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Executive function and visual attention in sport: A systematic review

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Abstract

Research has attested to the importance of three lower-order executive functions (EFs; inhibition, shifting, and updating) and visual attention (VA) for sport performance. However, there is limited research examining the association between EF and VA in sport. The present study systematically reviewed literature from Web of Science, Scopus, MEDLINE, APA PsycInfo, PubMed, SPORTDiscus, CINAHL, and Discover EBSCO that examined both EF and VA in sport following the PRISMA guidelines. Experiments that were full-texts published in English, contained original data, quantitatively measured EF and VA, and allowed for direct or inferred comments on the relationship between EF and VA were eligible for inclusion. Twenty-two experiments met the inclusion criteria. Results showed large discrepancies in the labelling of sporting *expertise*, that EF outcomes typically focus on response accuracy over response time, and that quiet eye and number and duration of fixations are popular VA variables. Though limited, studies comparing EF and VA directly indicated a positive relationship suggesting an important link between the two. In sum, more direct assessments of the association between EF and VA are needed to understand their respective and joint contribution to sport performance.

Keywords: Attentional control; Scoping study; Gaze; Cognition; Sport performance.

Introduction

Successful sport performance requires, in part, a combination of outstanding cognition, perception, and visual attention (VA; see Furley & Wood, 2016). For example, a basketballer may have to combine manipulating ever-moving player locations (i.e., perceptual-cognition) with current player locations (i.e., VA) to successfully pass the ball. Recent research supports the importance of executive function (EF, i.e., cognitive processes facilitating thoughts and behaviour; Scharfen & Memmert, 2019) and VA (e.g., the quiet eye; Lebeau et al., 2016) for successful sport performance. Studies have focused primarily on group differences and suggest that sporting experts may possess enhanced cognitive and visual abilities (Furley & Wood, 2016). However, given the theoretical links between EF and VA (Corbetta & Shulman, 2002) it is surprising that very few studies have considered the association between these processes in sport. We provide the first systematic review of the literature examining the EF and VA association in sporting samples. Research in this area encompasses a range of individual differences (e.g., sport type and participation level), measurement tasks and outcomes (e.g., sport-specific, domain-general, accuracy-based, and response times), and research designs (e.g., expert vs. novice, training paradigms, manipulation studies, and direct comparisons). Therefore, given such methodological heterogeneity, a qualitative synthesis of relevant studies was conducted.

Executive Function

Executive functions comprise a group of distinct, yet interrelated, top-down (i.e., conscious, and goal-directed) processes important for behavioural regulation (Zelazo & Carlson, 2012). Executive functions can be distinguished into lower- and higher-order processes (Diamond, 2013). The lower-order functions of inhibition (i.e., withholding a dominant response), shifting (i.e., switching between or within tasks), and updating (i.e., monitoring information in working memory) were initially outlined as the most postulated

EFs by Miyake et al. (2000). These functions were then outlined by Attentional Control Theory (Eysenck et al., 2007) and then Attentional Control Theory-Sport (ACT-S; Eysenck & Wilson, 2016) as being susceptible to anxiety and stress (Wood & Wilson, 2010). By comparison, higher-order functions comprise the co-ordination of lower-order cognitive processes working together (e.g., decision-making, planning, problem-solving; Diamond, 2013). Given its complex, constantly changing environment, sport provides an optimal platform to examine both higher- and lower-order EFs. For example, soccer requires the recognition and processing of game-specific situations (i.e., working-memory, updating; Wood et al., 2016) in which, the player must select the optimal outcome (i.e., decision-making, planning, anticipation; Huijgen et al., 2015). Also, soccer players often need to cease intended actions (i.e., inhibition; Verbruggen et al., 2019) and perform a new action instead (i.e., inhibition, shifting, problem solving; Sakamoto et al., 2018) based on internal and external cues within the environment.

Higher-order EFs like decision-making, anticipation, and problem solving (often assessed with sport-specific video tasks; Roca et al., 2013) are some of the most researched in sport psychology (e.g., Moore et al., 2019). Decision-making involves selecting the most suitable option from two or more alternatives in obvious and complex situations (VandenBos, 2006). Anticipation is facilitated by complex knowledge structures which allow for evaluative, predictive, and planning processes (North et al., 2011). Problem solving is involved in overcoming difficulties and achieving goals via higher mental functions (VandenBos, 2006) and may rely upon shifting and updating (Kotsopoulos & Lee, 2012). Research generally indicates those with higher sporting expertise score better on higher-order EF tasks compared to those with lower sporting expertise. For example, experts have outperformed novices in decision-making on both sport-specific (e.g., Moore et al., 2019) and general decision-making tasks (e.g., Vaughan et al., 2019). Anticipation was superior in skilled (professional/semi-professional) compared to less-skilled (recreational) soccer players (Roca et al., 2013) and greater problem solving was shown in athletes compared to non-athletes (Jacobson & Matthaeus, 2014).

Lower-order EFs (i.e., inhibition, shifting, updating), typically assessed via cognitive tasks, have been shown to be important for sport performance and have distinguished between athletic expertise groups. For example, inhibition and shifting ability (assessed via a Design Fluency task) were higher in 1st division soccer players (i.e., Swedish *Allsvenskan*) compared to 2nd and 3rd division soccer players (i.e., Swedish *Superettan* and *Ettan*; Vestberg et al., 2012) and inhibition (measured with a Stop Signal Task) significantly predicted self-report and coach rated performance in open-skill sports (Hagyard et al., 2021). Further, Vestberg et al. (2012) and Vestberg et al. (2017) found significant positive correlations between inhibition, shifting, and updating scores and sport performance (i.e., goals and assists), and Furley and Memmert (2012) reported that updating ability facilitated the focus of attention by enabling individuals to avoid distraction (Experiment 1) and resolve interference (Experiment 2) in computerised sport decision-making tasks.

Visual Attention

Research typically assesses attentional control through gaze behaviour from eye-trackers as they allow researchers to observe online attention during in-situ sports tasks (e.g., soccer penalty kicks; Brimmell et al., 2019). Visual attention typically refers to the current foveal location of attention and is concerned with knowing where to look (Mann et al., 2007). Popular foveal measures include the number and duration of fixations (sometimes together as search rate; Brimmell et al., 2019) and the location of fixations which may help understand which visual stimuli provide athletes with the most information (Wilson, 2008). The quiet eye phenomenon, which encompasses the length and location of the final fixation before initiating a critical movement (Vickers, 2007), is perhaps the most common visual measure in sport-related aiming tasks. A recent review from Klostermann and Moeinrad (2020) attest to the importance of this variable over and above other variables (e.g., number and duration of fixations). Like research exploring EF, studies examining VA have focussed on expert-novice performance differences (see Lebeau et al., 2016, for a review). However, such designs might provide obvious conclusions (i.e., experts attend to more relevant stimuli) and not clarify the mechanisms behind improved VA. Also, expert groups often include individuals with the capacity to become experts (i.e., youth academy athletes; Vaeyens et al., 2007) rather than those already with expert status.

Also of interest are the effects of training interventions (e.g., Wood & Wilson, 2011) and performance under different psychological states (e.g., anxiety/stress manipulations; Wilson, 2012). Training research has become popular as it may help individuals learn which information is most associated with success and enhance certain VA variables (e.g., quiet eye length and/or onset). For example, Wood and Wilson (2011) showed that orienteering individuals to areas of the soccer goal most associated with success could lead to improved quiet eye durations and subsequent soccer penalty performance. Measuring VA under various psychological states (e.g., anxiety or stress) is important given the prevalence of such states in sport (Harris et al., 2019). Attentional biases in the brain caused by anxiety may manifest as subpar VA in such anxiety-inducing situations. For example, anxious individuals may suffer from a bias toward threat-related visual stimuli at the expense of more goal-directed stimuli (Wilson, 2012).

Executive Function and Visual Attention

Though scant, sport research considering lower-order EFs and VA in the same experiment allude to an association (e.g., Ducrocq et al., 2017; Klostermann, 2020). Scharfen and Memmert (2021) provided one of the few examinations of a complete lower-order EF model and VA and showed small but significant associations between inhibition and visual clarity (i.e., processing non-moving information while stood still), but did not utilise an eye-tracker. Research examining higher-order EFs and VA in athletic samples is more prevalent but typically focuses on expertise group differences (e.g., expert vs novice; Alder et al., 2014). As a result, understanding around the direct relationship between EF and VA in sport is limited. However, there is ample neuroscientific evidence that a relationship between EF and VA exists. For example, both VA and EF are housed in the fronto-parietal network suggesting similar neurological bases (Carrasco, 2011; Gaillard & Ben Hamed, 2022).

Within the human visual system, attention is typically directed to the most salient and goal-orientated information (Fang et al., 2011). For example, a simple search for a red coloured target amongst blue distractor stimuli would require active and goal-directed visual search for the red target and suppression of attending to the blue stimuli. Two cortical attentional systems within the brain known as the dorsal (i.e., top-down) and ventral (i.e., bottom-up) systems are believed influence VA (Itti & Koch, 2001). The top-down system is involved in the active search for goal-directed visual stimuli while the bottom-up system is influenced more by unexpected but salient stimuli (Corbetta & Shulman, 2002). The neural responses are faster in the parietal region, compared to the pre-frontal cortex, to unexpected salient stimuli (i.e., bottom-up) while the reverse is true for goal-orientated stimuli (Gaillard & Ben Hamed, 2022). This evidence may allow inferences to be drawn about how EF and VA relate in sport. That is, given the neurological association between areas of the brain, particularly the fronto-parietal cortex, it may be reasonable to suggest that such a relationship exists within a sporting context.

Executive function and VA therefore, may be jointly housed under the perceptual-cognition banner (Broadbent et al., 2015) and neuroscience infers a relationship between these two areas. Specifically, skilled athletes are believed to show distinct gaze behaviour and enhanced visual information processing which promotes improved perception and action coupling (Klostermann & Moeinirad, 2020). Nevertheless, there is currently no synthesis of the EF and VA in sport literature and little comment on the association between these variables. Understanding the strength of the relationship may facilitate future work whereby researchers and practitioners can build training or intervention paradigms that target EF to promote subsequent improvements in VA, or vice versa. It may also allow for more targeted training by highlighting the underlying processes driving VA and information pick up. Moreover, if an association is absent or weak it may be better to target functions individually for intervention work.

The Present Study

The literature on EF and VA in sport is yet to be synthesised making it difficult for researchers to make informed decisions. Specifically, comparisons can be very difficult as lower- and higher-order experiments tend to use different tasks (e.g., sport-specific for higher-order EFs), the same EFs are measured with different tasks, outcome measures for EF and VA are varied, and study design, sport type, and sample characteristics vary. More importantly, though there is reason to suggest a relationship exists based on neuroscientific literature, our understanding of the relationship between EF and VA in sport is limited. Therefore, we conducted a robust systematic review that provided a synthesis of studies examining EF and VA in sport. Specifically, we aimed to provide the first comprehensive systematic review of the sample characteristics, general methodology (i.e., study design and sport type), and measurement and outcome variables for EF and VA. Although of considerable interest individually, and together in neuroscience, research has made little to no effort to directly review experiments examining the relationship between EF and VA in sport. Therefore, we aimed to offer future research a better understanding of how these constructs may relate.

Method

Search Strategy, Inclusion Criteria and Screening

An electronic search of Web of Science, Scopus, MEDLINE, APA PsycInfo, PubMed, SPORTDiscus, CINAHL, and Discover EBSCO was conducted. Unpublished dissertations and theses were also searched via ProQuest. Search terms were placed into one of four groups: (a) EF (higher- and lower-order); (b) VA; (c) sport context; and (d) exclusion criteria (as in Scharfen & Memmert, 2019). Specifically, for (a) the terms “executive function” OR “cognition” OR “executive control” OR “inhibition” OR “inhibitory control” OR “shifting” OR “cognitive flexibility” OR “updating” OR “working-memory” OR “planning” OR “decision-making” OR “problem solving” were used. For (b) the terms “visual attention” OR “gaze behaviour” OR “eye-tracking” OR “eye movement” OR “visual search” were used. Regarding (c), the terms “athlete” OR “sport” OR “sport performance” were used. For (d) the terms (searched using the “NOT” function) “concussion” OR “disability” OR “cognitive impairment” OR “clinical” were used. A backward search and search of reference lists for already to-be-included studies was conducted for further relevant titles and abstracts by the first author. The search was not restricted by year of publication. Researchers followed procedures outlined in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). The PRISMA abstract checklist and PRISMA checklist are available as supplementary files.

Inclusion criteria were established to ensure relevant studies were identified and were: 1) published in English, 2) contained original empirical data, 3) had a full-text available at the time of search, 4) quantitatively measured EF in sport, or simulated sport, 5) quantitatively measured VA with an eye-tracker in sport, or simulated sport-settings, and 6) used analytic techniques that allowed us to make a direct or inferred (i.e., indirect) statement about the relationship between EF and VA. Study title and abstracts were initially screened by the first author before being verified in two stages. First, the third author independently screened titles and abstracts with discrepancies discussed between the first and third authors. Next, the second author screened a random 30% of all abstracts. Inter-rater reliability between the first and second author was assessed via the percentage agreement rates (95.15%) and Cohen's Kappa (κ = .87). Studies selected for full-text screening underwent a similar two stage verification. First, the first author and third author independently assessed full-texts for inclusion with discrepancies discussed until consensus was reached. Next, the second author assessed a random 30% of full-text articles and assessed the suitability for inclusion. Once again, inter-rater reliability was assessed via percentage agreement rates (95.23%) and Cohen's Kappa (κ = .77).

Quality Assessment and Data Extraction

Quality assessment can help understand whether the reviewed experiments are methodologically sound (Gopalakrishnan & Ganeshkumar, 2013) and adhere to scientific standards (Borenstein et al., 2011). Payne et al. (2019) outlined that a standardised quality assessment instrument is yet to be established for laboratory-based observational studies. As such, study quality was assessed using items from The Appraisal Instrument (Genaidy et al., 2007), The Quality Index (Downs & Black, 1998), and The Evaluation of Research Articles Checklist (DuRant, 1994). As in Payne et al. (2019), the current study included an additional item to assess adherence to ethical procedures. The maximum possible score for study quality was 23 (see Table 1 for items used in the present review) and scores for identified studies are shown in Table 2. The first author completed the quality assessment and it was checked by the third author.

INSERT TABLE 1 ABOUT HERE

INSERT TABLE 2 ABOUT HERE

Data extraction for included studies was performed by the first author. As in previous literature (e.g., Harris et al., 2021a) the following study characteristics were obtained:

authors, date of publication, sample characteristics (sample size, mean age, female percentage, and sport), sport type (open- or closed-skill; Singer, 2000), expertise level, design (between- or within-subjects), EF measured, task used, EF outcome measured, the VA outcome measured, eye-tracker used, key findings regarding EF and VA, and any additional relevant notes. As an inclusion criterion was to include experiments that allowed for direct or inferred (i.e., indirect) comments on the EF and VA relationship we also extracted whether the analytic technique used in the experiment directly compared EF and VA (direct) or manipulated one key variable and measured the subsequent effect on the other (inferred).

Results

Search Results

An initial database search resulted in 6,382 citations suitable for further inspection. After an initial screening and then the removal of duplicates (*n* = 178), 344 titles were identified for abstract screening. Eighty-seven papers were deemed to have appropriate abstracts and subsequently received full-text review. Of the 87, 72 were located during the initial search, 12 from a backward search of reference lists, and three from ProQuest. The full-text review yielded a final total of 19 studies with 22 experiments (*n* = 21 from the initial search, *n* = 1 from the backward search, and *n* = 0 from ProQuest) appropriate for the present systematic review (see Figure 1 for a full breakdown and reasons for exclusion [*n* = 65]).

INSERT FIGURE 1 ABOUT HERE

Quality Assessment

Quality assessment scores for the 22 experiments ranged from 78.3%-100%, (mean = 89.1%; see Table 2). Quality assessment revealed one experiment high (scores between 61%-80%) and 21 experiments very high (scores between 81%-100%) in methodological quality (Payne et al., 2019) with six experiments achieving a maximum score in methodological quality (i.e., 100%). Items 1, 2, 4, 5, 8, 11, 14, 15, 16, 17, 18, 20, and 21 were achieved in all experiments within the systematic review. Lowest scoring (i.e., under 80%) items included item nine (recording precise probability values), 12 (intended sample representing the general population), 13 (actual sample representing the represented the general population), 22 (the relevance of findings to the eligible population), and 23 (the relevance of findings to other relevant populations).

Study Characteristics

Sample Characteristics, Sport Type and Design

The main information extracted from the experiments is presented in Table 3. The total number of participants in the reviewed experiments was 696 with an age range of 14.60-38.00 years (mean = 23.44 ± 2.82 years). Sample size varied between experiments with sample sizes ranging from 3-95 (mean = 31.64 ± 20.51). Gender information was reported in 18 of 22 experiments. Representation from female participants ranged from 0-100% (mean = 48.42 ± 32.60). The examined sports included: soccer (*n* = 5), volleyball (*n* = 2), basketball (*n* = 1), gymnastics (*n* = 1), tennis (*n* = 3), badminton (*n* = 1), shooting (*n* = 1), golf (*n* = 1), table tennis (*n* = 1), multiple sports (*n* = 5), and non-athletes (*n* = 1). Six sports were classified as open-sports while three could be classed as closed-sports (Singer, 2000). Sport type could be further broken down into static (*n* = 3), interceptive (*n* = 4), and strategic (*n* = 2; see Krenn et al., 2018, for full definitions). Fourteen experiments used a between-subjects design, six used a within-subjects design, and two applied a mixed between- and within-subjects design (Brimmell et al., 2021; van Maarseveen et al., 2018a). Substantial variation in the labelling of expertise groups was found across the experiments (see Table 3).

INSERT TABLE 3 ABOUT HERE

Executive Function

Table 3 shows a full breakdown of EF results. Ten experiments (45.45%) examined higher-order EF and 12 experiments (54.55%) examined lower-order EF. Higher-order EF experiments examined decision-making (*n* = 5), anticipation (*n* = 4), and decision-making, anticipation, and pattern recall (*n* = 1). Lower-order EF experiments had a somewhat even split between inhibition (*n* = 5) and working memory (*n* = 6) with only one experiment examining multiple lower-order EFs (i.e., inhibition, shifting, and updating; Brimmell et al., 2021). Ten different tasks were used to assess EF including: sport-specific video tasks (*n* = 8), sport-specific photo tasks (*n* = 1), visual search tasks (*n* = 2), Go/No-Go Task (*n* = 1), Flanker Task (*n* =1), *N*-back Task (*n* = 3), Operation Span Task (OSPAN; *n* = 3), Change Detection Task (*n* = 1), Structural Dimension Analysis of Mental Representation Task (*n* = 1), and in-situ manipulation tasks (*n* = 7). Five experiments used a combination of tasks (e.g., Brimmell et al., 2021). Higher-order EFs were more often measured with sport-specific media (video and photo) while lower-order EFs tended to be assessed using computerised cognitive tasks in manipulation designs.

A total of eight outcome measures were reported including: response accuracy (*n* = 14), response time (*n* = 4), efficiency score (i.e., accuracy by time; *n* = 2), difficulty level achieved (*n* = 2), recall scores (*n* = 1), distractor costs (*n* = 2), adjusted rand index (*n* = 1), and none (i.e., no outcome measure[s] associated with EF; *n* = 4). Decision-making experiments tended to either report just response accuracy or response accuracy and response time (see Bishop et al., 2014, for an exception). For anticipation experiments, all experiments included response accuracy and two also considered response time (though never in combination with accuracy). Inhibition experiments typically had no outcome measure (*n* = 3) while working-memory experiments often used response accuracy (*n* = 3).

Visual Attention

Table 3 shows a full breakdown of VA results. There was considerable variation in the eye-trackers used across experiments. Six eye-tracking brands were used across the 22 experiments including: Applied Science Laboratories (ASL; *n* = 8), SR Research (*n* = 4), SensoMotoric Instruments (SMI; *n* = 4), EyeSeeCam (*n* = 3), Tobii (*n* = 2), and Pupil Labs (*n* = 1). Twenty-four different outcome measures were reported. Three experiments used one outcome measure while 19 used at least two outcome measures (range 2-7). Outcome measures included: number of fixations (*n* = 11), fixation duration (*n* = 10), percentage time spent viewing key locations (*n* = 10), quiet eye duration (*n* = 8), search rate (*n* = 7), quiet eye onset (*n* = 4), quiet eye offset (*n* = 4), saccadic latency (*n* = 4), number of fixation locations (*n* = 2), fixation order (*n* = 2), first fixation time (*n* = 2), percentage of incorrect saccades (*n* = 2), percentage dwell time (*n* = 1), saccadic amplitude (*n* = 1), entropy (*n* = 1), scan paths (*n* = 1), peak saccadic velocity (*n* = 1), quiet eye location (*n* = 1), visual search time (*n* = 1), first fixation on selection (*n* = 1), final fixation on selection (*n* =1), number of fixations to correct option when incorrect (*n* = 1), and inter-fixation rate (*n* = 1).

Executive Function and Visual Attention

All 22 of the included experiments allowed for a direct or inferred (i.e., indirect) EF and VA comparison. Whether the EF and VA relationship was direct or inferred, the analytical method used, and key analytical result(s) are presented in Table 4. In sum, nine experiments allowed direct comments and 13 allowed for indirect comments only. The analytical methods of experiments allowing for direct comments were ANOVA (*n* = 1), regression (*n* = 2), mediation (*n* = 1), correlation (*n* = 4), and correlation plus descriptive (*n* = 1). For experiments allowing only indirect comments, the analytical methods included ANOVA (*n* = 10) and t-tests (*n* = 3). Such techniques were often used as the experimental design involved comparing groups. More specifically, the indirect experiments involved comparing participants split based on EF performance (*n* = 6), training vs. control groups (*n* = 4), and across tasks where demands were differentially manipulated (*n* = 3). Only one experiment that examined EF and VA found no significant association (i.e., Savelsbergh et al., 2002). Overall, there appears to be an association between EF and VA (21/22 experiments reported significance between at least one measure of EF and VA). Although the type of effect size calculated, the effect direction, and the size of the effect varied across experiments better task performance on one is often associated with better outcomes on the other (see Table 4, for full details).

INSERT TABLE 4 ABOUT HERE

Discussion

The present study reviewed experiments that examined the unique and associated relationship between EF (higher- or lower-order) and VA in sport. One key focus was on obtaining a greater understanding of how these two facets of perceptual-cognition (executive and visual processes) may relate despite research often omitting direct comparisons. Indeed, only 10 from 22 reviewed experiments were believed to allow for any direct comments on this relationship. Included experiments encompassed a range of sample characteristics, research designs, sport types, EF measures and VA tasks, and outcomes. The findings and specific comparisons and contrasts across experiments are discussed in detail below. The present study provides the first narrative and comprehensive review of research examining the association between both higher- and lower-order EFs and VA in sport. In doing so, the review has shown that neuroscientific accounts of attention may be relevant for sport research (Corbetta & Shulman, 2002; Gaillard & Ben Hamed, 2022). Overall, the present review provides substantial evidence of a relationship between EF and VA within sport and guides future research and practice.

Quality Assessment

The quality assessment check raised a number of issues within the included experiments. Reporting actual p values (item 9) rather than whether a value is greater or lesser than a standardised alpha value (e.g., $p < .05$) was low. Including specific values allows for greater transparency and for readers to interpret the findings themselves (Payne et al., 2019). However, in instances where the *p* value is less than .001, reporting $p < .001$ is suitable. Though exact *p* values are important, research has noted that best practice may be to prioritise effect sizes, rather than *p* values, given that large sample sizes can lead to a significant *p* value though statistical effects may actually be arbitrary (Sullivan & Feinn, 2012). Therefore, it is recommended that future work reports exact *p* values and the effect size in all relevant statistical analyses.

Various experiments were deemed to not meet item 12 (i.e., have a targeted sample that is fully representative of the larger population) nor item 13 (i.e., have an actual sample that is fully representative of the larger population). This was typically due to issues around generalising results of low sample size experiments (average sample size = 31.64) and in experiments examining athletes from a single sport (e.g., an experiment on basketball players is not likely representative of all athletes/sports; van Maarseveen et al., 2018b). It is recommended that future experiments opt for larger samples where possible, as we appreciate recruiting larger numbers, especially large professional/world class samples, is difficult, to allow more definitive inferences. Perhaps more important is to include power calculations that justify sample size to help avoid missing real effects (i.e., underpowered experiments) or over-spending on experimental resources (i.e., overpowered experiments; Green & MacLeod, 2015). Recommended methods for power calculations include G*Power (Faul et al., 2009) or using R (e.g., the "simr" package; Green & MacLeod, 2015).

Item 22 and Item 23 assessed whether the results could be applied to the eligible and other relevant populations, respectively. As the present review outlined that results were not applicable to all individuals within the target sport, they are therefore unlikely to represent all eligible athletes, or other relevant populations, as a whole. It is important to consider that a number of experiments used lab-settings where ecological validity can be low and transferring results to the "real-world" is difficult. When using a lab-setting we recommend that researchers consider ways to boost ecologically validity. For example, in a soccer task Roca et al. (2011) placed cameras at a height and angle reflective of a typical point of view for soccer players. Also, virtual reality environments may provide a useful avenue for increasing task validity (Wood et al., 2021). Some experiments utilised in-situ tasks which may yield higher ecological validity and show that the design is possible. Only higher-order EF experiments considered outcome measures within in-situ tasks. Whereas lower-order EF experiments opted instead to manipulate task demands and not use an outcome measure (e.g., Klostermann, 2020).

Twelve quality items were present in all 22 experiments suggested a generally high level of experimental quality. All experiments were deemed to meet item 20 (i.e., directly measured outcome variables) and item 16 (i.e., validly assessed outcome variables). Though all experiments included a direct and valid outcome for VA, not all experiments did so for EF. This only occurred in experiments examining lower-order EFs where demands were manipulated in-situ for updating (Williams et al., 2002) and inhibition (Klostermann, 2020, Experiment 1 and 2). While the use of in-situ tasks may increase ecological validity, it makes capturing outcome measures difficult and subsequently reduces understanding of how an individual’s EF influences VA. A number of lower-order EF tasks capture individual differences in response accuracy, response time, and/or combined measures (e.g., the Stop Signal Task for inhibition; Verbruggen et al., 2019). Though it may be reasonable to assume that tasks designed to place greater demands on the ability to withhold a prepotent response would be performed better by individuals with greater inhibitory control, the inclusion of a task-specific measure of inhibition would allow researchers to draw equivocal conclusions.

Discussion of Findings

Sample Characteristics, Sport Type, and Design

Age, sample size, and gender provided some interesting points of discussion. Age varied across studies. Given that EF develops with age (Diamond, 2013) caution should be taken when reconciling findings using samples with different ages and therefore, disparate cognitive development. Sample size was generally small so future works are encouraged to use larger samples (to produce more generalisable results) and utilise a priori power calculators (e.g., G*Power or R) to ensure confidence in effects. Indeed, Abt et al. (2020) note that many papers submitted to the Journal of Sport Sciences were without sample size justification and recommend future work includes such calculations. Though it is acknowledged that when working with elite groups obtaining a larger sample can be difficult (Koch & Krenn, 2021). Female representation was around 50% which appears acceptable. However, numerous experiments failed to provide gender information. Increased female representation in high-quality experiments will only help alleviate issues around the misapplication of previous findings from male samples to female samples (Emmonds et al., 2019) and act as a response to recent research calling for greater female specific research (Kryger et al., 2021).

Open-skill sports were predominant amongst the reviewed literature and may have been selected due to the increased attentional (executive and visual) demands of such sports (e.g., the need to efficiently and effectively process complex stimuli; Mann et al., 2007). Interestingly, ultra-marathon runners (e.g., closed-skill sport) have shown to be higher in motivation (Hammer & Podlog, 2016) and resilience (Roebuck et al., 2020) compared to other sports-people and non-athletes. Future research could examine how EFs allow individuals to maintain motivation and/or resilience rather than directly influence closed-skill sport performance. In the case of an ultra-marathon runner, EF may not directly impact performance outcomes but work with other desirable qualities for success (e.g., motivation) thus, suggesting an interaction effect. This suggestion, however, remains hypothetical and yet to be tested.

Expertise

There were discrepancies in the labelling of athletic expertise that could lead to non-generalisable findings (Polman, 2012). For example, the expert group in Piras et al., (2014) comprised professional volleyball players whereas the expert group in Alder et al. (2014) comprised Team GB level development athletes with potential to reach expert status. Comparisons across studies therefore are difficult as groups potentially share a label yet differ greatly in expertise. Vila-Maldonado et al. (2019) and van Maarseveen et al. (2018a) used different group labels but similar group definitions. Specifically, both included national level individuals in their participant definition but labelled the participants as players (Vila-Maldonado et al., 2019) and highly talented (van Maarseveen et al., 2018a), respectively.

The issue here is that researchers may not compare these experiments due to labels used, when really the experiments are comparable. The problem around defining expertise groups is not new (see Swann et al., 2015, a review). Swann et al. (2015) provided a taxonomy for rating expertise on a continuum, rather than using dichotomous groups, which may be pertinent for future research. This method was applied in one experiment in the current review (Brimmell et al., 2021) but has been applied in other relevant work (e.g., Hagyard et al., 2021). Also, creating an expertise score or placing individuals in groups can be difficult given potential inter- and intra-sport differences in what defines "expert". In response to this McAuley et al. (2022) propose a neat and simple option whereby experiments are more transparent and include all relevant information on the sample. From this, future researchers can then re-categorise or assess current categorisation with more accuracy. This method may also help alleviate issues when interpreting and assessing youth athlete expertise for inclusion. As youth athletes often only have potential to become world class conclusions must be cautious. This simple reporting method may help future researchers make more informed choices.

Executive Function, Tasks and Outcomes

Higher- (e.g., decision-making) and lower-order EFs (e.g., inhibition) were fairly evenly represented within reviewed literature. Higher-order EF experiments tended to focus on complex processes like decision-making and anticipation. This is not surprising given the importance of such complex processes in many sports, particularly open-skill sports (e.g., soccer). Therefore, training such processes in athletes may be desirable to increase on-field performance. It is important to consider that higher-order EFs are inherently more complex (i.e., driven by multiple simpler lower-order EFs), and as such it may be difficult to isolate specific functions and maximise intervention training. Experiments examining lower-order EFs (i.e., working memory and inhibition) alluded to their impact on sport performance and previous work has linked these EFs to sport performance (Vestberg et al., 2012; 2017). Future work may consider training lower-order EFs, or combined higher- and lower-order EFs, to compliment sport-training regimes as they are more easily isolated within a task (as in Ducrocq et al., 2016; 2017).

Higher-order EFs are predominately examined using sport-specific video tasks whereas lower-order EFs are often assessed with domain-general cognitive tasks or through task manipulation. The ecological validity and transferability to real word sport contexts has been questioned, though (van der Kamp et al., 2008). Specifically, sport-specific videos are sport-relevant but often lack haptic feedback while domain-general cognitive tasks assess the underlying cognitive procedures but lack sport-specificity. Future work may wish to focus on how performance on EF tasks that include haptic feedback, are sport-relevant, and assess how the underlying cognitive processes can influence subsequent sport performance. Though numerous lower-order EFs were examined, they were often not considered in the same experiment (see Brimmell et al., 2021, for an exception). This is surprising giving the proposed interplay between inhibition, shifting, and updating (Miyake et al., 2000). Also, Miyake et al. (2000), and the present review, note that experiments examining lower-order EFs often utilise a single task which may only allow researchers to comment on task-specific performance. Therefore, we call for more studies to examine multiple EFs in the same experiment and use multiple measures of the same EF to better understand the latent construct over task-specific performance.

Response accuracy appears to be the most common EF outcome measure. It is important to add that accuracy measures should include errors in their calculation to avoid negative participant effects (e.g., speed-accuracy trade-offs; Vaughan & Laborde, 2021). Somewhat surprisingly, few experiments combined time and accuracy (often termed efficiency score; Bishop et al., 2014) with experiments showing a tendency to report response accuracy only (effectiveness). Future research may wish to consider combined accuracy and time measures as success in sport often requires rapid and accurate responses under time constraints. Second, ACT-S outlines that response accuracy is usually an indicator of effectiveness only (i.e., performance quality) and does not consider performance efficiency (i.e., the relationship between effectiveness and resources used; Eysenck & Wilson, 2016). To better reflect genuine sporting situations and theoretical assumptions, it is recommended that future work include both indices of effectiveness (accuracy) and efficiency (ratio of accuracy to time).

Finally, a number of experiments examining lower-order EFs recorded no outcome measure at all. Instead, such experiments opted to manipulate task demands and attribute subsequent performance differences across conditions to the executive demands placed on the individual (e.g., Klostermann, 2020). Klostermann (2020) built a target-throwing paradigm with four conditions each of which placed different demands on inhibition. Klostermann

(2020) then assessed VA (quiet eye duration) differences across the conditions and assumed differences were due to varying inhibitory demands across conditions. However, this task also placed demands on peripheral attention (participants were asked to fixate centrally) and working memory (targets were shown only for a short time-period). Without any specific outcome measure of inhibition, it is difficult to understand the individual contribution to performance. It is suggested for future work to first include a direct outcome measure when examining lower-order EF.

Visual Attention

The reviewed experiments tended to use similar eye-tracker brands with 8/22 experiments opting for the ASL brand. However, the experimental results showed that, despite the eye-tracker used, the reported significance of VA variables was similar. It has become common to use multiple outcome measures when assessing VA (19/22 experiments used multiple) as single measures may not be sensitive enough to capture the complex visual processes involved in sport performance. Outcome measures like the number of fixations, fixation duration, fixation location, search rate, and the quiet eye have featured heavily in review work which may explain these decisions (Leabeau et al., 2016; Mann et al., 2007). An updated review from Klostermann and Moeinirad (2020) suggested that the number and duration of fixations may not be as meaningful as previously stated and that quiet eye variables and gaze location may be more informative. Interestingly, Klostermann and Moeinirad (2020) also suggest that VA outcome measures may be dependent on the operational task utilised (i.e., decision-making or aiming task) thus, VA outcomes may not be generalisable across tasks.

Rather than explicitly state the advantages of certain VA outcomes, the present review suggests that the importance of VA variables may fluctuate across sports and tasks. For example, Brimmell et al. (2021) found better soccer penalty performance was associated with a lower search rate while Vaeyens et al. (2007) reported that a higher search rate was associated with greater decision-making in soccer. Brams et al. (2019) may support this point in their systematic review on decision-making and anticipation (i.e., higher-order EFs). A medium-large effect size for fixation duration, fixations to key locations, and scan patterns was noted in experiments comparing experts and novices which supports the importance of such outcomes in higher-order tasks. We argue that researchers should carefully consider the sport and task being used when ascertaining the relevance of VA outcomes rather than using a generic approach. Finally, an interesting avenue for future work might be time course analysis (Vansteenkiste et al., 2014). Time course analysis focuses on the time at which performers fixated certain stimuli for successful performance, rather than using cumulative gaze behaviour. Such methods may help show the importance of measures like fixation duration and number and address Klostermann and Moeinirad’s (2020) concerns.

Executive Function and Visual Attention

A key purpose of the present review was to better understand the association between EF and VA and in general, better EF appears to be positively associated with better VA. Although outside of the sport domain, neuroscience may provide explanation for the EF and VA relationship (Corbetta & Shulman, 2002; Gaillard & Ben Hamed, 2022). Specifically, key attentional systems within the fronto-parietal areas of the brain (i.e., dorsal and ventral streams; Itti & Koch, 2001) are proposed to facilitate VA and information processing. Though research on this relationship in a sport-specific setting is lacking and is yet to be synthesised it may be that a similar relationship exists in sport. Gregoriou et al. (2009) outlined that the striate and extra-striate areas of the brain allow for enhanced visual processing of certain visual stimuli and the suppression of other, less relevant, stimuli. The results within the current review support the idea that a neurological basis may be at least partially responsible for the EF and VA relationship in sport.

Though the type and size of effect sizes varied, results suggested a positive relationship between EF and VA. For example, the reported effect sizes involving quiet eye variables (i.e., quiet eye duration, location, onset, and offset; Brimmell et al., 2021; Klostermann, 2020) were always positive in the reviewed experiments (r = .29, d = .61-.78, and $\eta\rho^2$ = .16-.46). This consistent finding may suggest that a practical and meaningful relationship exists between the EF and quiet eye variables. This has important applications for understanding the underlying processes of the quiet eye. For example, this review corroborates Klostermann's (2019; 2020) idea of an "inhibition hypothesis" that underpins the quiet eye. A number of experiments that examined fixation duration and fixations to key locations reported negative effect sizes. For example, Piras et al. (2014) showed that decision-making was improved when fixation durations were shorter. Regarding the location of fixations, it seems that this variable is less predictable and may vary between tasks and sports. For example, Van Maarseveen et al. (2018a) reported a negative effect between greater decision-making and fixations to the ball while Vila-Maldonado et al. (2019) reported a positive effect size between the same variables (i.e., decision-making and fixations to the ball).

Bishop et al. (2014) reported that an earlier first fixation to the soccer ball predicted greater decision-making efficiency. In this situation, early first soccer ball fixations may support the processing of such visual stimuli (i.e., individual assessment of how to interact with the object) at a certain time while suppressing the want/need to fixate other stimuli (e.g., upper body; Bishop et al., 2014). The ability to attend to this key visual stimulus then positively influence decision-making efficiency (i.e., faster and more accurate assessments of player movement direction). Interestingly, whether this effect is mono-directional (and if so, which way) or bi-directional remains unclear from the present review (i.e., does VA facilitate EF, vice versa, or do they influence one another). Brimmell et al. (2021) showed that inhibition (a lower-order EF located within the pre-frontal cortex) predicted soccer penalty performance through the mediator of quiet eye duration. This finding may suggest cognitive attentional processes like inhibition influence an individual's soccer penalty performance through their VA while the opposite could be said for Bishop et al. (2014). Though the direction is unclear, the present review shows how neuroscientific theory on EF and VA may extend to sport.

Making direct comment on the relationship between EF and VA in sport is difficult. This is predominately due to two factors: 1) the pool of experiments that allowed us to comment on the EF and VA relationship was small (i.e., 22 experiments) and 2) of these limited experiments only 10 allowed for direct comments on the relationship (with the remaining 12 experiments only affording indirect comments). Therefore, more work assessing the direct relationship between EF and VA is needed to be able to comprehensively comment on the application of neuroscientific theory in the sport context. It may also be of benefit to test specific neurological propositions within sport (e.g., rhythmic neural mechanisms; Gaillard & Ben Hamed, 2022). To this point, increased aerobic activity has been associated with greater attention performance (on a Posner visuospatial task) and increased beta and theta rhythm power (Wang et al., 2015). Though this finding is from exercise, the results may be applicable to sport performance.

A substantial number of the reviewed experiments allowed only indirect comments on the relationship between EF and VA. Indirect here refers to the idea that, though a predictor and dependent variable for EF and VA were not explicitly included, the design still allowed us to make a reasonable comment on the relationship. The specific designs included splitting participants based on EF score before comparing VA (Williams et al., 2002), training a group of participants on EF before comparing VA between groups (Ducrocq et al., 2017), and altering task demands to have greater and lesser effects on EF before measuring VA

(Klostermann, 2019). Such designs are informative as we now know that high working memory is associated with more task-relevant fixations (i.e., Williams et al., 2002), training working memory leads to lengthened quiet eye durations (Ducrocq et al., 2017), and that increasing inhibition demands can facilitate longer quiet eye durations and earlier quiet eye onsets (Klostermann, 2019). The issue is centred around a lack of direct outcome measures and therefore, less tangible evidence of a relationship. Also, future meta-analytic work is more difficult when a lack of outcome measures associated with EF in sport are available.

Experiments that included a measure of EF and VA in the same analyses allowed for a more direct comment on the relationship. Direct comments enable precise and strong statements on whether EF and VA do or do not relate. The types of analyses used in direct experiments were markedly different from those indirect ones. For example, regression, correlation, and mediation were more popular for direct comparisons compared to ANOVA which was more popular in indirect experiments. These experiments also show, to a greater extent than indirect experiments, that a relationship exists between EF and VA in sport. This is supportive of theoretical accounts from neuroscience and may help bring research concerned with Attentional Control Theory (Eysenck et al., 2007) and ACT-S (Eysenck & Wilson, 2016) together. Also, regarding strength of association, this evidence is perhaps indicating that training and intervention programmes can target EF and/or VA alone and expect subsequent developments in the untrained area (e.g., EF training may also lead to enhanced gaze). Moreover, it may show that an optimal approach combines sport-specific EF and visual training or intervention.

Together the direct and indirect experiments provide a strong argument that EF and VA relate in a sporting context, though more research is needed. Given the vast number of divergent EF tasks and variables, VA variables, and study designs a meta-analytical approach is beyond the scope of the literature at this time. Though we hope that this systematic review provides future researchers with a starting point to run targeted meta-analyses on more homogenous samples. Such an approach would further our understanding of the strength of the association between EF and VA. It is important to note that, so far, the focus has been on significant relationships between EF and VA. Attention to non-significant effects is also important for understanding the EF and VA relationship given their ability to further inform intervention work.

Despite forming part of the theoretical model of EF (Miyake et al., 2000) and appearing in relevant theory (i.e., ACT-S; Eysenck & Wilson, 2016) only one experiment examined shifting. Shifting has been outlined as important for attention (Ionescu, 2012) and has been positively related to sport performance (e.g., Vestberg et al., 2017). Results from Brimmell et al. (2021) suggested that shifting was not significant in any of the mediation models examining EF, VA, and soccer penalty performance. However, the authors noted that the Flanker task may not have been optimal and future works should use an alternate task before concluding on the relevance of shifting to VA (e.g., Category Switch Task; Friedman et al., 2008). Of the experiments that outlined a relationship between EF and VA only one found no significant relationships at all. Savelsbergh et al. (2002) compared VA across successful and unsuccessful anticipation trials and found no differences in performance attributable to gaze behaviour. This experiment may indicate that other perceptual processes are more important for anticipation than VA. In addition, the authors suggested that individuals may be able to extract and process information effectively during fixations (hypothetically through enhanced quiet eye periods) and make better use of peripheral vision (i.e., use anchor points and/or visual pivots; Vater et al., 2020).

Quiet eye variables are very popular in this research area. This could be because lengthened quiet eye durations can facilitate information processing in sport aiming tasks (Lebeau et al., 2016). Despite the popularity of duration, other quiet eye variables were examined by experiments and showed mixed results. Quiet eye offset results were mixed, but most often non-significant. Specifically, Klostermann (2019) and Klostermann (2020 experiment 2) showed that when inhibition demands were high, quiet eye offset was not significantly impacted while quiet eye duration was longer and onset was earlier. This may suggest that an enhanced ability to inhibit irrelevant stimuli (perhaps stemming from improved ventral/dorsal suppression; Itti & Kock, 2001) allows earlier quiet eye onset and longer quiet eye durations. In lay terms, helping athletes block distracting visual stimuli may allow the individual to begin selecting and performing the optimal motor action earlier. Caution is paramount here given the reported non-linear relationship between quiet eye duration and performance. Specifically, research from Harris et al. (2021b) showed that simply elongating the quiet eye duration doesn’t always lead to performance improvements when target location is known. Also, an increased time internally focusing on upcoming motor action can negatively impact subsequent performance (Beilock et al., 2002).

In a recent review, Klostermann and Moeinirad (2020) reported that the number and duration of fixations may not differentiate between sport performers as well as previous reviews noted (e.g., Mann et al., 2007). A number of the non-significant results between EF and VA in the present review involved both the number and duration of fixations. This may support Klostermann and Moeinirad (2020) and suggest that experts use alternate components of perceptual-cognition, or other skills, to perform optimally. However, this may not be a blanket statement given the notion that various fixation number and duration results were found to be significant between EF and VA in the present review. Therefore, we do not offer a blanket recommendation on the use of these variables but rather suggest that VA variables should be selected relative to the task, sport type, or study goals as they may require different variables of attentional patterns (i.e., fewer and longer fixations vs. more and shorter fixations).

Implications

The present review has a number of implications for future applied and theoretical work. Perhaps the largest implication is that, despite very little in the way of direct examination, there appears to be an association between EF and VA in sport. The present review outlines that EF and VA appear relevant for sport performance. From a practical standpoint, this information may provide individuals with an area to work on with their own athletes. Specifically, to look for ways to enhance EF and/or VA and hopefully see subsequent performance benefits. An interesting place to start might be with dual EF and VA training given their association. More work is needed to better understand the precise manner in which the two relate (e.g., longitudinal work where EF and VA are tracked over time). The present review highlights an issue with unstandardised expertise labels, and we suggest a unified method for labelling athletic expertise. Future studies could consider using Swann et al.'s (2015) framework for creating a continuous measure of expertise that does not require the artificial categorisation of participants into groups. Also, given the link between expertise and EF it would be important to consider other known covariates like physical activity and age (see Diamond, 2013) even when not explicitly looking for such differences between athletic groups.

The present review found that there is generally a lack of research examining EFs and VA together. Lower-order EFs comprise the fundamental processes used in perceptual-cognition and likely underpin more complex higher-order EFs (e.g., decision-making). Tasks designed to assess lower-order EFs are also more likely to tap only the targeted function providing a more sensitive examination of the underlying processes at work during gaze. The present review recommends that future work should deploy EF tasks that, where possible, assess both response time and accuracy together (i.e., efficiency scores) and VA tasks that assess some or all of fixation number and duration, fixation percentage to key locations, and quiet eye (despite concerns from Klostermann & Moeinirad, 2020). The key may be deciding on the relevance of certain outcome variables based on the sport and task being examined. The present review also highlights that theoretical accounts from neuroscience may be relevant and transferable to sport. Moreover, cognitive attentional processes that are housed within the fronto-parietal areas of the brain (i.e., EF) relate to VA when considered in a sporting context.

Limitations

Though the present review is an informative resource for understanding the current state of EF and VA literature in sport, it has some weaknesses. Despite following PRISMA guidelines (Moher et al., 2009) and adopting similar criteria to previous reviews (e.g., Payne et al., 2019) the items used for quality assessment were not specific to all the identified studies. Items were adapted from relevant previous works (Downs & Black, 1998; DuRant, 1994; Genaidy et al., 2007; Payne et al., 2019) yet the lack of general agreement in how to assess experiment quality can lead to differences in opinion (Payne et al., 2019). Until a list is psychometrically tested criteria may be considered somewhat hypothetical. Further, the review included many experiments covering a variety of sports, EFs, VA measures, and sample characteristics, and this may raise questions around comparing and drawing conclusions from very different works. However, we hope that our review provides a critique of the necessary ‘ingredients’ for future studies and becomes the catalyst for further work in EF and VA in sport.

Conclusion

The examination of EF and VA in sport is an exciting and growing area for researchers and sport practitioners alike. Overall, there appears to be a positive link between EF and VA that may suggest some interplay between the two for sports performance. Though the exact relationship, and between which variables the relationship is strongest or weakest, remains unclear. Moreover, it is likely that this relationship is more nuanced and dependent on the design used, such as type of task, as reported in the neuroscientific literature. The present review highlighted differences in tasks with sport-specific video tasks utilised for examining higher-order EFs and domain-general or manipulation tasks used for investigating lower-order EFs. A number of experiments examining lower-order EFs were limited by their outcome variables (i.e., some including no outcome measures and not all measured both effectiveness and efficiency) and the representation of EFs in relation to VA in the literature was limited (especially shifting). For athletic expertise there is an issue around definition with large discrepancies in how labels are used and a unified method of operationalising expertise is required. In sum, despite very limited direct research, it seems that EF and VA are positively associated and more focus on how this relationship impacts sport performance is needed.

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Table 1. Quality assessment items.

Item number	Item description
1	Is/are the hypothesis/aim/objective(s) of the study clearly described?
2	Are the main outcomes to be measured clearly described?
3	Have the authors established a theoretical framework for the study?
4	Is the study design clearly described and appropriate to test the hypothesis?
5	Are the characteristics of participants in the study clearly described?
6	Is there evidence of attention to ethical issues?
7	Are the main findings of the study clearly described?
8	Does the study provide estimates of the statistical parameters?
9	Have actual probability values been reported for the main outcomes, except where the probability value is less than .001?
10	Are conclusions substantiated by the data that are presented in the results?
11	Are results adequately compared to previous studies and in relation to theoretical frameworks?
12	Are the subjects asked to participate in the study representative of the entire population from which they were recruited?
13	Are those subjects who were prepared to participate, representative of the entire population from which they were recruited?
14	Were the statistical tests used to assess the main outcomes appropriate?
15	Do the operational definitions of the variables match the theoretical definitions?
16	Are the methods of assessing the outcome variables valid?
17	Is the control group/condition comparable to the exposed group/condition?
18	Are the methods of assessing the exposure variables valid?
19	Is the manipulation of the exposure variable successful?
20	Are the methods of assessing the outcome variables direct measurement?
21	Are the outcome data reported by levels of exposure?
22	Can the study results be applied to the eligible population?
23	Can the study results be applied to other relevant populations?

Note. Items were taken from The Appraisal Instrument (Genaidy et al., 2007), The Quality Index (Downs & Black, 1998), and The Evaluation of Research Checklist (DuRant, 1994). Item 6 was an additional item intended to assess attention to ethics as in Payne et al. (2019).

Table 2. Quality assessment scores.

Article	Items																							Total	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	Raw	%
Alder et al. (2014) exp. 2	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Bishop et al. (2014) exp 1	1	1	1	1	1	1	1	1	0	1	1	0	0	1	1	1	1	1	1	1	1	0	0	18	78.3
Brimmell et al. (2021)	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	0	19	82.6
del Campo & Gracia (2018)	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	0	0	19	82.6
Ducrocq et al. (2016) exp 1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Ducrocq et al. (2016) exp 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Ducrocq et al. (2017)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Frank et al. (2016)	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Klostermann (2019)	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Klostermann (2020) exp 1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Klostermann (2020) exp 2	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Luo et al. (2017) exp 1	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Luo et al. (2017) exp 2	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Piras et al. (2014)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Savelsbergh et al. (2002)	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Savelsbergh et al. (2005)	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Vaeyens et al. (2007)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
van Maarseveen et al. (2018a)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100

van Maarseveen et al. (2018b)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	23	100
Vila-Maldonado et al. (2019)	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Williams et al. (2002)	1	1	1	1	1	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	21	91.3
Wood et al. (2016)	1	1	1	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	19	82.6
Total item score	22	22	21	22	22	18	20	22	17	21	23	12	12	22	22	22	22	22	21	22	22	12	11		^Avg. %
Total item percentage	100	100	95.5	100	100	81.8	90.9	100	77.3	95.5	100	54.5	54.5	100	100	100	100	100	95.5	100	100	54.5	50.0		^ 89.1

Note. 1 = yes, 0 = no/unclear.

Table 3. Summary of reviewed studies that measured executive function and visual attention in a sporting context.

Article	Sample characteristics	Sport	Study design	Female %	Executive Function Measured		Eye-tracker	Visual Attention Measured	Relevant Findings	Notes and Additional Findings
					Executive task	Outcome variable				
Alder et al. (2014) exp. 2	8 expert (28.90 ± 3.10) and 8 novice (18.50 ± 1.10) players	Badminton	B-S	NS	Anticipation		ASL	No. fixations, fixation duration, final fixation duration, % time to key locations	Experts fixated on the racket more when responding correct than novices. Novices fixated on the wrist more when responding incorrectly than experts. Novices fixated the shuttle more in correct and incorrect conditions	Included various video occlusion points (pre-contact, contact, post-contact). Assessed type of error (depth, direction, or both). Looked at a preparation and execution phase. Experts had significantly longer fixation durations and final fixation durations. Experts showed significantly higher response accuracy
					Sport-specific video	Response accuracy				
Bishop et al. (2014) exp. 1	26 male (21.00 ± 1.70) and 14 female (21.40 ± 2.00) novice to semi-professional players	Soccer	W-S	35	Decision-making		SR Research Eyelink 1000	No. fixations, % dwell time, fixation duration, 1st fixation time, saccadic amplitude, saccadic latency, peak saccadic velocity	Despite 19 predictors (including no. fixations to 4 locations, % dwell time to 4 locations, time to first fixate 4 locations, mean fixation duration, mean saccade amplitude, mean peak saccade velocity, initial saccade latency, and 3 soccer participation items), the model accounted for 67% of the variance in efficiency scores. The only individual significant predictor was time to 1st fixate the ball	Overall participants were highly accurate (88.70 ± 0.10%)
					Sport-specific photos	Response accuracy and response time (combined to create efficiency scores)				
Brimmell et al. (2021)	95 undergraduate sport university students (25.07 ± 7.50)	Various/unspecified	B-S + W-S	38.95	Inhibition, shifting and updating		SMI	Quiet eye duration, quiet eye location, search rate, no. fixations	Several significant mediation models were reported. The inhibition-soccer penalty performance relationship was mediated by quiet eye duration, search rate and no. fixations to goal. The updating-soccer penalty performance relationship was mediated by quiet eye duration and location, and no. fixations to the goal	Between-subject analyses were non-significant (i.e., no group differences) so subsequent analyses collapsed across groups. Seem to be only study with mediation. Also, examined a performance outcome (soccer penalty performance) in relation to EF and VA
					Go/No-Go, Flanker, and Nback	Response accuracy and efficiency scores				
	1 expert judge (36.00), 1 expert	Gymnastics	B-S	0	Decision-making		ASL SE5000	No. fixations, fixation duration,	Improved decision-making when no. fixation and fixation duration near the shoulders	Videos of three different gymnastics skills (vault, uneven bars, and floor). Include some

del Campo & Gracia (2018)	coach (38.00), and 1 expert gymnast (22.00)				Sport-specific video	Response accuracy		% time to key locations	increased, but the opposite was found for the judge. The coach showed greatest decision-making when no. fixations and fixation duration to the trunk increased	individual difference data (i.e., gymnast had higher mean no. fixations and fixation duration to hips vs trunk). Included different gymnastic movements in video. Significant differences in no. fixations and fixation duration to the hips and the near legs. Post hoc showed the gymnast had the highest no. fixations and fixation durations and there were no differences between the coach and judge. No significant differences in response accuracy, judge performed marginally better. Correlation showed the gymnast
Ducrocq et al. (2016) exp. 1	33 participants (27.13 ± 4.86)	Tennis	B-S	66.66	Inhibition Visual search inhibition task	Distractor costs	SR Research Eyelink 1000	Saccade latency (anti and pro saccade)	The task x group and time x group interactions were non-significant. There was a trend for the group x task and the time x group x task interaction to be significant. Follow up showed that improvements were largely driven by the training groups decrease in response latency in the antisaccade task. For prosaccade there were no significant pre to post changes for either group	Participants were split into training and control groups. Pre, intervention, and post design. Inhibition improved across training (indicated by distractor costs). Antisaccade and prosaccade performance improved pre to post intervention. Antisaccade latencies were slower than prosaccade latencies. Groups did not differ from each other on saccadic latencies
Ducrocq et al. (2016) exp. 3	22 recreational tennis players (27.84 ± 5.63)	Tennis	B-S	50	Inhibition Visual search inhibition task	Distractor costs	SR Research Eyelink 1000	Time to 1st target fixation	A significant condition x group interaction was found. The control group had earlier first target fixations at high-pressure while the training group had later first target fixations (indicating greater attention)	Used cognitive anxiety measures to assess hypothesised differences between the high-pressure and low-pressure conditions. Also, included a physical tennis task. For performance, only the training group decreased the number of target misses. Participants were split into training and control groups. Pre, intervention, and post design. Regression showed that first target fixation predicted 13% of the variance in the tennis task. Distractor costs were lower post-training for the training group, indicating improved inhibition.

										Condition was significant, showing that first target fixation was significantly earlier in the high-pressure compared to low-pressure
Ducrocq et al. (2017)	30 recreational tennis players (33.00)	Tennis	B-S	16.66	Working-memory		Pupil Labs	Quiet eye duration, quiet eye onset, quiet eye offset	Quiet eye duration was longer in the high-pressure condition, but not significant between groups. All quiet eye onset analyses were non-significant. Quiet eye offset was later in the high-pressure condition. The training group had a later quiet eye offset than the control group indicating improved working-memory	Included a physical tennis task. Participants were split into training and control groups. Pre, intervention, and post design. Anxiety measures showed that the high- and low-pressure conditions were distinct. Only the training group improved on the tennis task from pre-training to post-training. Training group performed significantly better post-training vs pre-training on the nback task. In the near-transfer change detection task only the training group showed improvement from pre-training to post-training
					Nback and change detection task	Average level of difficulty in the nback and hits and false alarms in CDT				
Frank et al. (2016)	15 combined practice group (24.38), 15 physical practice group (25.73), and 15 no training group (27.00) university students	Golf	B-S	60	Mental representation and working-memory		SMI iViewX HED	Quiet eye duration	A small significant positive correlation between the cognitive representations (adjusted rand index) and quiet eye duration was found	Measured performance on a golf-putting task. Placed participants into three groups (combined practice, physical practice, and no practice). Both types of practice (i.e., combined and physical) improved putting accuracy compared to no practice at a retention test. Assessed imagery ability to be sure it did not influence results. The combined practice group increased functional clusters in regard to the putting action. Adjusted rand index increased in similarity to that of the expert. Physical practice group also improved, and no practice group showed no improvements in adjusted rand index scores. Only combined practice group showed improved quiet eye durations compared to the no practice group
					Structural dimension analysis of mental representation	Adjusted rand index				

Klostermann (2019)	40 undergraduate students (20.30 ± 1.30)	Non-athletes	B-S	45	Inhibition	In-situ/Manipulation	None	EyeSeeCam	Quiet eye duration, quiet eye onset, quiet eye offset	Quiet eye duration was longer and quiet eye onset was earlier when inhibition demands were high v low. No difference in quiet eye offset	The study manipulated inhibition demands and placed participants in one of two groups (i.e., high-response and low-response selection demands). Measured throwing performance as well between the conditions. Finally, they measured ball flight and throwing movement differences between the groups
Klostermann (2020) exp. 1	14 male (24.00 ± 3.60) and 12 female (20.90 ± 3.60) sport science university students	Various/unspecified	W-S	46.15	Inhibition	In-situ/Manipulation	None	EyeSeeCam	Quiet eye duration, quiet eye onset, quiet eye offset,	Quiet eye duration was longer, quiet eye onset was earlier, and quiet eye offset was later when inhibition demands were high vs low (i.e., target distance was small vs large)	Manipulated inhibition demands via response demands (i.e., high and low) and discriminability (i.e., high and low). Measured throwing performance as well between the conditions. Used a quiet eye median split and assessed throwing accuracy as well
Klostermann (2020) exp. 2	22 male (20.70 ± 1.20) and 4 female (20.00 ± 1.20) sport science university students	Various/unspecified	W-S	15.38	Inhibition	In-situ/Manipulation	None	EyeSeeCam	Quiet eye duration, quiet eye onset, quiet eye offset,	Quiet eye duration was longer and quiet eye onset was earlier when throwing to 1 of 4 targets than when throwing to a single target and when discriminability was low vs high. No differences of quiet eye offset	Manipulated inhibition demands, but this time continued to manipulate the demands during the throwing action. Measured throwing performance as well between the conditions. Used a quiet eye median split and assessed throwing accuracy as well
Luo et al. (2017) exp 1	56 undergraduate and graduate sport university students (21.34 ± 2.41)	Various/unspecified	B-S	76.79	Working-memory	OSPAN	Response accuracy	Tobii T120	Latency of 1st correct saccade, % incorrect saccades	Working-memory significantly affected the latency of 1st saccade (with faster latencies in high working-memory group), but not the % of incorrect saccades	Participants were placed into two groups based on OSPAN scores. Participants completed low- and high-anxiety conditions. Successful creation of high-anxiety was checked. Also, assessed effect of anxiety conditions on gaze
Luo et al. (2017) exp 2	32 undergraduate and graduate sport university students (21.00 ± 1.48)	Various/unspecified	B-S	71.88	Working-memory	Nback and OSPAN	Response accuracy and achieved difficulty level	Tobii T120	Latency of 1st correct saccade, % incorrect saccades	Working-memory trained group showed improvements in similar OSPAN task and also shorter latency of the 1st saccade. No effect of % of incorrect saccades	Training study where participants were in either a training or control group. Also, assessed effect of anxiety conditions on gaze and perceived difficulty and attention levels of participants. Only the training group showed improvements in training (indicated by nback scores)

Piras et al. (2014)	15 expert (24.87 ± 1.92) and 15 novice (24.07 ± 0.88) players	Volleyball	B-S	NS	Anticipation		Eyelink II	No. fixations, fixation duration, search rate, % time to key locations	Experts had a negative correlation between fixation duration and response time on correct responses. When incorrect, experts fixated longer on legs and hands vs novices. Experts spent more time fixating legs and hand area when correct	Experts had higher response accuracy, faster response times, had a lower no. fixation, and shorter fixation duration. Experts showed longer response times when making correct vs incorrect decisions
					Sport-specific video	Response accuracy and response time				
Savelsbergh et al. (2002)	7 expert (29.90 ± 7.10) and 7 novice (21.30 ± 1.40) goalkeepers	Soccer	B-S	NS	Anticipation		ASL 4000SU	No. fixations, fixation duration, search rate, no. fixation locations, % time to key locations	Regarding successful and unsuccessful anticipation trials (i.e., response accuracy) there were no significant differences in search rate and % time fixating key locations across the trials	No group differences in penalties saved but experts were better at anticipating side and height information (all under response accuracy). Experts made fewer corrective movements and initiated responses closer to foot-ball contact. Experts had fewer fixations of longer durations to fewer areas. Novices fixated the trunk, arm, and hips more while experts fixated the kicking leg, non-kicking leg, and ball. Early in the trial experts tended to fixate the head while novices fixated "unspecified" areas
					Sport-specific video	Response accuracy and response time				
Savelsbergh et al. (2005)	16 expert goalkeepers (25.70 ± 7.10)	Soccer	B-S	NS	Anticipation		ASL 4000SU	No. fixations, fixation duration, search rate, no. fixation locations, % time to key locations	No group differences on no. fixations, fixation duration, or no. fixation locations. The successful group fixated the non-kicking leg more, while the unsuccessful group fixated the head more. The successful group fixated the "unspecified" region more	A successful and unsuccessful group was created based on no. penalties saved (i.e., anticipation). The successful group had higher overall response accuracy, and greater anticipation of kick side and kick height. The successful group initiated movement closer to foot-ball contact
					Sport-specific video	Response accuracy				
Vaeyens et al. (2007)	21 elite (14.70 ± 0.50), 21 sub-elite	Soccer	B-S	0	Decision-making		ASL 5000	No. fixations, fixation duration,	Successful players had a higher number of fixations per second (search rate). No differences in	Videos scenarios varied in the number of players present (2v1, 3v1, 3v2, 4v3, and 5v3

	(14.60 ± 0.30), 23 regional (14.60 ± 0.60) players				Sport-specific video	Response accuracy and response time		search rate, % time to key locations, inter-fixation rate, fixation order	fixation duration. No differences in inter-fixation between groups. Successful group alternated gaze more between the player in possession and other areas of the display more (fixation order). The groups differed in % time to key locations in two conditions (3v2 and 4v3) with successful players fixating the ball, player in possession, and attacker closely marked more. Overall, successful players spent more time fixating the player in possession	scenarios). Participants were not compared across expertise level but rather split into “successful” and “unsuccessful” groups. Allocation was based on response accuracy. Authors offer more specific findings for differences between video scenarios. Successful players had faster response times across all video scenarios. Response time generally increased as the number of players increased. Successful group had higher response accuracy in all bar one condition (2v1)
van Maarseveen et al. (2018a)	22 highly talented players (16.30 ± 1.10)	Soccer	B-S + W-S	100	Anticipation, decision-making, and pattern recall		SMI	No. fixations, fixation duration, search rate, % time to key locations, fixation order, entropy	Better performance on the in-situ task was only associated with less time fixating the ball in the decision-making task, no other VA measures.	Used manipulation checks to assess the effect of different occlusion times (-100ms, 0ms, and 100ms) and whether repeated exposure to the same stimuli inadvertently facilitated learning effects. Also examined gaze differences across the three perceptual-cognitive (video) tasks. There was no relationship between in-situ performance and anticipation, decision-making, or pattern recall. A median split analysis using best and worst performers from both in-situ and perceptual-cognitive tasks, in separate analyses, revealed the same results
					Sport-specific video and in-situ	Response accuracy and anticipatory recall score				
van Maarseveen et al. (2018b)	13 skilled players (16.90 ± 1.30)	Basketball	W-S	100	Decision-making		SMI	First fixation on selection, final fixation on selection, % time to key locations, scan paths, no. fixations to correct option when incorrect	Participants often fixated upon their final decision. 95 of 188 final fixations were toward their final decision. The option players chose was not influenced by the % time to key locations. A higher response accuracy was associated with lower % time viewing the free outer space. Scan paths were different, and more diverse, when selecting to pass to teammate rather than drive to basket or shoot. Different scan	Used a manipulation check to assess the impact of wearing an eye-tracker during an in-situ task. The defender in the in-situ task was given one of three instructions (“under”, “over” and “hedge”). Also analysed potential performance differences based on the side of the court the action was performed (i.e., left and right). Looked at whether the side influenced preferences. Looked at the gaze behaviour across the
					Sport-specific in-situ	Response accuracy and response time				

										paths for correct and incorrect decisions were found. When incorrect, gaze was only directed to the optimal outcome in 12 of 56 trials	different decisions made (drive to basket, shoot, pass to teammate, or pass to corner). No differences based on defensive movement ("under", "over", "hedge") or court side (left/right) in response accuracy. Decisions were noted as different based on the side of the play. No differences in response time
Vila-Maldonado et al. (2019)	38 players (23.90 ± 4.20)	Volleyball	W-S	100	Decision-making	Sport-specific video and in-situ	Response accuracy	ASL	No. fixations, fixation duration, % time to key locations	Regression showed that longer fixation durations to the shoulders and head negatively affected total response accuracy (with similar results for "zone 3" and "zone 4" accuracy). Total response accuracy was positively impacted by no. fixations to the ball-wrist and negatively impacted by no. fixations to the head.	Divide their response accuracy variable into three ("zone 3" accuracy, "zone 4" accuracy, and total accuracy). Zones refer to areas on the court
Williams et al. (2002)	10 recreational players (28.90 ± 8.20)	Table tennis	W-S	20	Working-memory	In-situ/manipulation	None	ASL 501	No. fixations, fixation duration, search rate, % time to key locations	Participants fixated "other" areas of the display less vs the ball when anxiety was high in the high working-memory condition. No differences in fixation duration.	Used a manipulation check to assess the effectiveness of their anxiety manipulation (used high- and low-anxiety conditions). Manipulated the task to have low- and high-demands on working-memory. Also obtained mental effort scores. Obtained some kinematic measures (ball velocity, arm velocity at contact, peak velocity, and initial position). Performance was better under low-anxiety conditions vs high-anxiety and better when working-memory demands were low vs high. Anxiety impacted frequency of gaze.
Wood et al. (2016)	12 low working-memory (20.30 ±	Shooting	B-S	29.17	Working-memory			ASL XG		Low working-memory individuals had slower visual search times and shorter quiet	Manipulated situation to create a high threat (high-anxiety) and low threat (low-anxiety). Task

2.11) and 12 high working-memory (20.00 ± 1.70) undergraduate students	OSPAN	Response accuracy	Quiet eye duration, visual search	eye durations when the target was incongruent (marginally non-significant to congruent targets)	targets were congruent (word matches ink colour) and incongruent (word does not match ink colour). Also measured performance on the shooting task

Note. all sample ages are shown in parentheses in “Sample Characteristics”. B-S = between-subjects and W-S = within-subjects. NS = not specified.

Table 4. The direction, analysis technique, key result(s), and effect size(s) of reviewed experiments

Experiment	Direct or Inferred	Analysis	Key Results	Reported Effects
Alder et al. (2014) exp. 2	Direct	ANOVA	Significant three-way interaction between VA, anticipation accuracy and expertise	d = .31
Bishop et al. (2014) exp. 1	Direct	Regression	Time to 1st ball fixation predicted decision-making efficiency	Only effect included all variables R^2 = .67
Brimmell et al. (2021)	Direct	Mediation	Inhibition predicted soccer penalty performance through mediators of quiet eye duration, search rate, and no. fixations on goal. Updating predicted soccer penalty performance through mediators of quiet eye duration and location, and no. fixations on goal	Only provided unstandardised beta coefficients ranging from -.06 to 8.54
del Campo & Gracia (2018)	Direct	Correlation	Greater decision-making accuracy was positively correlated with no. and duration of fixations at shoulder in the judge and trunk in the coach	None
Ducrocq et al. (2016) exp. 1	Inferred	ANOVA	Inhibition training group had significantly faster antisaccade reaction times	$\eta\rho^2$ = .30
Ducrocq et al. (2016) exp. 3	Inferred	ANOVA	Control group had significantly earlier 1st fixation on tennis target vs inhibition training group	$\eta\rho^2$ = .10
Ducrocq et al. (2017)	Inferred	ANOVA	Working memory trained group had significantly later quiet eye offset	$\eta\rho^2$ = .28
Frank et al. (2016)	Direct	Correlation	Small significant positive correlation between adjusted rand index score and quiet eye duration	r = .29
Klostermann (2019)	Inferred	T-test	Longer quiet eye duration and earlier quiet eye onset in the “high” inhibition condition	Quiet eye duration – d = .78, quiet eye onset – d = .61
Klostermann (2020) exp. 1	Inferred	T-test	Longer quiet eye duration, earlier quiet eye onset, and later quiet eye offset in the “high” inhibition condition (i.e., small target distance)	Quiet eye duration - $\eta\rho^2$ = .43, quiet eye onset - $\eta\rho^2$ = .46, and quiet eye offset - $\eta\rho^2$ = .30
Klostermann (2020) exp. 2	Inferred	T-test	Longer quiet eye duration and earlier quiet eye onset when throwing to 1 of 4 targets and when discriminability was low	No. of targets: quiet eye duration - $\eta\rho^2$ = .19 and quiet eye onset - $\eta\rho^2$ = .34. Discriminability: quiet eye duration - $\eta\rho^2$ = .16 and quiet eye onset - $\eta\rho^2$ = .16
Luo et al. (2017) exp 1	Inferred	ANOVA	Higher working memory group had significantly shorter 1st saccade latency	$\eta\rho^2$ = .19
Luo et al. (2017) exp 2	Inferred	ANOVA	Working memory trained group had significantly shorter 1st saccade latency	$\eta\rho^2$ = .19
Piras et al. (2014)	Direct	Correlation	Experts had a negative correlation between fixation duration and response time on correct decisions.	r = -.22
Savelsbergh et al. (2002)	Inferred	ANOVA	Successful and unsuccessful decision groups did not significantly differ on any VA measure	None
Savelsbergh et al. (2005)	Inferred	ANOVA	Successful decision group fixated the non-kicking leg more, head less, and unspecified region more	Non-kicking leg - $\eta\rho^2$ = .36, head - $\eta\rho^2$ = .27, unspecified - $\eta\rho^2$ = .34
Vaeyens et al. (2007)	Inferred	ANOVA	Successful decision group had higher search rate, alternate fixation order, and differed in percentage time fixating “key” locations	Search rate - $\eta\rho^2$ = .20, alternate fixation order – $\eta\rho^2$ = .16, and “key” locations - $\eta\rho^2$ = .60 to .68
van Maarseveen et al. (2018a)	Direct	Correlation	In-situ soccer decisions accuracy significantly negatively correlated with time fixating the ball	r = -.66
van Maarseveen et al. (2018b)	Direct	Descriptive and Correlation	Half final fixations were to decision target. Greater decision accuracy associated with more time viewing free space. Difference scan paths in correct and incorrect decisions. When decision was wrong gaze was only at optimal choice 12/56 times	r = -.71
Vila-Maldonado et al. (2019)	Direct	Regression	Shorter fixations to head and shoulders lead to greater decision-making accuracy. Decision accuracy was positively influenced by the no. of fixations the ball and negatively by no. fixations to the head	Fixation length: head - β = -.32 and shoulders - β = -.90. No. of fixations: ball - β = .45 and head - β = -.36
Williams et al. (2002)	Inferred	ANOVA	High working memory group was associated with fewer fixations to “other” areas of the display and more to the ball	ω^2 = .23 for the whole interaction term
Wood et al. (2016)	Inferred	ANOVA	Low working memory group had shorter quiet eye durations and slower visual search times	Quiet eye duration - $\eta\rho^2$ = .32 and visual search time - $\eta\rho^2$ = .44

Figure 1. Stages and results of the search process having followed PRISMA guidelines (adapted from Moher et al., 2009).