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Time to start training: A review of cognitive research in sport and bridging the gap from academia to the field

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Abstract

Research demonstrates the importance of perceptual-cognitive skills, such as pattern matching, anticipation, and decision making in numerous sports, including badminton (Abernethy & Russell, 1987), baseball (Burroughs, 1984), basketball (Allard, Graham, & Paarsalu, 1980), handball (Johnson & Raab, 2003), rugby (Lorains, Ball, & MacMahon, 2013), soccer (Ward & Williams, 2003), squash (Abernethy, 1990), tennis (Haskins, 1965), and volleyball (Borgeaud & Abernethy, 1987). While other factors may be important (e.g., visual search patterns), the accuracy and/or speed with which athletes anticipate their opponent's intentions and/or decide on an appropriate course of action, as assessed in domain-specific tests designed to simulate and represent real-world sporting demands have been shown to be the best and most reliable predictors of skilled performance in the field (see Mann, Williams, Ward, & Janelle, 2007). Moreover, several studies indicate that when training is based on expert models of superior performance, these skills can be improved and transfer to the field (e.g., Fadde, 2009; Ward, Suss, & Basevitch, 2009). In most elite and everyday sports training contexts, expensive research technology (such as eye-tracking equipment) is not always available to practitioners that would help us better understand the cognitive basis, and ecological constraints of anticipation and decision-making in a way that could be leveraged to tailor training to improve individual and team performance. However, other technologies are now more readily available to support the development of perceptual-cognitive skills. This is particularly timely. Although there is a growing body of research demonstrating the trainability of perceptual-cognitive skills in sport and their transfer to the field, few researchers have attempted to translate this research into accessible and useful training tools for everyday coaches and athletes (for an example, see Belling, Suss, & Ward, 2014). Moreover, research on the validation of such perceptual-cognitive or decision-making skill training tools is startlingly absent from the literature, not just in sport, but more broadly across a range of human factors domains. In this research, we review what has worked in the past, how we can leverage simple but effective training tools designed for accessible devices (e.g., personal computer, tablet), and the utility of

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these tools based on their impact on real world performance following implementation. We review the experience of NCAA Division 1 baseball team players who were given access to a video-scenario-based training technology designed to improve pitch recognition and pitch location assessment training (Axon Sports Cognitive Training). Batting statistics are compared between the 2012 season when this training was not available to athletes, to 2013 season when the Axon training was made available. The results suggest that use of cognitive training improved batting performance in the field, likely a result of their enhanced skill to ‘read’ the pitcher’s action. Implications for future research and application are discussed.

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1. Introduction

Most modern sports require athletes to perform both physically and cognitively. Just as physical demand may vary across different sports, positions, and situations, so does the demand on the athlete’s perceptual-cognitive system. Athletes must attend to and encode relevant information cues in the environment, interpret that information in the context of the current game situation and past experiences, and use it to anticipate the intentions and actions of others successful so that they can make high quality decisions about what to do next. While these macrocognitive functions and processes are important for many other complex and dynamic environments, this research focuses on those supporting perceptual-cognitive expertise within sport situations. Specifically, in this study, we equipped a baseball team with tools for training key macrocognitive functions and observe the change in performance following their implementation.

1.1. Expert-Novice Differences in Perceptual-Cognitive Skill in Sport

Fantastic stories about the innate, mystical and even divine basis of talent, including tales of superior and untrainable ‘vision’ of talented athletes, are commonly bounded around the media, in public fora, and even in professional sports contexts. Empirically, while there is some evidence that talented athletes have some superior domain-general ‘abilities’ (i.e., relatively stable perceptual or cognitive abilities on which skill can be developed), such as superior cognitive processing speed, and enhanced attentional and working memory capacities (see Voss, Kramer, Basak, Prakash, & Roberts, 2010), these effects are typically small; so much so that they are undetectable outside of meta-analyses. Moreover, when compared to domain-specific perceptual-cognitive skills (such as the ability to anticipate the outcome of a given play, assess the current threat in a specific situation, and decide on an effective course of action given the current situational constraints), such individual differences in general, perceptual and cognitive basic abilities are simply drowned out by the overwhelming influence of these acquired skills (see Mann et al., 2007; Helsen & Starkes, 1999; Ward & Williams, 2003).

Typically, key macrocognitive functions (e.g., anticipation, situation assessment, decision making), frequently termed ‘perceptual-cognitive skills’ in sport, have been measured using simulated task environments (STEs), such as interactive simulations that make use of video-based scenarios. These simulations use technology to recreate challenging performance tasks experienced by the athletes in the field, by representing the perceptual, cognitive, and often, psychomotor demands of the task via scenarios filmed from a first-person perspective. A popular method of constraining information that has been incorporated in to these simulations—used to determine temporal information requirements—is the temporal-occlusion method (for a review, see Ward, Williams, & Hancock, 2006). Using this method, scenarios are presented up until a pre-specified critical moment in the play, such as foot-to-ball contact in soccer (e.g., Belling et al., 2014), the moment the ball leaves the pitcher’s hand in baseball (e.g., Fadde, 2006), or racket-to-shuttlecock contact in badminton (e.g., Abernethy & Russell, 1987). At this point, the scenario is unexpectedly occluded (i.e., by removing all or part of the contextual information and replacing with a blank screen, or by freezing video on the last frame of action; e.g., Johnson & Raab, 2003; Ward & Williams, 2003; Ward, Ericsson, & Williams, 2013), and participants are immediately asked to predict what will, could or should happen next, and/or decide how they will respond. The temporal occlusion method has also been used in naturalistic settings

by using technological occlusion techniques such as liquid crystal glasses, which can be triggered to occlude the scene during ball flight (e.g., Starkes, Edwards, Dissanayakee, & Dunn, 1995) or during a participant's response (e.g., Oujedans & Coolen, 2003).

Since the temporal occlusion method was first pioneered by Haskins (1965), several researchers have employed this approach successfully to assess expert-novice differences, and train perceptual-cognitive skill in sports. For instance, using an interactive simulation, Helsen and Pauwels (1988) presented soccer players with video scenarios involving soccer game play, in which they had to make a decision about where to pass the virtual ball when it was passed to them from a team mate. The participant responded by kicking an actual ball (placed in front of them). The chosen course of action was used to assess their decision making accuracy and speed of response. Experts were significantly faster than novices when making the correct decision.

In a similar interactive simulation study, Ripoll, Kerlizin, Stein, and Reine (1995) examined expertise in boxing by presenting video scenarios of an attacking boxer. The participants responded using a joystick to signal which part of their body they would block/defend in response to the simulated attack. The data indicated that expert boxers made significantly more accurate decisions than novices, although responded at similar speeds.

Belling et al. (2014) tested the validity of an online perceptual-cognitive skill assessment tool using interactive simulation; the Online Assessment of Strategic Skill In Soccer (OASSIS). In a similar manner to the interactive simulations developed previously for off-line use (e.g., Ward & Williams, 2003), OASSIS presents participants with near-first-person-perspective, video-based scenarios depicting typical soccer play. At an unexpected moment immediately prior to a critical decision (e.g., pass, dribble, shoot; pass to location A, B, C; pass to player 1, 2, 3, 4, etc.) by an opposing player with the ball, the screen was occluded and all contextual information except pitch markings and ball position (as depicted on the last video frame of action prior to occlusion) were removed from the screen. NCAA Division 1 soccer players and recreational-level soccer players were assessed and the participants' task—at the moment of occlusion—was to determine, from the multiple options presented on screen, which one the opposing player with the ball was going to take next. The OASSIS was presented and completed online. The Div. 1 soccer players more accurately anticipated the actual outcome of each play than novices, across all types of scenarios presented.

This expert advantage in perceptual-cognitive skill has been demonstrated in numerous sports, in addition to those mentioned above, including but not limited to squash (Abernethy, 1990), badminton (Abernethy & Russell, 1987), and field hockey (Williams, Ward, & Chapman, 2003). In general, experts have tended to more accurately anticipate the outcome of a play, make more accurate decisions, and/or respond more quickly than novices, suggesting that simulation-based methods provide a useful means to identify and assess important macrocognitive functions in a simulated setting.

1.2. Training Perceptual-Cognitive Skill in the Lab

In addition to providing a means to measure and assess skill effects, interactive simulations have been used as a platform for developing training designed to improve perceptual-cognitive skill in sport (for a review, see Ward et al., 2006). For example, Williams, Ward, Knowles, and Smeeton (2002) created a perceptual-cognitive skill training program in tennis (using what would later become known as Expert Performance-based Training [ExPerT]; see Ward et al., 2009). Tennis ExPerT, based on an informal model of expertise created from expert performance data and visual scan patterns, was instantiated in a simulated task environment, using temporally occluded scenarios similar to those used previously (see above). Using this platform, the authors demonstrated that those who received one hour of ExPerT were quicker at anticipating the direction of an opponent's groundstrokes compared to a control group when tested in the simulated environment. Importantly, the improvements in perceptual-cognitive skill, and ensuing performance, observed using simulation were corroborated by 'on-court' improvements using field tests. Similar findings were observed by Smeeton, Williams, Hodges, and Ward (2005), who employed the same methods using longer periods of training (4hrs over 4 weeks) and training regional-level tennis players (i.e., journeyman).

Fadde (2006) used a similar method (which later became known as Expertise-based Training [XBT], see Fadde, 2009) designed to increase baseball hitting capability by improving skill at recognizing the type and predicting the location of a baseball pitch. NCAA Division 1 collegiate baseball players were assigned to a training and control

group. The training group received temporal-occlusion-based simulation training over a two-week period in which they, as a baseball player at bat, were shown first-person perspective video scenarios of a pitcher throwing a pitch, and asked to identify the type of pitch and predict its location as it crossed the plate. The control group did not complete any training. Following the training period, the transfer of both groups was assessed via performance over the next 18 preseason games. The training group recorded a significantly higher batting average—a common metric of baseball hitting skill—than the control group during those games, suggesting that training was influential at improving the skill of batters to hit successfully during a game.

Despite the ever growing body of evidence that perceptual-cognitive skill contributes to expertise across a number of sports and can be improved using the types of simulation training methods described above, few researchers have attempted to develop readily accessible assessment and training tools for use directly by players and coaches in private industry and professional sports.

While it is encouraging that previous research has made measurement tools available online that assess perceptual-cognitive skill in soccer (e.g., Belling et al., 2014), the value of such tools in applied settings (i.e., for semi-/professional athletes and coaches) for the purposes of training macrocognitive functions that are central to skilled sports performance is, as yet, unknown. Such training tools need to be made available on a readily accessible platform designed specifically for use in applied settings (e.g., intuitive interface, ecologically valid, etc.), so that their effectiveness, utility, and value to the sports community can be fully evaluated. Using a naturalistic approach, we equipped a collegiate baseball team with a simulation tool for training perceptual-cognitive skill. Players and coaches were permitted to use this tool at their own discretion. As an assessment of this tool's validity we compare the batting statistics of the collegiate team from 2012, prior to the implementation of this training, to the 2013 season, when the team had access to training. As a result of exposure to this training (described below), we expected that batting statistics during the 2013 season, namely batting average, runs scored, hits, doubles, triples, homeruns, walks, and on-base percentage (for definitions, see section 2.2 *Analysis* below) would be indirectly improved relative to 2012 via increased opportunity to develop the macrocognitive functions that should support such statistics (i.e., pitch recognition [PR], and prediction of pitch location [PL]).

2. Methods

2.1. *Participants, Materials, and Procedure*

Members of a NCAA Division 1 collegiate baseball team during the 2012 and 2013 seasons took part in this training assessment. Only players who had at least 50 at-bats in a season were included in the data analysis. From the 2012 season, 15 players were included. From the 2013 season, 13 players were included. Of the 13 players with at least 50 at-bats in 2013, 9 were returning players from 2012. All 13 players from the 2013 season were given access to the Axon Sports Baseball Perceptual-Cognitive Training for Baseball Hitters—an interactive simulation training system using video-based scenarios filmed from a first-person perspective. Training included the pitch location (PL) and pitch recognition (PR) tasks (see Fadde, 2006; Fadde, 2009). The simulation was presented via a 65-inch touch screen monitor. During PR, participants watched a pitcher throw a pitch from the perspective of the batter. The pitch was set to occlude, as in the temporal-occlusion task described above, following the moment of release (MOR)—the last frame in the video in which the ball was touching the hand of the pitcher. Initially, occlusion occurred at 10 frames after MOR. Immediately after occlusion, response options appeared on screen, each representing a possible type of pitch (e.g., fastball, changeup, and curveball). The participant responded by touching the option on screen which represented the type of pitch that he thought the pitcher had thrown. During the PL task, as in the PR task, players watched the pitcher pitch, followed by occlusion, at which point nine response options appeared, each one representing a section of the strike zone (an area commonly referred to in baseball). The players responded by touching the area within the strike zone which they thought the ball would fly through. The simulation training was designed to be adaptive—as a player's accuracy in PR or PL improved, the occlusion point would regress backwards in time toward the MOR (see Ward et al., 2009). In other words, once participants could correctly recognize a pitch or predict its location within the strike zone at a given occlusion point (e.g., 10 frames after MOR), they were then forced to build accuracy earlier in the pitching action (e.g., < 10 frames after MOR).

2.2. Analysis

The players' statistics from the 2012 season, which reflects performance without the benefit of training using the Axon Sports training tool, to the players' performance in 2013 season, when they had access to the training tool. Since each season contained a slightly different number of games, statistics that are normally summed over the span of a season (e.g., homeruns, runs, walks) were calculated on a per-at-bat basis (i.e., divided by the total number of at-bats for that season)—the typical procedure used to calculate batting average, slugging percentage, and on-base percentage. The batting statistics on which players were evaluated each season are consistent with those used in previous evaluations of perceptual-skill training in an experimental setting (e.g., Fadde, 2009), and are defined below.

- *Batting Average (BA)* is defined as the average number of hits (i.e., when a player hit the ball and reached first base).
- *Homeruns per at-bat (HR)* is defined as the average number of homeruns (i.e., when a player recorded a hit and reached home plate, for example, by hitting the ball past the outer wall).
- *Runs per at-bat (R)* is defined as the average number of runs made (i.e., the number of times a player reached home plate).
- *Walks per at-bat (W)* is defined as the average number of times that a player walked to first base (e.g., was thrown four balls and did not record a hit).
- *Slugging percentage (S)* is a common measure of the power of a player and calculated as the sum of the number based reached (i.e., total bases) which includes singles, doubles, triples, and homeruns, all divided by the number of at bats. Rather than an actual percentage it is expressed on a scale from 0 to 4.
- *On-base percentage (OBP)* is defined as the average number of times a batter reaches a base (whether by hit or walk).

For each variable, one-way ANOVA and effect size were used to compare means across seasons. Effect size (*ES*) was calculated as the difference in mean in standard units, using the baseline condition (i.e., the 2012 season, prior to implementation of training) *SD* as the denominator (see Hedges & Olkin, 1985).

3. Results

Significant improvements in batting statistics were observed at the end of the 2013 season (during which Axon training was undertaken) relative to the 2012 season (note that similar improvements were observed among data from only returning players from 2012 to 2013). The number of homeruns (HR) was significantly greater in 2013, $F(1,26) = 8.283$, $p = .008$, and the observed effect was large. Likewise, number of runs scored (R) and slugging percentage (S), $F(1,26) = 3.463$, $p = .037$, were both significantly greater in 2013, $F(1,26) = 3.175$, $p = .043$, and the observed effects were moderate-large. The effect on walks approached significance in the hypothesized direction (W), $F(1,26) = 1.953$, $p = .087$, and a moderate-large sized effect was observed. Lastly, the effect on on-base percentage (OBP) approached significance in the hypothesized direction, $F(1,26) = 2.370$, $p = .068$, and a moderate-large effect size was observed. Batting average (BA) was not statistically different across the two seasons, $F(1,26) = .682$, $p = .208$, though a small-moderate effect was still observed in the hypothesized direction. Descriptive statistics for each year are provided in Table 1.

Table 1. Means (SD) for batting statistics.

Year	BA	HR	R	W	S	OBP
2012	.265 (.058)	.004 (.009)	.149 (.040)	.102 (.044)	.334 (.083)	.350 (.057)
2013	.281 (.045)	.017 (.015)	.177 (.042)	.126 (.048)	.393 (.083)	.380 (.044)
<i>ES</i>	.283	1.483	.690	.550	.707	.529

4. Discussion

Homeruns, runs scored, and slugging percentage were statistically greater in 2013 compared to 2012. This improved level of performance suggests that the 2013 batters were able to generate better contact with the ball, presumably as the result of a better ability to recognize and locate the pitches they faced. Quick recognition and location of the pitch would allow the necessary fine-tuning to the swing in order to hit the ball with “sweet spot” of the bat. Additionally, walks and on-base percentage were greater in 2013, although the differences did not quite reach statistical significance. Moderate-large effect sizes were still observed, though a larger sample size is likely needed for these effects to reach a statistically significant level. The observation of more walks and higher on-base percentage is encouraging because it suggests that the batters were better able to recognize and locate pitches outside of the strike zone and make the correct decision not to swing. Batting average showed a small-moderate increase, though also not statistically significant.

There are some limitations to this research which should be acknowledged. Without a control group it is difficult to ascertain whether the greater batting statistics observed in 2013 were caused by the players’ engagement with the training tool. However, it is important to note that the effectiveness of this kind of training has been demonstrated in previous research that has compared an intervention against a control group (see Fadde, 2006; Fadde, 2009). Previous research employing a control group has shown significant improvements, even in those statistics where only small effects were observed in the current research (i.e., batting average; see Fadde, 2009). We take the effects discussed here in a naturalistic environment in the context of previous research (Fadde, 2009) as another case of evidence that the type of perceptual-cognitive training in pitch recognition and pitch location has potential to improve hitting performance in baseball. Another limitation was tracking of training among the players. While players were permitted unmonitored and unregulated training to increase ecological validity, a system for tracking the amount of training may allow a more thorough investigation of performance improvement. While most players improved on average, some did not, which contributed to the lack of statistical significance in some of the effects. By tracking the training time that each player invests in training, and comparing the same players across seasons, we can identify those players that do and do not improve and investigate potential reasons for the presence/absence of change (e.g., degree of effort invested, number of repetitions, motivation level, etc.). The observation of these results in spite of these limitations suggests that this type of training in baseball is useful when applied.

In conclusion, this research suggests tools based on previous research can be used effectively by players and coaches in (semi-)professional settings. We consider this research an exploration of the process for evaluating these types of tools and a call to action for more researchers to test in other applied environments (e.g., law enforcement, medical, military), while addressing the methodological limitations presented here. Several decades of research have demonstrated that perceptual-cognitive training in the lab is effective in sport domains and can even transfer to the field (see Ward et al., 2006; Fadde, 2009), but very few researchers have validated methods for distributing and evaluating training tools in applied environments. The findings discussed here suggest that new and applied tools continue to show effectiveness similar to laboratory settings when they are deployed in the real world. We encourage researchers to explore these types of tools in new domains.

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