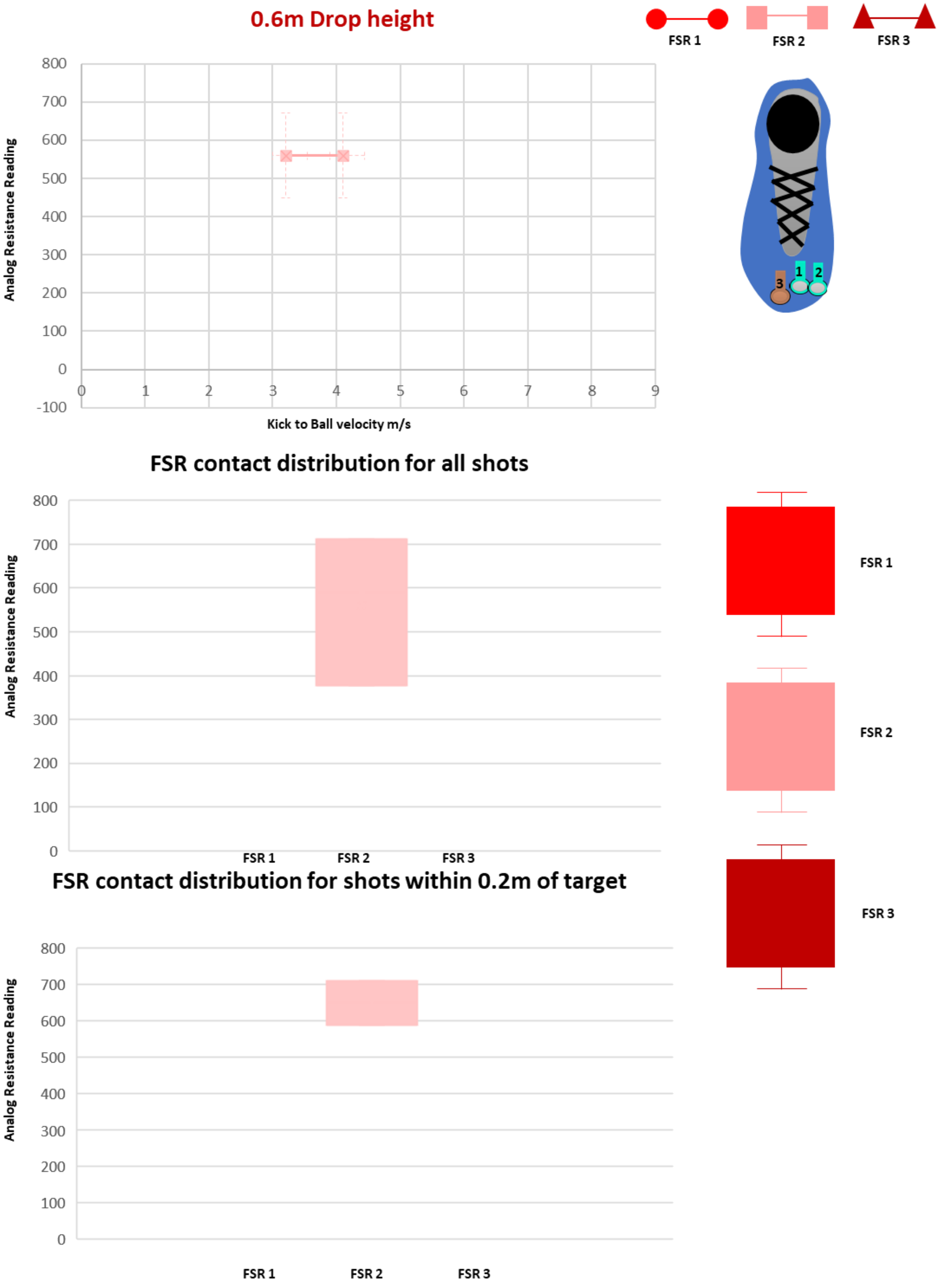
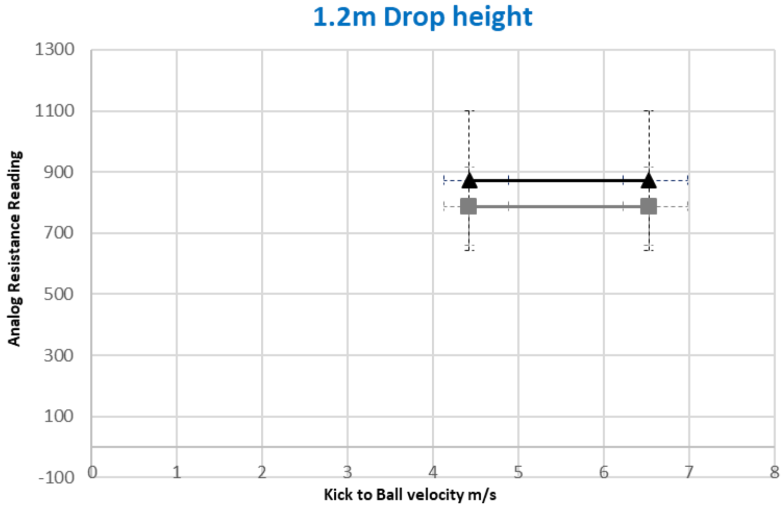
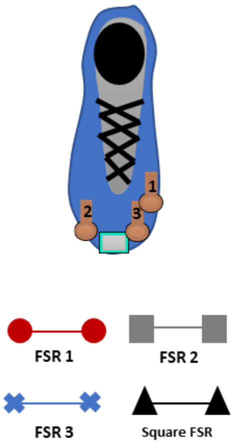


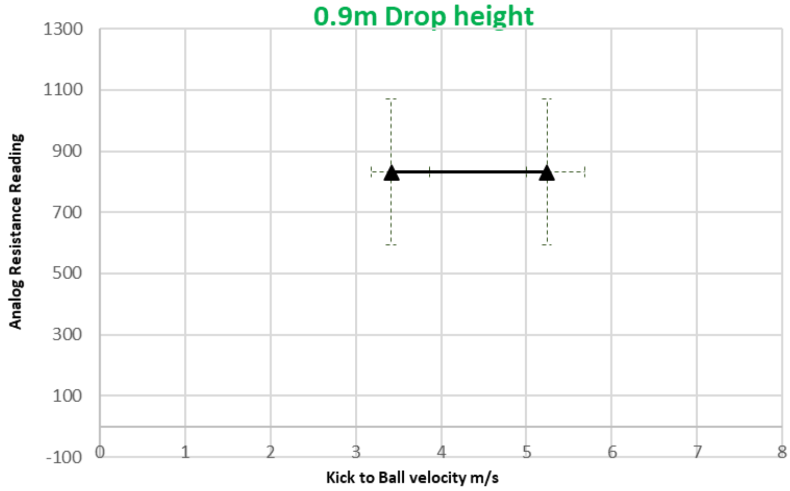
Figure 10.7.63

Laces Square FSR Set 1

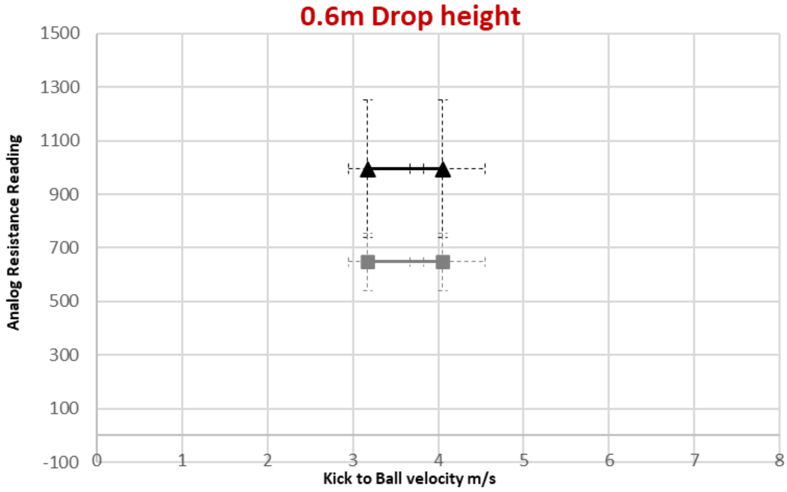


(a)





(b)



(c)

Figure 10.7.64

Laces Square FSR Set 1 with contact distribution : 1.2m Drop height

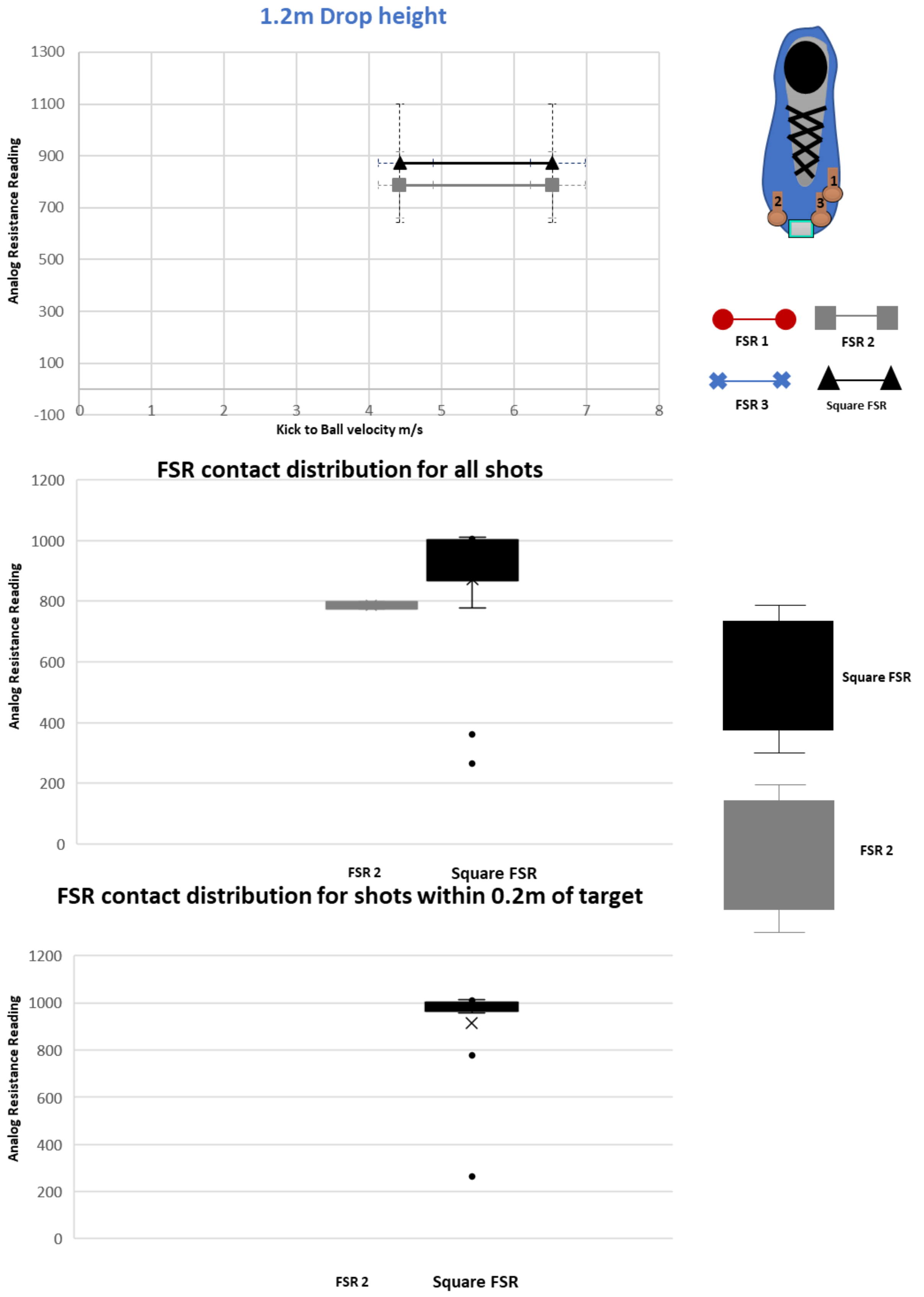


Figure 10.7.65

Laces Square FSR Set 1 with contact distribution : 0.9m Drop height

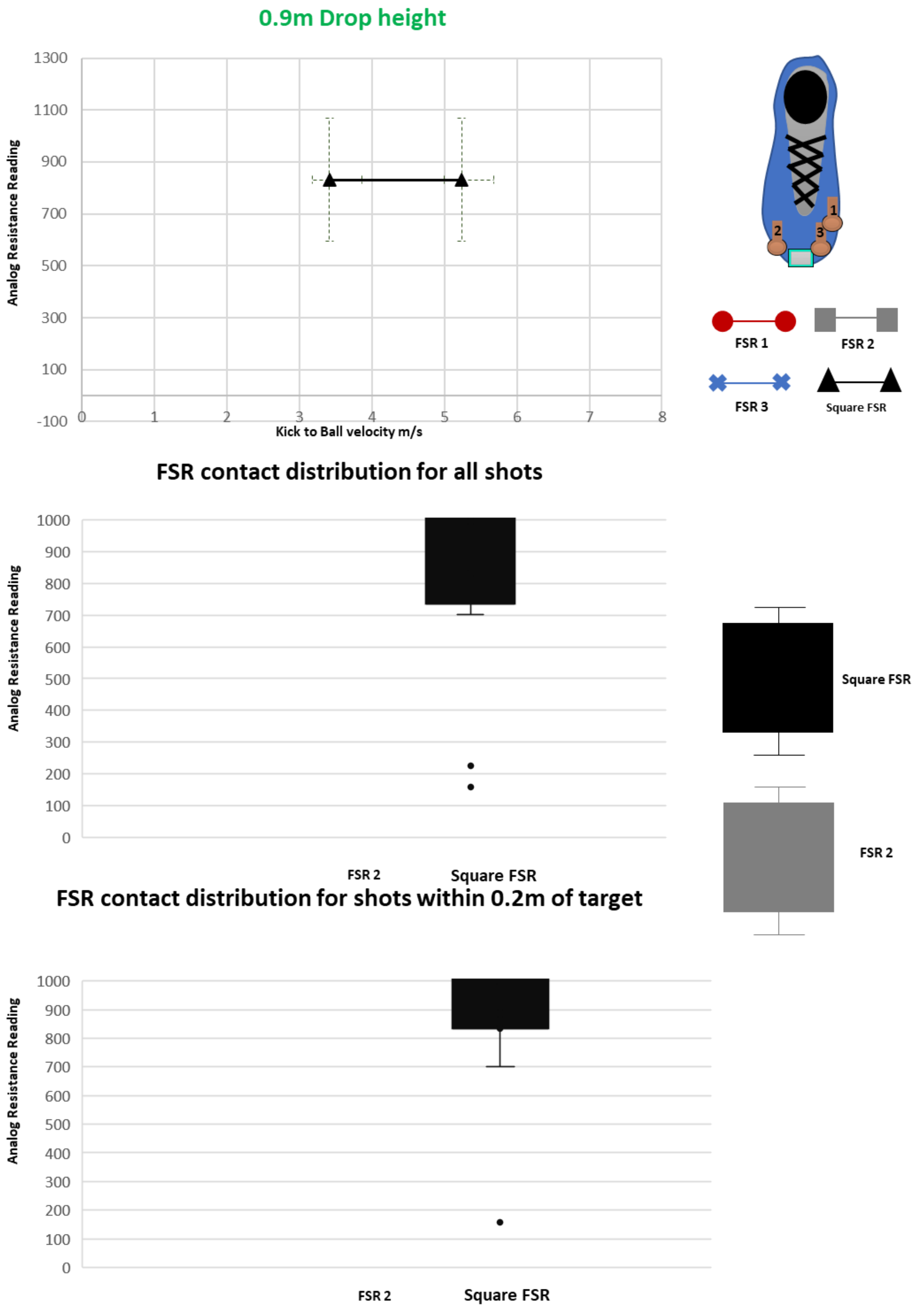
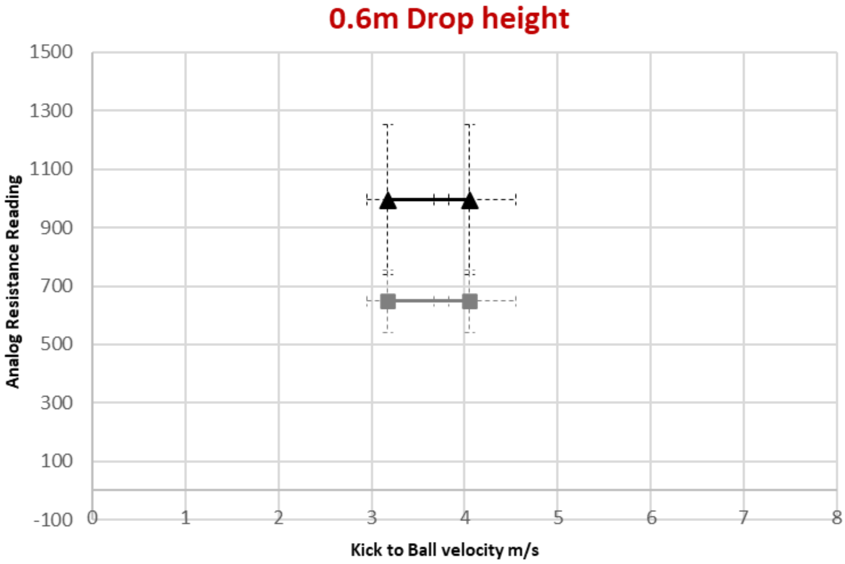
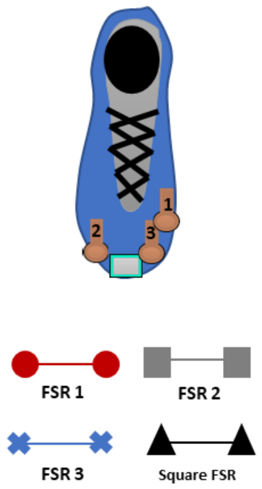
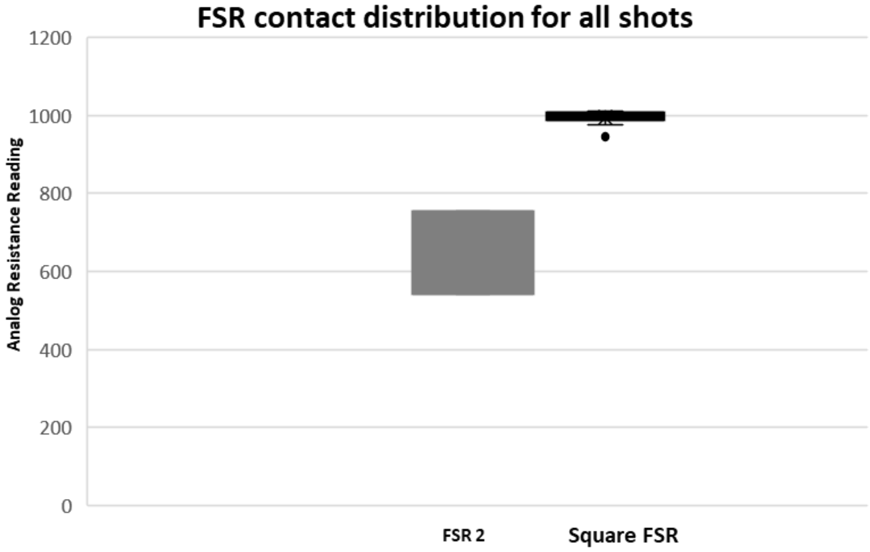


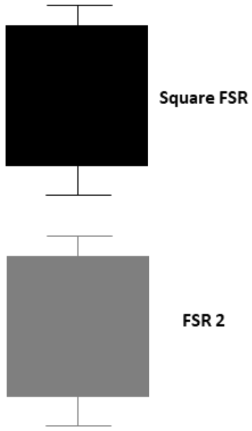
Figure 10.7.66

Laces Square FSR Set 1 with contact distribution : 0.6m Drop height









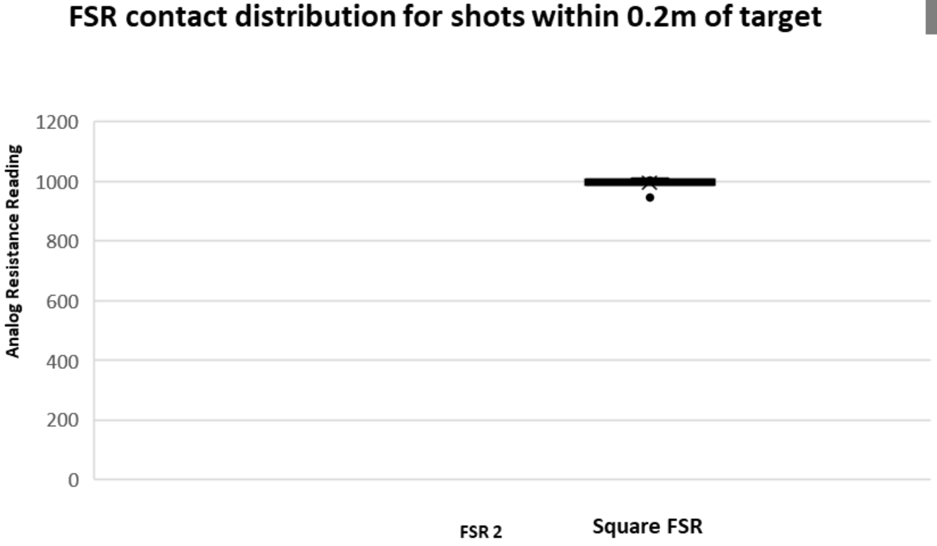


Figure 10.7.67

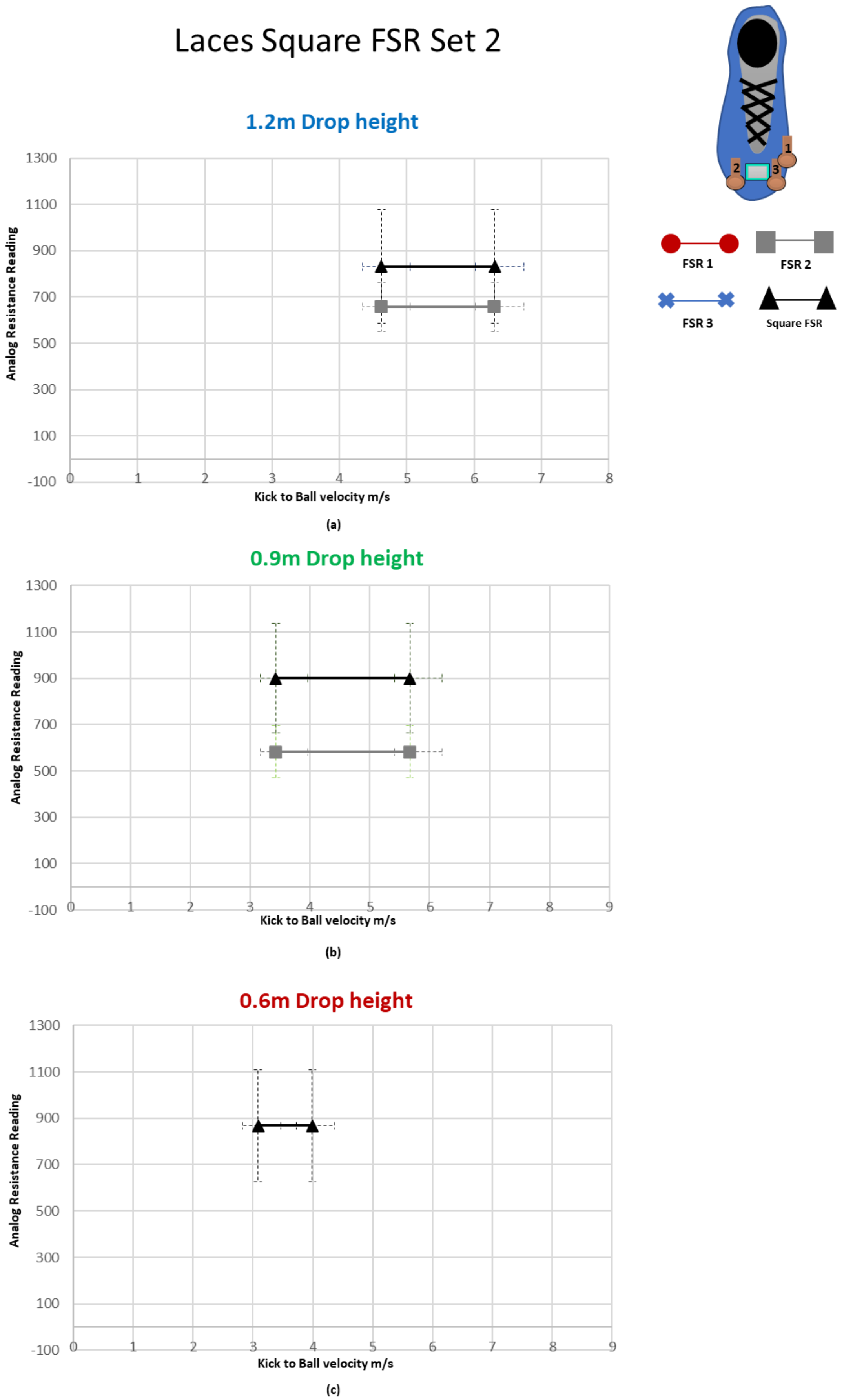


Figure 10.7.68

Laces Square FSR Set 2 with contact distribution : 1.2m Drop height

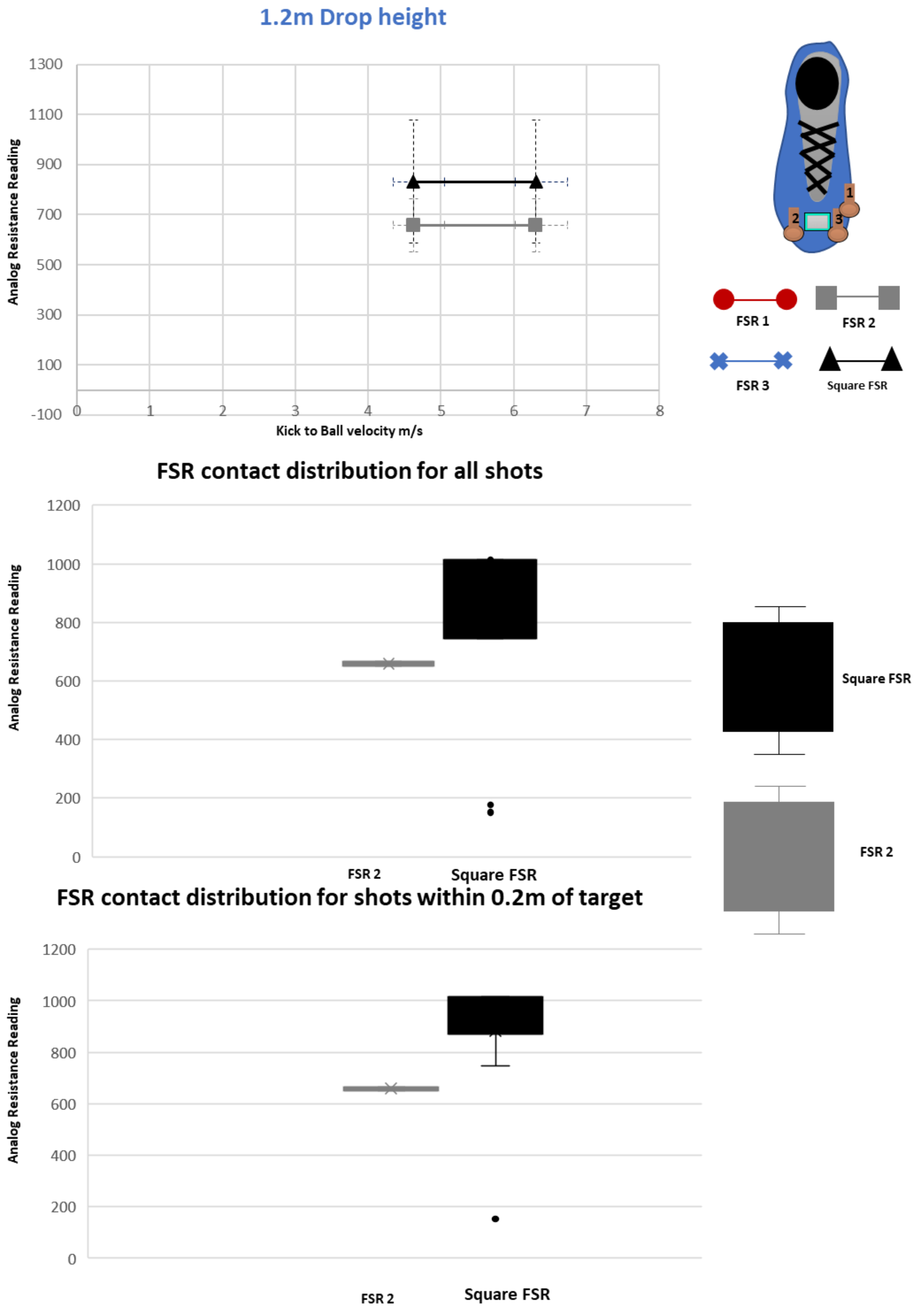
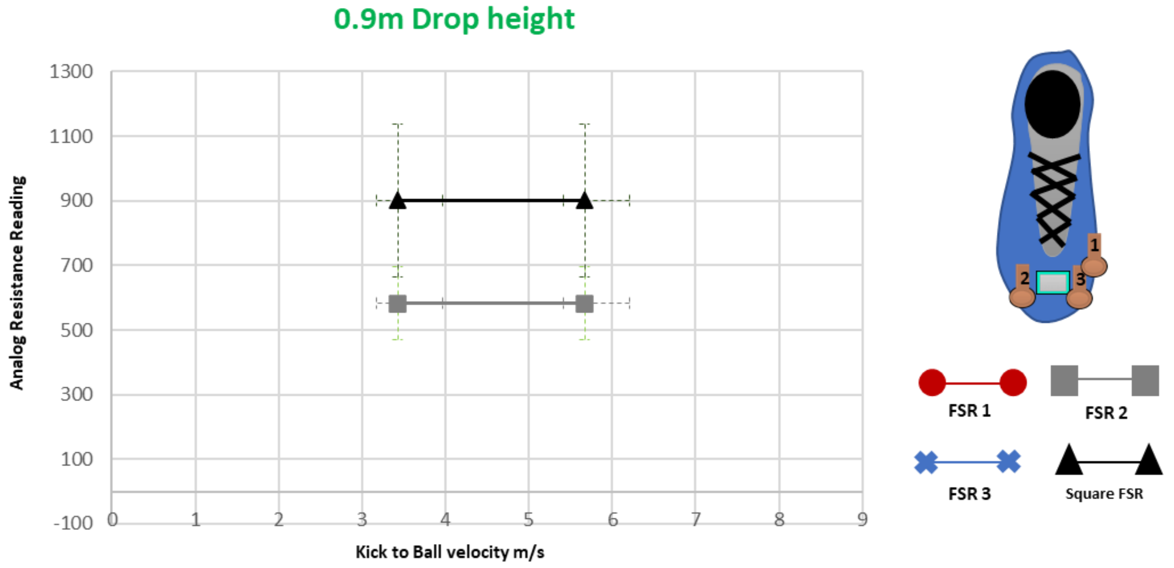
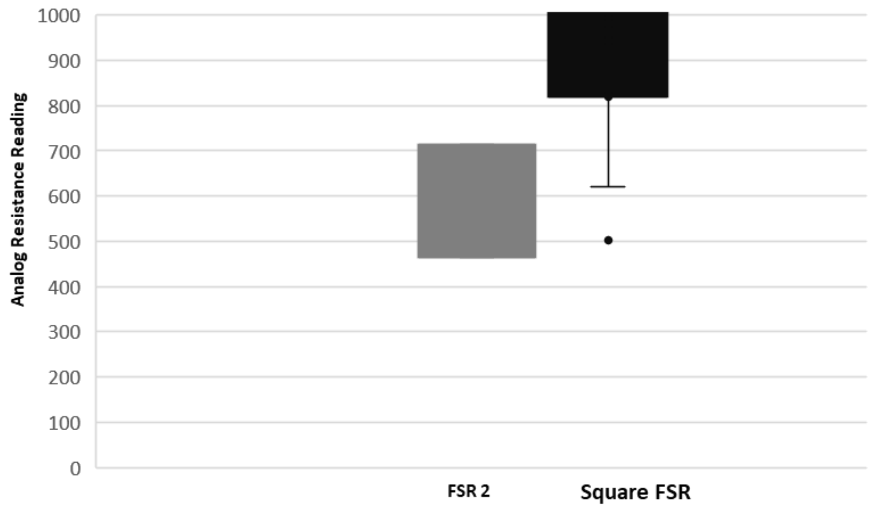


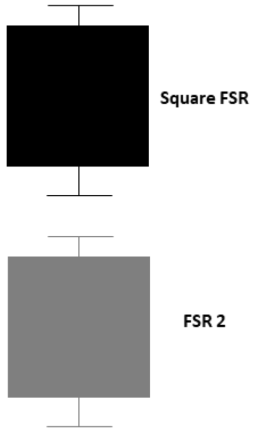
Figure 10.7.69

Laces Square FSR Set 2 with contact distribution : 0.9m Drop height



FSR contact distribution for all shots





FSR contact distribution for shots within 0.2m of target

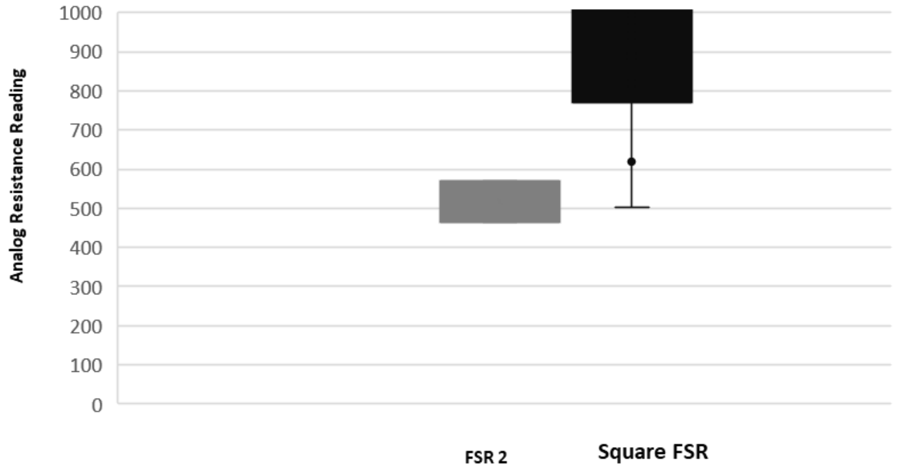


Figure 10.7.70

Laces Square FSR Set 2 with contact distribution : 0.6m Drop height

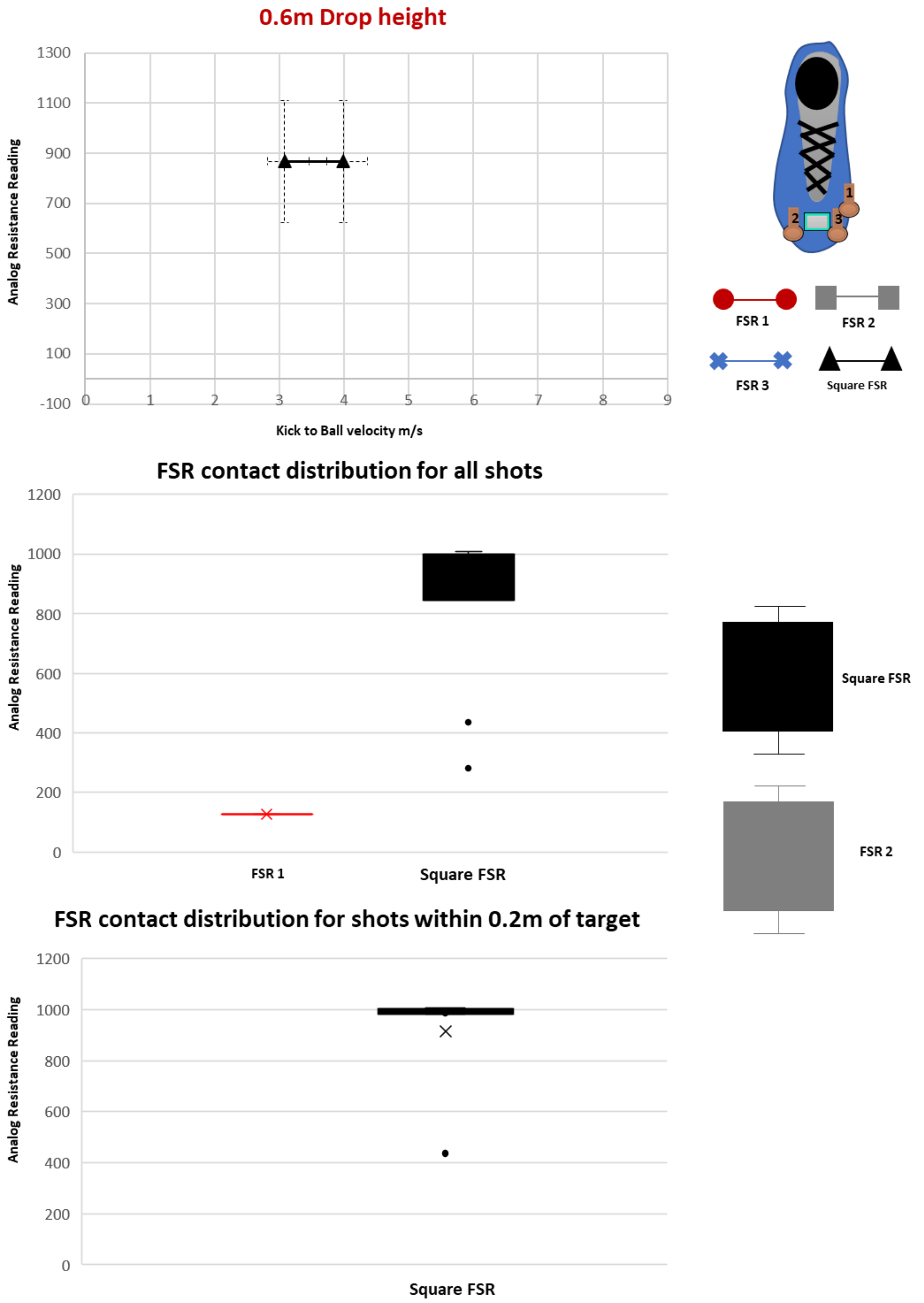
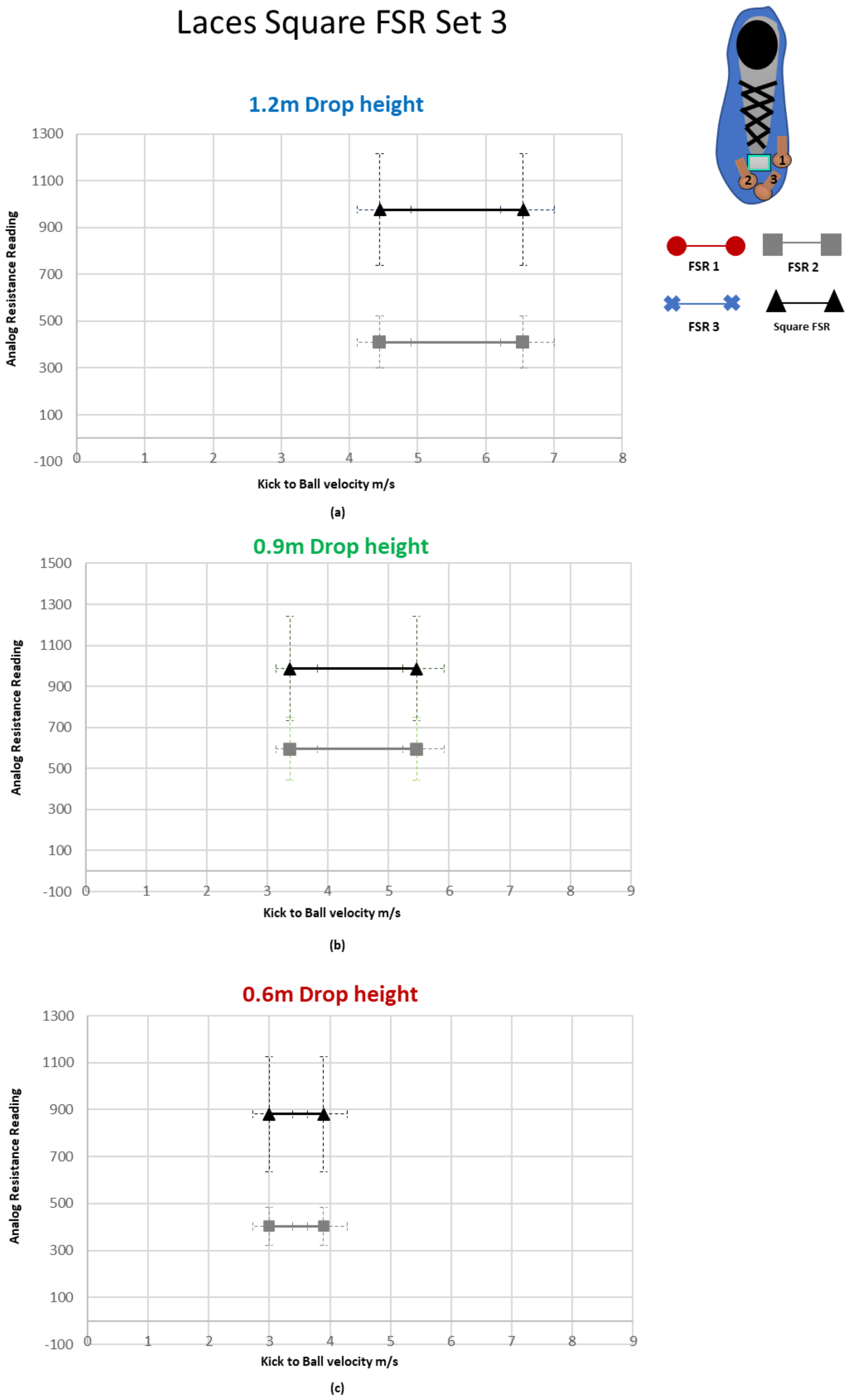


Figure 10.7.71



Laces Square FSR Set 3

1.2m Drop height

(a)

0.9m Drop height

(b)

0.6m Drop height

(c)

Figure 10.7.72

Laces Square FSR Set 3 with contact distribution : 1.2m Drop height

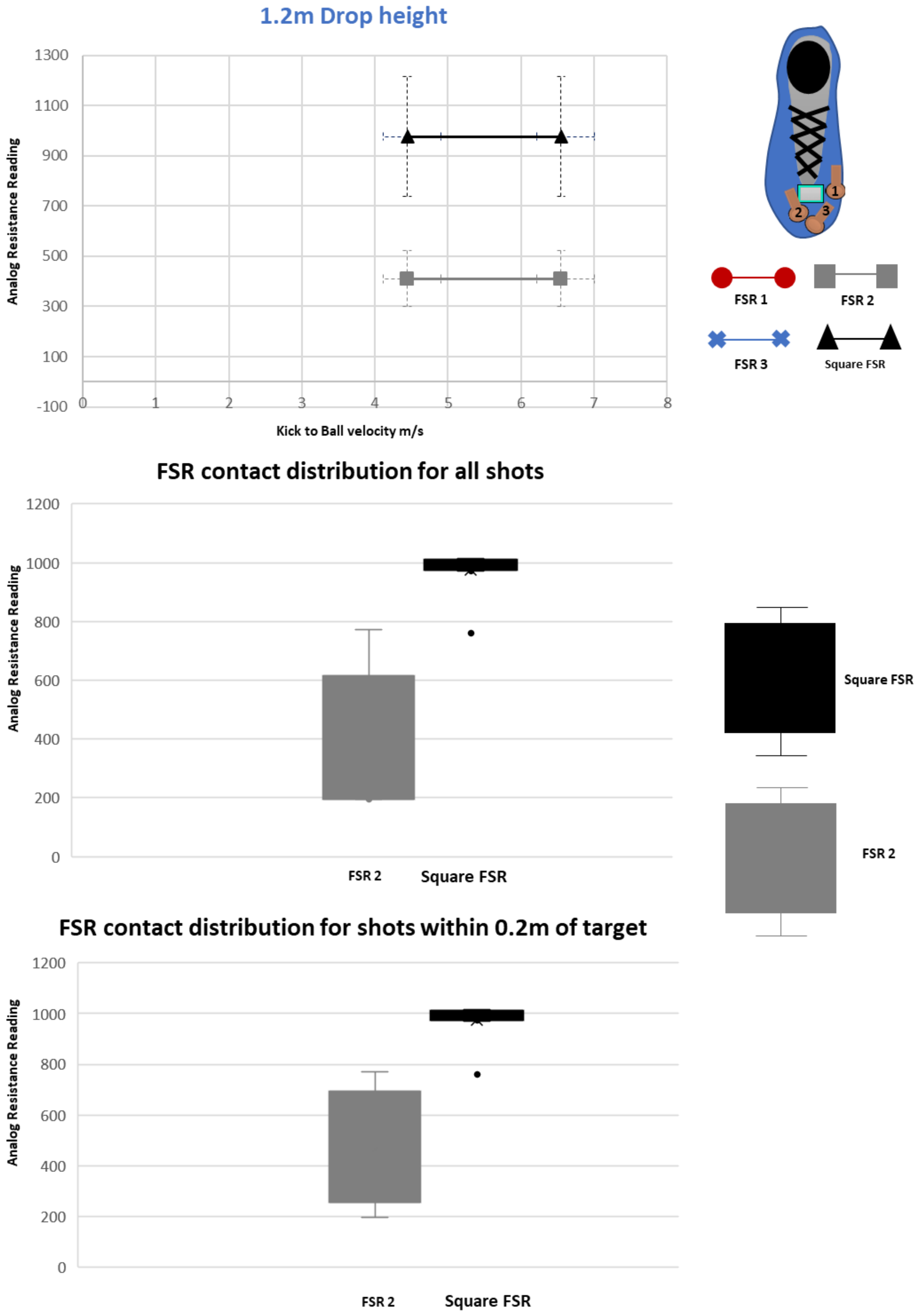


Figure 10.7.73

Laces Square FSR Set 3 with contact distribution : 0.9m Drop height

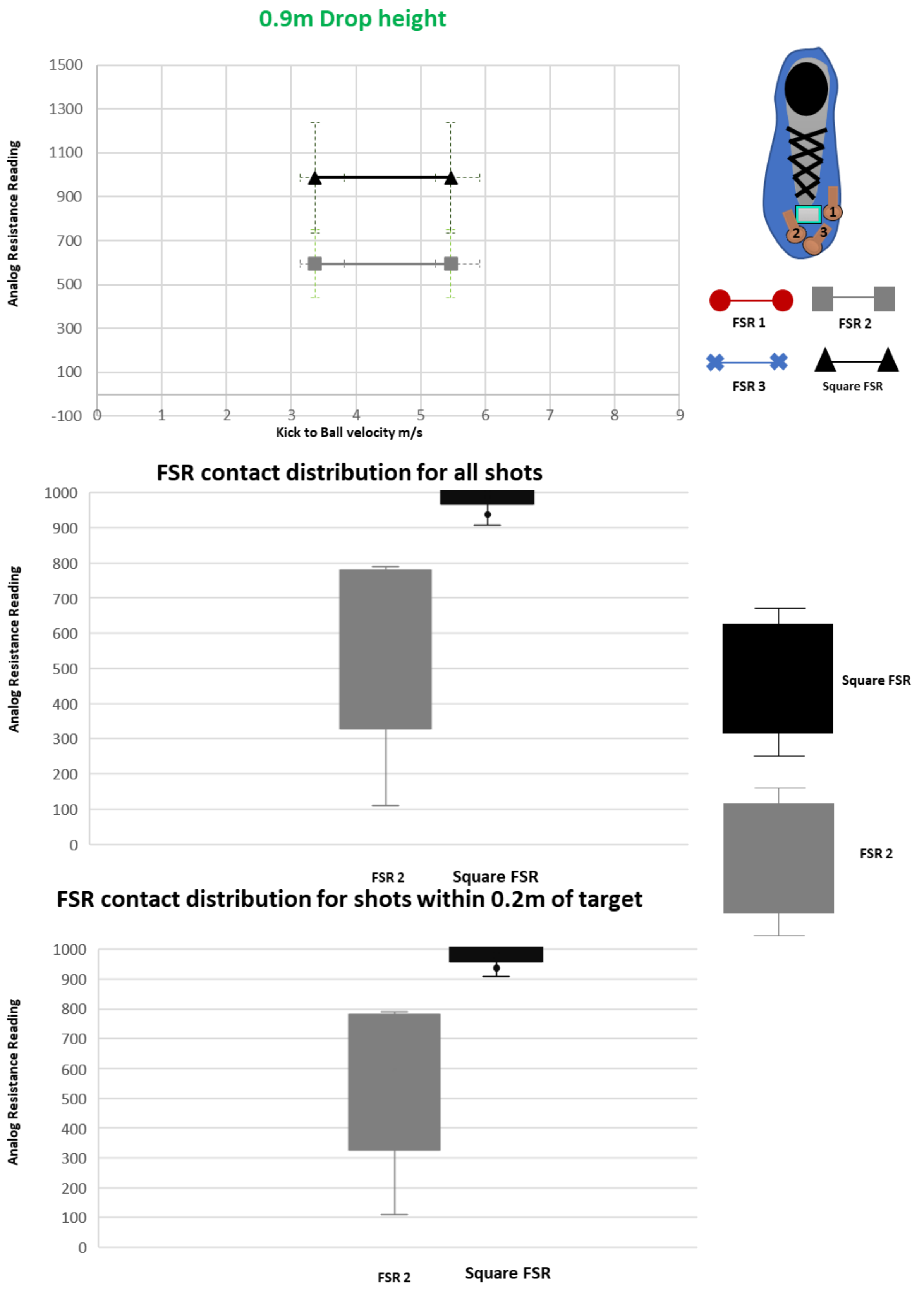


Figure 10.7.74

Laces Square FSR Set 3 with contact distribution : 0.6m Drop height

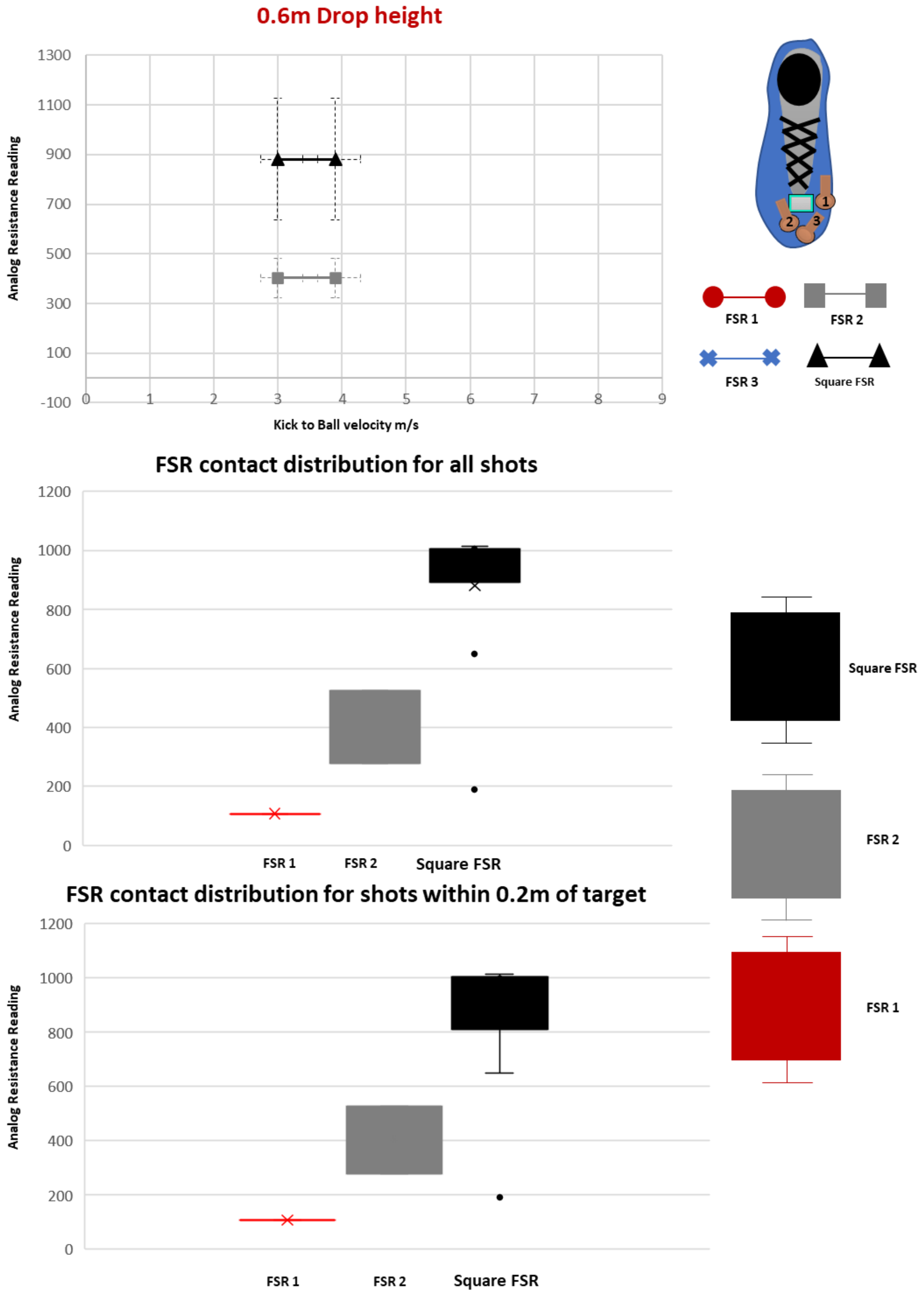


Figure 10.7.75

Laces Square FSR Set 4

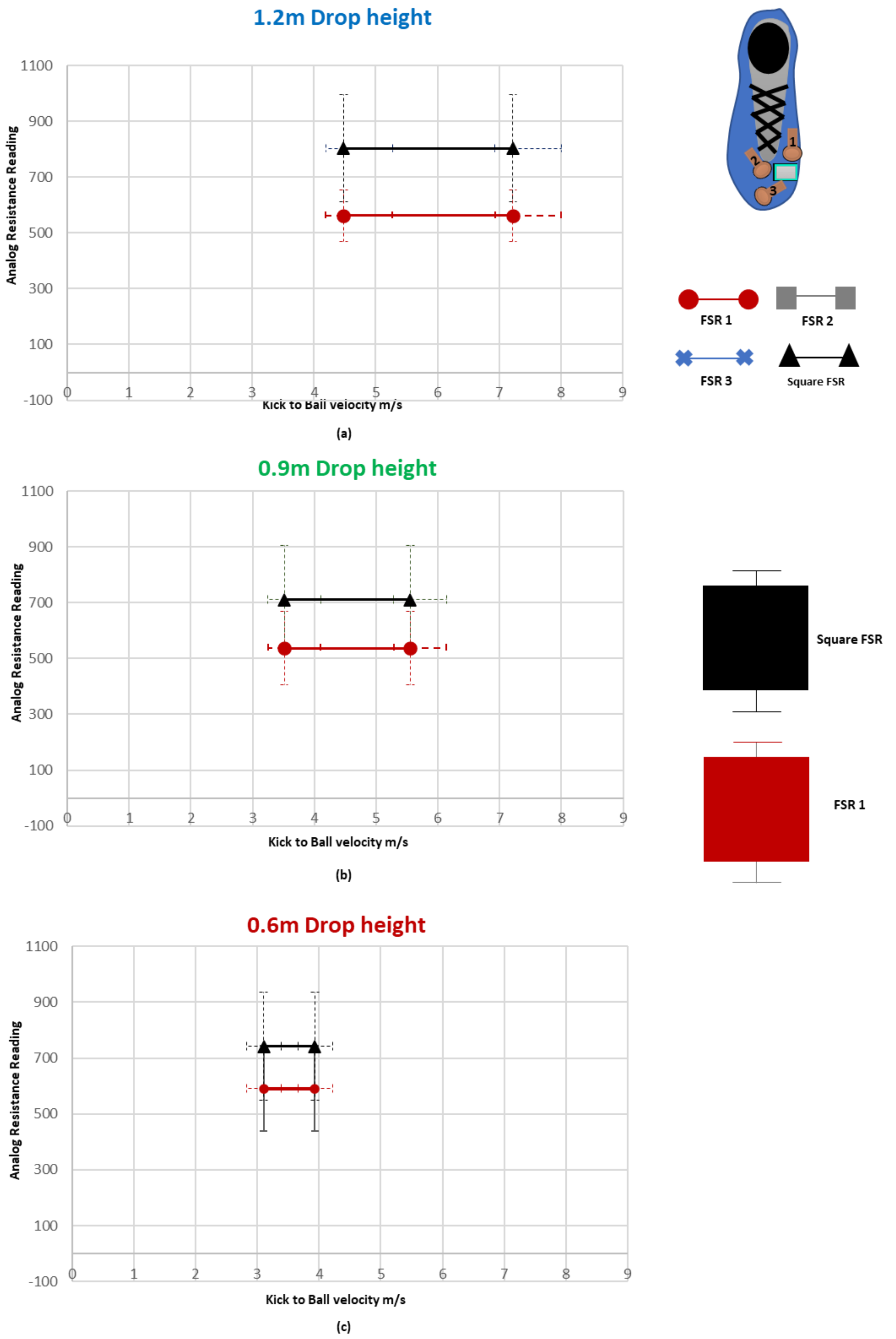


Figure 10.7.76

Laces Square FSR Set 4 with contact distribution : 1.2m Drop height

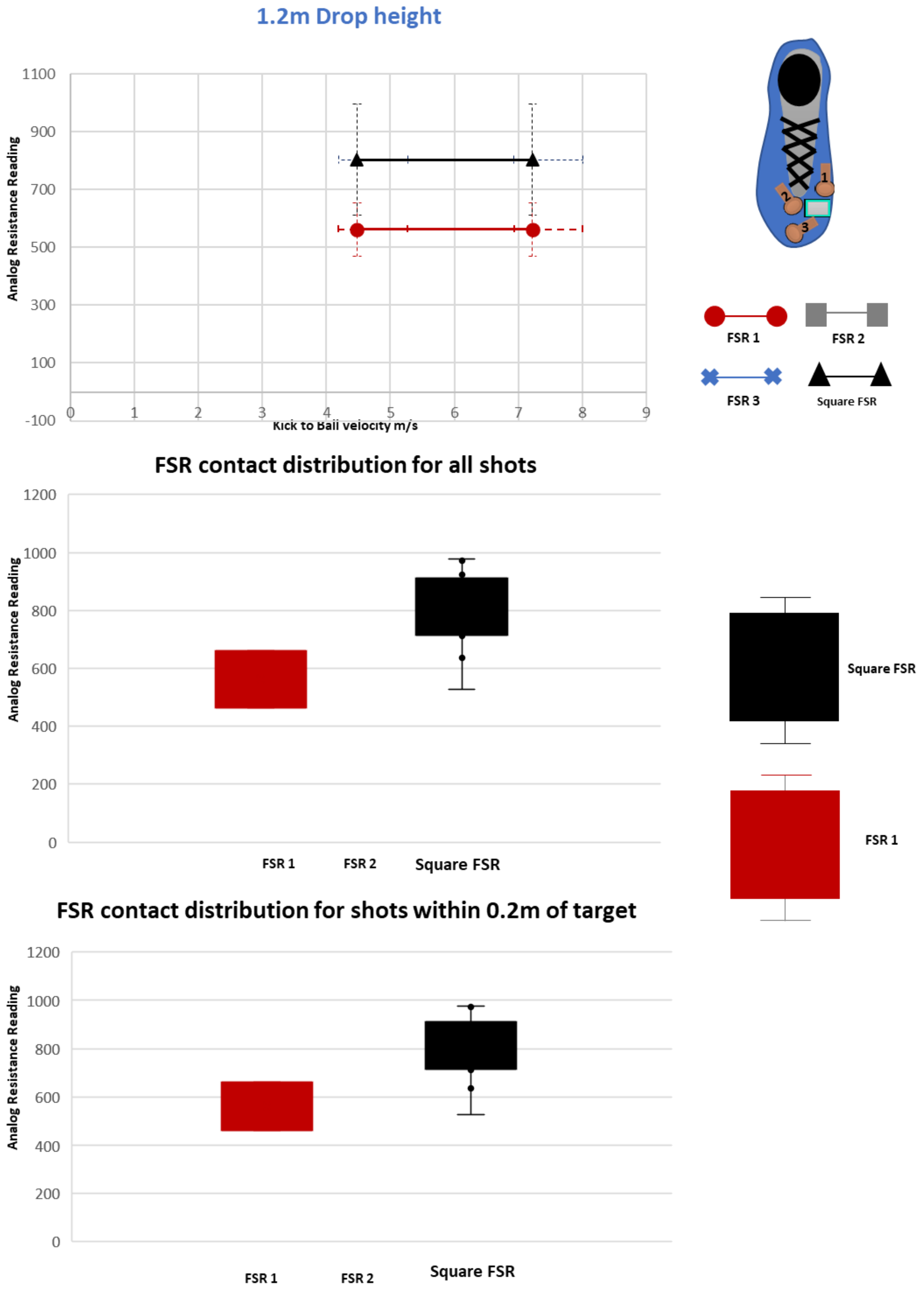


Figure 10.7.77

Laces Square FSR Set 4 with contact distribution : 0.9m Drop height

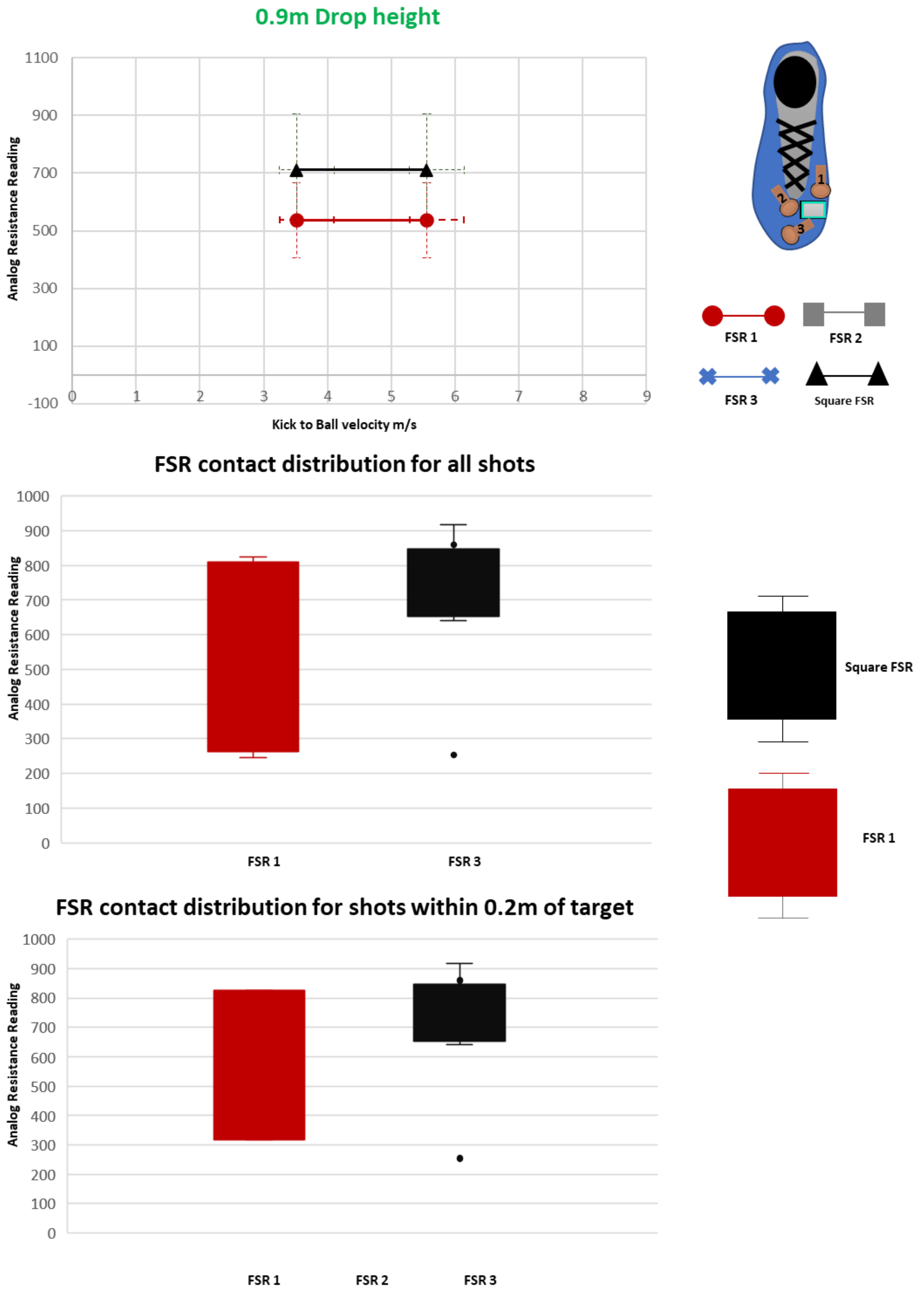
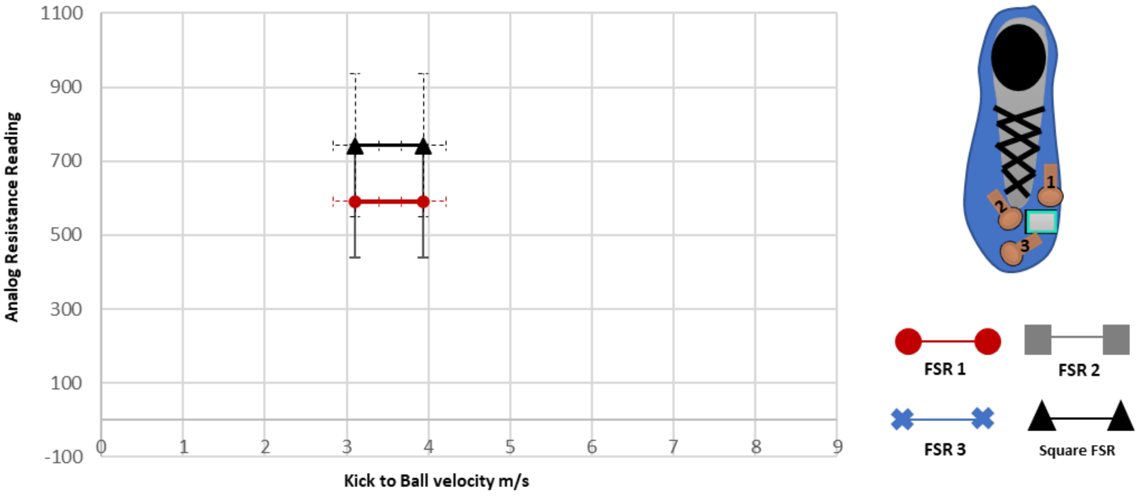


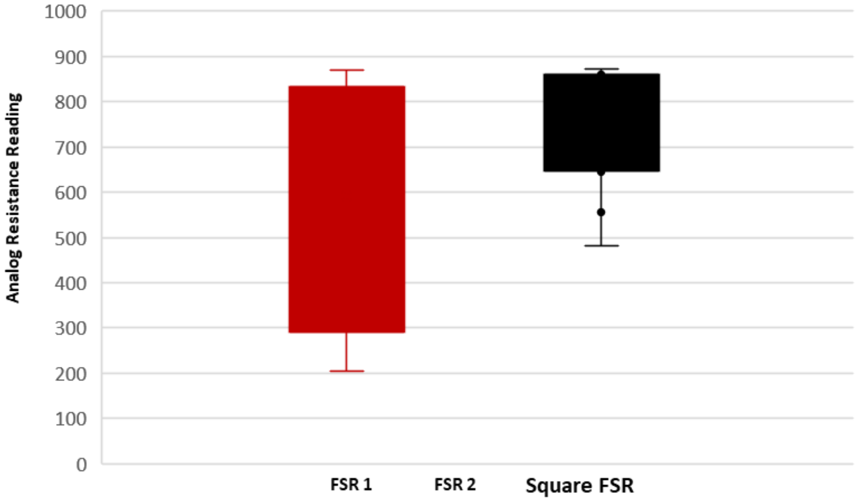
Figure 10.7.78

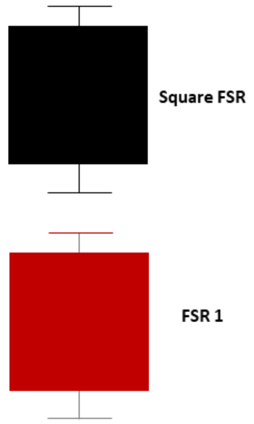
Laces Square FSR Set 4 with contact distribution : 0.6m Drop height

0.6m Drop height



FSR contact distribution for all shots





FSR contact distribution for shots within 0.2m of target

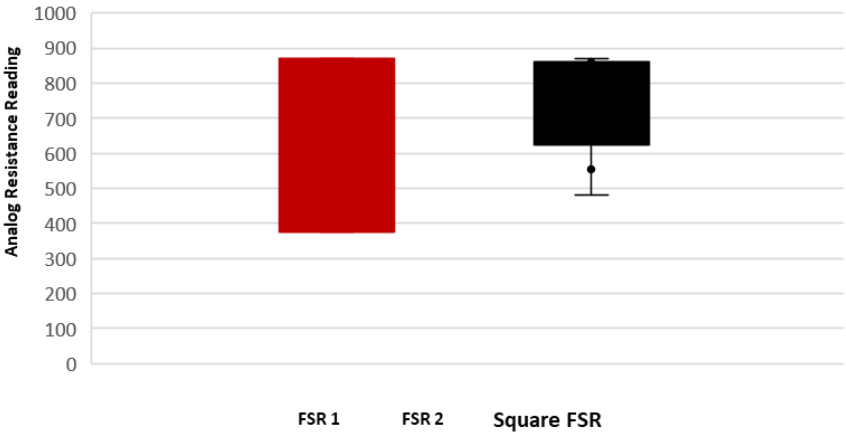


Figure 10.7.79

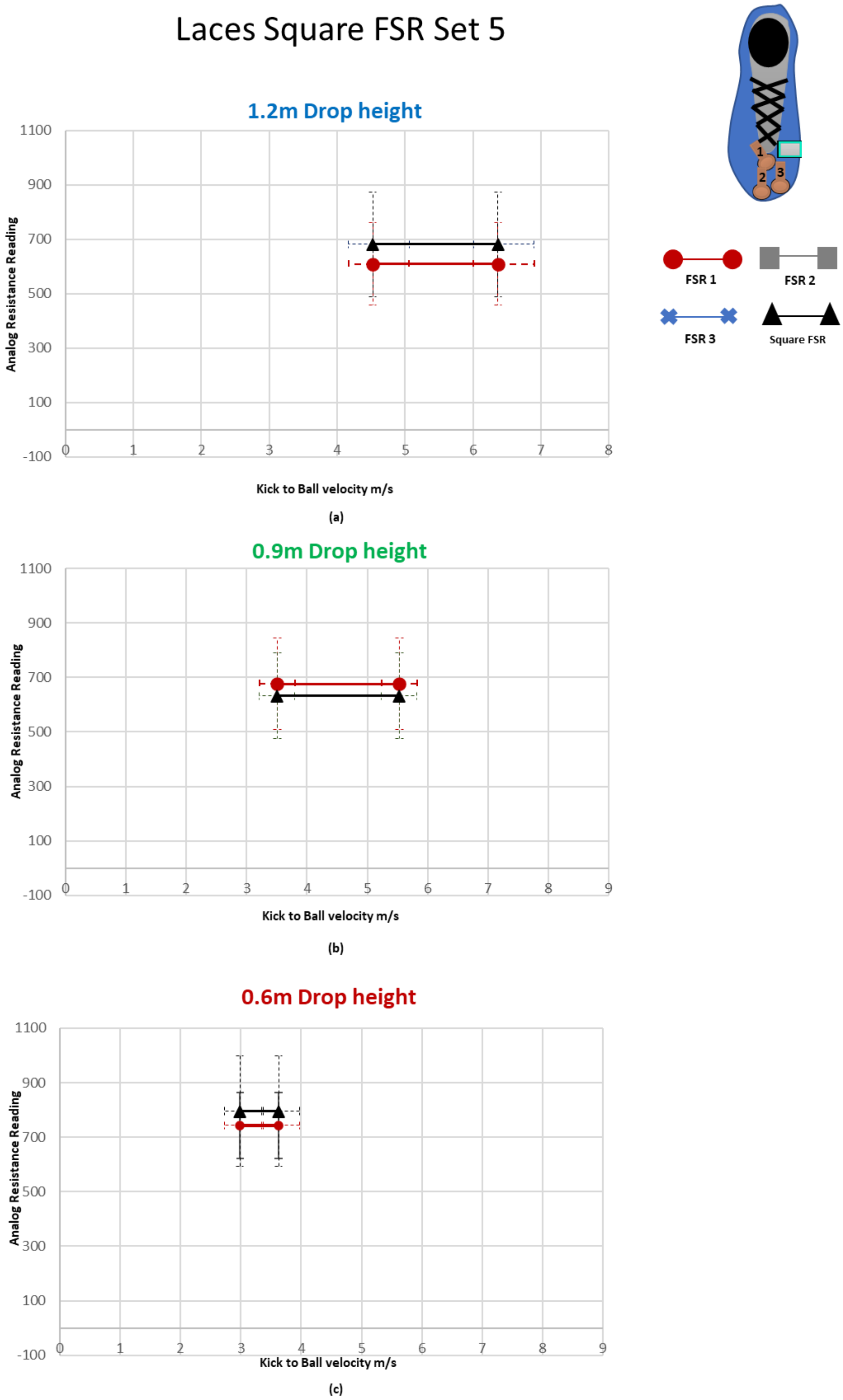


Figure 10.7.80

Laces Square FSR Set 5 with contact distribution : 1.2m Drop height

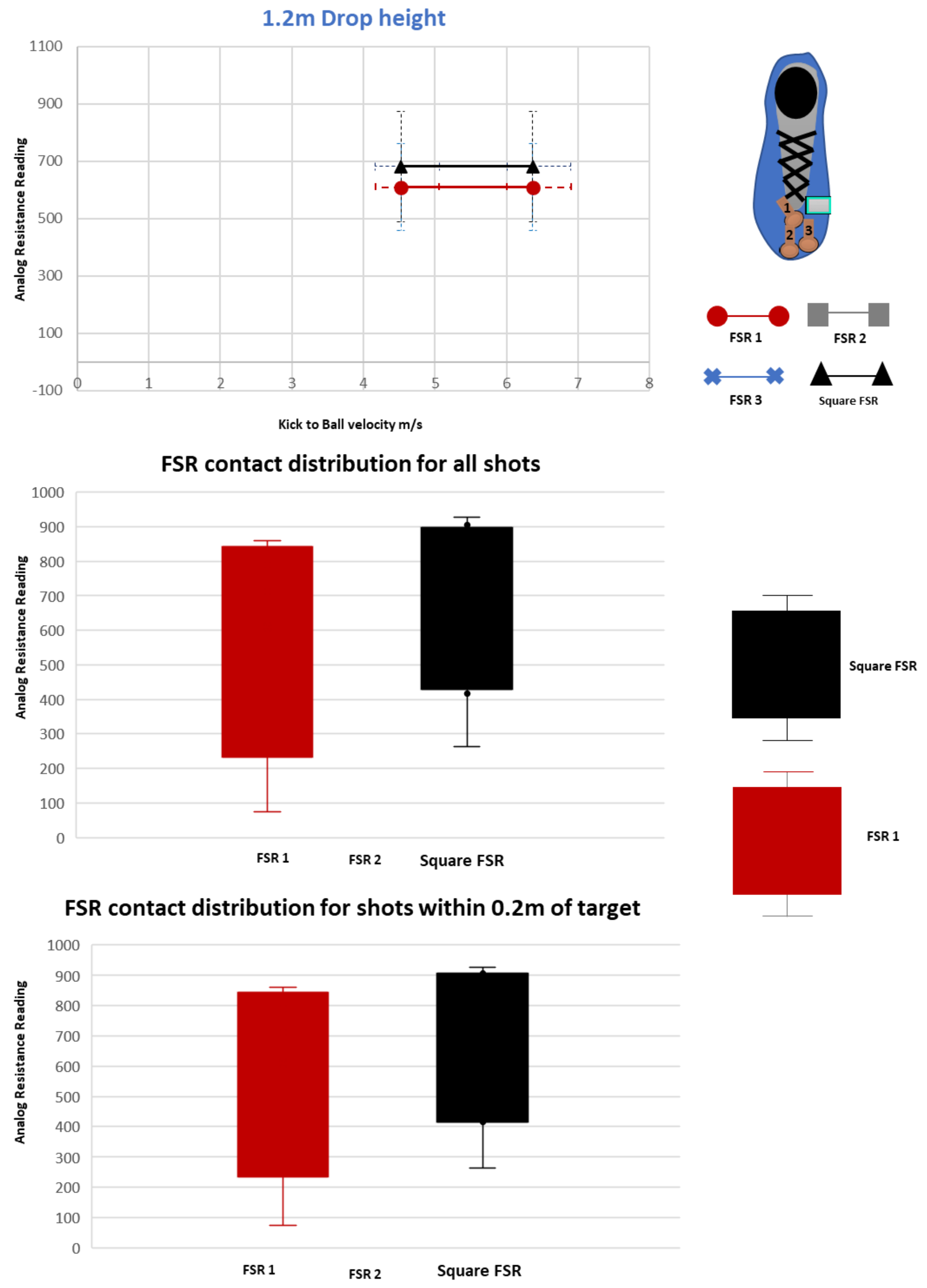


Figure 10.7.80

Laces Square FSR Set 5 with contact distribution : 0.9m Drop height

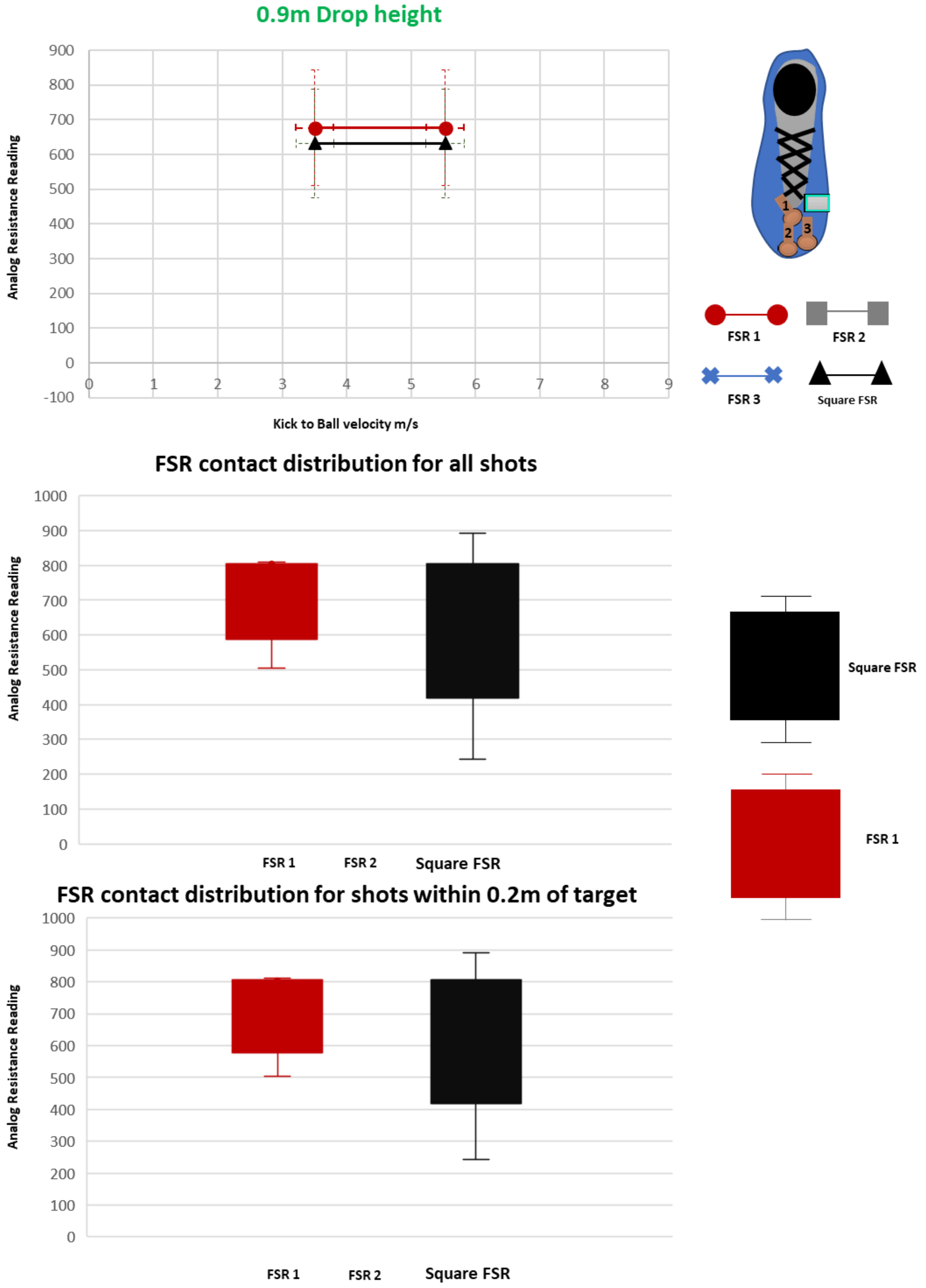


Figure 10.7.81

Laces Square FSR Set 5 with contact distribution : 0.6m Drop height

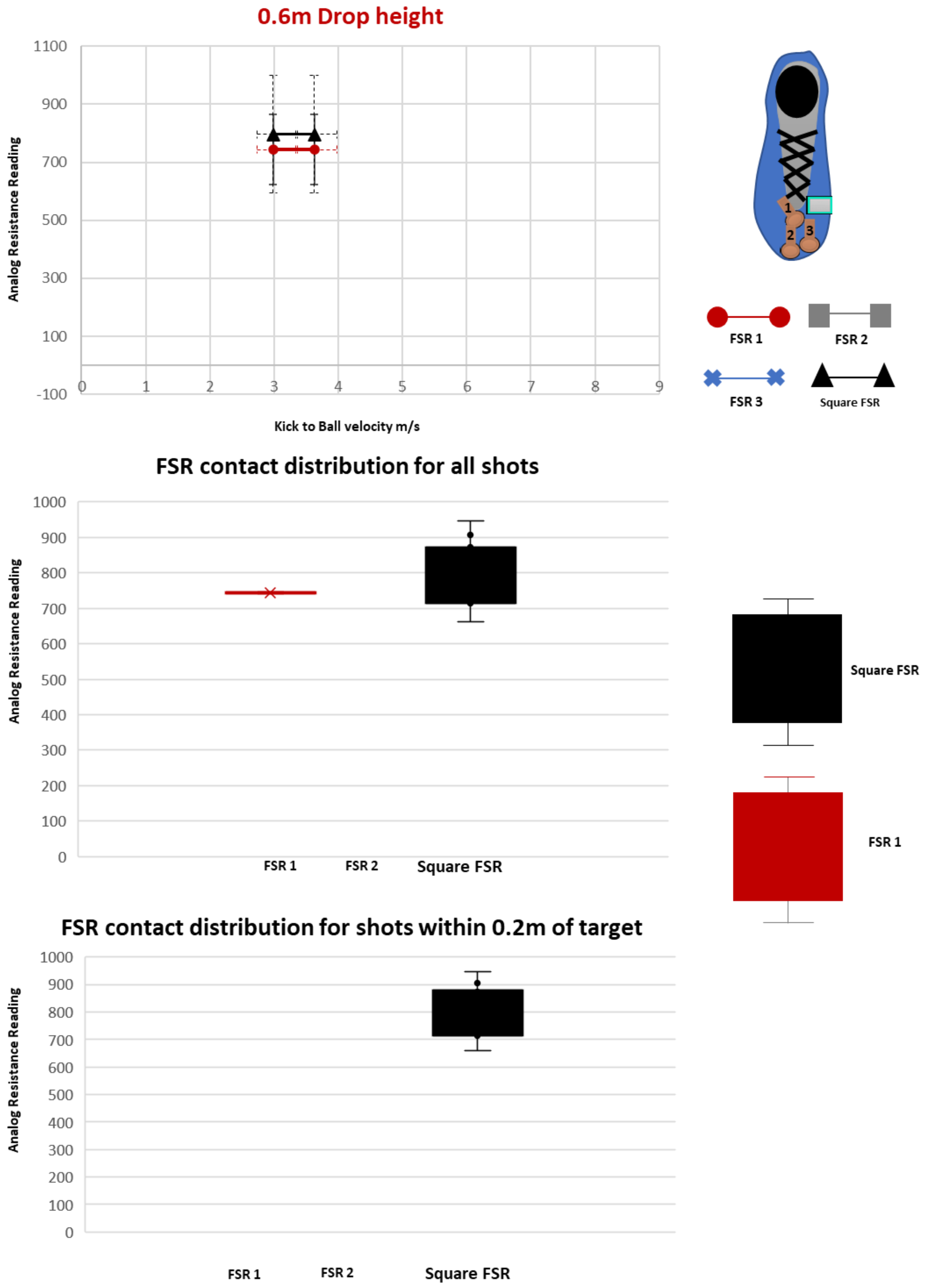
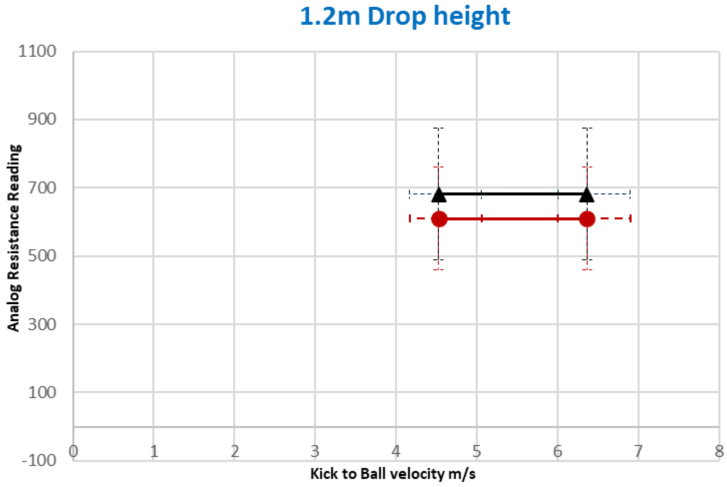
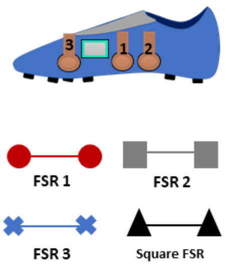


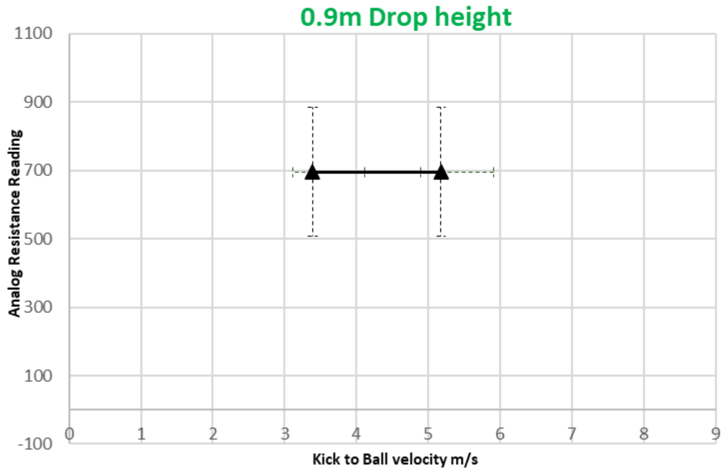
Figure 10.7.82

Inside Square FSR Set 1

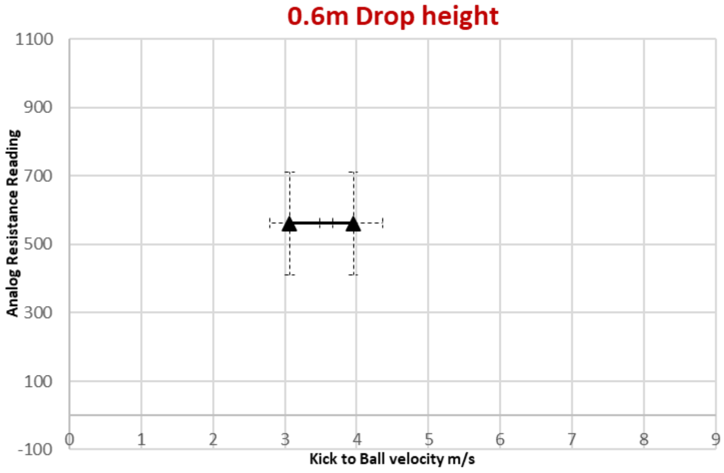


(a)





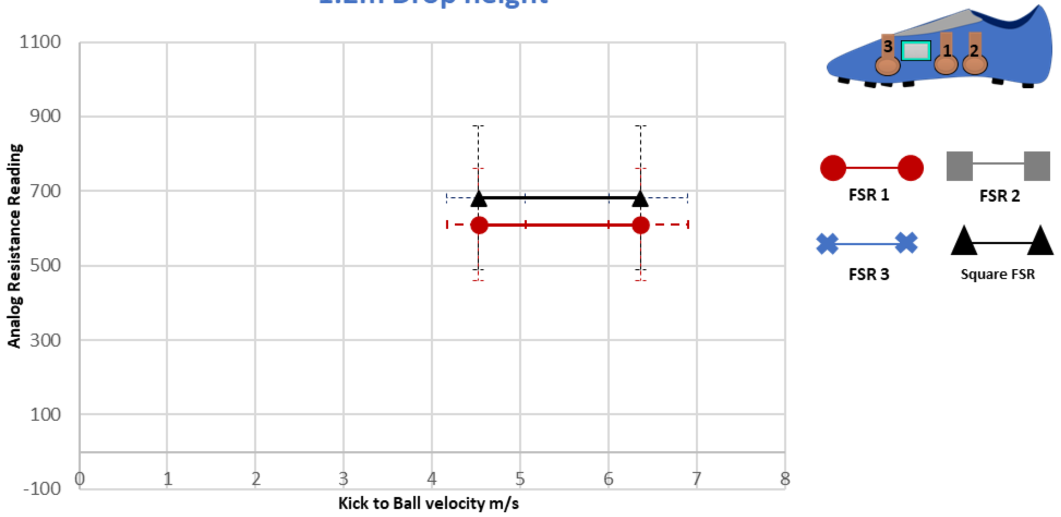
(b)

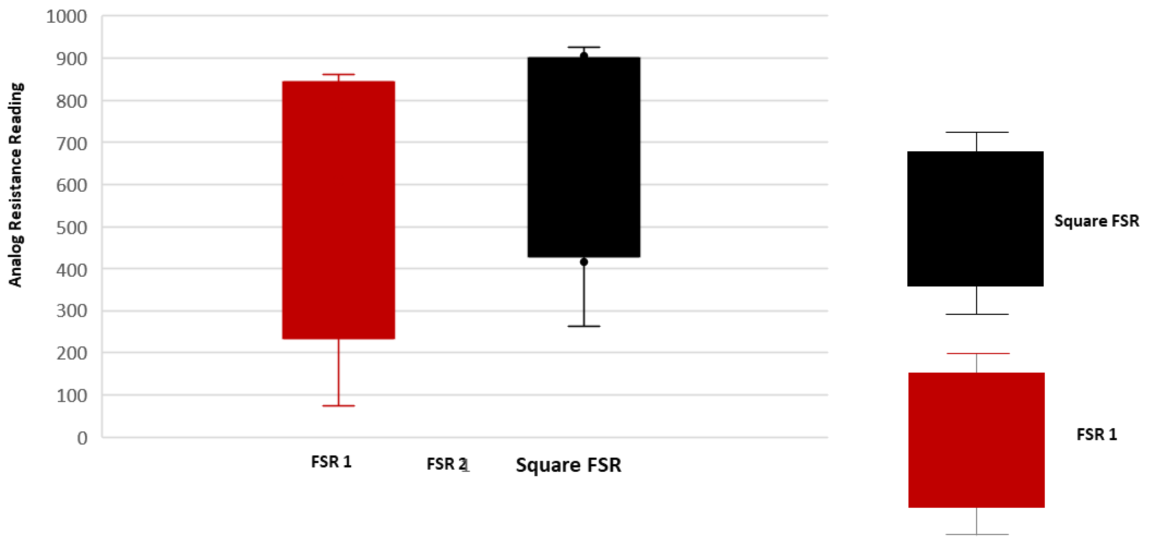


(c)

Figure 10.7.83

Inside Square FSR Set 1 with contact distribution : 1.2m Drop height


1.2m Drop height


FSR contact distribution for all shots

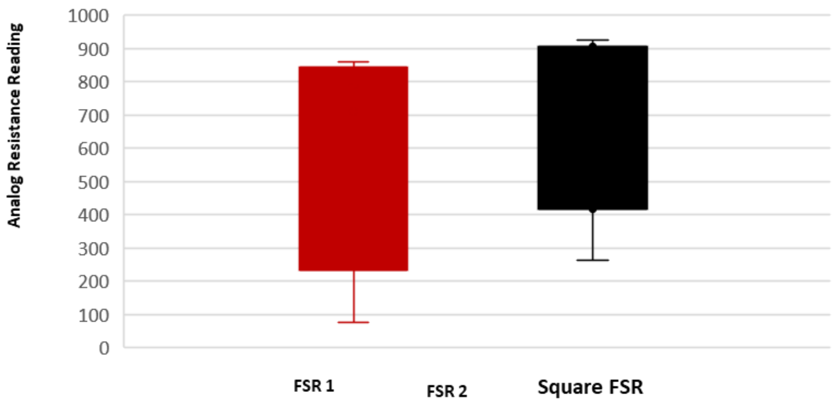

FSR contact distribution for shots within 0.2m of target

Figure 10.7.84

Inside Square FSR Set 1 with contact distribution : 0.9m Drop height

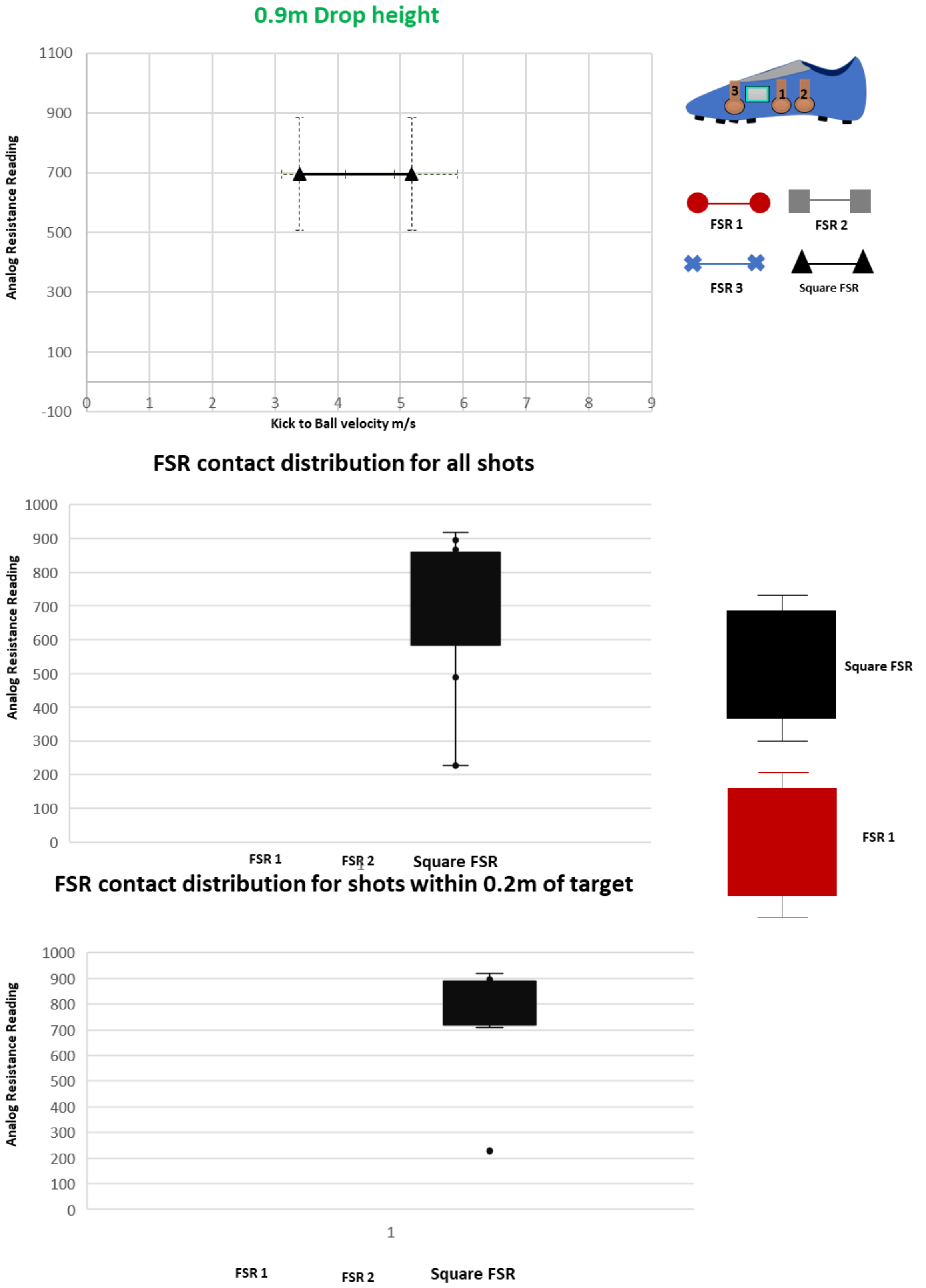


Figure 10.7.85

Inside Square FSR Set 1 with contact distribution : 0.6m Drop height

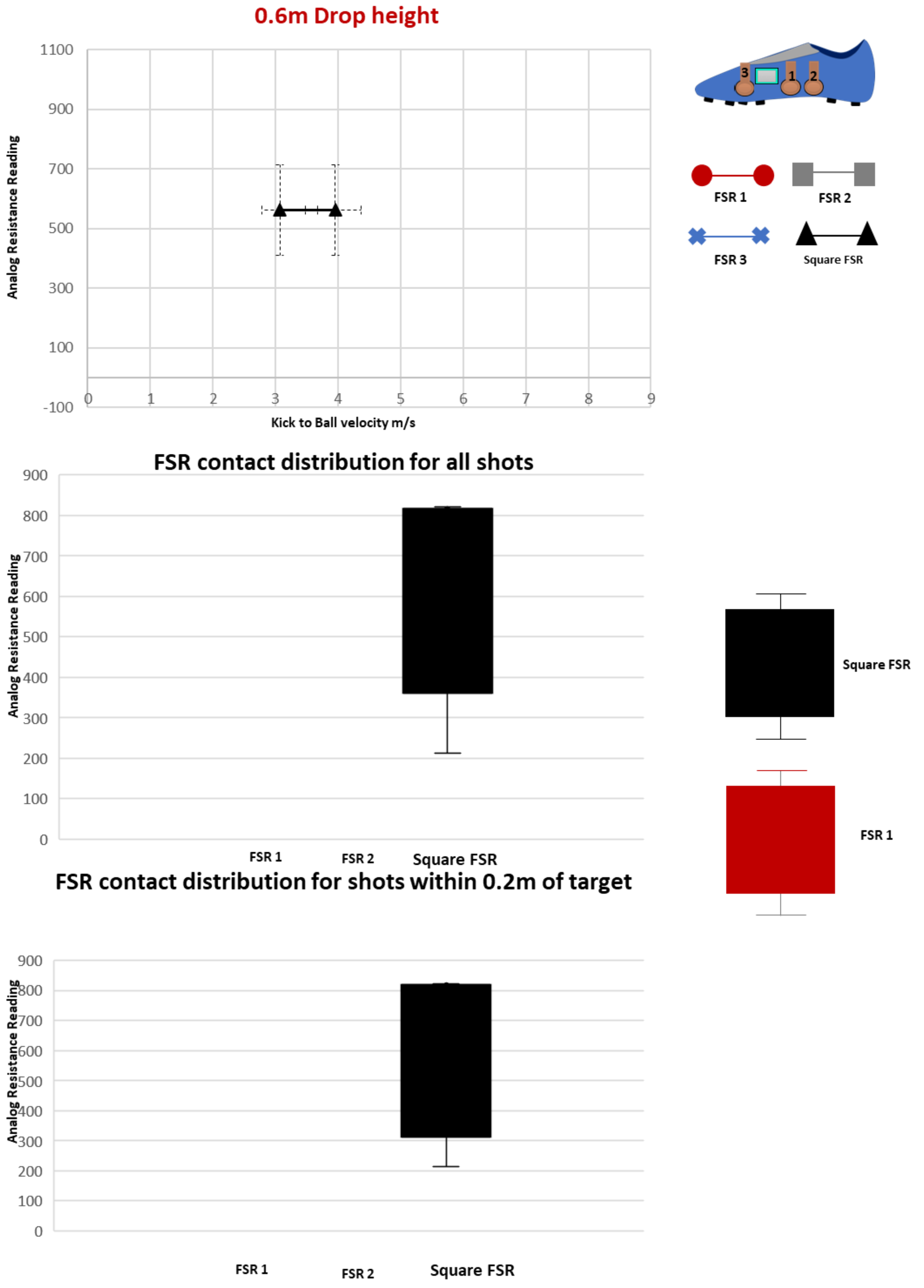
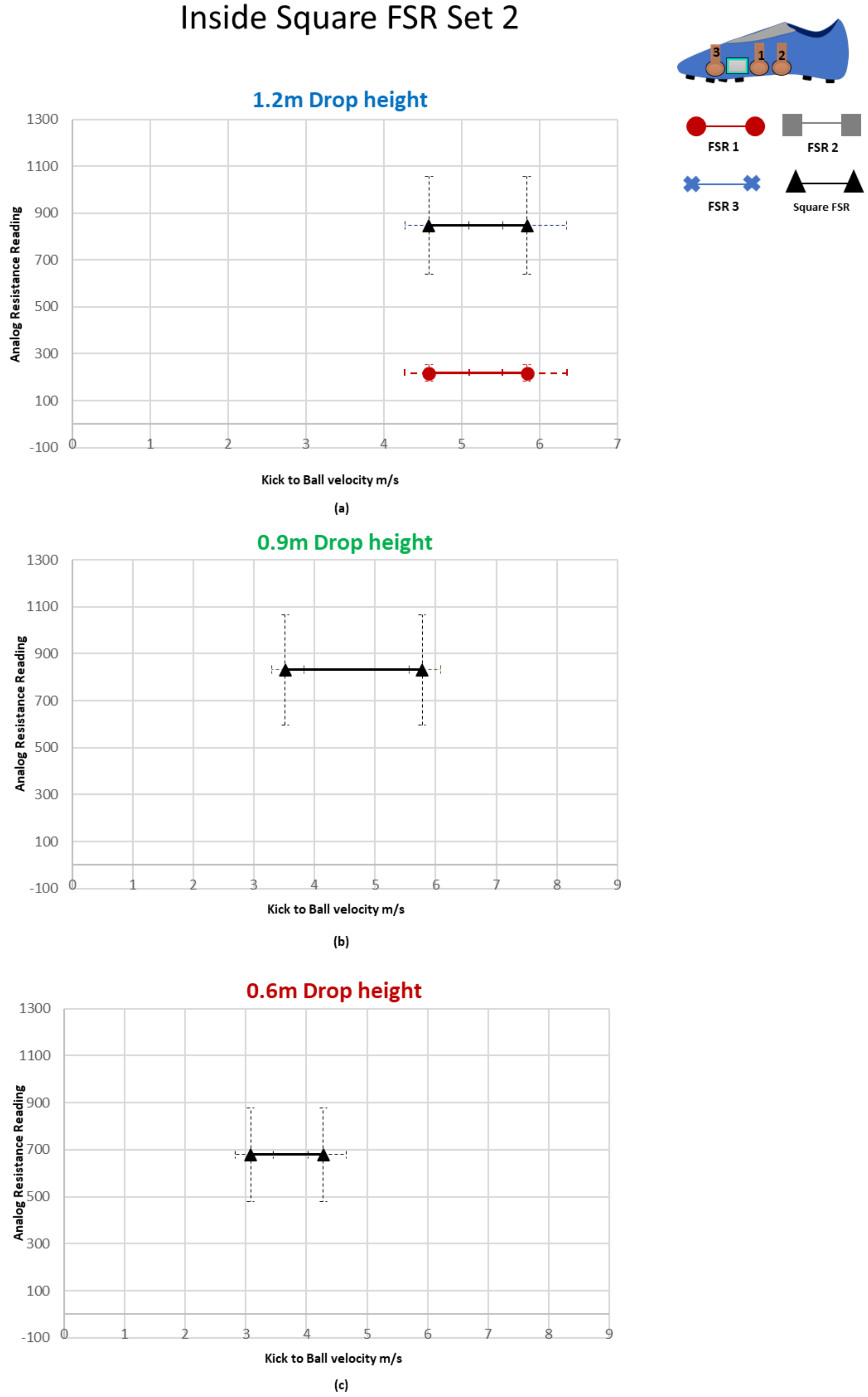


Figure 10.7.86

Inside Square FSR Set 2



(a)

(b)

(c)

Figure 10.7.87

Inside Square FSR Set 2 with contact distribution : 1.2m Drop height

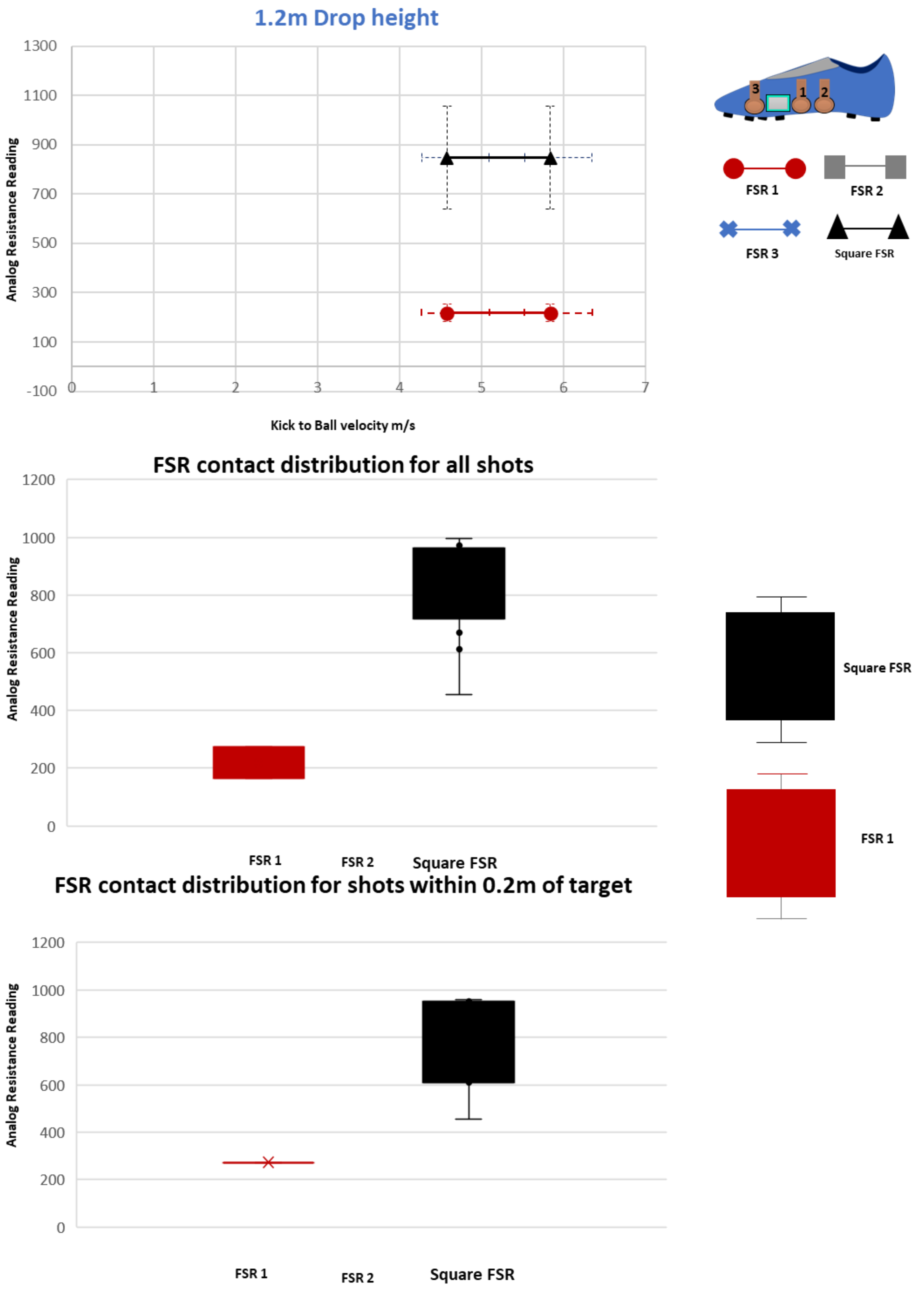
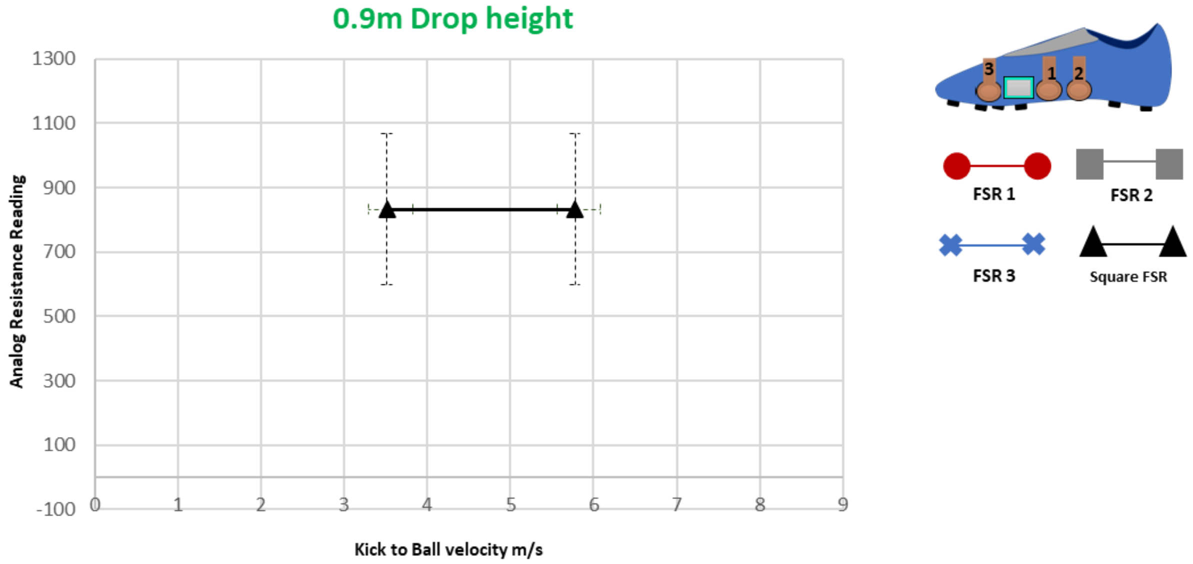
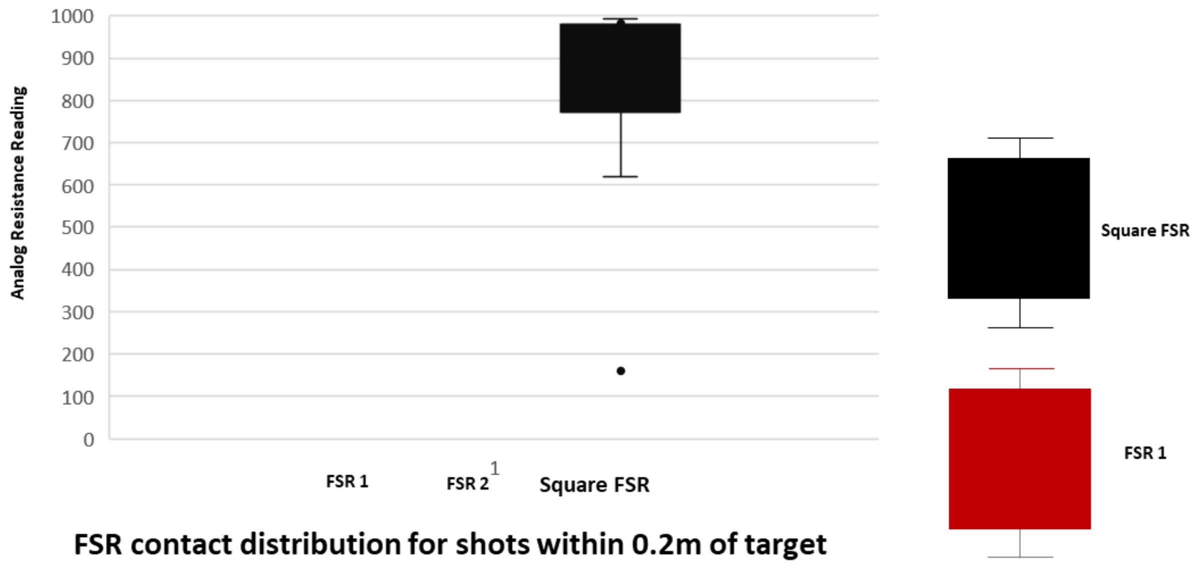


Figure 10.7.88

Inside Square FSR Set 2 with contact distribution : 0.9m Drop height



FSR contact distribution for all shots



FSR contact distribution for shots within 0.2m of target

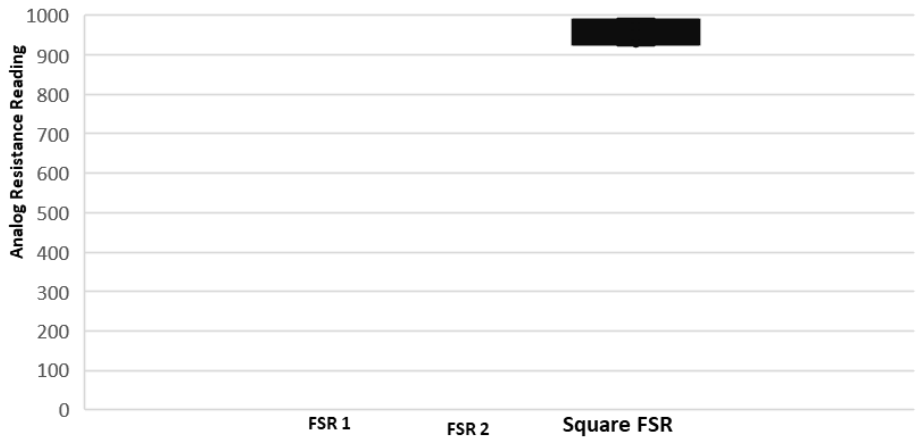


Figure 10.7.89

Inside Square FSR Set 2 with contact distribution : 0.6m Drop height

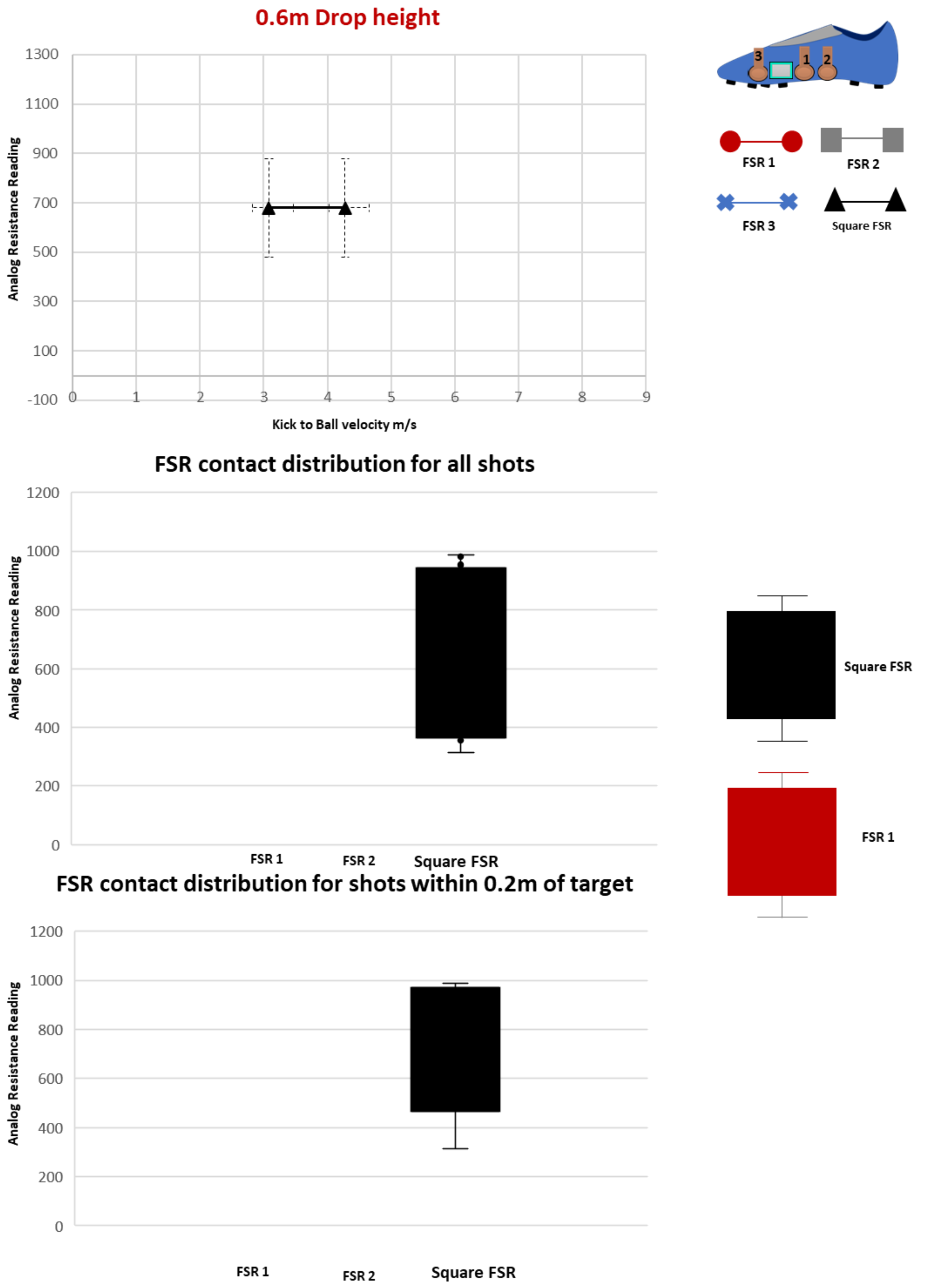


Figure 10.7.90

Inside Square FSR Set 3

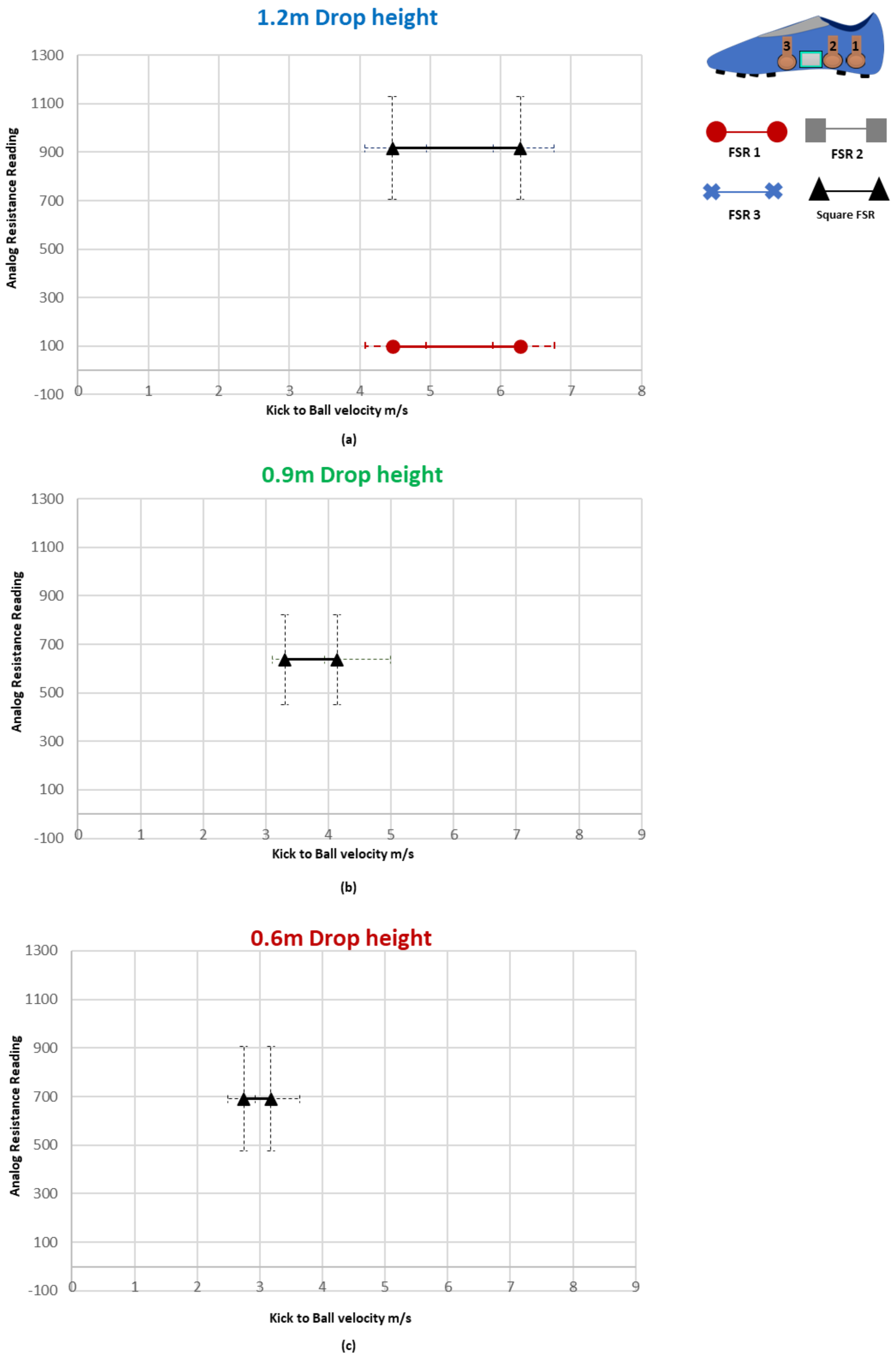


Figure 10.7.91

Inside Square FSR Set 3 with contact distribution : 1.2m Drop height

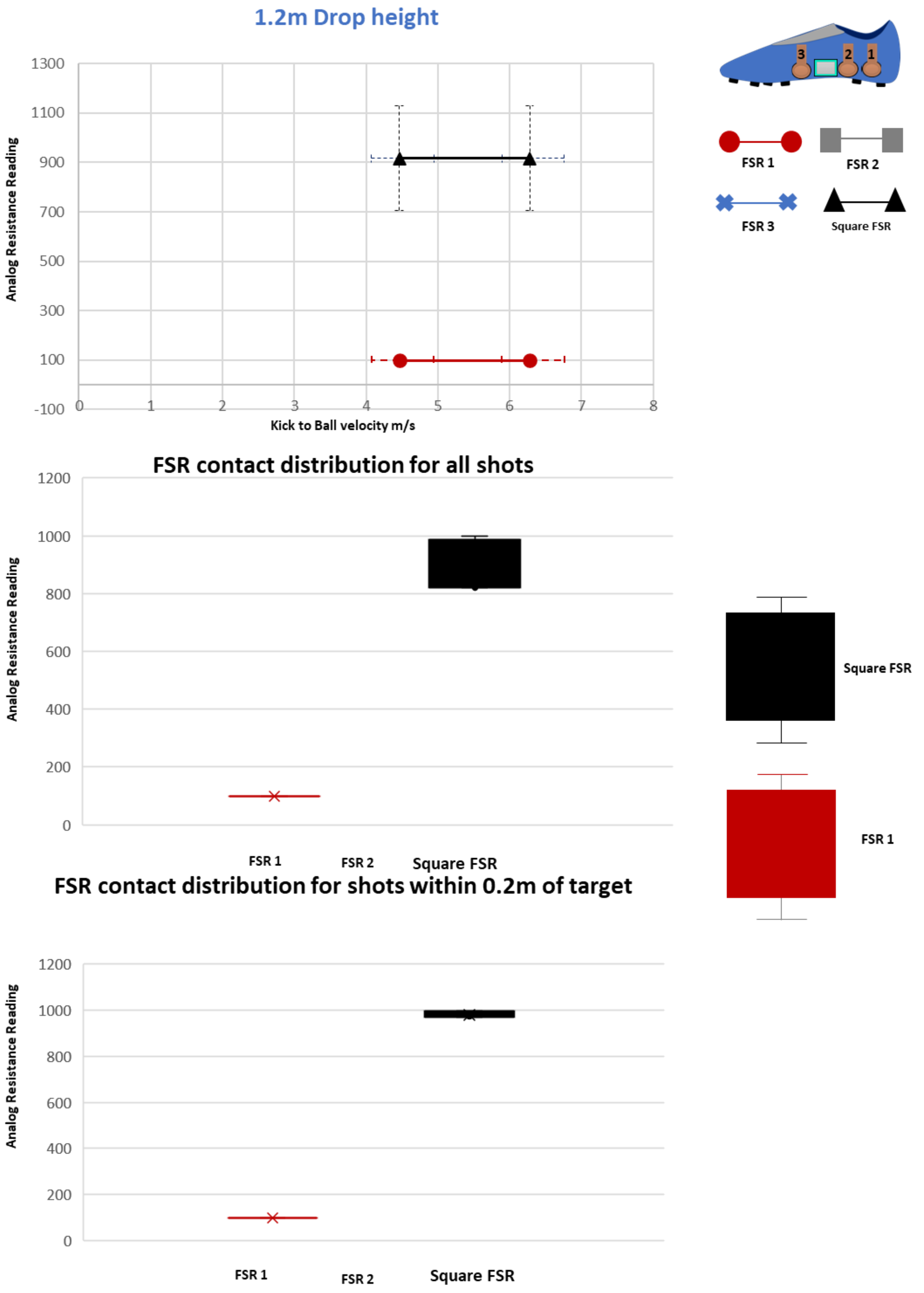


Figure 10.7.92

Inside Square FSR Set 3 with contact distribution : 0.9m Drop height

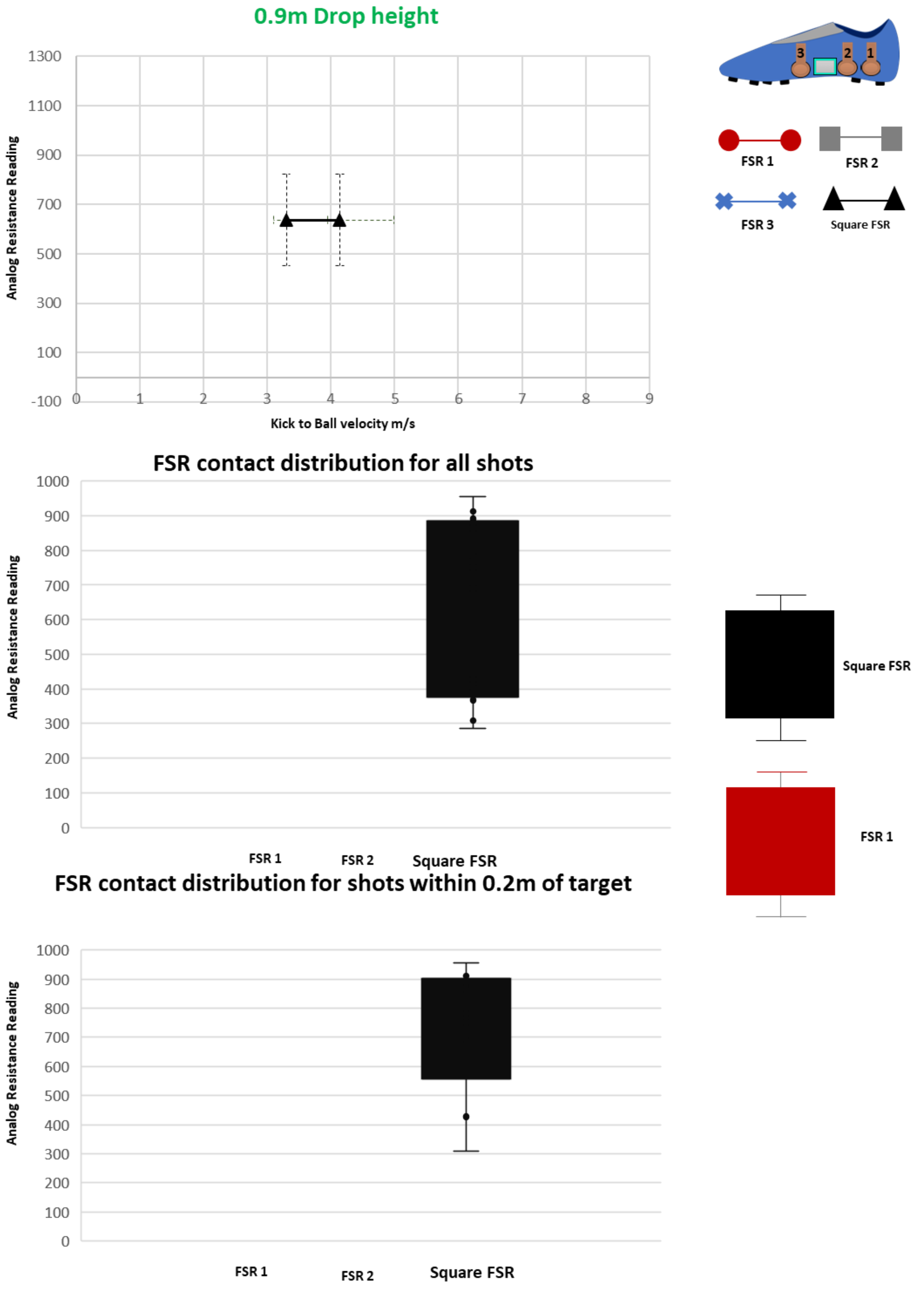
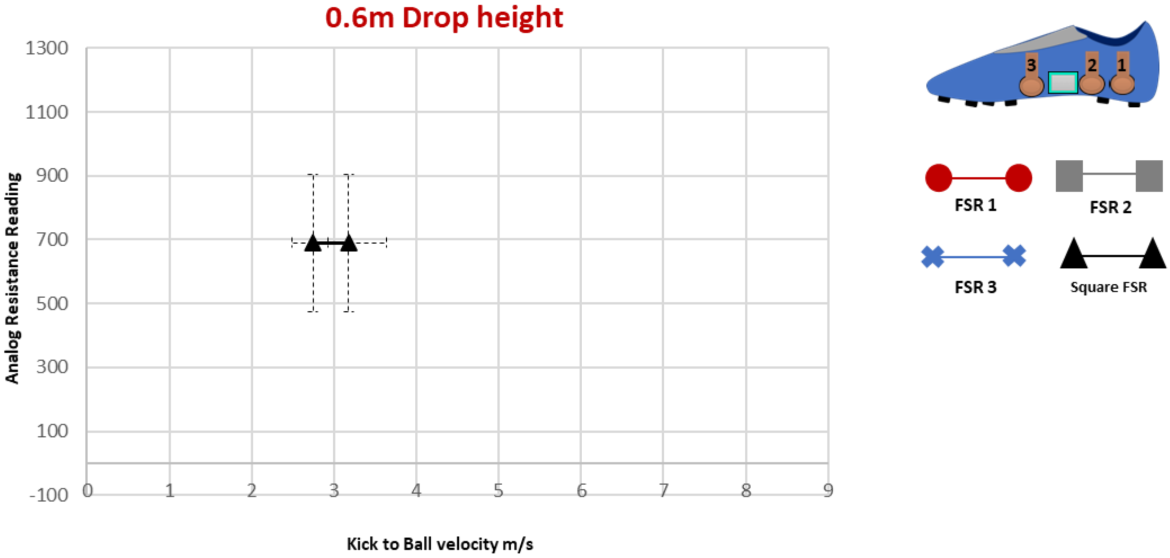
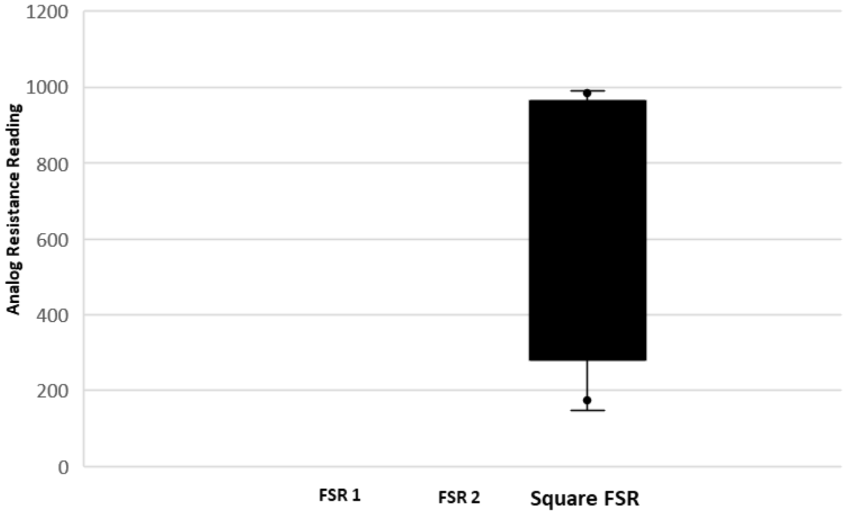


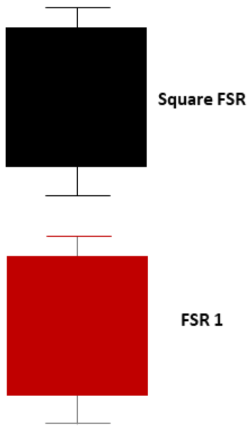
Figure 10.7.93

Inside Square FSR Set 3 with contact distribution : 0.6m Drop height


0.6m Drop height

FSR contact distribution for all shots





FSR contact distribution for shots within 0.2m of target

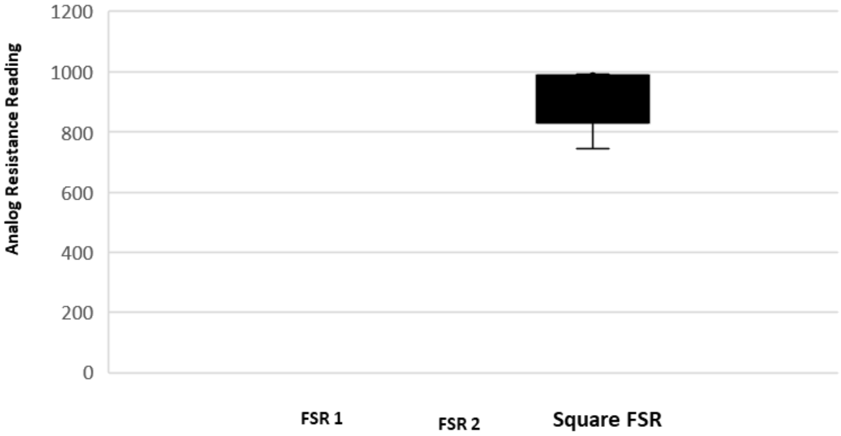


Figure 10.7.94

Inside Square FSR Set 4

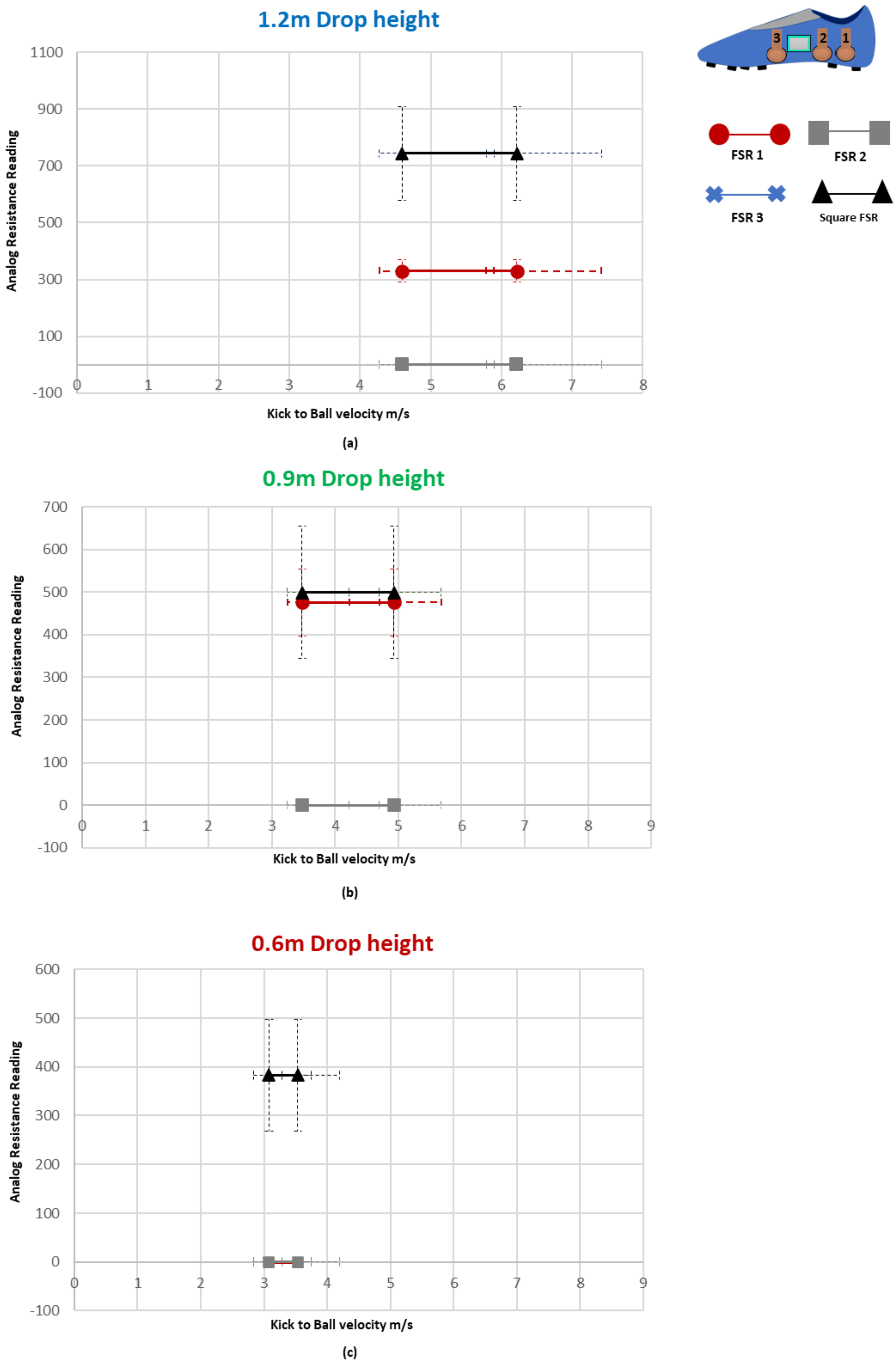


Figure 10.7.95

Inside Square FSR Set 4 with contact distribution : 1.2m Drop height

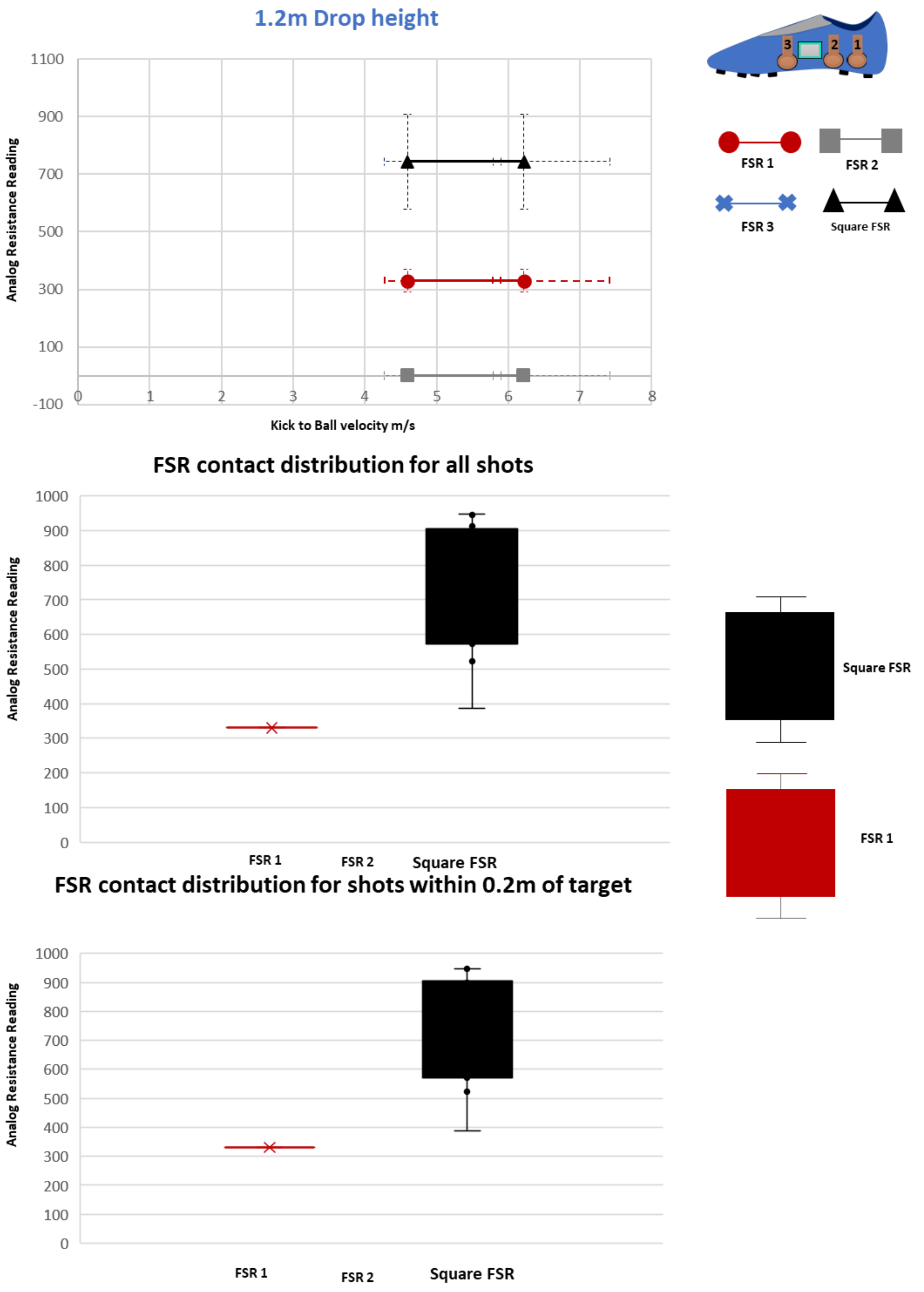


Figure 10.7.96

Inside Square FSR Set 4 with contact distribution : 0.9m Drop height

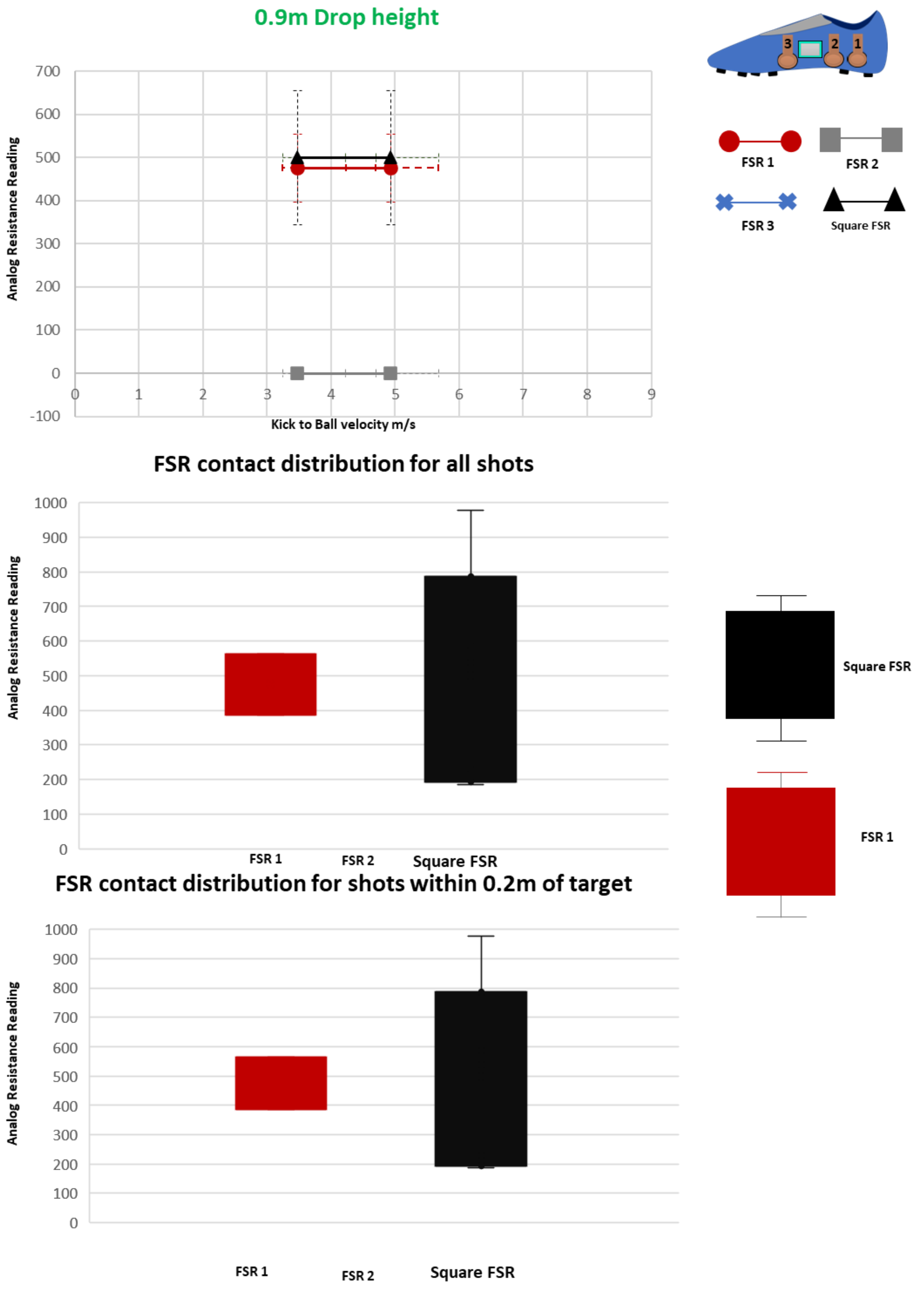


Figure 10.7.97

Inside Square FSR Set 4 with contact distribution : 0.6m Drop height

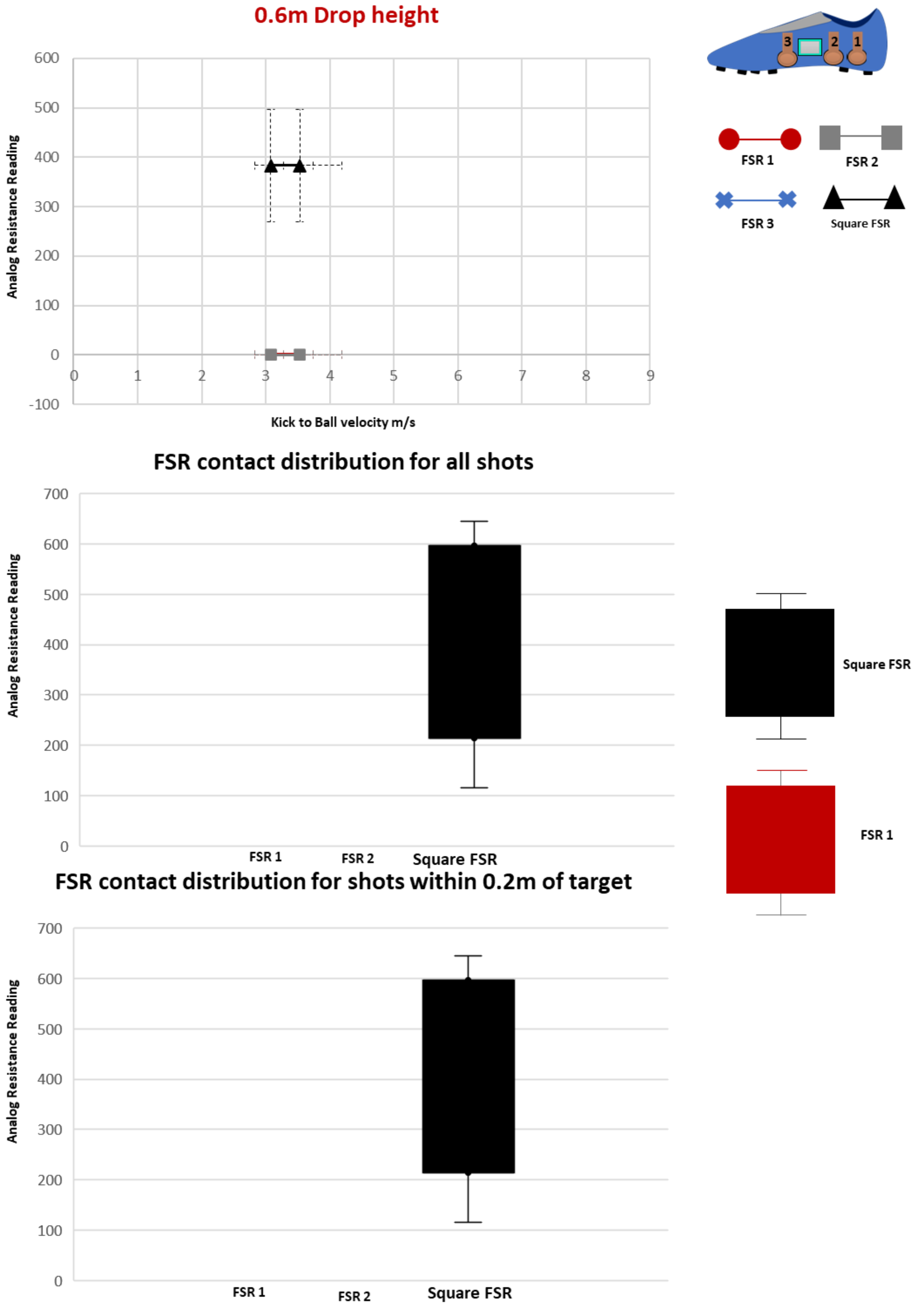


Figure 10.7.98

Inside 2 Circle FSR Set 1

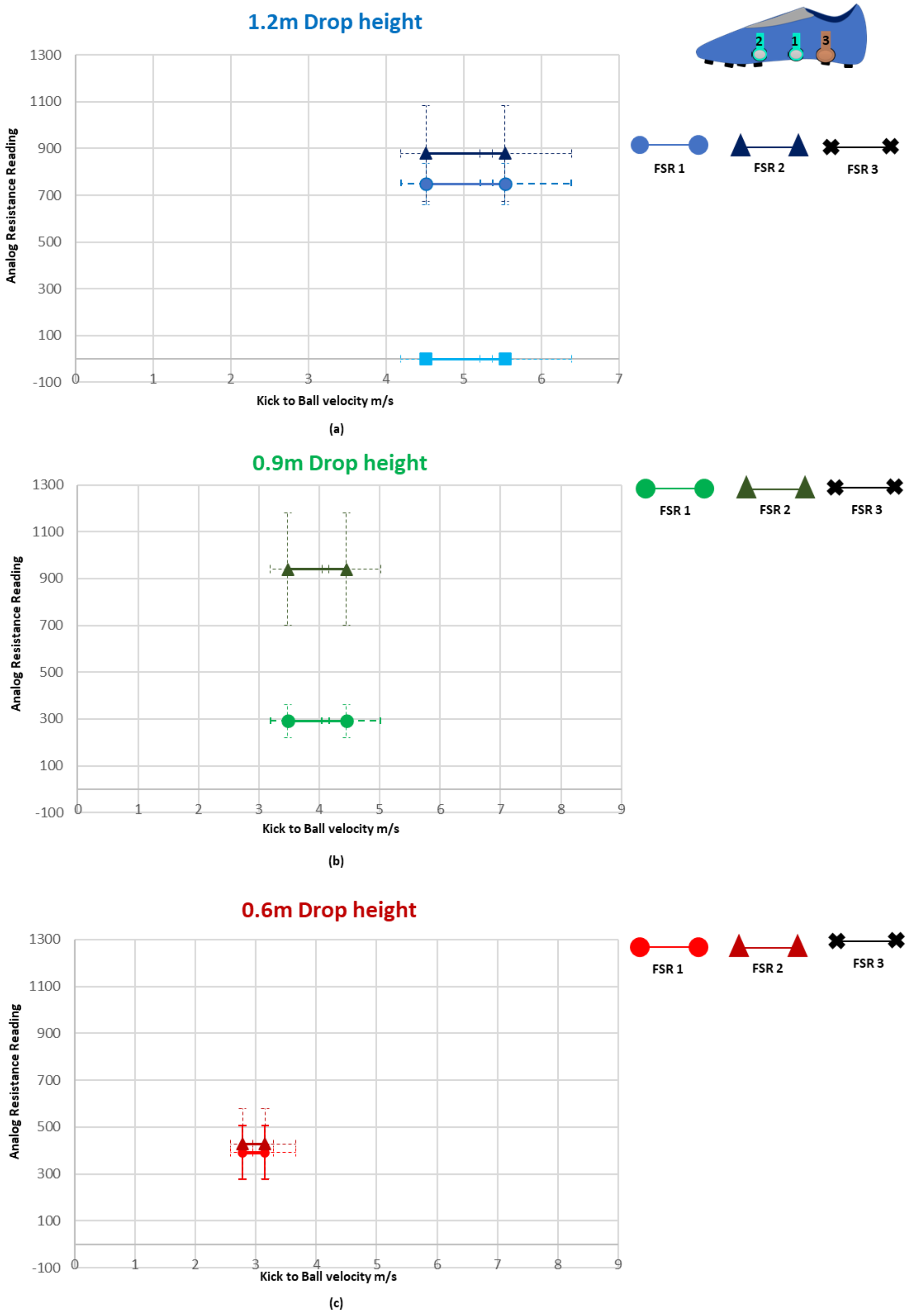


Figure 10.7.99

Inside 2 Circle FSR Set 1 with contact distribution : 1.2m Drop height

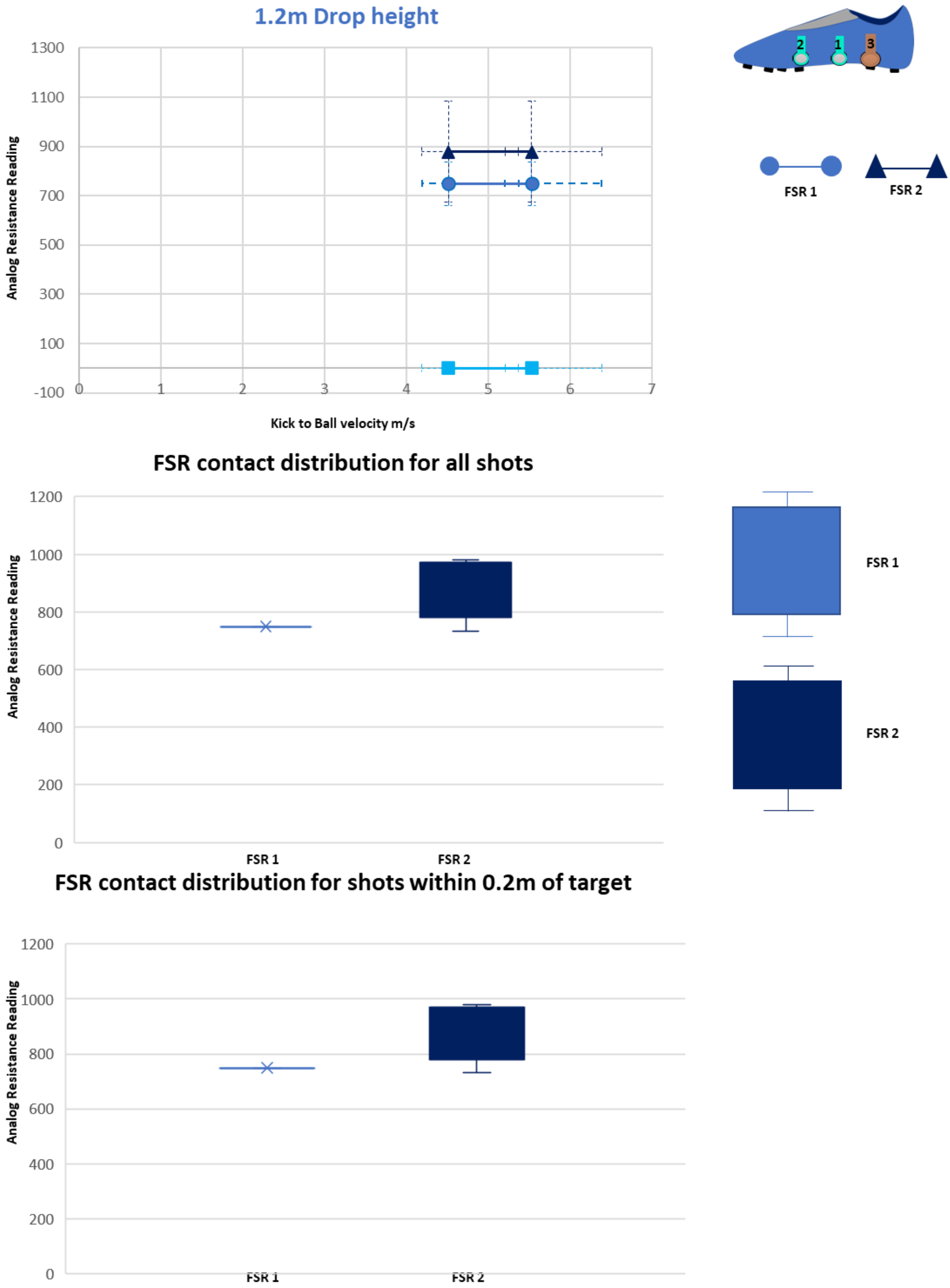


Figure 10.7.100

Inside 2 Circle FSR Set 1 with contact distribution : 0.9m Drop height

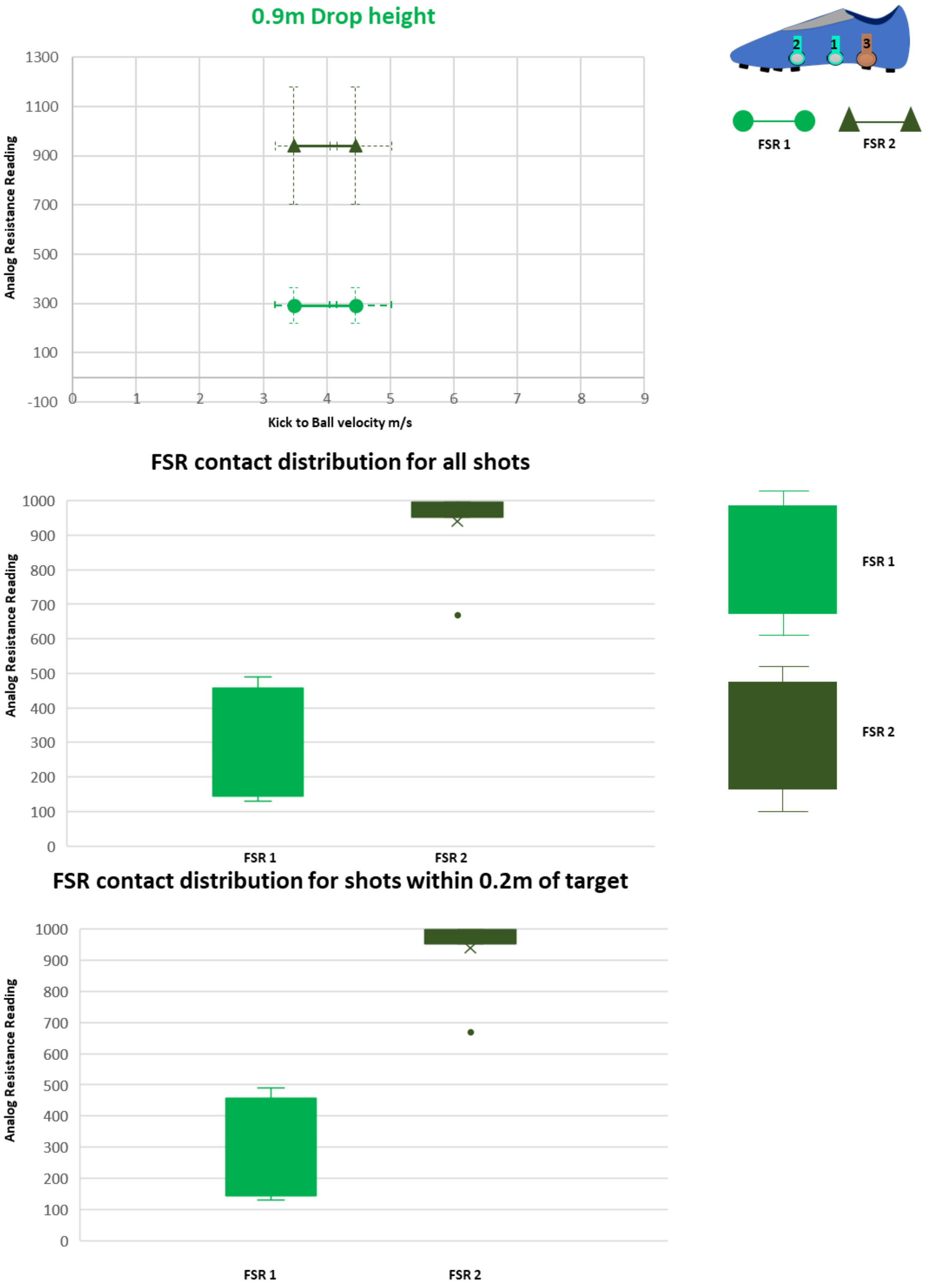
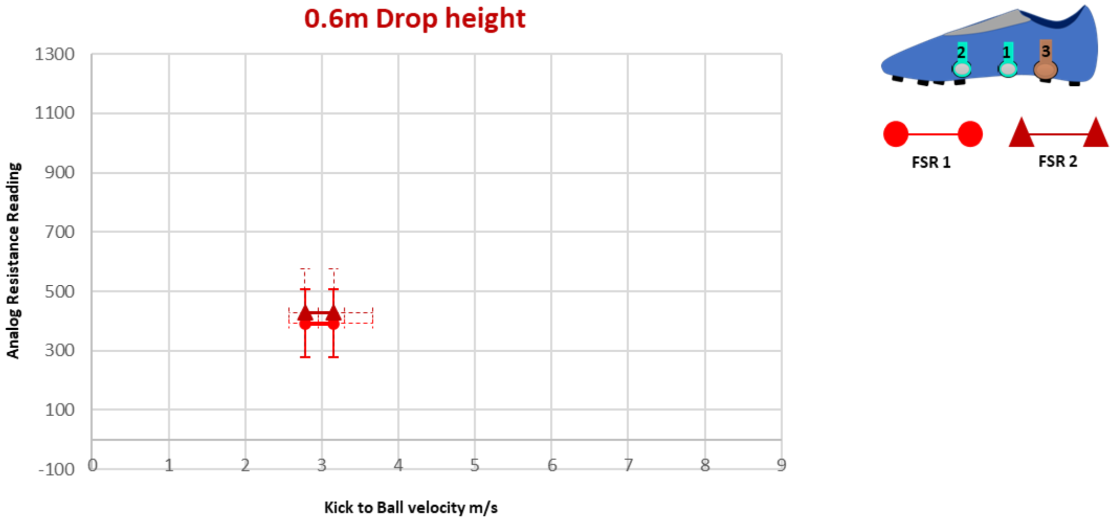
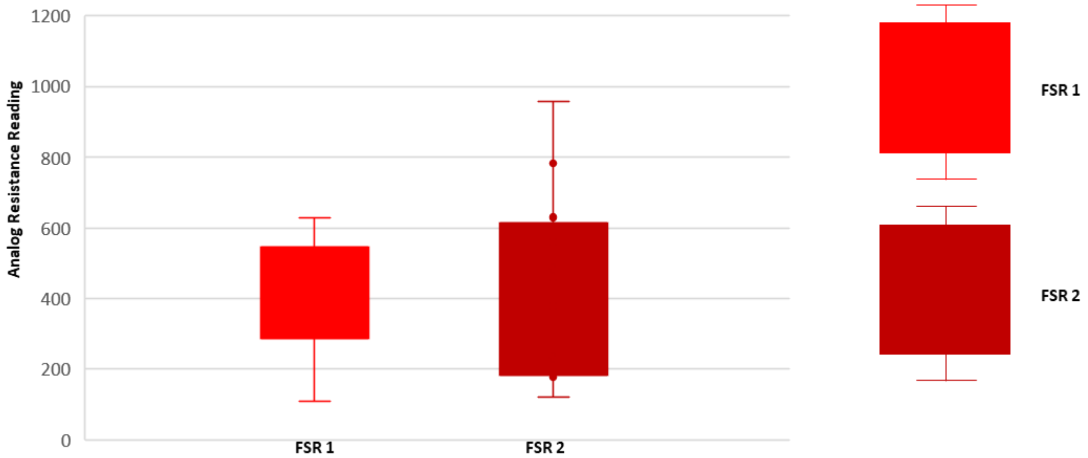


Figure 10.7.101

Inside 2 Circle FSR Set 1 with contact distribution : 0.6m Drop height


0.6m Drop height

FSR contact distribution for all shots



FSR contact distribution for shots within 0.2m of target

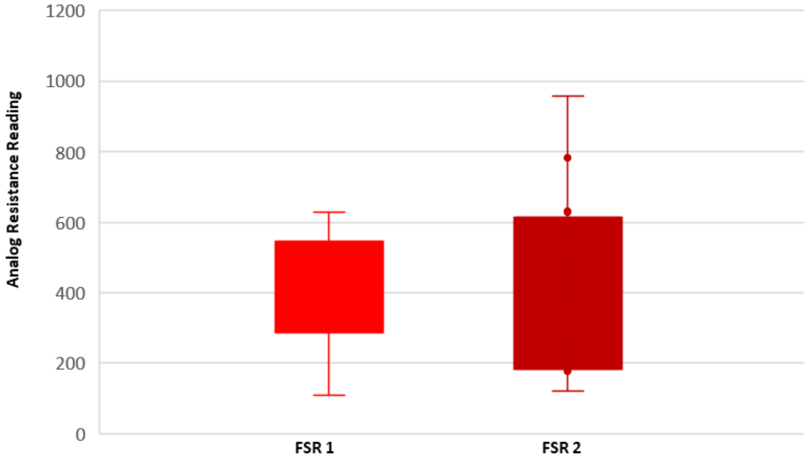


Figure 10.7.102

Inside 2 Circle FSR Set 2

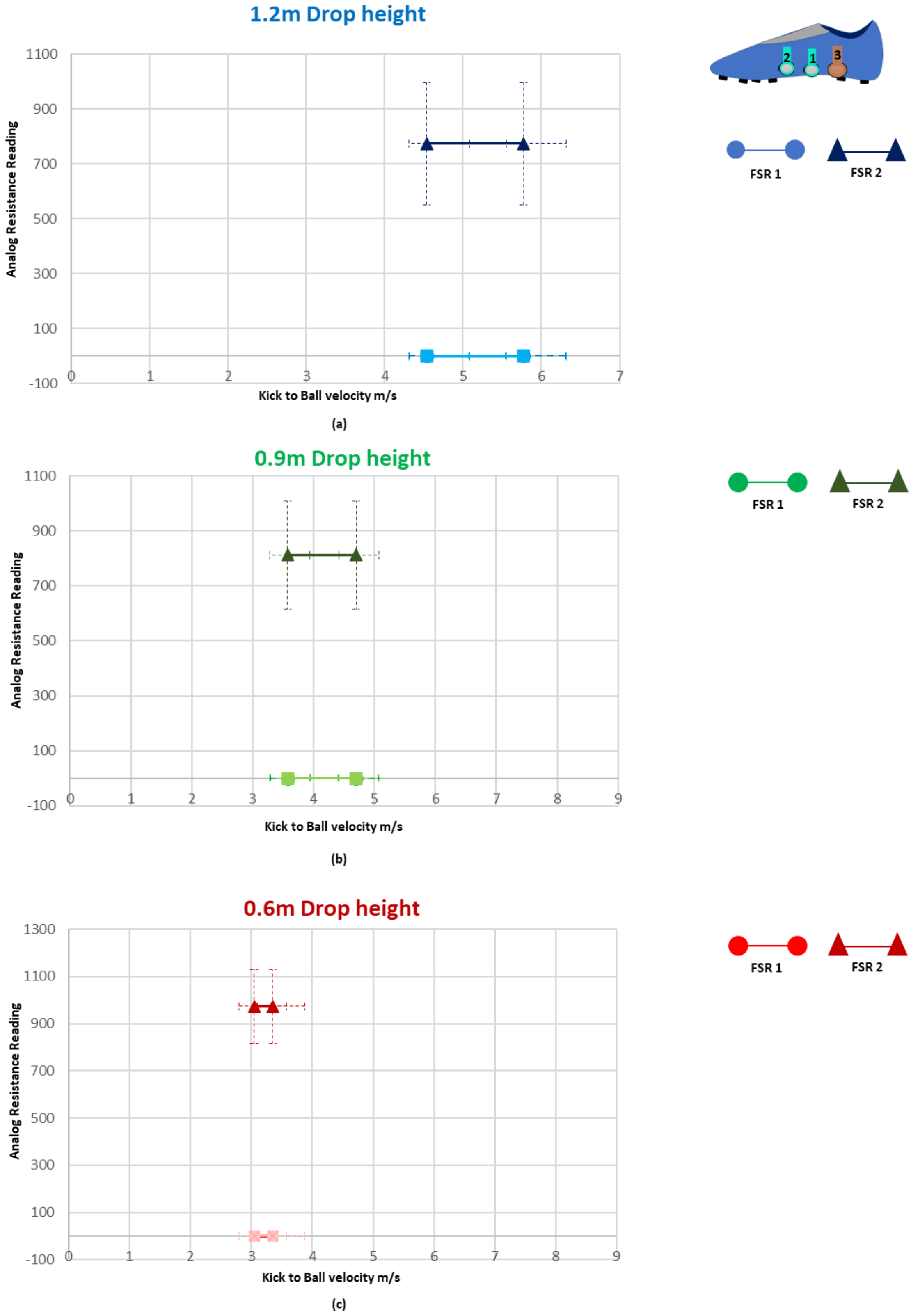
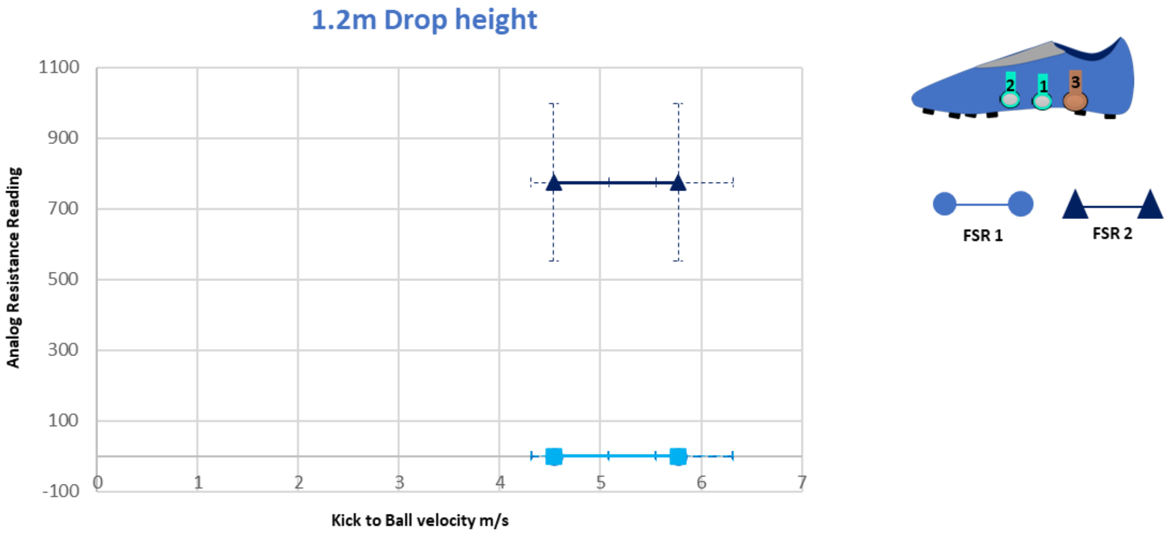
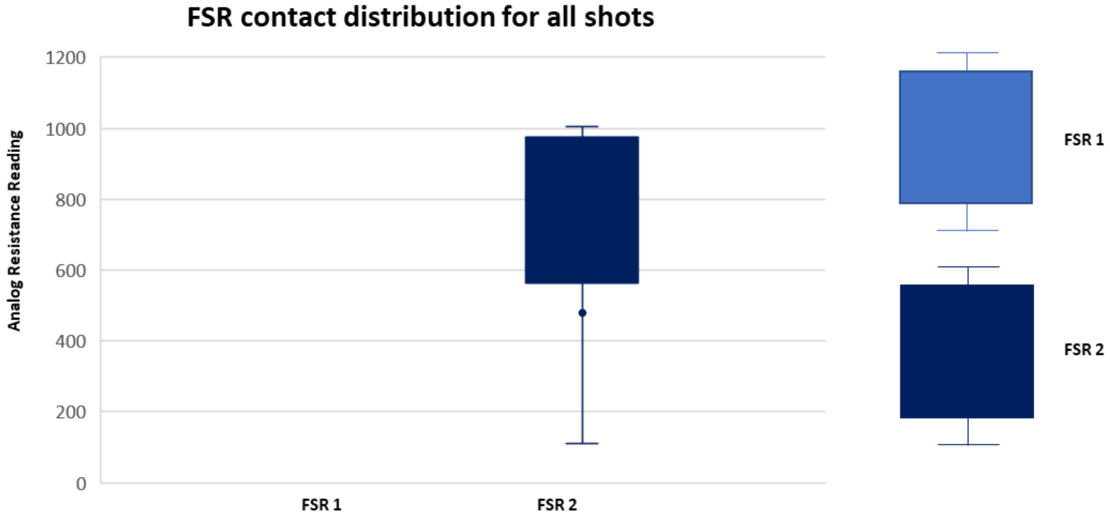


Figure 10.7.103

Inside 2 Circle FSR Set 2 with contact distribution : 1.2m Drop height





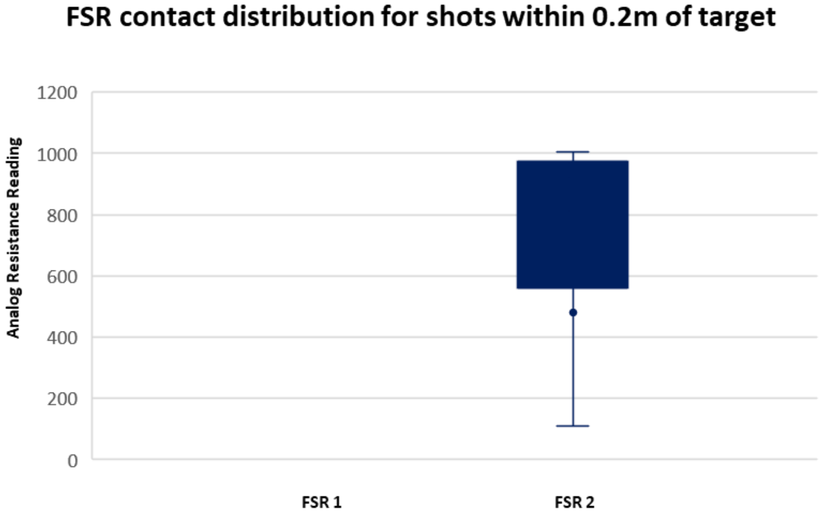
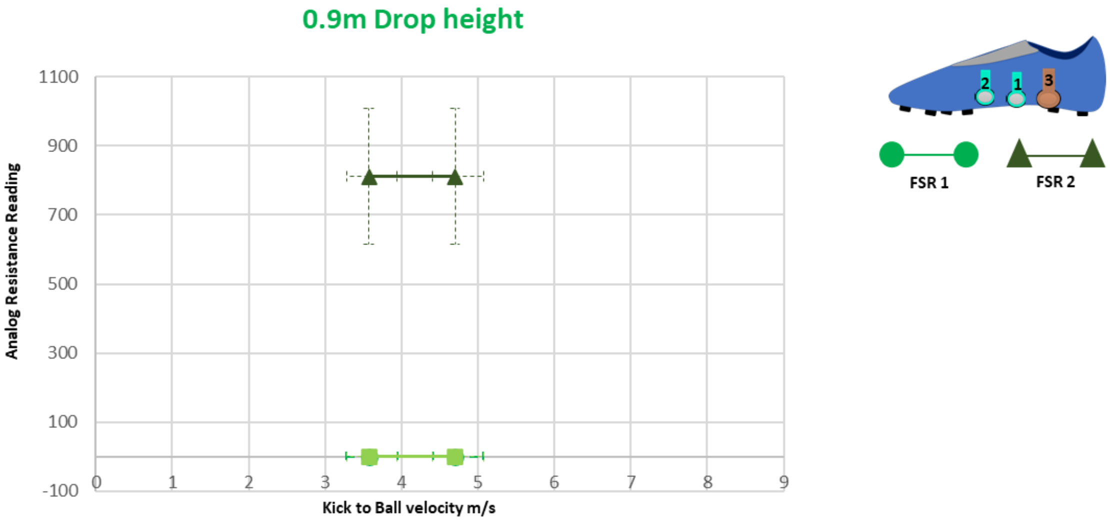
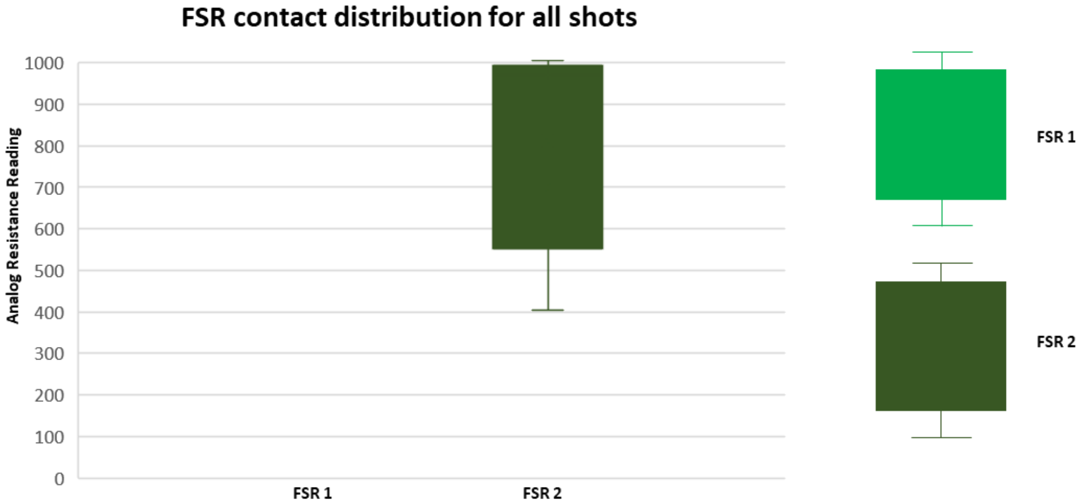


Figure 10.7.104

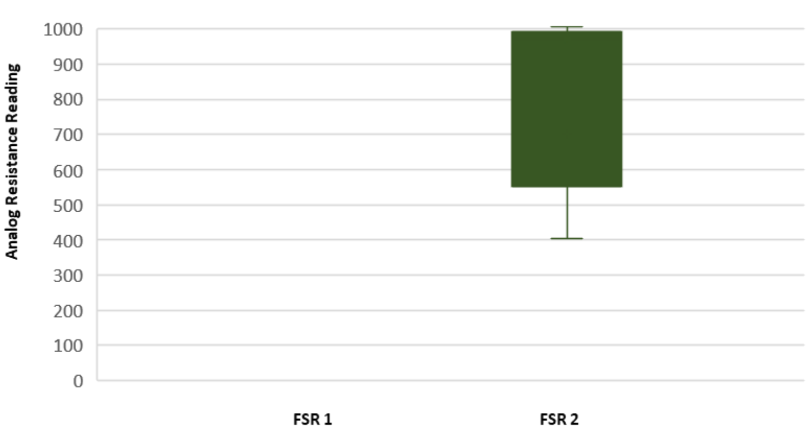
Inside 2 Circle FSR Set 2 with contact distribution : 0.9m Drop height



0.9m Drop height



FSR contact distribution for all shots



FSR contact distribution for shots within 0.2m of target

Figure 10.7.105

Inside 2 Circle FSR Set 2 with contact distribution : 0.6m Drop height

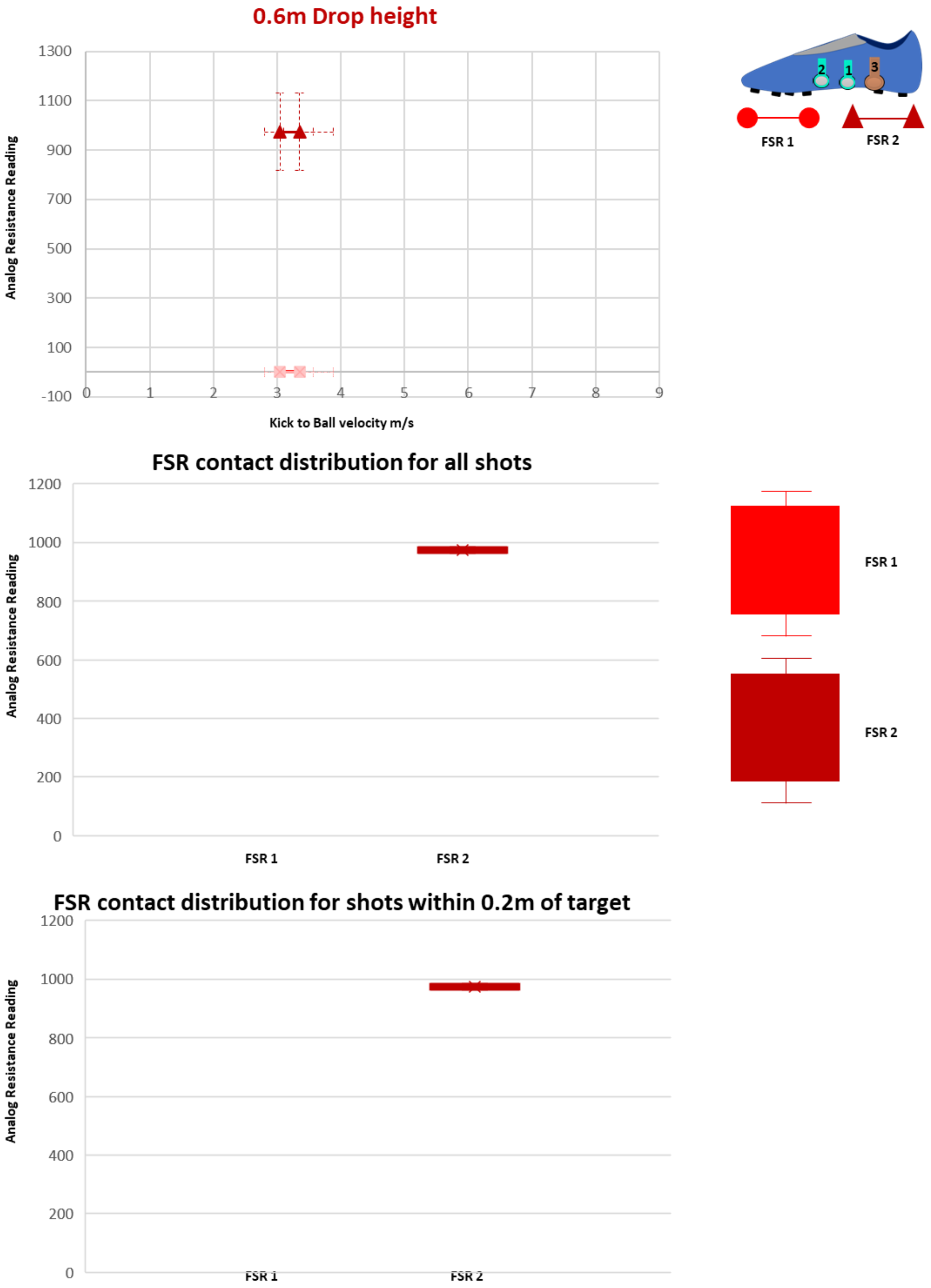


Figure 10.7.106

Inside 2 Circle FSR Set 3

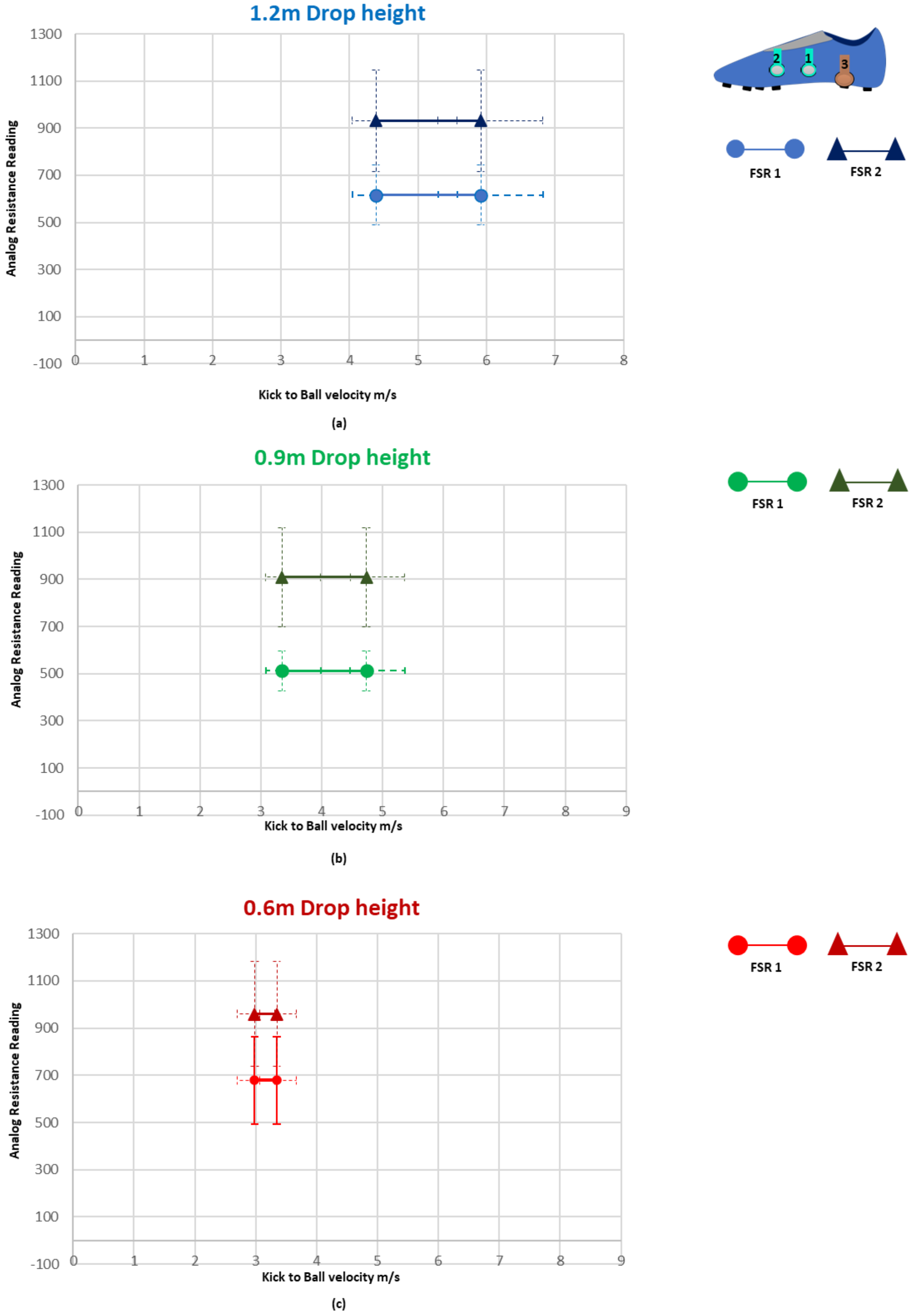
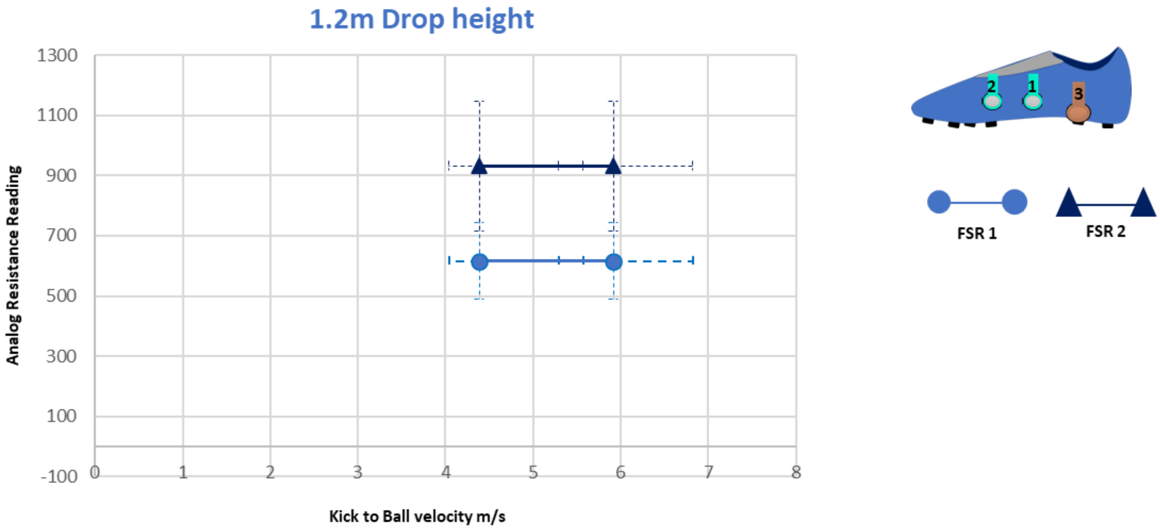
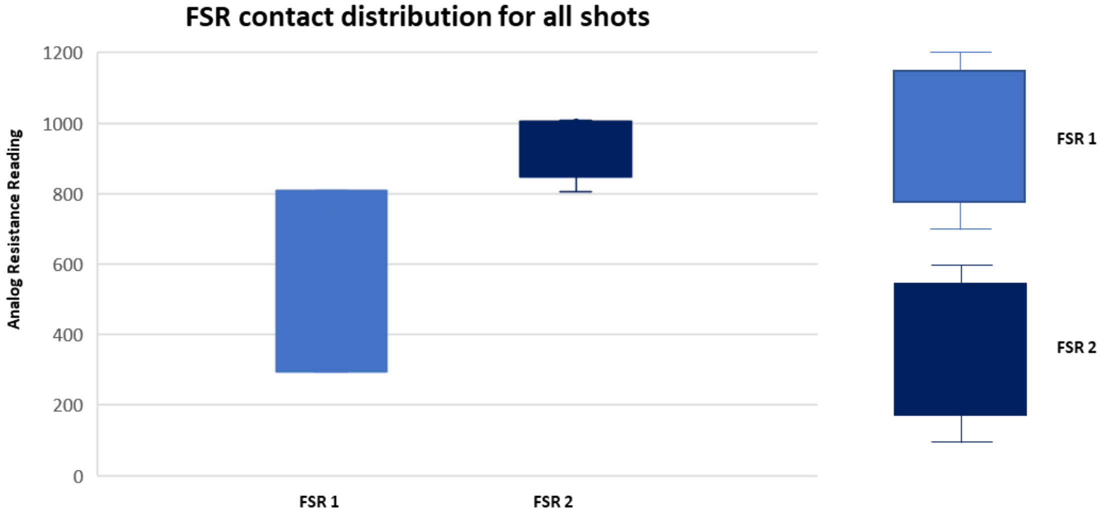


Figure 10.7.107

Inside 2 Circle FSR Set 3 with contact distribution : 1.2m Drop height





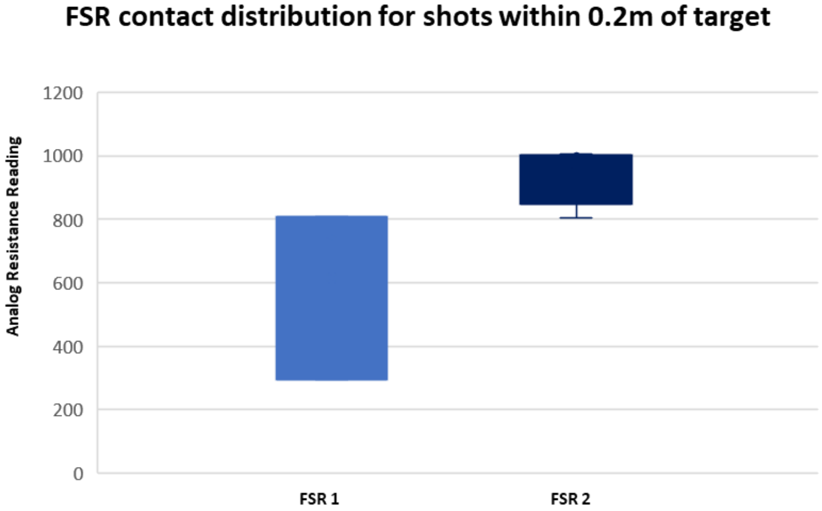
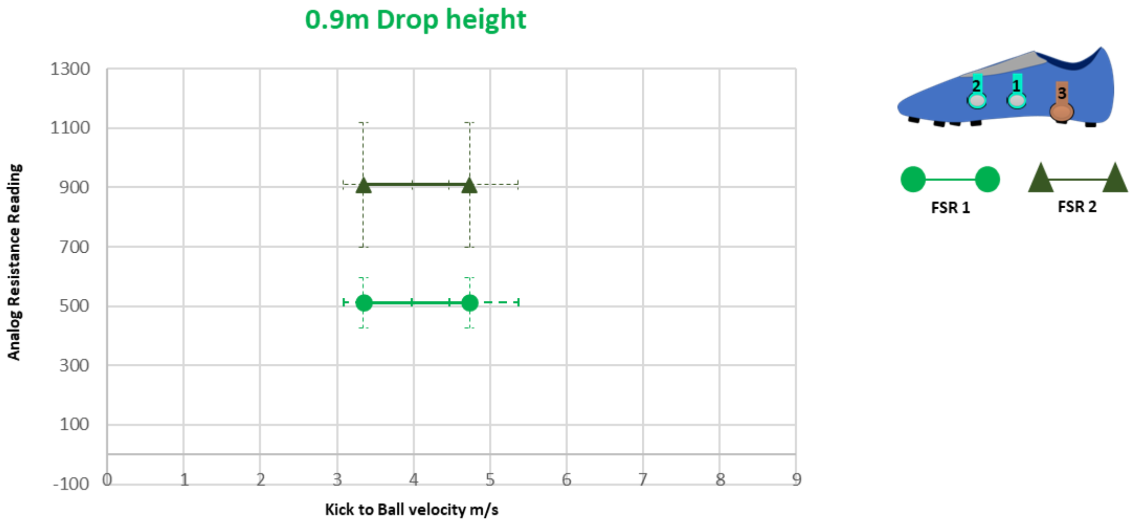
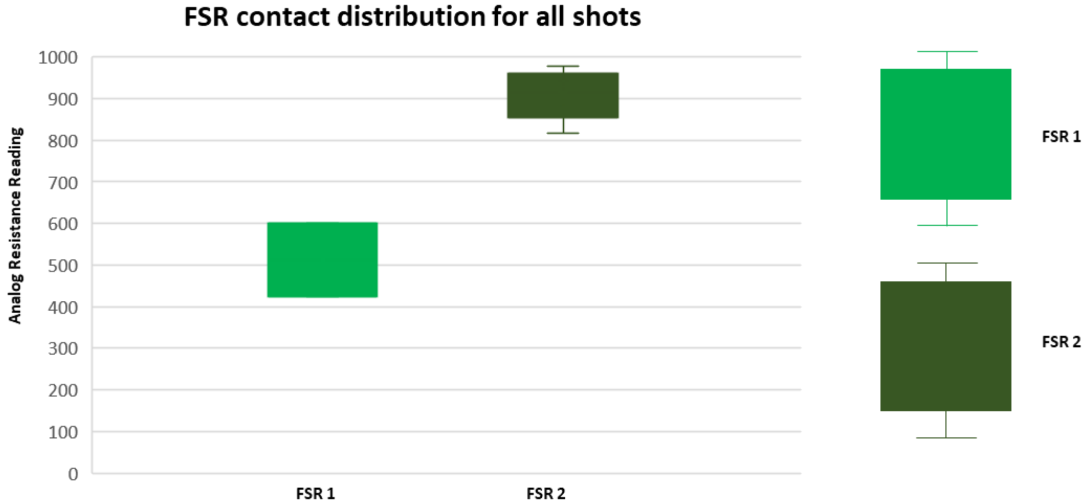


Figure 10.7.108

Inside 2 Circle FSR Set 3 with contact distribution : 0.9m Drop height





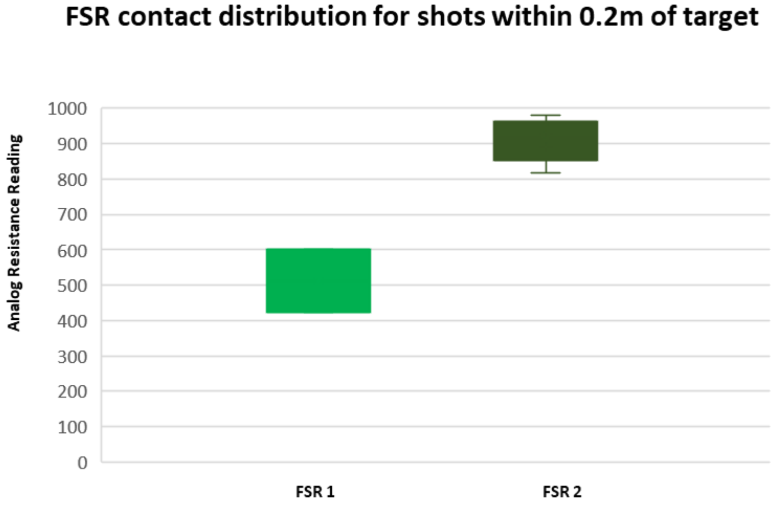


Figure 10.7.109

Inside 2 Circle FSR Set 3 with contact distribution : 0.6m Drop height

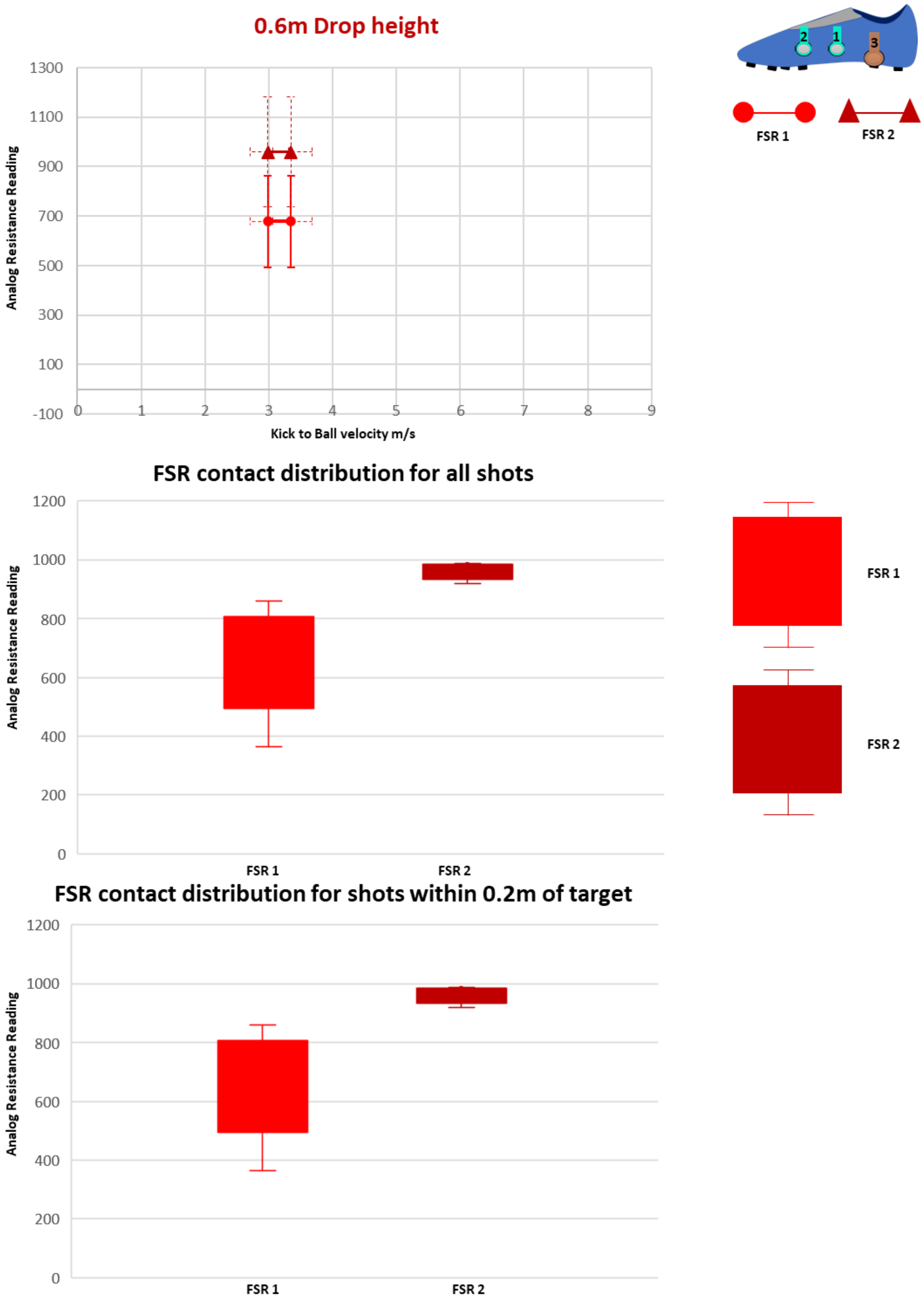
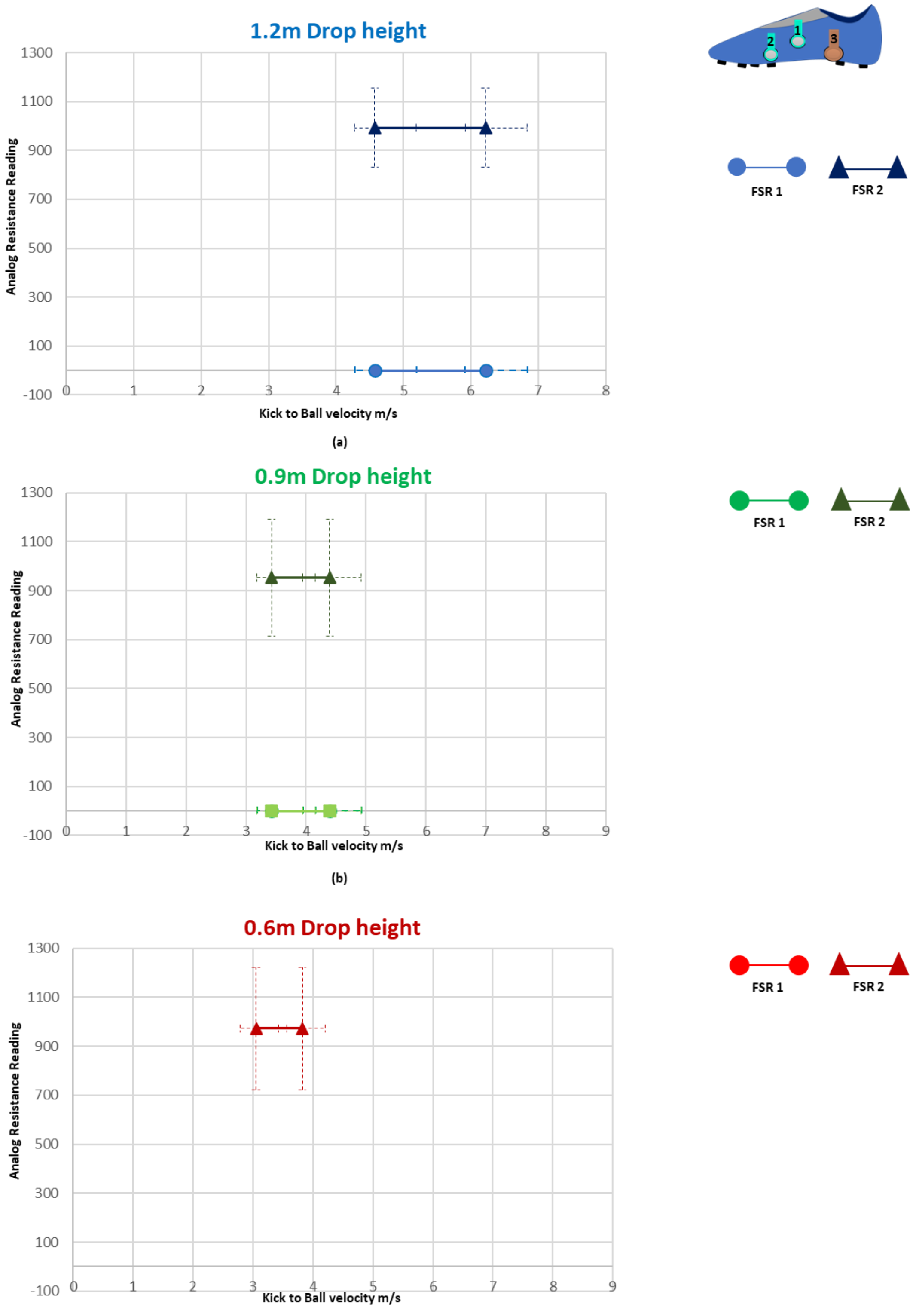


Figure 10.7.110

Inside 2 Circle FSR Set 4



(a)

(b)

(c)

Figure 10.7.111

Inside 2 Circle FSR Set 4 with contact distribution : 1.2m Drop height

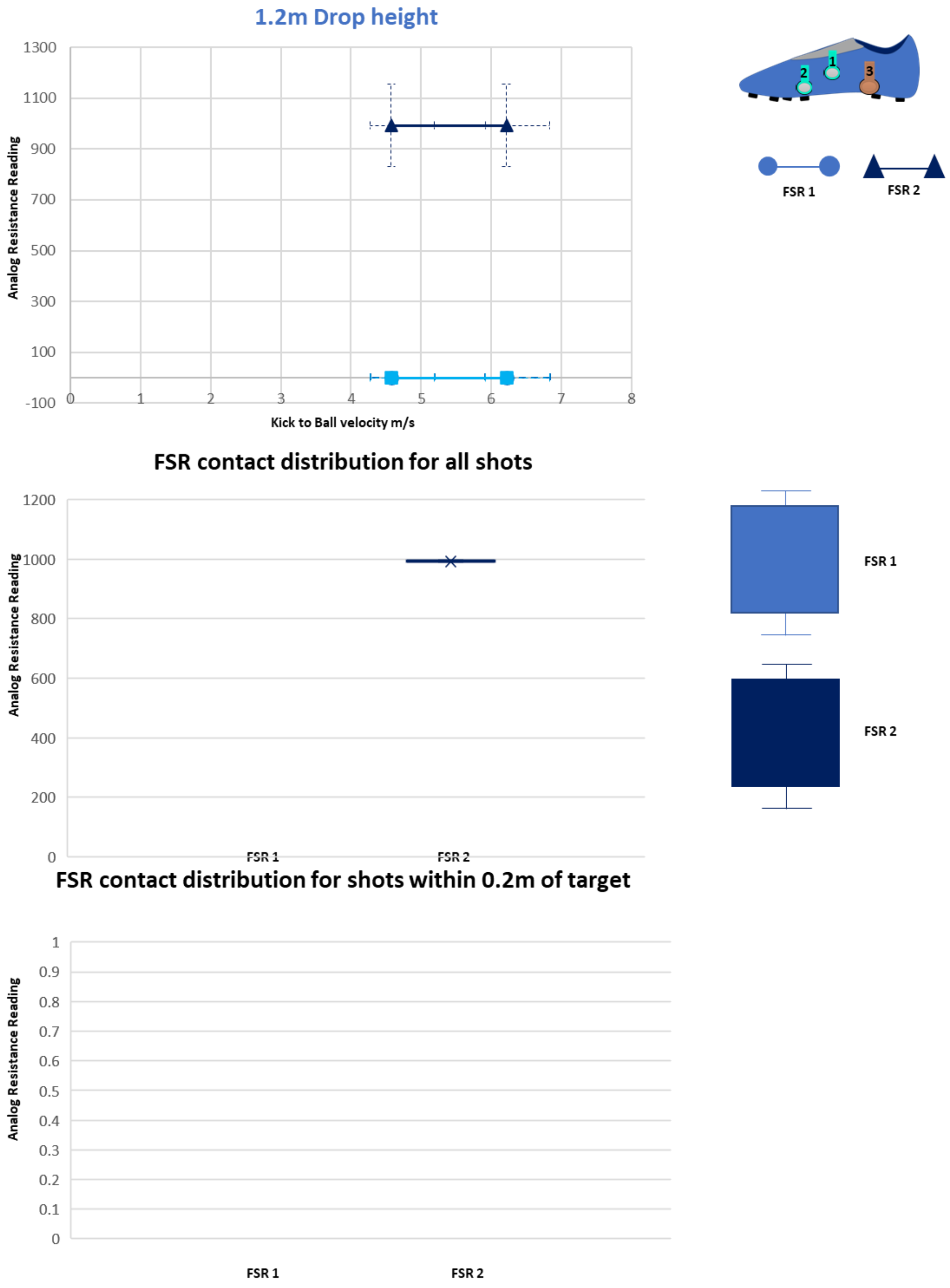


Figure 10.7.112

Inside 2 Circle FSR Set 4 with contact distribution : 0.9m Drop height

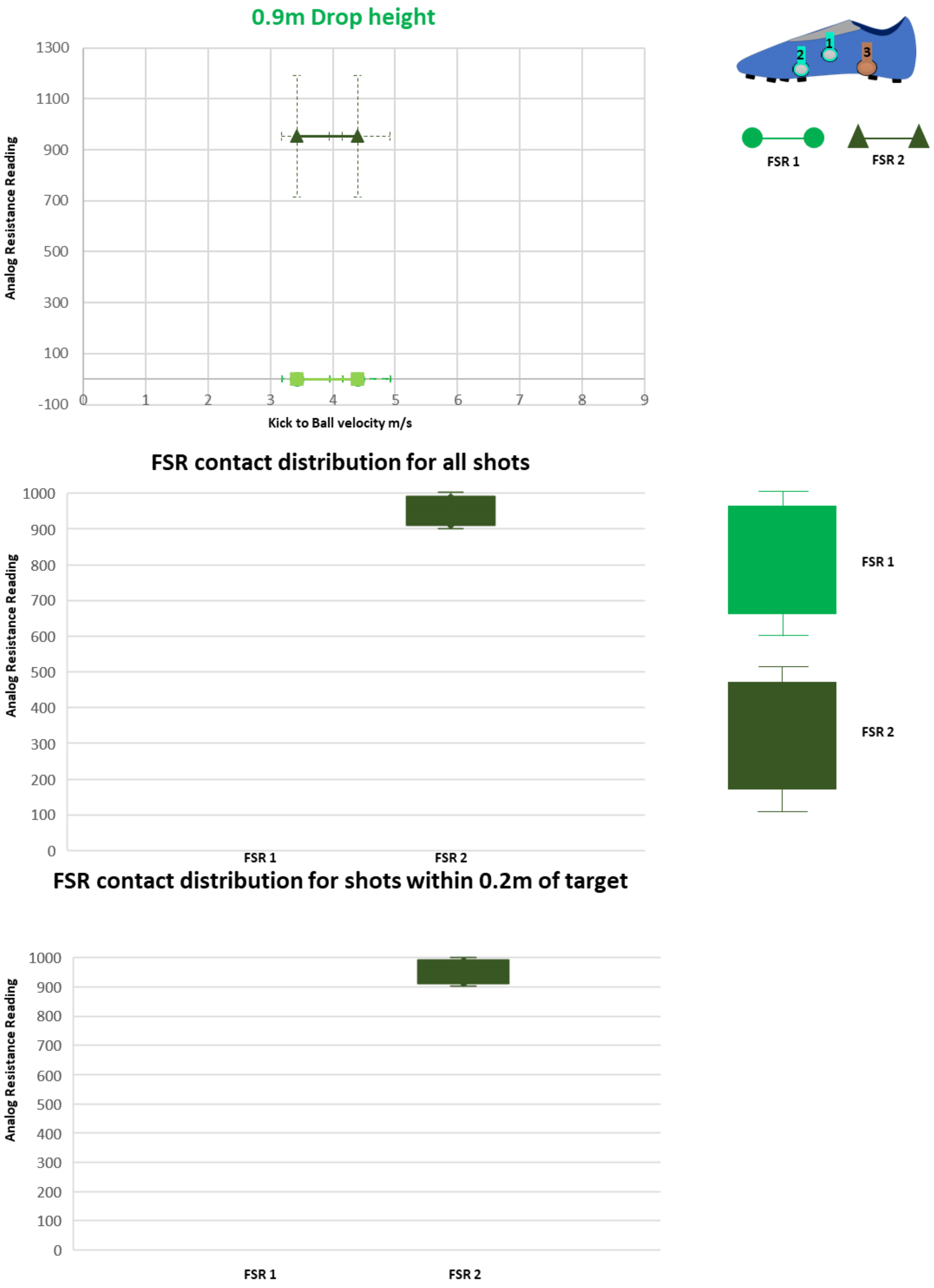


Figure 10.7.113

Inside 2 Circle FSR Set 4 with contact distribution : 0.6m Drop height

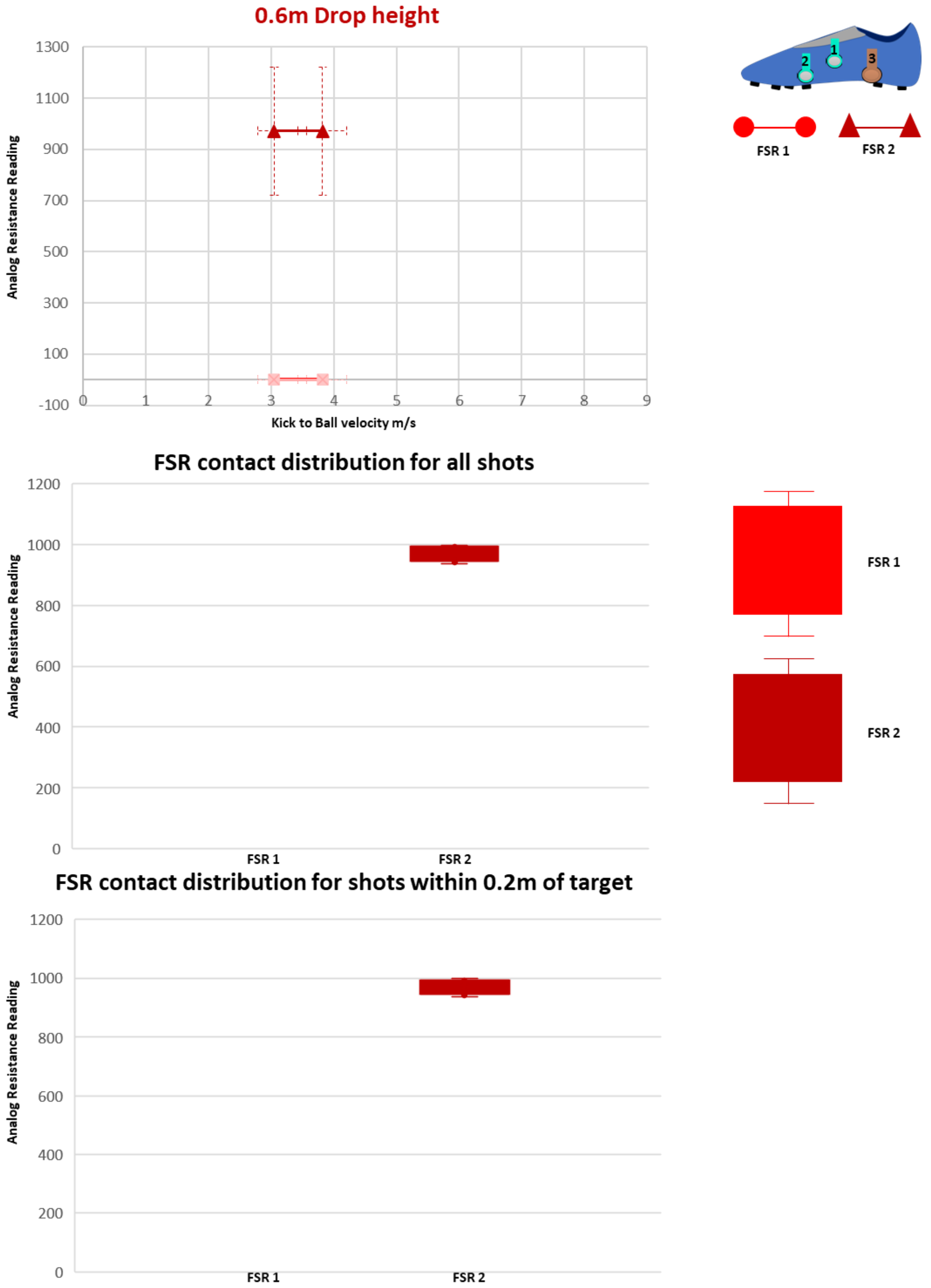
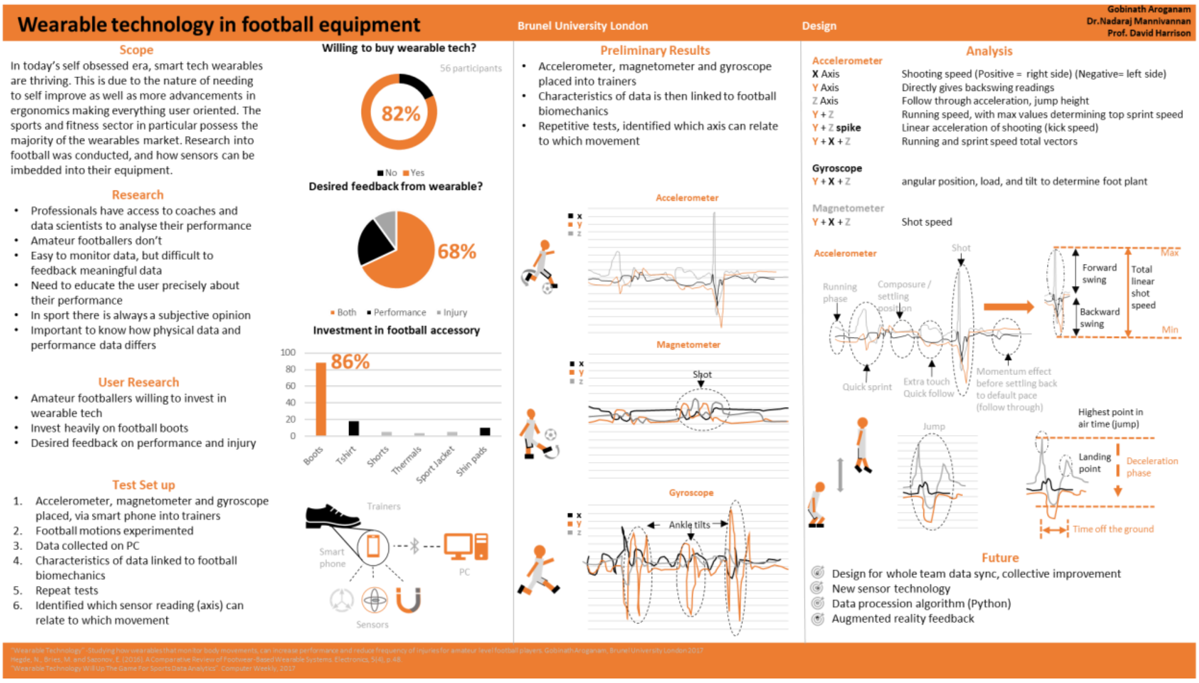


Figure 10.7.114

Conference Submissions



Wearable technology in football equipment

Brunel University London | Design

Gobinath Aroganam
Dr.Nadaraj Mannivannan
Prof. David Harrison

Scope

In today's self obsessed era, smart tech wearables are thriving. This is due to the nature of needing to self improve as well as more advancements in ergonomics making everything user oriented. The sports and fitness sector in particular possess the majority of the wearables market. Research into football was conducted, and how sensors can be imbedded into their equipment.

Research

- Professionals have access to coaches and data scientists to analyse their performance
- Amateur footballers don't
- Easy to monitor data, but difficult to feedback meaningful data
- Need to educate the user precisely about their performance
- In sport there is always a subjective opinion
- Important to know how physical data and performance data differs

User Research

- Amateur footballers willing to invest in wearable tech
- Invest heavily on football boots
- Desired feedback on performance and injury

Test Set up

1. Accelerometer, magnetometer and gyroscope placed, via smart phone into trainers
2. Football motions experimented
3. Data collected on PC
4. Characteristics of data linked to football biomechanics
5. Repeat tests
6. Identified which sensor reading (axis) can relate to which movement

Preliminary Results

- Accelerometer, magnetometer and gyroscope placed into trainers
- Characteristics of data is then linked to football biomechanics
- Repetitive tests, identified which axis can relate to which movement

Analysis

Accelerometer

X Axis	Shooting speed (Positive = right side) (Negative= left side)
Y Axis	Directly gives backswing readings
Z Axis	Follow through acceleration, jump height
Y + Z	Running speed, with max values determining top sprint speed
Y + Z **spike**	Linear acceleration of shooting (kick speed)
Y + X + Z	Running and sprint speed total vectors

Gyroscope

Y + X + Z	angular position, load, and tilt to determine foot plant

Magnetometer

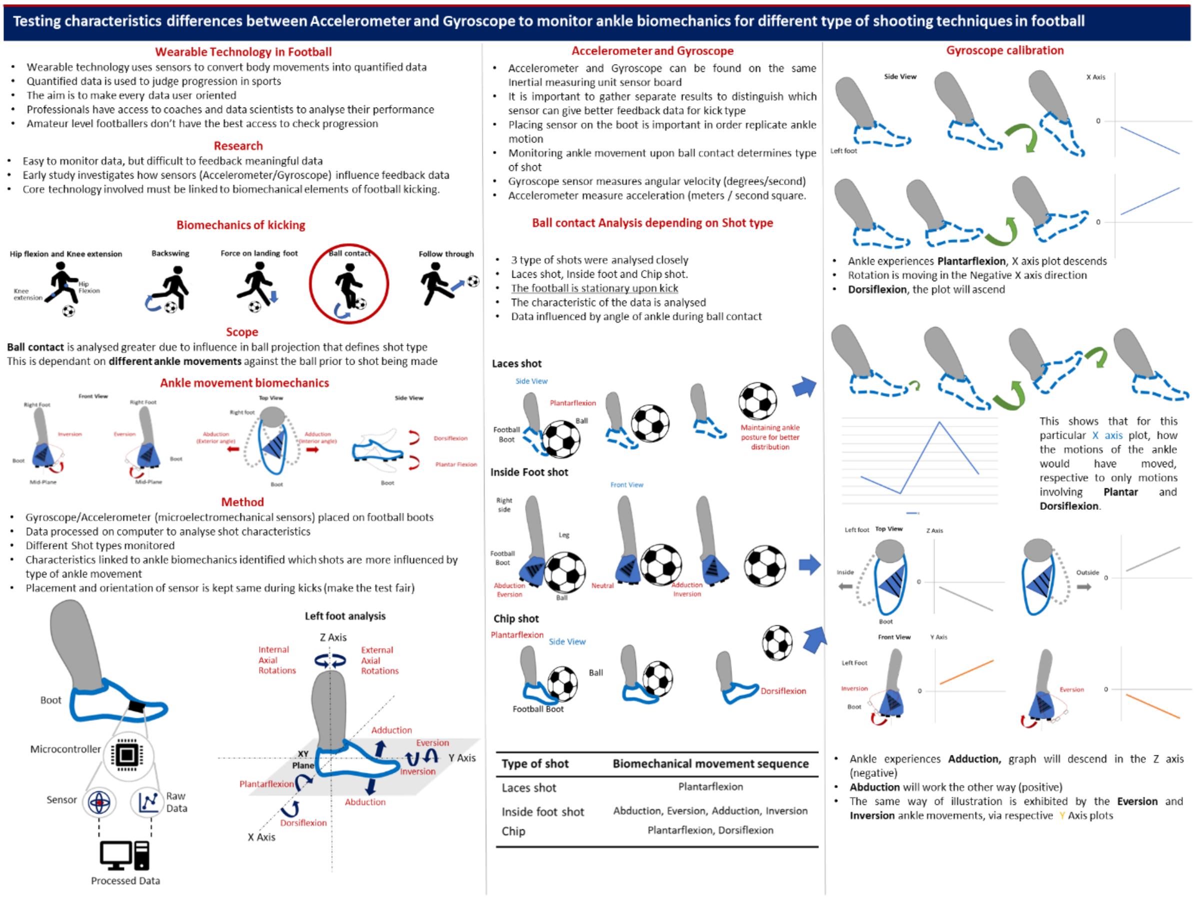
Y + X + Z	Shot speed

Future

- Design for whole team data sync, collective improvement
- New sensor technology
- Data procession algorithm (Python)
- Augmented reality feedback

"Wearable Technology" -Studying how wearables that monitor body movements, can increase performance and reduce frequency of injuries for amateur level football players. Gobinath Aroganam, Brunel University London 2017
Hegde, N., Bries, M. and Sazonov, E. (2016). A Comparative Review of Footwear-Based Wearable Systems. Electronics, 5(4), p.48.
"Wearable Technology Will Up The Game For Sports Data Analytics". Computer Weekly, 2017

Figure 10.A.1: WEAR Tech show 2019 Poster



Testing characteristics differences between Accelerometer and Gyroscope to monitor ankle biomechanics for different type of shooting techniques in football

Wearable Technology in Football

- Wearable technology uses sensors to convert body movements into quantified data
- Quantified data is used to judge progression in sports
- The aim is to make every data user oriented
- Professionals have access to coaches and data scientists to analyse their performance
- Amateur level footballers don't have the best access to check progression

Research

- Easy to monitor data, but difficult to feedback meaningful data
- Early study investigates how sensors (Accelerometer/Gyroscope) influence feedback data
- Core technology involved must be linked to biomechanical elements of football kicking.

Biomechanics of kicking

Scope

Ball contact is analysed greater due to influence in ball projection that defines shot type
This is dependant on **different ankle movements** against the ball prior to shot being made

Ankle movement biomechanics

Method

- Gyroscope/Accelerometer (microelectromechanical sensors) placed on football boots
- Data processed on computer to analyse shot characteristics
- Different Shot types monitored
- Characteristics linked to ankle biomechanics identified which shots are more influenced by type of ankle movement
- Placement and orientation of sensor is kept same during kicks (make the test fair)

Accelerometer and Gyroscope

- Accelerometer and Gyroscope can be found on the same Inertial measuring unit sensor board
- It is important to gather separate results to distinguish which sensor can give better feedback data for kick type
- Placing sensor on the boot is important in order replicate ankle motion
- Monitoring ankle movement upon ball contact determines type of shot
- Gyroscope sensor measures angular velocity (degrees/second)
- Accelerometer measure acceleration (meters / second square.

Ball contact Analysis depending on Shot type

- 3 type of shots were analysed closely
- Laces shot, Inside foot and Chip shot.
- The football is stationary upon kick
- The characteristic of the data is analysed
- Data influenced by angle of ankle during ball contact

Type of shot	Biomechanical movement sequence
Laces shot	Plantarflexion
Inside foot shot	Abduction, Eversion, Adduction, Inversion
Chip	Plantarflexion, Dorsiflexion

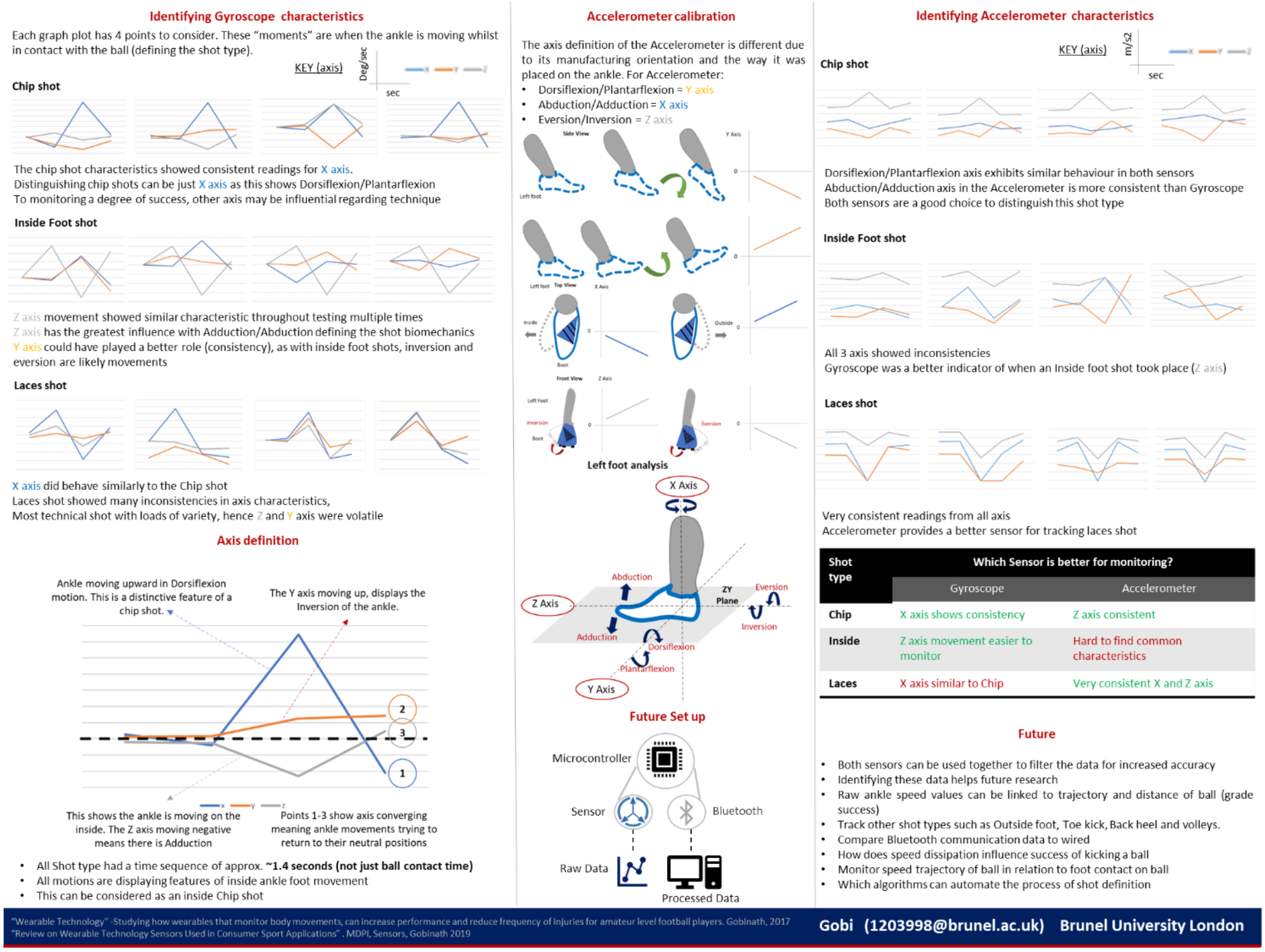
Gyroscope calibration

- Ankle experiences **Plantarflexion**, X axis plot descends
- Rotation is moving in the Negative X axis direction
- **Dorsiflexion**, the plot will ascend

This shows that for this particular X axis plot, how the motions of the ankle would have moved, respective to only motions involving **Plantar** and **Dorsiflexion**.

- Ankle experiences **Adduction,** graph will descend in the Z axis (negative)
- **Abduction** will work the other way (positive)
- The same way of illustration is exhibited by the **Eversion** and **Inversion** ankle movements, via respective Y Axis plots

Figure 10.B.1: Brunel Conference 2020



Identifying Gyroscope characteristics

Each graph plot has 4 points to consider. These "moments" are when the ankle is moving whilst in contact with the ball (defining the shot type).

Chip shot

The chip shot characteristics showed consistent readings for X axis.
Distinguishing chip shots can be just X axis as this shows Dorsiflexion/Plantarflexion
To monitoring a degree of success, other axis may be influential regarding technique

Inside Foot shot

Z axis movement showed similar characteristic throughout testing multiple times
Z axis has the greatest influence with Adduction/Abduction defining the shot biomechanics
Y axis could have played a better role (consistency), as with inside foot shots, inversion and eversion are likely movements

Laces shot

X axis did behave similarly to the Chip shot
Laces shot showed many inconsistencies in axis characteristics,
Most technical shot with loads of variety, hence Z and Y axis were volatile

Axis definition

Ankle moving upward in Dorsiflexion motion. This is a distinctive feature of a chip shot.

The Y axis moving up, displays the Inversion of the ankle.

This shows the ankle is moving on the inside. The Z axis moving negative means there is Adduction

Points 1-3 show axis converging meaning ankle movements trying to return to their neutral positions

- All Shot type had a time sequence of approx. **~1.4 seconds (not just ball contact time)**
- All motions are displaying features of inside ankle foot movement
- This can be considered as an inside Chip shot

Accelerometer calibration

The axis definition of the Accelerometer is different due to its manufacturing orientation and the way it was placed on the ankle. For Accelerometer:

- Dorsiflexion/Plantarflexion = Y axis
- Abduction/Adduction = X axis
- Eversion/Inversion = Z axis

Left foot analysis

Future Set up

Identifying Accelerometer characteristics

Chip shot

Dorsiflexion/Plantarflexion axis exhibits similar behaviour in both sensors
Abduction/Adduction axis in the Accelerometer is more consistent than Gyroscope
Both sensors are a good choice to distinguish this shot type

Inside Foot shot

All 3 axis showed inconsistencies
Gyroscope was a better indicator of when an Inside foot shot took place (Z axis)

Laces shot

Very consistent readings from all axis
Accelerometer provides a better sensor for tracking laces shot

Shot type	Which Sensor is better for monitoring?	
	Gyroscope	Accelerometer
Chip	X axis shows consistency	Z axis consistent
Inside	Z axis movement easier to monitor	Hard to find common characteristics
Laces	X axis similar to Chip	Very consistent X and Z axis

Future

- Both sensors can be used together to filter the data for increased accuracy
- Identifying these data helps future research
- Raw ankle speed values can be linked to trajectory and distance of ball (grade success)
- Track other shot types such as Outside foot, Toe kick, Back heel and volleys.
- Compare Bluetooth communication data to wired
- How does speed dissipation influence success of kicking a ball
- Monitor speed trajectory of ball in relation to foot contact on ball
- Which algorithms can automate the process of shot definition

"Wearable Technology" -Studying how wearables that monitor body movements, can increase performance and reduce frequency of injuries for amateur level football players. Gobinath, 2017
"Review on Wearable Technology Sensors Used in Consumer Sport Applications". MDPI, Sensors, Gobinath 2019

Gobi (1203998@brunel.ac.uk) Brunel University London

Figure 10.B.2: Brunel Conference 2020