Changes in Chester Step test performance, predicted sub-maximal oxygen pulse and heart rate response following the Westminster MyAction cardiovascular prevention & rehabilitation programme.

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Abstract

Introduction: Improvements in cardiorespiratory fitness (CRF) are associated with better health outcomes. The Chester step test (CST) is used to assess the changes in CRF following a protocol-driven cardiovascular prevention and rehabilitation programme (CPRP) entitled MyAction. CRF expressed as predicted VO_2max, can be influenced by physiological adaptations and/or retest familiarity-efficiency. Therefore, we employed an index ratio between oxygen uptake and heart rate (O_2 pulse) to determine if the improvement in CRF is related to a true physiological adaptation.

Methods: 169 patients, mean age 66.8 ± 7.3 years attended a 12 week MyAction CPRP. All were assessed using the CST on the initial and end of programme assessment. O_2 pulse was estimated from the CST and was calculated by dividing VO_2 into the exercise heart rate multiplied by 100.

Results: Following the CPRP, VO_2max increased by 2.8 ml/kg/min. These changes were associated with an overall increase in O_2 pulse by 0.6 ml/beat (p=<0.001) and a 4.1 beats/min (p=<0.001) reduction in the exercise HR response on the CST.

Conclusions: O_2 pulse provides transparency on the physiological adaptations following a CPRP and can be used to help patients recognise the benefits of exercise training. For example, the average patient increased his/her O_2 pulse by 0.6 ml/beats and saved 4-7 heart-beats on the CST.

Key words: predicted VO_2 max, sub-maximal oxygen pulse, sub-maximal heart rate, cardiovascular prevention and rehabilitation, exercise training

Key messages

- This service analysis demonstrates that the Westminster MyAction cardiovascular prevention and rehabilitation programme favourably influenced predicted VO_2 max and sub-maximal O_2 pulse.

- An increase in predicted VO_2 and sub-maximal O_2 pulse appears to be driven by a reduction in the sub-maximal heart rate response across 4 stages of the Chester Step Test at 3 different step heights.

- Patients following a 12 week structured exercise programme consisting of a supervised exercise session and a home programme performed 2-3 times per week can expect to save up to7 heart-beats on the Chester step test which could potentially reduce myocardial ischemia and lower risk of arrhythmias during exercise.

Introduction

In the UK it is recommended that patients participating in the exercise component of a cardiovascular prevention and rehabilitation programme (CPRP) should undergo a baseline assessment of their cardiorespiratory fitness (CRF).[1,2] The rationale behind this assessment is to measure programme outcomes, risk stratification and provide information for physical activity advice. In the UK, many CPRP use the Chester step test (CST), Incremental shuttle walk test (ISWT), or the 6-minute walk test (6MWT) to assess the changes in CRF following an exercise intervention[2]. The choice of exercise test is usually dependent on the patient's physical activity habits, comorbidities and the availability of equipment and space[2]. These tests are normally carried out using standardised protocols with predetermined end points such as 70% of age predicted heart rate reserve max, symptom-limited and or a score of 14 on the Borg 6-20 ratings of perceived exertion (RPE) scale[2].

There are several advantages to using these simple functional capacity tests as they require minimal equipment and represent activities of daily living. As a main outcome measure, these tests typically report improvements in CRF as a change in distance (ISWT, 6MWT), workload (CST) and or predicted VO_2 max (CST, ISWT). In order to achieve an accurate change in performance, previous studies have recommended using a practice test to eliminate the learning effect.[3,4] The learning effect can count towards a 8-28% improvement in walking performance on the 6MWT and ISWT respectively.[5,6] However, in the clinical setting it is not always practical or cost effective to perform a practice test. To overcome this limitation, Buckley et al[6] have recommended using the heart rate walking speed index during the ISWT and 6MWT in order to tease out the true physiological adaptations that are associated with regular exercise training. In spite of this there is a paucity of data that provides an index, which measures the physiology adaptations in patients performing the CST. Therefore, we employed a simple index ratio between oxygen uptake (VO_2) and heart rate (O_2 pulse) to determine

if the improvement in exercise performance following a CPRP is related to a true physiological adaptation.

Materials and methods

This was a retrospective service evaluation study, designed to establish a change in predicted VO_2 max, submaximal O_2 pulse and HR following the Westminster MyAction programme. The Westminster MyAction programme is an innovative nurse-lead multidisciplinary community-based CPRP, which provides integrated care to those with established cardiovascular disease (coronary heart disease, peripheral arterial disease, transient ischaemic attack) as well as those identified to be at high multifactorial risk (QRisk2> 15%[7]) through the NHS Health Checks programme. The programme was founded on the principles of the successful EUROACTION cluster randomised-controlled trial.[8]

The Westminster MyAction programme receives referrals from general practitioner practices, cardiology clinics and on discharge from cardiology wards. Patients referred to the Westminster MyAction programme attend an initial assessment (IA) and end of programme (EOP) assessment following a 12 week exercise and educational programme. During the assessments, the patients were assessed by a Cardiac Specialist Nurse, Dietitian and an Exercise Specialist (figure 1). Following the assessment a consultant cardiologist led on the prescribing and up-titration of the patient's medication. Data was collected on patients between September 2009 and March 2014. The present study's exclusion criteria can be seen in box 1.

Submaximal exercise test

Patients were assessed at IA and EOP using the CST, which consists of five, two minute stages with a total test duration lasting 10 minutes. All patients were familiarized with stepping up and down on the CST and it was conducted using a standardised protocol[9] on a step height of 15cm, 20cm or

25cm. HR, O_2 pulse using predicted oxygen uptake and RPE were recorded after each minute and the CST was stopped if either the HR exceeded 70% of HR reserve max, or the patient reported an RPE of >14 or reported symptoms of chest pain or dizziness. O_2 pulse provides an index for stroke volume/cardiac efficacy[10] and was calculated by dividing VO_2 uptake (ml/kg/min) by HR. In order to make the mathematical manipulations of the study easier, all results related to the O_2 pulse were multiplied by 100 and expressed in ml/beat. This calculation is consistent with previous studies.[11]

Prediction of VO_2 Max

The prediction of VO_2 max was based on the linear relationship between HR and VO_2 consumption and the ''line of best fit'', was drawn through the submaximal HR responses recorded on each stage of the CST, up to a level which equals the participant's age estimated HR max (220-age). At this point a vertical line was dropped down to the x axis of the graph, which represents the estimated VO_2 max.[9] The VO_2 was expressed ml/kg/min and an example is presented in figure 2.

Training protocol

The patients attended a community or hospital-based supervised exercise training session once per week for up to 12 weeks and they were encouraged to take part in a home exercise programme or exercise DVD 2 –3 times per week. The supervised exercise training programme consisted of a 15 minute warm-up, 24 minutes of circuit interval training; comprised of aerobic and low-intensity resistance exercises, and a 10 minute cool-down. During the training programme, the patients exercised at an intensity range of between 40 and 70% of their age predicted HR reserve max and/or an RPE of 12 to 14, as recommended by the ACPICR[2]. Over the 12 weeks, the exercise programme was progressed on the basis of increasing the duration of time spent on the aerobic exercise stations

and decreasing the time spent on the resistance exercise stations until 24 minutes of continuous aerobic exercise was achieved.

Statistical analysis

All data was assessed for parametric assumptions prior to statistical analysis using Stata version 13.0. Data are expressed as mean ± standard deviation (sd). Paired *t* tests are conducted on each variable and no correction has been made for multiple hypothesis testing as this was a retrospective service evaluation study design. A sub-group analysis was carried out on each variable (predicted VO_2 max, sub-maximal O_2 pulse and HR) on a 15cm and 20cm step height. However, it should be noted that due to small numbers, data was not analysed separately on patients achieving stage 5 on the CST or in those taking part on a 25cm step height.

Results

The final analysis included 169 patients, 59% were Caucasian, 110 were men and 59 were women with mean age 66.8 ±7.3 years. Out of the 169 patients, 127 patients were stratified as high multifactorial risk (risk score 26.2% ± 8), 20 patients had type 2 diabetes and 28 patients had established atherosclerotic disease. The patients attended 12.3 ±2.9 exercise sessions and 94 (56%), 68 (40%) and 7 patients (4%) took part in the CST on a 15cm, 20cm and 25cm step height respectively. Demographic variables can be seen in table 1.

Changes in Chester Step test performance

At the EOP assessment, the overall CST time increased from 346 ± 91 seconds to 402 ± 94 (55 seconds, 45- 65, 95% CI p=<0.001). The predicted VO_2 max across the 3 step heights increased from 28 ± 5.95 ml/kg/min at IA to 30.8 ± 6.65 ml/kg/min at EOP (2.8 ml/kg/min, 2.1-3.5, 95% CI p=0.001). A sub group analysis demonstrated that patients taking part in a 15 cm step height significantly

increased their predicted VO_2 max from 25.9 ± 5.25 ml/kg/min at IA to 28 ± 5.25 ml/kg/min at EOP assessment (2.1 ml/kg/min, 1-3.1, 95% CI p=<0.001) and patients taking part in a 20cm step height increased their predicted VO_2 max from 29.7 ± 5.6 ml/kg/min at IA to 33.6 ± 5.6 ml/kg/min at EOP assessment (3.8 ml/kg/min, 2.8-4.9, 95% CI p=<0.001) (figure 3).

Changes in predicted O_2 pulse

Overall, O_2 pulse increased from 14.2 ml/beat to 14.8 ml/beat (0.6 ml/min, 0.5 - 0.7, 95% CI p=0.001) at the EOP with the largest change occurring at stage 4, with a mean increase of 1.2 ml/beat (0.4- 1.9 95% CI p = 0.007). On a 15cm step height, O_2 pulse significantly increased at EOP assessment from 13.2 ± 2.8 ml/beat to 13.6 ± 2.7 ml/beat (0.4 ml/beat, 0.3-0.6 95% CI p=<0.001) and from 14.9 ± 2.4 ml/beat to 15.6 ± 2.8 ml/beat (0.7 ml/beat, 0.5-0.9 95% CI p=<0.001) on a 20cm step height. Table 4 demonstrates the overall changes in O_2 pulse.

Changes in sub-maximal heart rate

Overall HR on average decreased by 4.1 bpm (-5.0, -3.2, 95% CI p =0.001) with smaller reductions at stage 1 (- 3.1 bpm, -4.5, -1.8 95% CI p =0.001) and larger reductions at stage 4 (-7.3 bpm, -11.9, -2.7 95% CI p=0.004). In the sub-group analysis, HR on average decreased by -2.8 bpm, (-1, -4.6 95% CI p =0.001) on stage 1 with a larger reduction of 7.2 bpm at stage 4 (-0.8, -15 95% CI p=0.03) on a 15 cm step height. These trends were similar for a 20cm step height with smaller reductions in HR at stage 1 (- 3.3 bpm, -1.1, -5.5.6 95% CI p =0.001) and larger reductions at stage 4 (-6.5 bpm, -1.5, -14.7 95% CI p=0.04).

Discussion

The aim of this study was to apply the O_2 pulse ratio to determine if the improvement in exercise performance on the CST is related to a true physiology adaptation following the Westminster MyAction programme. The results of this study demonstrated that the performance on the CST increased by 16% with a subsequent increase in predicted VO_2 max across the 3 step heights from 28 ± 5.95 ml/kg/min to 30.8 ± 6.65 ml/kg/min (2.8 ml/kg/min, 2.1-3.5, 95% CI p=0.001) at the EOP assessment. The O_2 pulse significantly increased from 14.2 ml/min to 14.8 ml/min (0.6 ml/min, 0.5 - 0.7, 95% CI p=0.001) at the EOP assessment demonstrating that a true physiological adaptation had occurred following the exercise sessions.

One of the main mechanisms that contributed towards both the improvement in predicted VO_2 max and O_2 pulse in this study was related to the reduction in the submaximal HR response on each stage of the CST (table 3). A reduction in the submaximal HR is a classical physiological training adaptation and is suggestive of an adjustment in the autonomic balance between parasympathetic and sympathetic nervous activity, resulting in the proficiency of the myocardium to accomplish a similar cardiac output at a lower myocardial oxygen demand.[12-14] These favourable adaptations also allow for a greater ventricular filling time,[15] enhanced coronary perfusion[16] and a lower rate pressure product.[17] Such changes have been associated with a reduction in myocardial ischemia and lower risk of arrhythmias.[13,17]

The magnitude of the reduction in the sub-maximal HR response appears to be dependent on the exercise training intensity and volume. In the present study, patients attended a supervised exercise session once per week for up to 12 weeks and they were encouraged to participate in a home exercise programme 2-3 times per week. During the supervised exercise sessions, patients worked between 40%-70% of their age-predicted HR reserve max and/or a RPE of 11-14 on the Borg 6-20 scale.[18] Working at this intensity resulted in an overall submaximal HR reduction of -4.1 bpm (-5.0, -3.2, 95% CI p =0.001) with larger reductions at stage 4 of around 7.3 bpm (-11.9, -2.7 95% CI

p=0.004). There were insufficient numbers to calculate a meaningful reduction in sub-maximal HR at stage 5. However, one patient who completed stage 5 on a 25cm step height achieved a 24 bpm reduction in their sub-maximal HR response after completing the MyAction programme. In support of these findings, a recent randomised controlled trial of 140 patients with an abdominal aortic aneurysm, demonstrated a 7bpm-14 bpm reduction in their sub-maximal HR response during exercise testing following a high exercise volume (1999 ± 1030 kcal.wk^{-1} energy expenditure) and a high intensity (98.8% of HR training zone) exercise programme.[14]

Despite the positive outcomes of the present study, it is important to acknowledge the main study limitations. The majority of the patients (75%) were stratified as high multi-factorial risk, therefore limiting the applicability of the results to programmes only offering cardiovascular prevention and rehabilitation to those with established cardiovascular disease. The second limitation is that the data was collected from clinical practice with no control group and it needs to be verified in a randomised prospective study design. The third limitation is related to O_2 pulse, which is normally measured through direct gas analysis during maximal cardiopulmonary exercise testing. In the present study O_2 pulse was estimated from the predicted VO_2 on each stage of the CST. Such predictions in VO_2 using metabolic calculations are open to considerable individual variability, especially in patients with known heart disease.[19,20] In addition, extrinsic variables such as room temperature was not controlled, which could potentially influence the HR response during the CST. Future research is needed to control for these variables and should also confirm what difference would be clinically meaningful to the patient.

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Table 1 Patient demographics and clinical history

Demographics	Summary
Age, mean ± SD (yr)	66.8 ± 7.3
Gender (% male)	110 (63%)
Ethnicity (% Caucasian)	100 (59)
BMI, mean ± SD (kg.m^{-2})	28.7 ± 4.9
Waist, mean ± SD (cm)	100.1 ± 13.3
Predicted VO$_2$ max, mean ± SD (ml/kg/min)	28 ± 5.95
Step height (%)	
15 cm	94 (56)
20 cm	68 (40)
25 cm	7 (4)
Clinical History (%)	
Acute coronary syndrome	8 (5)
Angina	6 (4)
CVA/TIA	6 (4)
Congenital heart disease	2 (1)
Valve disease	1 (0.5)
Heart failure/LVH	2 (1.0)
Peripheral artery disease	3 (2)
Type II Diabetes	20 (12)
High risk	127 (75)
Medications (%)	
Anti-platelets	34 (20)
Ace inhibitors/ARB	21 (12)
Beta-blockers	16 (9)
Calcium Channel Blockers	48 (28)
Diuretics	26 (15)
Statins/Ezetimibe	83 (49)
Sulfonylureas/Biguanide/Human log	16 (9)

Variables are presented as prevalence (%), unless otherwise noted. BMI, body mass index; CVA/TIA, cardiovascular accident/transit ischaemic attack; LVH, left ventricular hypertrophy ACE, angiotensin converting enzyme; ARB, angiotensin receptor blocker.

Table 2 Overall Changes in O$_2$ pulse on each stage of the Chester Step test

Stage	No. participants	Initial Assessment (ml/beat)	End of Programme (ml/beat)	Mean Change (ml/beat)	95% CI	P value
1	169	12.1±2.2	12.5±2.2	0.4	0.2-0.6	<0.001
2	156	14.5±2.4	15.2±2.6	0.7	0.5-0.9	<0.001
3	90	16.6±2.6	17.2±2.8	0.6	0.3-1.0	<0.001
4	18	18.5±3.6	19.6±4.0	1.2	0.4-1.9	<0.007
5	1	24.1 (-)	29.5 (-)	5.4	-	-
All	-	14.2±3.1	14.8±3.3	0.6	0.5-0.7	<0.001
15cm Step Height						
1	94	11.2±1.7	11.5±1.6	0.3	0.1-0.5	<0.01
2	86	13.5±2.0	14±1.9	0.5	0.2-0.8	<0.001
3	43	16.0±2.5	16.4±2.0	0.4	0.0-0.9	<0.05
4	9	16.5±2.4	17.2±4.0	0.7	-0.2-2	<0.10
20cm Step Height						
1	68	12.9±1.5	13.5±1.9	0.5	1.1-5.5	<0.001
2	66	15.4±1.8	16.2±2.2	0.8	3-7	<0.001
3	42	16.5±1.7	17.2±2.2	0.7	0.2-1.2	<0.01
4	7	19.0±1.7	20.1±2.9	1.1	-0.5-2.7	0.13

Table 3 Overall changes in heart rate response on each stage of the Chester Step test

Stage	No participants	Initial Assessment (bpm)	End of Programme (bpm)	Mean Change (bpm)	95% CI	P value
1	169	96.7±13.5	93.5±12.8	-3.1	-4.5,-1.8	<0.001
2	156	107.5±14.7	102.9±14.3	-4.7	-6.2,-3.2	<0.001
3	90	114.4±14.5	110.3±14.3	-4.1	-6.3,-1.9	<0.001
4	18	129.7±16.7	122.4±16.1	-7.3	-11.9,-2.7	<0.004
5	1	132 ±-	108 ±-	-24	-	-
All	-	105.7±16.6	101.6±15.7	-4.1	-0.5,-3.2	<0.001
15cm Step Height						
1	94	95.6±1.4	92.7±1.3	-2.8	-1,-4.6	<0.01
2	86	105.6±15.7	101.6±14.5	-4	-1,-6	<0.001
3	43	112±16.5	108±13	-3.9	-0.8,-7	<0.006
4	9	130±19.3	122±16.4	-7.2	-08,-15	<0.03
20cm Step Height						
1	68	98.6±11.2	95.2±12.8	-3.3	-1.1-5.5	<0.001
2	66	110.7±12.9	105.2±13.8	-5.4	-3,-7	<0.001
3	42	117.4±11.6	113±14.4	-3.9	-0.3-7.5	<0.01
4	7	133.7±12.4	127±15.1	-6.5	-1.5,-14.7	<0.04

Box 1 Exclusion Criteria

- Patients starting heart rate limiting medication or had their dose up-titrated following their initial assessment
- Patients with uncontrolled arrhythmias
- Patients who had completed less than 1 stage on the Chester Step Test
- Change in step height between the initial and end of programme assessment
- Patients attended less than 6 supervised exercise sessions
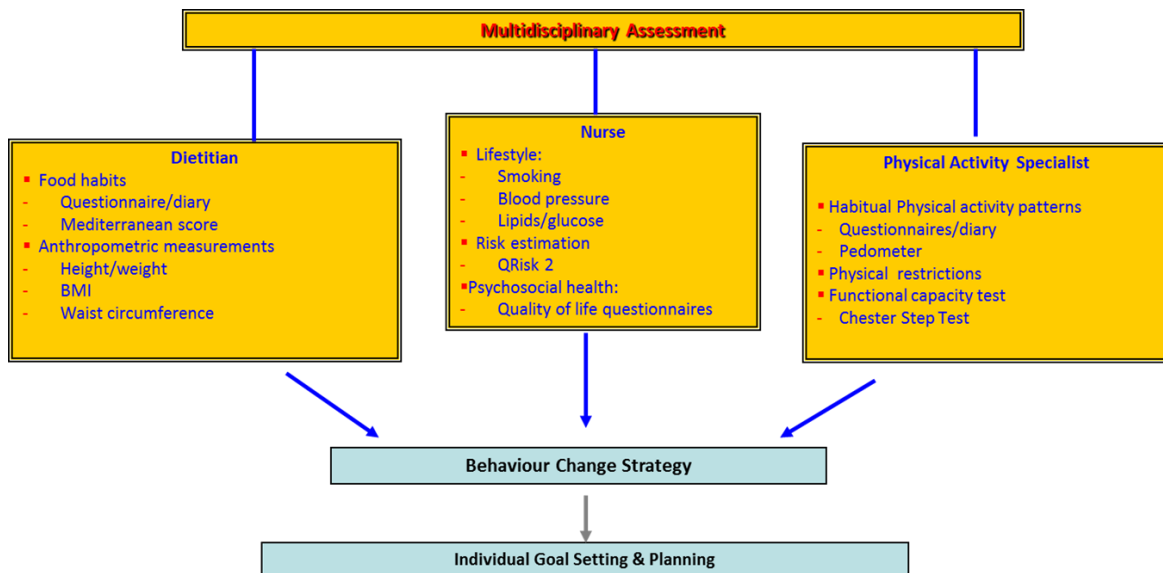
Figure 1. Multidisciplinary team assessment

Figure 2 Linear relationship between heart rate and work rate in the prediction of VO$_2$ max
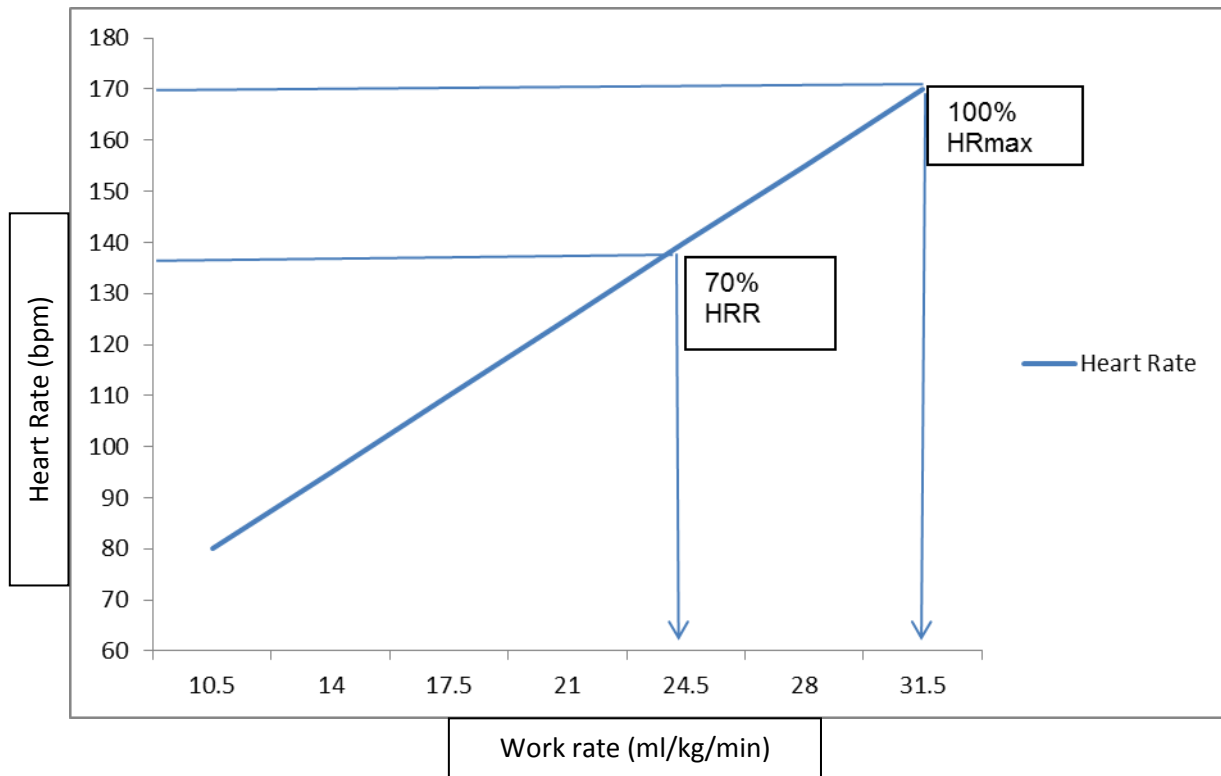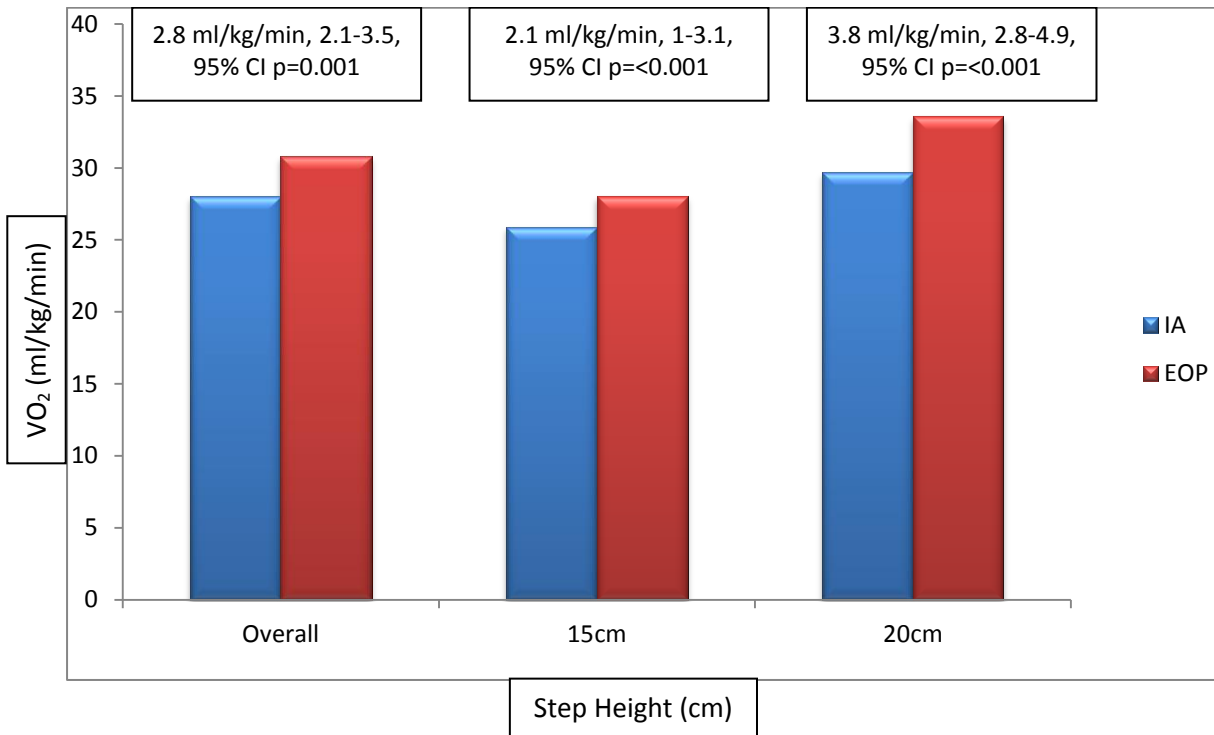
Figure 3. Overall changes in predicted VO$_2$ max on a 15cm and 20cm step height

2.8 ml/kg/min, 2.1-3.5, 95% CI p=0.001

2.1 ml/kg/min, 1-3.1, 95% CI p=<0.001

3.8 ml/kg/min, 2.8-4.9, 95% CI p=<0.001

VO$_2$ (ml/kg/min)

Overall · 15cm · 20cm

Step Height (cm)

IA
EOP

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Conflict of interest

None declared.