

Perceptual-Cognitive Expertise in Sport: A Meta-Analysis

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Research focusing on perceptual-cognitive skill in sport is abundant. However, the existing qualitative syntheses of this research lack the quantitative detail necessary to determine the magnitude of differences between groups of varying levels of skills, thereby limiting the theoretical and practical contribution of this body of literature. We present a meta-analytic review focusing on perceptual-cognitive skill in sport ($N = 42$ studies, 388 effect sizes) with the primary aim of quantifying expertise differences. Effects were calculated for a variety of dependent measures (i.e., response accuracy, response time, number of visual fixations, visual fixation duration, and quiet eye period) using point-biserial correlation. Results indicated that experts are better than nonexperts in picking up perceptual cues, as revealed by measures of response accuracy and response time. Systematic differences in visual search behaviors were also observed, with experts using fewer fixations of longer duration, including prolonged quiet eye periods, compared with nonexperts. Several factors (e.g., sport type, research paradigm employed, and stimulus presentation modality) significantly moderated the relationship between level of expertise and perceptual-cognitive skill. Practical and theoretical implications are presented and suggestions for empirical work are provided.

Key Words: expert, skill acquisition, anticipation, advance-cue usage, visual search

Sport expertise has been defined as the ability to consistently demonstrate superior athletic performance (Janelle & Hillman, 2003; Starkes, 1993). Although superior performance is readily apparent on observation, the perceptual-cognitive mechanisms that contribute to the expert advantage are less evident. Perceptual-cognitive skill refers to the ability to identify and acquire environmental information for integration with existing knowledge such that appropriate responses can be selected and executed (Marteniuk, 1976). Knowing where and when to look is crucial for successful sport performance, yet the visual display is vast and often

saturated with information both relevant and irrelevant to the task. Sport performers must be able to identify the most information-rich areas of the display, direct their attention appropriately, and extract meaning from these areas efficiently and effectively (Williams, Davids, & Williams, 1999).

For nearly three decades, researchers have sought to better understand the psychological factors that discriminate outstanding from less outstanding individuals in sport (Starkes & Ericsson, 2003). Researchers have demonstrated that experts possess extensive procedural and declarative knowledge that enables them to extrapolate important information from the environment to anticipate and predict future events (French & Thomas, 1987; French, Spurgeon, & Nevett, 1995; McPherson, 1999, 2000). Experts are typically more proficient at making decisions and possess an unparalleled ability to foreshadow or predict future events and outcomes (Holyoak, 1991; Starkes & Allard, 1993; Williams et al., 1999). Furthermore, expert performers possess enhanced perceptual-cognitive skills, such as effective attention allocation and cue utilization, each of which have been demonstrated across sporting and other domains. This has led to further inquiry into the role of perceptual skill acquisition in the development of sport expertise (Abernethy & Russell, 1987a, 1987b). Consequently, emphasis has been placed on clarifying how experts learn to acquire perceptual cues, as well as understanding the superior ability of experts to process task- and domain-specific information (Abernethy, 1999).

Regardless of their individual attributes, all sport contexts require athletes to focus attention on the most appropriate cues so as to perform effectively. It is not surprising, therefore, that experts have been shown to differ from nonexperts on sport-specific measures of attention allocation and information pickup. Despite these empirical efforts, widely pervasive conceptual and methodological variability has made it difficult to extract information that can clearly advance the science of expertise while offering practical recommendations for training perceptual-cognitive skills. Several issues worthy of consideration are briefly presented in the following section and then revisited in the description of moderator variables given in the Method section as they directly affect the ability to determine the magnitude of the expert advantage.

Limitations of Extant Research

A multitude of research protocols (anticipation, decision making, recall, task performance, spatial and temporal occlusion, and eye-movement registration) have been used to elicit expertise differences in cognitive and perceptual skill. Although valuable, such a rich and diverse research base has hindered the ability to compare effects across different protocols. For example, although the occlusion paradigm has been instrumental in identifying the importance of specific cues, research employing this paradigm may not maintain ecological saliency on the perceptual dimension (see Hoffman & Deffenbacher, 1993) or the essential characteristics of the task to be captured in a holistic manner. As such, examination of the expertise effects noticed in various paradigms is warranted.

A critical factor in the study of expert performance concerns the ability to create experimental tasks and conditions that allow the expert advantage to emerge (Ericsson & Smith, 1991). Detailed consideration of the experimental settings, whether

laboratory-based or otherwise, is paramount to expertise researchers in attempting to reproduce this advantage. However, researchers have relied on a wide range of stimulus presentation and task performance modalities. For example, the use of video (film) and slide presentations is often employed in visual search investigations, potentially altering the perceptual and sensory experience (Isaacs & Finch, 1983). Although construct validity has repeatedly been demonstrated in dozens of experiments, one could argue that two-dimensional stimulus presentations may not adequately capture the dynamic nature of sport (Abernethy, Burgess-Limerick, & Parks, 1994a). Few researchers have made explicit comparisons of presentation modality in this regard.

Related to the mode of stimulus presentation, response characteristics have often been insufficiently considered in the experimental design. The expert advantage may be disguised or even masked by an inability to link stimulus characteristics to response selection and execution in contrived settings. For instance, a baseball player who watches a video segment of a pitch and then responds with a button press (e.g., Radlo, Janelle, Barba, & Frehlich, 2001) may rely upon a different perception-action coupling than when facing an actual pitcher and swinging a bat. Therefore, it is relevant to compare the magnitude of the expert/nonexpert performance difference across tasks, including those in the laboratory and those in the actual sport setting.

The Current Project

As described, a number of techniques, protocols, and measurement tools have been used to index differences in expert sport performance. The inability to extract definitive conclusions regarding the magnitude of the overall effects warrants a quantitative synthesis of the extant literature. Pursuant to this goal, the purpose of this project was to conduct a meta-analysis of sport expertise to assess the most prevalent outcome measures identified in the literature concerning perceptual-cognitive differences between expert and nonexpert athletes (Rosenthal & DiMatteo, 2001). These measures included response accuracy, response time, number of fixations, fixation duration, and quiet eye period. *Response accuracy* represents the participant's frequency of producing appropriate responses according to objective standards and in accord with environmental constraints and task demands. *Response time* is defined as an objective measure of the elapsed time between stimulus onset and the overt production of a response.

In addition to performance metrics, several indices of attentional allocation differences between experts and nonexperts have been used by expertise researchers. During eye movement registration, both the *number of fixations* and *fixation duration* index an individual's point of interest and relative attention allocation. The longer the eye remains fixated on a given target, the more information is thought to be extracted from the display (albeit not necessarily from the locus of fixation), permitting detailed information processing. Additionally, the number of visual fixations during a given period of time provides an index of the search characteristics representative of the most pertinent cues extracted from the environment to facilitate the decision-making process. It should be noted, however, that corresponding movements of 5° or less are often considered noise and statistically removed from the calculation of fixation duration, which typically ranges from 150 ms up to

600 ms (Irwin, 1992). Sport scientists have recorded fixations as short as 100 ms and as long as 1,500 ms with corresponding movements of 1° or less (Williams et al., 1999). Eye movements between successive fixations, known as *saccades*, are believed to suppress information processing. In sport, given the typically dynamic context, researchers have typically interpreted visual search strategies involving fewer fixations of longer duration to be more representative of the expert than the nonexpert performer, as this would allow more time for information extraction. Finally, *quiet eye* is believed to be a period of time when task-relevant environmental cues are processed and motor plans are coordinated for the successful completion of an upcoming task (Vickers, 1996). Specifically, the quiet eye period represents the elapsed time between the last visual fixation on a target and the initiation of the motor response (Vickers, 1996).

Given the diverse approaches for examining the expert/nonexpert difference put forth in the literature, coupled with the numerous dependent measures for quantifying the expert/nonexpert difference, our aims were threefold. First, our primary aim was to determine the overall effect of perceptual cue usage and visual search behaviors on performance. More specifically, we sought to determine the extent to which perceptual cue usage discriminates between experts and nonexperts. A second aim was to evaluate the relationship between visual search strategies and expertise. We were specifically interested in whether experts require fewer fixations of longer duration in order to extract relevant information from the environment. Furthermore, narrative reviews have failed to differentiate the impact of various moderating variables. Therefore, our third aim was to assess the extent to which the expert/nonexpert differences varied as a function of the research paradigm and participant characteristics.

Hypotheses

Experts were expected to demonstrate superior *response accuracy* coupled with faster *response times*, while executing fewer *visual fixations* of longer *duration*. Furthermore, experts were hypothesized to exhibit a significantly longer *quiet eye period* than the nonexpert comparison group. We also predicted that across all dependent measures (a) the research paradigm employed would significantly moderate the expert/nonexpert relationship, with more commensurate tasks on both the perceptual and action dimensions evoking a greater expert advantage; (b) a larger effect in favor of the experts would be evident for real-world tasks as compared with film and static slide presentations; and (c) sport type would moderate the expertise relationship *only* for response time, fixation duration, number of fixations, and quiet eye, but *not* for response accuracy. Regardless of the sport type, performance accuracy was expected to be superior for the experts across comparisons with nonexpert performers.

Method

Literature Search

An exhaustive search of the expertise literature was conducted in an effort to locate all relevant studies, including the ancestry and descendancy approach and a computer-generated key word search of Dissertation Abstracts Online (1861–2004), PsychINFO (1967–2004), and SPORTDiscus (1830–2004). The key words included *anticipation, cue use, expertise, decision-making, eye movement, eye-tracking, information processing, occlusion, quiet-eye, sport, visual attention, and visual search*. In accord with the ancestry approach, the reference lists of all obtained review articles and research studies were perused, followed by a manual search of the following peer-reviewed journals: *Canadian Journal of Sports Sciences, Human Movement Science, International Journal of Sport Psychology, Journal of Applied Sport Psychology, Journal of Sport & Exercise Psychology, Perceptual and Motor Skills, Quest, Research Quarterly for Exercise and Sport, and Sport Science Review*. In accord with the descendancy approach, reference to several seminal works were entered into a database (e.g., Social SciSearch, Get Cited) in an effort to locate those studies referencing the early work used to compile the working database from which this meta-analysis was derived.

Studies were considered for inclusion in this meta-analysis if they assessed performance differences (response accuracy and response time) or visual search characteristics (fixation duration, number of fixations, and quiet eye), if they employed an expert/nonexpert paradigm, and if data (means and *SD*, *t* value, exact *p* value, or a simple effect *F* ratio) were available to compute an effect size (point-biserial correlation; Rosenthal, 1984) expressed as r_{pb} (Cooper & Hedges, 1994). Additionally, studies were retained for inclusion if the author failed to include the requisite data to compute an effect size but clearly stated the direction and significance of the expert/nonexpert relationship (i.e., no significant difference). The Results section provides an elaborate discussion of this inclusion procedure. The multidimensional search process resulted in approximately 240 related abstracts, and research and review papers. Of the 180 articles retrieved, 42 met the inclusion criteria, generating 388 effect sizes from studies involving 1,288 participants, with 45.6% ($n = 588$) classified as expert and 54.35% ($n = 700$) classified as nonexpert performers.

Independent study ratings were conducted for each study included in this meta-analysis to assess potential coder drift and study quality. Interrater reliabilities were computed for a number of study characteristics, including skill level, paradigm, sport type, presentation modality, and study quality. Rater agreement ranged from 0.83 to 0.95 across categories and was therefore deemed acceptable. In the case of an interrater discrepancy, a consensus was met before inclusion into the study. Given that study quality was deemed consistent across those studies retained for inclusion, study quality was not assessed a potential moderator variable.

Moderator Variables

The extent to which the magnitude and direction of the expert/nonexpert relationship varied as a function of several moderator variables was examined. Based on the limitations presented earlier, the (a) research paradigm employed, (b) mode of stimulus presentation, and (c) type of sport, were identified and assessed as a function of expertise.

Research Paradigm

Researchers have argued that perception and action are mutually interdependent, cyclical processes that directly constrain and influence one another (Williams et al., 1999). Although it has been well documented that the effective use of relevant advance visual cues facilitates sport performance by means of anticipating opponents' intentions (Williams & Davids, 1998; Williams et al., 1999), the development of research protocols that permit relevant perception and action are warranted. Furthermore, a comparison of the paradigms inherently restricting the perception–action coupling (i.e., when individuals are asked to verbally or physically respond in a manner that is inconsistent with the way in which they would typically perform the task) with those more representative paradigms (i.e., verbally or physically performing the task in a manner that is consistent with the way in which they would typically perform the task in the real world) may provide valuable insight into the effects that the decoupling of perception and action may have on performance, the visual search processes, and the corresponding expert/nonexpert difference (Williams et al., 1999).

Researchers have made extensive use of the recall paradigm to assess the degree to which the expert maintains a cognitive advantage over the lesser skilled performer. The recall paradigm comprises both static and dynamic images, portraying either a structured or unstructured task-specific display. In either case, upon brief exposure to the image, the participant is required to recall the location of each player present in the display. Performance is then ascertained as the level of agreement between a priori–identified features in the actual display (e.g., player positions) and the participant's recall of those features (Williams & Davids, 1995). Although expert/nonexpert differences have been reliably demonstrated across tasks, the degree to which this task captures the essence of domain-specific performance is questionable. Another concern in the task design is that it measures only the accuracy of recall, neglecting the time taken to respond. Given the inherent time constraints in sport, athletes must not only retrieve, encode, and respond accurately, but also must respond under severe time pressure. Furthermore, the two-dimensional representation of the sport context coupled with the frequent use of static images may not truly capture expertise differences in sport given that movement may be an integral component of the pattern recognition process (Williams et al., 1999). As such, including the recall paradigm as a distinct level of a moderating variable will help identify its utility on parsing the expert/nonexpert differences.

The occlusion paradigm, popularized by Jones and Miles (1978), was traditionally espoused as the paradigm of choice to probe the perceptual behaviors of athletes. Both temporal and spatial occlusion techniques have been employed to systematically demonstrate expert/nonexpert differences in the use of information

presented early in the visual display across a variety of sports, including tennis, badminton, squash, cricket, baseball, and volleyball (Abernethy & Russell, 1987a, 1987b; Buckolz, Prapavessis, & Fairs, 1988; Starkes, Edwards, Dissanayake, & Dunn, 1995). A summary of these experiments suggests that (1) experts are better able to predict the direction and force of an opponent's stroke based on kinematic information that maintain subtle clues (such as the dominant arm of a tennis player) (Abernethy, 1990b; Wright, Pleasants, & Gomez-Mesa, 1990) and (2) experts are more adept than nonexperts at using early flight cues to predict the ball's end location. These findings have been relatively consistent, signifying the attunement of expert-level performers to advance cues otherwise neglected by nonexpert performers (Abernethy & Russell, 1987a; Buckolz et al., 1988; Jones & Miles, 1978).

Although the utility of occlusion paradigms has been clearly confirmed, the inherent limitations of this approach should be mentioned. First, both temporal and spatial occlusion paradigms capture only a specific aspect of the task. When these paradigms have omitted a physical or real-world response (e.g., Singer, Cauraugh, Chen, Steinberg, & Frehlich, 1996; Williams & Burwitz, 1993), they may negate the expert advantage, and may only partially capture specific elements of the decisions made (Abernethy, Thomas, & Thomas, 1993). Second, the use of occlusion techniques prohibits the connections of perceptual information (either temporal or spatial) by restricting the sequential processing of subsequent perceptual cues and therefore promotes the use of alternative cognitive strategies for decision making. That is, rarely in sports are the athletes unable to view their opponents in their entirety, yet occlusion paradigms inherently restrict the presentation of information. From an information-processing approach, this may yoke very different connections between perceptual stimuli and the declarative knowledge necessary to reach an accurate problem solution (Abernethy et al., 1993; Williams et al., 1999).

A major point of contention thus far has been the lack of an ecologically valid means for evaluating the expert/nonexpert difference. Therefore, studies implementing sport-relevant tasks including the observation of actual performance were isolated to in order to construct a "task performance classification" for subsequent moderator analyses. As such, those investigations preserving the tendency to contrive the environment by means of occlusion, static slide, video, and or other artificial means of manipulation (Williams, Singer, & Frehlich, 2002) were excluded from the task performance classification.

Several researchers (e.g., Bard & Fleury, 1987; Abernethy & Russell, 1987b) have made extensive use of the frequency and duration of visual fixations in the absence of other performance measures or dependent variables in an effort to unveil expert/nonexpert differences (Petraakis, 1986). These studies were classified independently.

Stimulus Presentation

Static slide presentations inherently fail to present the participant with the dynamic attributes of the visual environment consistent within most sporting domains (Abernethy et al., 1994a). The use of dynamic film or video may offer a more natural perception of the scene when compared with static slides. However, both slides and film or video presentations reduce a three-dimensional world into a two-dimensional image, potentially changing the perceptual and sensory experience. Abernethy et al.

(1993) suggested that tasks that take place in the real world should further discern expert/nonexpert differences by exposing the participant to additional sources of information not available in two-dimensional media, such as stereoscopic depth information. Few explicit comparisons of these media have been made within a single study. Therefore, a comparison of the effect sizes associated with film, slide, and real-world stimulus presentations were examined as potential moderators.

Sport Type

The current status of the perceptual-cognitive expertise literature suggests that the perceptual strategies and corresponding decision-making processes of experts and nonexperts is task dependent (Williams, Davids, Burwitz, & Williams, 1993; Williams et al., 1994; Williams & Davids, 1995). As such, the visual search behaviors of expert and nonexpert players from one sport may be inconsistent with those from another. For example, the contextual demands of anticipating a passing shot in tennis may require different information-processing strategies when compared with the underlying processes associated with anticipating a pass destination in a 3-on-3 soccer task. Therefore, sports were classified as interceptive (or coactive), strategic (or interactive or invasive), and other (or independent or propulsive) to determine the effect of sport type on expert/nonexpert comparisons. An *interceptive sport* was defined as any sport that requires coordination between a participant's body, parts of the body or a held implement, and an object in the environment (Davids, Savelsbergh, Bennett, & Van der Kamp, 2002; e.g., squash, badminton, tennis); a *strategic sport* was operationalized as a sport that involves multiple teammates, often resulting in tactical formations during offensive and defensive series, and emphasizing the importance of allocating attention to both the projectile involved and the diverse array of participants (i.e., field hockey, soccer); finally, a sport classified as *other* included such characteristics as being closed, self-paced, and aiming at a target (e.g., billiards, golf, target shooting). As a result of the varied contextual demands of sport, it is not altogether surprising to suspect mixed perceptual-cognitive strategies across sport. Therefore, conducting a moderator analysis on the expert/nonexpert difference across sport types is necessary to further our current understanding of the role of task specificity on expertise.

Calculation of Effect Sizes and Statistical Analyses

Meta-analytic procedures and statistical techniques outlined and advocated by Hedges and Olkin (1985), Cooper and Hedges (1994), Rosenthal (1984, 1995), and Rosenthal and DiMatteo (2001) were used to conduct a fixed effects meta-analysis. To clarify, a fixed effects analysis restricts significance testing to the total number participants and not to the total number of studies. As such, a fixed effects approach results in greater statistical power (Rosenthal, 1995). Effect size estimates, r_{pb} , and overall mean r_{pb} were calculated for each dependent variable. Many studies in the expertise literature have assessed multiple dependent measures relevant to this research synthesis, including response time, response accuracy, number of visual fixations, total fixation duration, and quiet eye duration. Although each dependent measure provides important information furthering our understanding of expert and nonexpert differences, including multiple dependent measures in one quantitative

synthesis inflates the sample size beyond the number of independent studies, rendering it difficult to estimate the true error associated with the overall effect size, while also inflating the Type I error rate (Wolf, 1986). Grouping the various dependent variables into one quantitative synthesis perpetuates the “apples and oranges” criticism of meta-analytic reviews. To avoid this pitfall, and in accordance with Rosenthal (1984), each dependent variable was analyzed separately.

Estimates of effect size are subject to positive bias in small samples and therefore should be adjusted to account for the within-study sample size variability. Each effect size was therefore weighted by the reciprocal of its variance by using Fisher’s (1925) variance stabilizing z -transform. An overall weighted mean effect size and an estimate of the associated variance was obtained. Subsequent analyses included the calculation of the mean r_{pb} , 95% confidence intervals (CI) around the mean to determine whether effects were significantly different from zero, and comparisons of the mean r_{pb} between levels of moderator variables (Cooper & Hedges, 1994, pp. 265-268). Additionally, the omnibus test statistics Q , Q_{BET} , and Q_w , were computed to determine within-group and between-group sources of variation (Hedges & Olkin, 1985). Heterogeneity was calculated and indicated whether Q (the weighted total sum of squares about the grand mean; Cooper & Hedges, 1994) exceeded the upper tail critical value of χ^2 at $k - 1$ degrees of freedom (Cooper & Hedges, 1994, p. 266). To test the between-group differences for each moderator variable, the Q_{BET} was calculated (Cooper & Hedges, 1994). Furthermore, preplanned linear contrasts were performed on each moderator variable to test the difference among levels of a given moderator variable. As such, the 95% confidence interval and corresponding χ^2 value were calculated for each preplanned comparison (Cooper & Hedges, 1994). In an effort to avoid the inflation of the Type I error rate, only the following linear contrasts were computed for the moderator variable, paradigm: temporal – spatial, anticipation – decision-making, task – anticipation, decision-making – task.

According to Rosenthal (1991), the probability of a meta-analyst accessing all research, published and unpublished, is low, and furthermore the research is unlikely to be a random sample of the existing research owing to publication bias. To estimate the hypothetical effects of these limitations on the aggregated effect size, a fail-safe n is necessary to estimate the number of studies averaging null results needed to attenuate the observed effect and was thereby computed for each dependent variable. Details for this calculation are provided by Rosenthal (1991). Simply stated,

$$\text{Fail-safe } n = [(\Sigma Z)/1.96]^2 - k$$

where Z is the sum of the standard normal deviates for k studies.

All qualifications of the magnitude and effects of the estimated effect size reported here are based on the recommendations of Cohen (1977) for correlational effect sizes, such that the values of .10, .30, and .50, represent small, medium, and large effect size estimates, respectively. Furthermore, to facilitate the interpretation and practical significance of the corresponding effect size, the results of a binomial effect size display (BESD) will be presented for each dependent measure (Cooper & Hedges, 1994). The BESD is a practical interpretation of the overall effect size expressed as the difference in outcome rates between, in this case, the expert and nonexpert groups for each of the dependent measures.

Results

As mentioned previously, 388 effect sizes were calculated across the five dependent measures: response accuracy, response time, fixation duration, number of fixations, and quiet eye duration. Each dependent measure was analyzed separately (see Rosenthal, 1984). A common finding across all but one dependent variable (i.e., quiet eye duration) was a significant test of heterogeneity.

The source of total variation around the grand mean can be divided into within and between sources of variability (Cooper & Hedges, 1994). Repeated calculation of Q_i (which is identical to Q with the i th effect removed) indicated that the source of heterogeneity was explained by those studies that reported a lack of statistical significance and failed to provide sufficient data to allow the actual effect size to be calculated. These studies were assigned an effect size of $r_{pb} = 0.00$ and a corresponding one-tailed p value of 0.50 (Rosenthal, 1995). Inclusion of this procedure is conservative; simply ignoring such null findings would result in the inflation of the overall observed effect size for each dependent measure. Therefore, despite the heterogeneity around the mean r_{pb} , and in accord with the recommendations of Rosenthal (1995), an overall estimate of the mean r_{pb} was computed and moderator analyses were conducted. Therefore, the results of each dependent measure will include the overall Q statistic, in addition to the Q_{removed} statistic, to account for the aforementioned source of variability (i.e., studies claiming “no effects”).

Response Accuracy

The analysis of 214 effect sizes in which response accuracy was assessed revealed a medium mean effect size of 0.31 (95% CI 0.29–0.34), which was significant ($z = 13.83, p < .001$). The fail-safe n was 1,386.9, indicating that approximately 1,400 studies averaging null results would be necessary to attenuate the significance of the current effect size at the .05 level. The distribution of effect sizes was heterogeneous, $Q(213) = 331.95, p < .001$. When the effect sizes derived from missing data were removed, the results approached significance, $Q_{\text{removed}}(195) = 226.60, p = .060$. From a practical perspective, it can be inferred that the experts were approximately 31% more accurate across research studies as indexed by the BESD. Lastly, Q_{BET} was calculated along with preplanned contrasts to test the difference between levels of stimulus presentation, sport type, and study paradigm on the aggregated effect size for response accuracy. A summary of these effect sizes is presented in Figure 1.

Sport Type. The type of sport performed was of primary interest as a potential moderator to determine whether sport type (i.e., interceptive, strategic, and other) influenced the skill-based performance difference. Although slight differences in effect size magnitude were observed between the classifications of other ($r_{pb} = .37, p < .001$), interceptive ($r_{pb} = .32, p < .001$), and strategic ($r_{pb} = .28, p < .001$) sports, these differences were not significant, $Q_{\text{BET}}(2) = 2.53, p = .28$.

Research Paradigm. As Figure 1 indicates, the overall estimate of the between-group difference is significant, $Q_{\text{BET}}(6) = 36.97, p < .001$, suggesting that the paradigm adopted to assess skill-based performance can yield variable effects. Although significant, no statistical differences were found for the preplanned comparisons of interest.

Moderator and Level		Q			$Q_{(removed)}$			
		ES	95% CI	N	ES	95% CI	N	
Overall	$Q_{(T)} = 331.95, p = 0.00$	0.31	0.29 - 0.34	214	$Q_{(T)} = 226.60, p = 0.06$	0.37	0.34 - 0.40	195
Sport Type	$Q_{(BET)} = 2.53, p = 0.28$				$Q_{(BET)} = 11.10, p = 0.00$			
Interceptive		0.32	0.29 - 0.35	132		^a 0.36	0.33 - 0.39	126
Strategic		0.28	0.23 - 0.33	64		^b 0.36	0.30 - 0.41	54
Other		0.37	0.26 - 0.49	18		^{ab} 0.61	0.46 - 0.75	15
Paradigm	$Q_{(BET)} = 36.97, p = 0.00$				$Q_{(BET)} = 25.18, p = 0.00$			
Temporal		0.25	0.21 - 0.30	64		0.3	0.26 - 0.35	58
Spatial		0.33	0.26 - 0.41	22		0.36	0.28 - 0.43	20
Anticipation		0.36	0.30 - 0.43	27		^a 0.39	0.33 - 0.46	25
Recall		0.17	0.07 - 0.26	21		0.34	0.21 - 0.47	18
Recognition		0.29	0.16 - 0.42	9		0.31	0.18 - 0.44	8
Decision Making		0.42	0.36 - 0.48	44		^a 0.49	0.42 - 0.55	41
Task Performance		0.41	0.32 - 0.50	26		0.44	0.34 - 0.53	25
Presentation	$Q_{(BET)} = 7.60, p = 0.02$				$Q_{(BET)} = 3.98, p = 0.14$			
Video		^{ab} 0.31	0.28 - 0.34	156		0.36	0.33 - 0.39	143
Static		^{bc} 0.25	0.17 - 0.33	25		0.42	0.32 - 0.53	20
Field		^{ac} 0.42	0.33 - 0.50	33		0.44	0.35 - 0.53	32

Note: Like superscripts denote significant contrasts

Figure 1 — Summary of expertise difference for response accuracy.

Stimulus Presentation. Researchers have questioned the degree to which various stimulus presentation modalities adequately identify expert/nonexpert performance differences in sport. A comparison of the presentation modalities yielded a significant effect, $Q_{(BET)}(2) = 7.60, p = .02$. The field ($r_{pb} = .42, p < .001$), video ($r_{pb} = .31, p < .001$), and static slide ($r_{pb} = .25, p < .001$) stimulus presentations elicited large-to-moderate effects with significant increases in the magnitude of effects as the mode of stimulus presentation became progressively more representative of a real-world task (i.e., static, video, field). Specifically, the preplanned comparison between field and static ($\chi^2 = 16.99, p < .001$), field and video ($\chi^2 = 5.19, p = .02$), and video and static were significant ($\chi^2 = 7.27, p < .001$).

Response Time

The analysis of 62 effect sizes in which response time was assessed revealed that the aggregated effect was moderate, mean $r_{pb} = 0.35$ (95% CI 0.30–0.40) and significant ($z = 11.90, p < .001$). The fail-safe n was 198.13, indicating that approximately 200 studies averaging null results would be necessary to attenuate the significance of the current effect size at the .05 level. The distribution of effect sizes was heterogeneous, $Q(61) = 93.22, p < .001$, and $Q_{(removed)}(55) = 55.55, p = .79$. From a practical perspective, it can be inferred that the experts responded approximately 35% faster across research studies as indexed by the BESD. Lastly, $Q_{(BET)}$ was calculated along with preplanned contrasts to test the difference among levels of the aforementioned moderator variables. A summary of these findings is presented in Figure 2.

Moderator and Level		Q			Q _(removed)			
		ES	95% CI	N	ES	95% CI	N	
Overall	Q _(T) = 93.22, p = 0.00	0.35	0.30 - 0.40	62	Q _(T) = 55.55, p = 0.79	0.43	0.37 - 0.48	55
Sport Type	Q _(BET) = 6.14, p = 0.05				Q _(BET) = 6.76, p = 0.03			
Interceptive		^a 0.37	0.26 - 0.49	9		^a 0.46	0.33 - 0.59	8
Strategic		^b 0.37	0.31 - 0.43	41		0.44	0.38 - 0.51	36
Other		^{ab} 0.15	-0.02 - 0.32	12		^a 0.19	0.00 - 0.38	11
Paradigm	Q _(BET) = 13.55, p = 0.01				Q _(BET) = 8.95, p = 0.03			
Spatial		0.37	0.23 - 0.53	8		0.37	0.23 - 0.53	8
Anticipation		^a 0.43	0.34 - 0.52	17		0.49	0.40 - 0.58	16
Recognition		0.25	0.11 - 0.39	6		0.25	0.11 - 0.39	6
Decision Making		^a 0.31	0.22 - 0.39	30		0.46	0.36 - 0.56	24
Presentation	Q _(BET) = 1.50, p = 0.22				Q _(BET) = 7.46, p = 0.00			
Video		0.37	0.31 - 0.43	50		0.39	0.34 - 0.46	49
Static		0.25	0.17 - 0.33	12		0.65	0.48 - 0.81	6

Note: Like superscripts denote significant contrasts

Figure 2 — Summary of expertise differences for response time.

Sport Type. Although the expert was reportedly more accurate than the nonexpert across the various sport classifications, the magnitude of this difference was relatively consistent, suggesting that ■RA was not moderated by the nature of the sport. Conversely, response time significantly differed across sport type as a function of expertise, $Q_{BET}(2) = 6.14, p = .05$. Specifically, experts responded quicker than their less skilled counterparts during interceptive sports ($r_{pb} = .37, p < .001$), strategic ($r_{pb} = .37, p < .001$), and other ($r_{pb} = .15, p = .085$) sports as evidenced by the magnitude of the respective effect sizes across sport type, with notable sport differences apparent between interceptive sports and those labeled *other* (e.g., billiards; $\chi^2 = 4.51, p = .033$), and strategic sports and other ($\chi^2 = 6.02, p = .014$).

Research Paradigm. The paradigm adopted to assess response time significantly moderates the expert/nonexpert relationship, $Q_{BET}(3) = 13.55, p = .01$. The anticipation paradigm evoked the largest performance difference ($r_{pb} = .43, p < .001$), followed by spatial occlusion ($r_{pb} = .37, p < .001$), decision-making ($r_{pb} = .31, p < .001$), and recognition ($r_{pb} = .25, p < .001$) paradigms. The preplanned comparison of the decision-making and anticipation paradigms was significant ($\chi^2 = 4.46, p = .034$).

Stimulus Presentation. Although the experts evoked a quicker response than the nonexpert performers during video presentation ($r_{pb} = .37, p < .001$) as compared with static slide presentations ($r_{pb} = .25, p < .001$), this difference was not statistically significant, $Q_{BET}(1) = 1.50, p = .22$. An assessment of the field condition as a moderator was not included as a result of insufficient data.

Number of Fixations

A total of 58 effect sizes were calculated for number of fixations. The aggregated effect was small to moderate, mean $r_{pb} = 0.26$ (95% CI 0.20–0.32) and significant ($z = 9.21, p < .001$). The fail-safe n was 94.09, indicating that approximately 94 studies reporting null results would be necessary to attenuate the significance of the current effect size at the .05 level. The distribution of effect sizes was heterogeneous, $Q(57) = 117.11, p < .001$, and $Q_{removed}(49) = 63.72, p = .09$. Q_{BET} was calculated along with preplanned contrasts to test the difference between levels of stimulus presentation, sport type, and study paradigm on the aggregated effect size for number of fixations. A summary of these findings is presented in Figure 3.

Sport Type. As indicated in Figure 3, sport type—specifically strategic sports ($r_{pb} = .49, p = .011$)—exacerbate the expert/nonexpert visual search differences. Experts executed fewer fixations as compared with the lesser skilled performers when completing strategic tasks as compared with interceptive ($r_{pb} = .10, p = .435$) and other sports ($r_{pb} = .35, p = .197$), $Q_{BET}(2) = 37.66, p < .001$. However, owing to the presence of within-group heterogeneity, these differences are not significant.

Paradigm. Temporal and spatial occlusion paradigms were removed from the analysis of number of fixations as a result of insufficient data. The results demonstrated significant skill-based differences across research paradigms, $Q_{BET}(3) = 29.01, p < .001$. Accordingly, the preplanned comparison of the moderate effects

Moderator and Level	Q				Q (removed)			
	ES	95% CI	N		ES	95% CI	N	
Overall	$Q_{(T)} = 117.11, p = 0.00$				$Q_{(T)} = 63.72, p = 0.09$			
Sport Type	$Q_{(BET)} = 37.66, p = 0.00$				$Q_{(BET)} = 25.08, p = 0.00$			
Interceptive	0.10	-0.14 - 0.34	19		^{ab} 0.18	0.07 - 0.29	15	
Strategic	0.49	0.11 - 0.88	18		^b 0.54	0.43 - 0.65	16	
Other	0.35	-0.18 - 0.87	21		^a 0.53	0.40 - 0.66	18	
Paradigm	$Q_{(BET)} = 29.01, p = 0.00$				$Q_{(BET)} = 25.54, p = 0.00$			
Anticipation	^a 0.12	0.04 - 0.20	17		^{ab} 0.23	0.12 - 0.35	13	
Decision Making	^a 0.44	0.33 - 0.55	17		^a 0.6	0.47 - 0.73	15	
Task Performance	0.40	0.28 - 0.53	19		^b 0.49	0.36 - 0.63	16	
Eye Movement	0.05	-0.33 - 0.43	3		0.05	-0.33 - 0.43	3	
Presentation	$Q_{(BET)} = 10.99, p = 0.00$				$Q_{(BET)} = 18.66, p = 0.00$			
Video	^{ab} 0.19	0.12 - 0.26	28		^a 0.30	0.21 - 0.39	24	
Static	^a 0.41	0.26 - 0.55	8		^{ab} 0.75	0.56 - 0.94	6	
Field	^b 0.37	0.25 - 0.49	22		^b 0.44	0.31 - 0.57	19	

Note: Like superscripts denote significant contrasts

Figure 3 — Summary of expertise differences for number of fixations.

for decision making ($r_{pb} = .44, p < .001$) as compared with the small effects associated with anticipation ($r_{pb} = .12, p = .003$) was significant ($\chi^2 = 21.47, p < .001$). No other preplanned comparisons were significant; however, expertise differences were evident, with the expert group demonstrating significantly fewer fixations across paradigms, with the only exception being eye movement paradigm ($r_{pb} = .05, p = .795$).

Stimulus Presentation. Skill-based differences were observed across presentation modalities, $Q_{BET}(2) = 10.99, p = .004$: video ($r_{pb} = .19, p < .001$) and static slides ($r_{pb} = .41, p < .001$), with the expert performers committing fewer fixations as compared with the nonexpert performers.

Fixation Duration

The analysis of 49 effect sizes in which response time was assessed revealed that the aggregated effect was small to moderate, mean $r_{pb} = 0.23$ (95% CI 0.16–0.30) and significant ($z = 6.68, p < .001$). The fail-safe n was 11.9, indicating that approximately 12 studies averaging null results would be necessary to attenuate the significance of the current effect size at the .05 level. The distribution of effect sizes was heterogeneous, $Q(48) = 102.00, p < .001$, and $Q_{removed}(39) = 66.28, p < .001$. From a practical perspective, it can be inferred that the experts exhibited fixation durations lasting approximately 23% longer across research studies as indexed by the BESD. Q_{BET} was calculated along with preplanned contrasts to test the difference between levels of stimulus presentation, sport type, and study paradigm on the aggregated effect size for fixation duration. A summary of these findings is presented in Figure 4.

Moderator and Level	Q				$Q_{(removed)}$			
	ES	95% CI	N		ES	95% CI	N	
Overall	$Q_{(T)} = 102.00, p = 0.00$	0.23	0.16 - 0.30	49	$Q_{(T)} = 66.28, p = 0.00$	0.29	0.21 - 0.37	39
Sport Type	$Q_{(BET)} = 36.09, p = 0.00$				$Q_{(BET)} = 13.85, p = 0.00$			
Interceptive		^a 0.14	0.03 - 0.25	14		^{ab} 0.14	0.03 - 0.25	14
Strategic		0.23	0.09 - 0.36	9		^b 0.36	0.22 - 0.51	8
Other		^a 0.32	0.21 - 0.43	26		^a 0.45	0.31 - 0.59	17
Paradigm	$Q_{(BET)} = 35.66, p = 0.00$				$Q_{(BET)} = 9.35, p = 0.05$			
Temporal		0.22	0.01 - 0.43	3		0.22	0.01 - 0.43	3
Anticipation		0.24	0.11 - 0.37	9		0.24	0.11 - 0.37	9
Decision Making		^a 0.15	0.03 - 0.27	20		0.36	0.21 - 0.51	12
Task Performance		^a 0.40	0.25 - 0.55	13		0.42	0.26 - 0.58	12
Eye Movement		-0.11	-0.49 - 0.26	3		-0.11	-0.49 - 0.26	3
Presentation	$Q_{(BET)} = 38.25, p = 0.00$				$Q_{(BET)} = 18.32, p = 0.00$			
Video		^a 0.30	0.21 - 0.39	26		^a 0.34	0.24 - 0.42	20
Static		^{ab} -0.36	-0.56 - -0.16	6		^{ab} -0.29	-0.57 - -0.01	3
Field		^b 0.32	0.18 - 0.46	17		^b 0.34	0.19 - 0.48	16

Note: Like superscripts denote significant contrasts

Figure 4 — Summary of expertise differences for fixation duration.

Sport Type. Sport type significantly moderated the expert/nonexpert fixation duration relationship. The effect sizes for each sport type were as follows: interceptive ($r_{pb} = .14, p = .016$), strategic ($r_{pb} = .23, p = .003$), and other ($r_{pb} = .32, p < .001$); $Q_{BET}(2) = 36.09, p < .001$. Only the preplanned comparison of interceptive tasks to other tasks was significant ($\chi^2 = 5.06, p = .024$).

Paradigm. Although slight differences were present among the varied paradigms used to assess fixation duration—including temporal occlusion ($r_{pb} = .22, p = .041$), anticipation ($r_{pb} = .24, p < .001$), decision making ($r_{pb} = .15, p = .011$), task performance ($r_{pb} = .40, p < .001$), and eye movement ($r_{pb} = -.11, p = .542$) paradigms; $Q_{BET}(4) = 35.66, p < .001$ —only the preplanned comparison between decision making and task performance was significant ($\chi^2 = 6.38, p = .011$).

Stimulus Presentation. Not unlike the findings associated with the number of fixations, presentation modalities significantly moderated the expert/nonexpert relationship, with the expert performer committing longer fixations as compared with the nonexpert group: video ($r_{pb} = .30, p < .001$), static slides ($r_{pb} = -.36, p < .001$), and field ($r_{pb} = .32, p < .001$); $Q_{BET}(2) = 38.25, p < .001$. However, contrary to hypotheses, when viewing static slides, the nonexpert group engaged in longer fixations than did the expert group. Specifically, the preplanned comparison between video and static ($\chi^2 = 35.97, p < .001$) and static and field presentation modalities were significant ($\chi^2 = 30.40, p < .001$).

Quiet Eye

The analysis of five effect sizes derived from 150 participants across three separate laboratories in which the quiet eye duration was assessed revealed a moderate-to-large mean r_{pb} of 0.62, (95% CI 0.40–0.82) and significant ($z = 5.76, p < .001$) aggregated effect. The fail-safe n was 0.38, indicating that 1 study reporting null findings would be necessary to attenuate the significance of the current effect size at the .05 level. The distribution of effect sizes was homogeneous, $Q(4) = 6.158, p = .189$. As a result of the small sample, subsequent analyses of potential moderators were not conducted. The magnitude and direction of the reported effect size supported the hypothesis that experts exhibit longer quiet eye periods coupled with superior performance as compared with their less skilled counterparts. Experts maintain a quiet eye period that is approximately 62% longer in duration across research studies as indexed by the BESD.

Discussion

The purpose of this investigation was to provide a quantitative synthesis of the research on perceptual-cognitive expertise in sport and to assess the moderating effects of a number of commonly employed research paradigms, participant characteristics, and presentation modalities. Perceptual cue usage and visual gaze behaviors were assessed using a number of dependent measures. These outcome measures provided a natural framework from which this meta-analysis was constructed.

The analysis of performance measures confirmed expectations that experts were more accurate in their decision making relative to their lesser skilled counterparts

(mean $r_{pb} = .31, p < .001$). Moreover, experts anticipated their opponents' intentions significantly quicker (mean $r_{pb} = .35, p < .018$) than less skilled participants. These results are consistent with the notion that the use of advance perceptual cues has been demonstrated to facilitate sport performance by means of aiding in the anticipation of opponent's actions and decreasing overall response time (e.g., Goulet, Bard, & Fluery, 1989; Helsen & Starkes, 1999). As Abernethy (1991) contends, decision making in sport is the product of a sequence of events occurring well before overt movement is required. For example, during racquet sports, an ordered sequencing of events occurs, commencing with a range of reliable kinematic cues preceding ball flight, which, when processed, can foretell the probability of a given outcome. The ability of expert performers to extract perceptual cues can alleviate the temporal constraints imposed by reaction time alone (Buckholz et al., 1988). The presumption is that the experts possess qualitatively different cognitive mechanisms and strategies that facilitate anticipation, permitting reduced response times and increased response accuracy (e.g., Ericsson & Kintsch, 1995).

In addition to performance indices, we were able to quantify the functional significance of the expert performers' eye movement behaviors relative to their nonexpert counterparts. Experts were characterized by fewer fixations (mean $r_{pb} = .26, p < .001$) of longer duration (mean $r_{pb} = .23, p < .001$). These findings support the interpretation that experts in sport extract more task-relevant information from each fixation than do lesser skilled performers. Conversely, nonexperts typically require more fixations of shorter duration to gather sufficient information to respond. Because the ability to extract information from the display is reduced during saccadic eye movements (Duchowski, 2002), one could argue that a strategy involving more fixations of shorter duration is less efficient and effective than one involving fewer fixations or longer duration (Williams et al., 1993). Without sufficient time to process task-relevant cues, oversights and incorrect decisions are inevitable as indicated by the inferior performance outcomes displayed by the novices.

In addition to typical fixations and fixation durations—although only few effects were included in the analysis—the quiet eye period resulted in a large positive mean effect size ($r_{pb} = .62, p < .001$). Researchers have reliably demonstrated relatively prolonged quiet eye periods as an effective marker for differentiating skilled and lesser skilled athletes. Moreover, these findings have shown consistency across domains as diverse as rifle shooting (Janelle et al., 2000) and billiards (Williams et al., 2002), for tasks that require aiming at a target (e.g., billiards and shooting), and those that require the individual to receive a projectile momentarily while aiming and releasing it to a designated target (e.g., volleyball; Vickers & Adolphe, 1997).

Several possible moderating effects of these results were examined. Results indicated that *sport type* is not a significant moderator of the expertise relationship for *response accuracy*. Regardless of the type of sport performed, experts maintain a perceptual advantage over their less skilled counterparts, facilitating response accuracy. *Response time*, however, was influenced by sport type, with the largest expert/nonexpert differences evident for interceptive sports ($r_{pb} = .37, p < .001$), and strategic sports ($r_{pb} = .37, p < .001$), followed by other ($r_{pb} = .15, p = .085$) sports. The inherent temporal constraints associated with interceptive sports (e.g., tennis, squash) render this finding intuitively appealing. Strategic sports (e.g., soccer, field hockey), in contrast, typically consist of a more elaborate sequencing of events,

which may reduce the impending temporal pressures necessary to perform at a superior level. However, the source of the greatest difference lies between interceptive sports and with those tasks classified as other (e.g., billiards, golf), which are rarely faced with temporal constraints. Thus, although experts' responses were quicker, the speed with which this response occurs is at least partly constrained by the nature of the task.

Similarly, the number of fixations employed varied across sport type, with the smallest margin of expert/nonexpert difference evident across interceptive sports ($r_{pb} = .10$). Clearly, this finding is attributable to the temporal constraints of task duration. For example, an anticipation task in tennis, in which the service duration from ball toss to racket contact may take no more than 300 ms (Abernethy, 1991), is substantially shorter than a similar anticipation task in soccer, which may take upwards of 9,000 ms (Williams et al., 1994b). In reality, however, the latter reflects the time taken from the onset of a trial, whereas the anticipation response to some critical event within that trial is likely to be more equivalent to that observed in racket sports. Therefore, task duration alone will permit more fixations in the soccer task than is possible in a tennis task designed to assess the same ability. However, the duration of each corresponding fixation did not differ across sports, supporting the contention that experts seek the most information-dense areas of a display while extracting task-relevant cues (Williams et al., 1993).

As predicted, the expert's superior attunement to perceptual cues was moderated by the research paradigm employed. For example, the effect sizes for response time and response accuracy differed across paradigms, with the smallest expertise difference noted with recall and recognition paradigms (Figures 1 and 2), that is, tasks associated with the simple encoding and retrieval of sport specific information. This finding questions whether performance on these tasks is predictive of skilled performance (see also Ward & Williams, 2003). More likely, the primary differentiation between expertise levels occurs when confronted with more complex operations that occur rapidly, lack regularity, and are unpredictable. The remaining protocols require the participant to not only encode and retrieve perceptual information, but also to apply that information to a task that is skill dependent (i.e., anticipation and decision making).

The manner by which the testing stimulus was delivered to participants (i.e., video, static slide, and field presentations) revealed a difference for response accuracy and fixation duration. The largest effect was reported in the field studies, followed by video, and static slides (Figures 1 and 4, respectively), suggesting that there is a greater likelihood of finding an expert advantage when skilled participants are asked to perform in ecologically valid environments. Although a number of the video-based paradigms have appropriately captured the essence of expertise during task performance, other researchers have asked participants to respond in an alternate manner or have changed the nature of the task such that the expert advantage is diminished. Expert decision making was facilitated under field conditions, suggesting that the more realistic the paradigm, the greater the measurement sensitivity.

Our quantitative findings support the early intuition of Jones and Miles (1978), who discuss the inherent sterility of the laboratory and the inability of the laboratory setting and task to accurately elicit comparable performance states. Such limitations may confound the empirical estimates of perceived expert/nonexpert differences

garnered from such paradigms (see Abernethy et al., 1993). Although the argument proposed by Abernethy and colleagues would appear to have merit, when field-based approaches are not permissible, video is a superior means of stimulus presentation than static slides. Without question, field-based approaches have elicited the greatest differences; however, the real crux of the matter is whether the paradigm or mode of presentation used accurately captures the superior performance of experts. Moreover, one has to pay particular attention to the level of experimental control achieved when testing in the naturalistic environment. Although effects sizes are largest in the field, it is difficult to ascertain whether participants are responding to different stimuli, rendering reliable comparison highly problematic.

To summarize, in this meta-analysis we have synthesized and quantified a conceptually intricate body of expertise research. The locus of expert/nonexpert difference has been a difficult phenomenon to capture, given the diverse research paradigms and varied experimental control, coupled with the wide-ranging operational definitions, techniques, and sampling characteristics. However, our quantitative analysis has provided a means to objectively evaluate commonly held beliefs concerning expertise in sport, confirming that sports experts are typically more accurate and quicker in their responses and generally employ fewer fixations of longer duration. More importantly, however, several factors (i.e., sport type, research paradigm, and stimulus presentation modality) have been found to significantly moderate the various relationships between level of sport expertise and perceptual-cognitive skill that should be used to guide expertise research in future years.

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