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7 **Perceptual-cognitive skill training and its transfer to expert performance in the field:**
8 **Future research directions**

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Abstract

Perceptual-cognitive skills training provides a potentially valuable method for training athletes on key skills, such as anticipation and decision making. It can be used when athletes are unable to physically train or are unable to experience repeated key situations from their sport. In this article, we review research on perceptual-cognitive skills training and describe future research areas focusing on a number of key theories and principles. The main aim of any training intervention should be the efficacy of retention and transfer of learning from training to field situations, which should be the key consideration when designing the representative tasks used in perceptual-cognitive skills training. We review principles that seek to create practice tasks that replicate those found in the field, so as to increase the amount of transfer that occurs. These principles are perception-action coupling, the contextual interference effect and contextual information, which suggest there should be a high level of similarity between training and real-life performance when designing perceptual-cognitive skills training. In the final section, we discuss the transfer of retained skill acquisition from perceptual-cognitive skills training to field performance, which we suggest to be the key area for future research in this area.

Keywords: Expert performance; skill acquisition; anticipation; decision making

1 **Introduction**

2 Expert performance in sport involves a combination of both motor and perceptual-
3 cognitive skills (Williams & Ericsson, 2005). Perceptual-cognitive skill refers to the ability of
4 an individual to locate, identify and process environmental information so as to integrate it
5 with existing knowledge and current motor capabilities in order to select and execute
6 appropriate actions (Marteniuk, 1976). Perceptual-cognitive skills underpinning performance
7 include, among others, a more efficient and effective use of vision to scan the environment in
8 order to extract relevant information (Williams, Ward, Smeeton, & Allen, 2004).
9 Additionally, expert performers have the ability to recognise sport-specific patterns of play as
10 they emerge (North, Williams, Hodges, Ward, & Ericsson, 2009) and to pick up the early or
11 advance cues emanating from opponents postural movements (Jones & Miles, 1978;
12 Williams & Burwitz, 1993; Williams, Ward, Knowles, & Smeeton, 2002). Moreover, experts
13 are able to generate accurate options of likely outcomes in any given situation based on the
14 refined use of situational probabilities (McRobert, Ward, Eccles, & Williams, 2011). These
15 skills are likely due to the experts having more refined domain specific knowledge and
16 memory structures (Williams & Ward, 2007).

17 **These perceptual-cognitive skills combine to produce two judgments, namely,**
18 ***anticipation* and *decision making* (Williams et al., 2004), which are the focus of this review.**
19 Anticipation is the ability to recognise the outcome of other athlete's actions prior to those
20 actions being executed. Decision making is the ability to plan, select and execute an action
21 based on the current situation and the knowledge possessed (Williams & Ford, 2013). The
22 majority of researchers have examined anticipation processes, with less research being
23 conducted on decision making or how experts acquire the skills underpinning these
24 judgments. Researchers have demonstrated that perceptual-cognitive skills can be trained in
25 sports, including soccer (e.g., Savelsbergh, Van Gastel, & Van Kampen, 2010), badminton

1 (e.g., Hagemann, Strauss, & Cañal-Bruland, 2006), and tennis (e.g., Smeeton et al., 2005;
2 Williams et al., 2002). Review papers spanning the last 15 years have highlighted key future
3 research areas for individuals examining perceptual-cognitive skill and its training (for
4 reviews, see Causer, Janelle, Vickers, & Williams, 2012; Williams & Grant, 1999; Williams
5 & Ward, 2007; Vine, Moore, & Wilson, 2014).

6 In this paper, we review perceptual-cognitive skills training involving off-field
7 techniques or *representative tasks*, such as video-based simulations, and we begin the paper
8 with a review of these tasks. Attempts have been made using these tasks to train anticipation
9 (Williams et al., 2002) and decision making judgments (Raab, 2003), as well as skills, such as
10 pattern recognition (North et al., 2009), visual search (Roca, Ford, McRobert, & Williams,
11 2011) and quiet eye (Causer, Holmes, & Williams, 2011). Perceptual-cognitive skills training
12 has utilised various instructional approaches (Farrow & Abernethy, 2002), manipulations of
13 focus of attention (Hagemann, Strauss, & Cañal-Bruland, 2006), and transfer to fatigue-
14 (Casanova et al., 2013) and anxiety-inducing conditions (Smeeton, Williams, Hodges, &
15 Ward, 2005). To cover all of these topics in detail is beyond the scope of this review, with
16 most of them having been covered well elsewhere in the literature. Therefore, in later sections
17 we concentrate on three areas for future research that may advance the use of perceptual-
18 cognitive skill training beyond its current limits, namely perception-action coupling, structure
19 of practice, and contextual information. These concepts seek to create training conditions that
20 are homogenous to those experienced when physically playing the sport, so as to increase the
21 transfer of learning from training to competition performance. In the final section, we review
22 the transfer of retained skill acquisition from perceptual-cognitive skills training to field
23 performance, which we consider to be the key area for future research in this area.

24 **Representative tasks**

1 The majority of researchers use representative tasks, such as video-based simulations,
2 to train perceptual-cognitive skills (see Figure 1). Representative tasks recreate key situations
3 normally encountered in the performance environment, so that experts are able to reproduce
4 their superior performance under standardized and repeatable conditions (Ericsson, 2003;
5 Pinder, Davids, Renshaw, & Araujo, 2011a). A representative task should allow individuals
6 to search the environment for reliable information, integrate this information with existing
7 knowledge, and complete an appropriate action. To achieve this, life-sized video is often used
8 of key situations from sport that are filmed from the perspective of an athlete. These tasks
9 enable athletes to experience repetition of key situations from their sport in a shorter space of
10 time than they would normally experience when actually playing. They have been used in
11 training to highlight the links between important environmental or opponent cues and
12 outcomes (e.g., Williams & Burwitz, 1993), with the majority of researchers using these
13 methods to train anticipation, as opposed to decision making.

14 Representative tasks examining perceptual-cognitive skills have often been paired
15 with the temporal occlusion paradigm. Temporal occlusion involves editing video images in
16 order to occlude vision at different time points around key events within the actions of an
17 opposing player (Farrow, Abernethy, & Jackson, 2005). In their seminal study, Jones and
18 Miles (1978) had professional and novice tennis coaches face tennis strokes and predict
19 where the ball would land from footage occluded at various time points. The professional
20 coaches were able to pick-up early information emanating from opponent movements, which
21 led to significantly more accurate predictions in the two earlier occlusion conditions
22 compared to the novices. Whilst the temporal occlusion paradigm demonstrates the expert
23 advantage in anticipation, it does not show the sources of information used when making
24 these judgments.

1 Researchers have used the spatial occlusion paradigm to reveal the sources of
2 information used by experts during anticipation. Spatial occlusion involves editing video to
3 remove particular areas or information sources from the opponent, such as an arm. It enables
4 researchers to infer which body region provides information that cannot be picked up
5 elsewhere, through decrements in anticipation occurring when that body region is occluded
6 (Williams & Davids, 1998). However, this does not necessarily mean that the body region or
7 cue in isolation is critical. It may be the removal of the cue that distorts or removes the
8 relative motion between regions of the body. Alternatively, it may be that removal of a
9 critical cue does not impact on performance, as expert performers are able to extract
10 information from several different sources.

11 The temporal and spatial occlusion methodologies have been used to train anticipation
12 and decision making in athletes. Williams and Burwitz (1993) used the temporal occlusion
13 paradigm to examine the anticipation of soccer penalty kicks by expert and novice
14 goalkeepers. The expert group were significantly more accurate at saving penalties under the
15 two conditions that occluded prior to foot-ball contact, when compared to the novice group.
16 Based on the accuracy scores and responses to a questionnaire about the kinematic cues used,
17 the researchers developed a penalty saving strategy and training program. For example, in
18 order to predict shot height, individuals were directed towards the trunk position prior to foot-
19 ball contact, and then to the initial portion of ball flight (Williams & Burwitz, 1993). The
20 training program involved video-based coaching to improve the anticipation judgments of the
21 novices. The training group significantly improved their response accuracy compared to a
22 control group. Subsequently, other researchers have successfully improved anticipation using
23 occlusion techniques alongside various instructional methods during training (e.g. Smeeton et
24 al., 2005).

1 Much of the research conducted on perceptual-cognitive skill is in line with one or
2 more of the stages in the *Expert Performance Approach* (Ericsson & Smith, 1991). The
3 approach is a three-stage model for the empirical analysis of expertise. In the first stage,
4 naturally occurring domain-specific tasks that capture superior performance are presented in
5 a standardized and realistic form using representative and reproducible experimental tasks
6 (Ericsson & Ward, 2007). The second stage is to use the representative tasks to identify the
7 mediating mechanisms underlying the superior performance by recording process-tracing
8 measures, such as eye movement recording, verbal protocol analysis, and/or representative
9 task manipulations (Williams & Ericsson, 2005). Finally, the third stage should examine how
10 the mediating mechanisms are acquired and the effects of different practice activities on their
11 acquisition (Ericsson, 2003). The approach provides a framework for future research in the
12 area of perceptual-cognitive skill.

13 **Perception-action coupling**

14 Some researchers have raised concerns over the use of representative tasks for
15 training, particularly in regards to the ecological validity of this approach, or how closely the
16 actions in the training environment replicate those in the performance environment (Pinder et
17 al., 2011a; Van der Kamp, Rivas, Van Doorn, & Savelsbergh, 2008). Early methods were
18 criticized for using simplistic responses to small and static visual displays, all of which were
19 thought to limit the expert advantage (Williams & Grant, 1999). The size of the visual display
20 may be more important for research on certain perceptual-cognitive skills, such as the use of
21 postural cues, compared to some other skills, such as recognition judgments where experts
22 perceive relative motion within the display (Williams, North, & Hope, 2012). Many
23 researchers now use large screens that allow life-size images to be projected and show
24 dynamic rather than static images. However, some studies in this area are still criticised for
25 the use of simplistic responses, such as button pressing and written or verbal responses (e.g.

1 Savelsbergh, van der Kamp, Williams, & Ward, 2005). Two critical components proposed in
2 the design of training environments are *functionality* of the task and *action fidelity* (Pinder et
3 al., 2011a). Functionality refers to whether the constraints a performer is exposed to, and
4 must act upon in the task, match those that they will be exposed to in the performance
5 environment. Similarly, action fidelity requires that the performer is allowed to complete a
6 response that is the same as that produced in the performance environment. Central to these
7 ideas is the reciprocal relationship between perceptual and motor processes and the
8 complementary contributions of the ventral and dorsal cortical visual systems to performance
9 (Milner & Goodale, 2008; Van der Kamp et al., 2008). There is evidence to suggest that the
10 maintenance of both functionality and action fidelity in practice is critical to accurately
11 capture the action of interest (Pinder, Davids, Renshaw, & Araujo, 2011b).

12 Differences between laboratory studies and the real-world have been shown for some
13 of the perceptual-cognitive processes underpinning expert performance (Farrow &
14 Abernethy, 2003; Mann, Abernethy, & Farrow, 2010; Mann, Williams, Ward, & Janelle,
15 2007; Van der Kamp et al., 2008). A recent meta-analysis has shown that the advantages of
16 expert over novice participants in perceptual-cognitive skills studies are directly proportional
17 to how close the action completed in a simulated environment is to the actual action required
18 in sport (Travassos, Araujo, Davids, O'Hara, Leito, & Cortinhas, 2013). The majority of the
19 studies investigating perception-action coupling have concentrated on the use of postural cues
20 for anticipation of an action (for an exception, see Paterson, van der Kamp, Bressan, &
21 Savelsbergh, 2013). Dicks, Button, and Davids (2010) investigated visual search and
22 response behaviours of soccer goalkeepers facing penalty kicks. The goalkeepers faced kicks
23 in five experimental conditions that had all been previously used in perceptual-cognitive
24 skills studies. The experimental protocols included two video conditions in which the keepers
25 either produced a verbal response or a simulated joystick movement. They also included three

1 *in situ* conditions in which the keepers either produced a verbal response, a simplified body
2 movement, or an actual interceptive movement response or “save” as they would during
3 match-play. The study did not include a complex movement condition in the video conditions
4 (e.g. Pinder et al., 2011b). Participants were more accurate in the *in situ* conditions compared
5 to the video simulation conditions. In the conditions with limited movements for participants,
6 the keepers spent more time fixating on the movements of the penalty kick taker (head and
7 feet), rather than the ball. In comparison, when goalkeepers were required to attempt an
8 actual penalty save *in situ* they fixated earlier and for a longer duration on the ball when
9 compared to the movements of the taker and to the other conditions. However, the number of
10 possible shot locations was lower ($n = 2$) in the “save” condition compared to all other
11 conditions ($n = 6$) and the video condition showed less ball flight than *in-situ*, which may
12 have led to the observed differences in visual search between conditions. Overall, findings
13 suggest that laboratory tasks may fail to adequately recreate the environmental characteristics
14 of many real-world settings (Dicks et al., 2010).

15 However, some researchers have found no difference between coupled and uncoupled
16 responses in perceptual-cognitive skill studies (Ranganathan & Carlton, 2007, Williams et al.
17 2004). Williams et al. (2004) examined the effect of perception-action coupling during
18 *training* of anticipation skill. Participants practiced anticipating tennis serves in an on-court
19 scenario, either responding verbally during practice, or physically returning the serves,
20 whereas a third control group just received technical training. There were no significant
21 differences between the three groups in the pre-test, but in the post-test both the perception-
22 action and perception only training groups recorded faster anticipation compared to the
23 technical training group, with no difference found between the two perception groups.
24 Further research is required to assess perception-action coupling and also to examine whether

1 these findings extend to other perceptual-cognitive skills, such as pattern recognition and
2 situational probabilities.

3 High levels of task functionality and action fidelity seem to be required for
4 researchers examining the processes and mechanisms that underpin expert performance in
5 sport. However, a suitable balance is required between the need to maintain ecological
6 validity on the one hand and the desire for internal validity and experimental control on the
7 other (Causer, Barach, & Williams, 2014). A related question for future research is whether
8 perceptual-cognitive skill training that *does not* involve a movement response can lead to
9 improved physical performance during competition. One advantage of perceptual-cognitive
10 skills training is that athletes can engage in it when they are not able to physically practice;
11 such as when injured, travelling to competition, resting at home, or recovering from training
12 (Williams & Ford, 2013). In cases where athletes are unable to physically respond, then
13 perceptual-cognitive skills training without a movement response may be superior to other
14 activities, acting as a form of observational learning (Horn, Williams, & Scott, 2002), albeit
15 with greater cognitive effort (Lee, Swinnen, & Serrien, 1994). Well-designed physical
16 practice is likely superior in maintaining the coupling between perception, cognition and
17 action when compared to perceptual-cognitive skills training and should take priority when
18 athletes are able to engage. The main test of any practice activity in sport is how well the
19 aspects of performance being practiced transfer to retained improved performance in the
20 competition format of the sport (Rosalie & Mueller, 2012). In the following sections, we
21 review research and make recommendations on the structure of practice and transfer of
22 learning from perceptual-cognitive skills training to the field.

23 **Structure of practice**

24 There is little doubt that extensive practice and training is necessary to reach the very
25 highest levels of performance in sport (Ericsson, 2003). Researchers have demonstrated that

1 the manner in which practice is organized influences the performance and learning of skills.
2 A robust finding in the motor learning literature is the *contextual interference* (CI) effect
3 (Magill & Hall, 1990). Practice schedules involving high CI (i.e., random schedule) result in
4 poorer performance during acquisition, but promote superior long-term learning and transfer
5 of the skills, when compared to low CI conditions (i.e., blocked schedule; Lee, 2012). The CI
6 effect has been extensively examined in a variety of motor learning tasks (for reviews, see
7 Lee, 2012; Magill & Hall, 1990).

8 To date, there is limited research examining whether the CI effect extends to
9 perceptual-cognitive skill training in sport. Memmert, Hagemann, Althoetmar, Geppert, and
10 Seiler (2009) investigated the CI effect in the acquisition of anticipation by novice badminton
11 athletes. Participants practiced under either two blocked conditions (lateral before depth or
12 depth before lateral dimension), or a random schedule. The protocol involved viewing
13 temporally occluded overhead badminton shots from the perspective of the returning player
14 that were shown in the upper left-hand corner of a computer screen. On the right-hand side of
15 the screen was an image of a badminton court that participants had to click on to report where
16 they predicted the shuttlecock would land. All participants completed a pre-test, 6 training
17 sessions where feedback was provided after each trial, a mid-test, a post-test, and a 7-day
18 retention test. There were no between-group differences in the accuracy of anticipatory
19 judgments across acquisition and retention. The lack of differences is most likely due to
20 participants only practicing anticipatory judgments of one skill, the badminton overhead
21 stroke to different landing locations. By definition, CI is the scheduling of practice for a
22 number of different skills, not a single skill.

23 In comparison, Broadbent et al. (under review) required intermediate tennis players to
24 anticipate the direction of three distinct tennis shots (groundstroke; volley; smash shot)
25 shown on life-size video filmed from a first person perspective and occluded around ball-

1 racket contact. Response accuracy scores were recorded in a pre-test, during acquisition, on a
2 7-day retention test and in an on-court test used to measure transfer of learning. Participants
3 responded by executing the movement of a return shot and verbalising the anticipated shot
4 location. During the acquisition phase, one group had a blocked schedule of practice in which
5 the three types of tennis shots were practiced in separate blocks. The other group had a
6 random schedule of practice in which the three shot types were practiced in a quasi-random
7 order. Findings showed some support for the previous literature and the CI effect. There were
8 no between-group differences in response accuracy across the acquisition phase, which
9 contradicts the 'typical' CI effect. However, the random practice group reported significantly
10 higher response accuracy in the 7-day laboratory-based retention tests compared to the
11 blocked group (Figure 2). Moreover, in the 7-day transfer test to an on-court protocol the
12 random group significantly reduced their decision time compared to the blocked group
13 (Figure 3). Findings provide the first indication that the CI effect extends beyond the motor
14 learning literature into the perceptual-cognitive skills literature.

15 From an applied perspective, practitioners engaging athletes in simulation training to
16 improve perceptual-cognitive skills should look to promote high CI in order to incur long-
17 term learning and transfer of the skills. From a theoretical perspective, future research should
18 investigate whether the explanations for the CI effect from the motor skills literature can be
19 applied to this new domain. Two main theories have been forwarded to explain the CI effect
20 (Lee, 2012). First, the elaboration hypothesis holds that random practice promotes more
21 comparative analysis between the multiple skills being practiced, whereas the repetitive
22 nature of blocked practice promotes less analysis (Schmidt & Lee, 2011). Second, the
23 reconstruction hypothesis postulates that random practice promotes short-term forgetting due
24 to the interference between tasks, causing participants to reconstruct an action plan in order to
25 execute each new attempt at the task. In contrast, during blocked practice only one action

1 plan is used across the multiple attempts at the same task (Schmidt & Lee, 2011). Further
2 research is required to reveal the underlying cognitive mechanisms that lead to the CI effect.

3 There are other aspects of practice structure that have not been addressed fully in
4 perceptual-cognitive skills training. When performing in sport competition, an athlete's
5 perceptual-cognitive skills are constrained not only by their level of expertise in the sport and
6 the current situation in the performance, but also by the contextual information within the
7 situation (McRobert et al., 2011). Contextual variables include the score of the game; the
8 time in the game; the athlete's characteristics, tactics, and tendencies; opponent
9 characteristics, tactics and tendencies; pitch surface; and the weather, as well as in some
10 sports the characteristics and tendencies of teammates (McPherson & Kernodle, 2003).
11 Contextual variables are rarely examined in perceptual-cognitive skill training in sport
12 despite their potential importance. An exception in the perceptual-cognitive skills literature is
13 McRobert et al. (2011; see also Paull & Glencross, 1997) who investigated context-specific
14 information and its effect on anticipation performance in cricket. Skilled and less-skilled
15 batters faced life-size video of deliveries from bowlers that were occluded after 80 ms of ball
16 flight. In a low-context condition, participants responded to 24 balls from six bowlers
17 presented in a random order. In the high-context condition, participants responded to four fast
18 bowlers who each delivered six balls in one block. The high-context condition replicated an
19 actual match condition known as an "over" in cricket. It exposed participants to contextual
20 variables linked to their opponent's characteristics, tactics and tendencies. The high-context
21 condition led to higher response accuracy scores for both groups when compared to the low-
22 context condition. Moreover, visual search data revealed that fixation duration was shorter in
23 the high- compared to the low-context condition, suggesting that the additional pre-
24 performance information allowed the skilled batters to extract the information from the
25 display more efficiently. Contextual information may act as an informational constraint on

1 performance (Vicente & Wang, 1998), increasing the functionality of the task. Further
2 research is required to examine the effect on skill acquisition of real-world contextual
3 variables in perceptual-cognitive skills training.

4 **Retention and transfer of learning from practice**

5 The key consideration when designing any practice activity is the retention and
6 transfer of learning from that activity to the complexity of field performance. Retention is a
7 measure of learning and refers to the persistence or lack of persistence of the performance
8 once a period of time has passed after the practice trials ended. There is extensive research on
9 the long-term retention of various motor skills (Schmidt & Lee, 2011). Neumann and
10 Ammons (1957) provide a classic example where they assessed learning of a discrete motor
11 skill at retention intervals of one min, 20 min, two days, seven weeks, and one year. They
12 showed that decrements in performance became progressively greater as the length of the
13 retention interval increased. Researchers examining perceptual-cognitive skills training have
14 started to include retention conditions as opposed to just a post-test. Some researchers have
15 shown that perceptual-cognitive skills training has led to improved anticipation and decision
16 making that has been retained after periods of 14 days (Gorman & Farrow, 2009), four weeks
17 (Gabbet, Rubinoff, Thorburn, & Farrow, 2007; Raab, 2003) and five months (Abernethy,
18 Schorer, Jackson, & Hagemann, 2012).

19 However, much of the previous research on perceptual-cognitive skills training does
20 not assess whether improvements during acquisition actually transfer to field situations
21 (Rosalie & Mueller, 2012). In the previously mentioned studies, only the paper by Gabbet et
22 al. (2007) demonstrated significant improvements to an actual match situation following a
23 retention period. Other researchers either failed to include a transfer test (Raab, 2003),
24 administered a laboratory-based transfer test to a stressful condition (e.g., Abernethy et al.,
25 2012), or found no significant improvement to performance in actual competition (Gorman &

1 Farrow, 2009). A few researchers *have* assessed the transfer of perceptual-cognitive skills
2 from laboratory-based training to the field (Farrow & Abernethy, 2002; Smeeton et al., 2005;
3 Williams et al., 2002). While these studies have shown successful transfer, the field-based
4 protocol is administered as part of a pre- and post-test occurring close to the practice phase
5 and so not assessing the retention of these transferrable skills.

6 Researchers investigating the benefits of quiet eye (QE) skills training have
7 demonstrated retained transfer of learning to real competition (Causer et al., 2011; Vine,
8 Moore, & Wilson, 2011). The QE period is defined as the final fixation on a specific location
9 or object for a minimum of 100 ms (Vickers, 1996). The onset of QE occurs before the final
10 movement of the task where the performer is thought to set the final parameters of the
11 movement to be executed (Causer et al., 2011). Longer QE periods are associated with
12 greater expertise and success when compared to shorter QE periods, and this ability can be
13 trained (for a review, see Vine et al., 2014). Vine et al. (2011) randomly assigned a group of
14 elite golfers to either a QE training or control group. Participants recorded their putting
15 statistics over 10 rounds of competitive golf (maximum of 3 months) before and after the
16 training interventions. The training for both groups consisted of video feedback of their gaze
17 behaviour while they completed putts, with the QE-trained group receiving additional
18 instructions related to maintaining a longer QE period. Pre-test performance was not different
19 between groups, but post-intervention the QE-trained group holed more putts and left the ball
20 closer to the hole more frequently compared to the control group, and these advantages
21 transferred to real competition. The successful transfer of QE training to real-world
22 performance may be due to the high fidelity of the actions executed during training.
23 Alternatively, QE may be a simpler skill to acquire and transfer to competition compared to
24 other perceptual-cognitive skills, such as decision making. However, it is beyond the scope of

1 the current paper to review issues surrounding QE training as these have been discussed at
2 length elsewhere in the literature (for a review, see Vine et al., 2014).

3 In relation to anticipation training studies, generally researchers have found high
4 scores and no between-group differences for response accuracy in the field-based post-test
5 compared to the pre-test (Smeeton et al., 2005; Williams et al., 2002). The high scores and
6 lack of improvement in response accuracy in the field-based tests could be as a function of
7 the speed-accuracy trade-off inherent in these tasks. Moreover, many anticipation-training
8 studies contain responses that are low in fidelity, which may further affect the transfer of
9 learning. Alternatively, it may highlight the difficulty of creating challenging enough
10 conditions for participants in the field. In the field, participants can usually wait to respond
11 until the ball is in flight, whereas in the laboratory the occlusion paradigm forces them to
12 make decisions before the ball is in flight. Therefore, researchers investigating anticipation
13 should seek to use sports tasks that actually require anticipatory responses in the field, such as
14 a tennis volley, as opposed to those that require it less so, such as deep ground stroke in
15 tennis (Triolet, Benguigui, Le Runigo, & Williams, 2013). Furthermore, the temporal
16 occlusion paradigm can be recreated *in situ* by using liquid crystal goggles that are capable of
17 quick transitions between transparency and opacity (Milgram, 1987). Researchers examining
18 perceptual-cognitive skills *in situ* using liquid crystal goggles have usually reproduced the
19 expert advantage that has been found in laboratory studies using video simulation (Farrow et
20 al., 2005; Mann, Abernethy, Farrow, Davis, & Spratford, 2010). In the future, researchers
21 should seek to use field-based transfer protocols as the norm to investigate whether skills
22 acquired during perceptual-cognitive skills training actually transfer to improved complex
23 performance in the field. Those transfer conditions should also look to recreate arousal states
24 that occur in competition, such as high-anxiety (e.g., Alder, Ford, Causer & Williams, under
25 review) or fatigue (e.g., Casanova et al., 2013), so as to increase the fidelity of the test.

1 **Conclusion**

2 Perceptual-cognitive skill training provides an ideal method for developing
3 anticipation and decision making judgments in athletes. Although researchers have made
4 much progress in examining this area, further research is required to resolve the key question
5 from this review as to whether perceptual-cognitive skills training provokes transfer of
6 learning to improved and retained performance in the field. A number of the principles
7 outlined in this review suggest that the representative tasks used in perceptual-cognitive skills
8 training should replicate as closely as possible the real-world to improve the transfer of
9 learning. These principles include the structure of practice, perception-action coupling, and
10 contextual information, which we believe should be the focus of future research towards
11 answering the main question on transfer. Future research should seek to include field-based
12 transfer tests as the norm and where possible long-term transfer tests to gain a true
13 understanding of the benefits of perceptual-cognitive skills training.

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Figure 1. Example set up of a laboratory video simulation technique for the acquisition of anticipation skills in tennis from Broadbent et al. (under review).

Figure 2. Mean (SE) response accuracy (%) for the blocked and random groups in a video simulation tennis anticipation task in the pre-test, 3 training sessions, 7-day, and 2-month retention test. * $p < .05$. Adapted from Broadbent et al. (under review).

Figure 3 Mean (and standard deviation) response accuracy percentage (RA; %) and decision time (DT; ms) in the field pre-test and 7-day transfer tests for the blocked and random group. * $p < .05$. Adapted from Broadbent et al. (under review)

Figure 4. Mean (SD) response accuracy (%) for experienced and inexperienced soccer goalkeepers in a penalty anticipation task across four occlusion conditions; 120 ms before foot-ball contact, 40 ms before contact, at contact (0 ms), and 40 ms after foot-ball contact. * $p < .05$. Adapted from Williams & Burwitz (1993)