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Executive function and visual attention in sport: A systematic review

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22 **Abstract**

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

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

47 **Introduction**

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

65 **Executive Function**

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

72 EFs by Miyake et al. (2000). These functions were then outlined by Attentional Control
73 Theory (Eysenck et al., 2007) and then Attentional Control Theory-Sport (ACT-S; Eysenck
74 & Wilson, 2016) as being susceptible to anxiety and stress (Wood & Wilson, 2010). By
75 comparison, higher-order functions comprise the co-ordination of lower-order cognitive
76 processes working together (e.g., decision-making, planning, problem-solving; Diamond,
77 2013). Given its complex, constantly changing environment, sport provides an optimal
78 platform to examine both higher- and lower-order EFs. For example, soccer requires the
79 recognition and processing of game-specific situations (i.e., working-memory, updating;
80 Wood et al., 2016) in which, the player must select the optimal outcome (i.e., decision-
81 making, planning, anticipation; Huijgen et al., 2015). Also, soccer players often need to cease
82 intended actions (i.e., inhibition; Verbruggen et al., 2019) and perform a new action instead
83 (i.e., inhibition, shifting, problem solving; Sakamoto et al., 2018) based on internal and
84 external cues within the environment.

85 Higher-order EFs like decision-making, anticipation, and problem solving (often
86 assessed with sport-specific video tasks; Roca et al., 2013) are some of the most researched in
87 sport psychology (e.g., Moore et al., 2019). Decision-making involves selecting the most
88 suitable option from two or more alternatives in obvious and complex situations (VandenBos,
89 2006). Anticipation is facilitated by complex knowledge structures which allow for
90 evaluative, predictive, and planning processes (North et al., 2011). Problem solving is
91 involved in overcoming difficulties and achieving goals via higher mental functions
92 (VandenBos, 2006) and may rely upon shifting and updating (Kotsopoulos & Lee, 2012).
93 Research generally indicates those with higher sporting expertise score better on higher-order
94 EF tasks compared to those with lower sporting expertise. For example, experts have
95 outperformed novices in decision-making on both sport-specific (e.g., Moore et al., 2019) and
96 general decision-making tasks (e.g., Vaughan et al., 2019). Anticipation was superior in

97 skilled (professional/semi-professional) compared to less-skilled (recreational) soccer players
98 (Roca et al., 2013) and greater problem solving was shown in athletes compared to non-
99 athletes (Jacobson & Matthaeus, 2014).

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

112 **Visual Attention**

113 Research typically assesses attentional control through gaze behaviour from eye-
114 trackers as they allow researchers to observe online attention during in-situ sports tasks (e.g.,
115 soccer penalty kicks; Brimmell et al., 2019). Visual attention typically refers to the current
116 foveal location of attention and is concerned with knowing where to look (Mann et al., 2007).
117 Popular foveal measures include the number and duration of fixations (sometimes together as
118 search rate; Brimmell et al., 2019) and the location of fixations which may help understand
119 which visual stimuli provide athletes with the most information (Wilson, 2008). The quiet
120 eye phenomenon, which encompasses the length and location of the final fixation before
121 initiating a critical movement (Vickers, 2007), is perhaps the most common visual measure in

122 sport-related aiming tasks. A recent review from Klostermann and Moeinrad (2020) attest to
123 the importance of this variable over and above other variables (e.g., number and duration of
124 fixations). Like research exploring EF, studies examining VA have focussed on expert-novice
125 performance differences (see Lebeau et al., 2016, for a review). However, such designs might
126 provide obvious conclusions (i.e., experts attend to more relevant stimuli) and not clarify the
127 mechanisms behind improved VA. Also, expert groups often include individuals with the
128 capacity to become experts (i.e., youth academy athletes; Vaeyens et al., 2007) rather than
129 those already with expert status.

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

142 **Executive Function and Visual Attention**

143 Though scant, sport research considering lower-order EFs and VA in the same
144 experiment allude to an association (e.g., Ducrocq et al., 2017; Klostermann, 2020). Scharfen
145 and Memmert (2021) provided one of the few examinations of a complete lower-order EF
146 model and VA and showed small but significant associations between inhibition and visual

147 clarity (i.e., processing non-moving information while stood still), but did not utilise an eye-
148 tracker. Research examining higher-order EFs and VA in athletic samples is more prevalent
149 but typically focuses on expertise group differences (e.g., expert vs novice; Alder et al.,
150 2014). As a result, understanding around the direct relationship between EF and VA in sport
151 is limited. However, there is ample neuroscientific evidence that a relationship between EF
152 and VA exists. For example, both VA and EF are housed in the fronto-parietal network
153 suggesting similar neurological bases (Carrasco, 2011; Gaillard & Ben Hamed, 2022).

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

168 Executive function and VA therefore, may be jointly housed under the perceptual-
169 cognition banner (Broadbent et al., 2015) and neuroscience infers a relationship between
170 these two areas. Specifically, skilled athletes are believed to show distinct gaze behaviour and
171 enhanced visual information processing which promotes improved perception and action

172 coupling (Klostermann & Moeinirad, 2020). Nevertheless, there is currently no synthesis of
173 the EF and VA in sport literature and little comment on the association between these
174 variables. Understanding the strength of the relationship may facilitate future work whereby
175 researchers and practitioners can build training or intervention paradigms that target EF to
176 promote subsequent improvements in VA, or vice versa. It may also allow for more targeted
177 training by highlighting the underlying processes driving VA and information pick up.
178 Moreover, if an association is absent or weak it may be better to target functions individually
179 for intervention work.

180 **The Present Study**

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

196 **Method**

197 **Search Strategy, Inclusion Criteria and Screening**

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

215 Inclusion criteria were established to ensure relevant studies were identified and were:
216 1) published in English, 2) contained original empirical data, 3) had a full-text available at the
217 time of search, 4) quantitatively measured EF in sport, or simulated sport, 5) quantitatively
218 measured VA with an eye-tracker in sport, or simulated sport-settings, and 6) used analytic
219 techniques that allowed us to make a direct or inferred (i.e., indirect) statement about the
220 relationship between EF and VA. Study title and abstracts were initially screened by the first
221 author before being verified in two stages. First, the third author independently screened titles

222 and abstracts with discrepancies discussed between the first and third authors. Next, the
223 second author screened a random 30% of all abstracts. Inter-rater reliability between the first
224 and second author was assessed via the percentage agreement rates (95.15%) and Cohen's
225 Kappa ($\kappa = .87$). Studies selected for full-text screening underwent a similar two stage
226 verification. First, the first author and third author independently assessed full-texts for
227 inclusion with discrepancies discussed until consensus was reached. Next, the second author
228 assessed a random 30% of full-text articles and assessed the suitability for inclusion. Once
229 again, inter-rater reliability was assessed via percentage agreement rates (95.23%) and
230 Cohen's Kappa ($\kappa = .77$).

231 **Quality Assessment and Data Extraction**

232 Quality assessment can help understand whether the reviewed experiments are
233 methodologically sound (Gopalakrishnan & Ganeshkumar, 2013) and adhere to scientific
234 standards (Borenstein et al., 2011). Payne et al. (2019) outlined that a standardised quality
235 assessment instrument is yet to be established for laboratory-based observational studies. As
236 such, study quality was assessed using items from The Appraisal Instrument (Genaidy et al.,
237 2007), The Quality Index (Downs & Black, 1998), and The Evaluation of Research Articles
238 Checklist (DuRant, 1994). As in Payne et al. (2019), the current study included an additional
239 item to assess adherence to ethical procedures. The maximum possible score for study quality
240 was 23 (see Table 1 for items used in the present review) and scores for identified studies are
241 shown in Table 2. The first author completed the quality assessment and it was checked by
242 the third author.

243 INSERT TABLE 1 ABOUT HERE

244 INSERT TABLE 2 ABOUT HERE

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

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

255 **Results**

256 **Search Results**

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

265 **INSERT FIGURE 1 ABOUT HERE**

266 **Quality Assessment**

267 Quality assessment scores for the 22 experiments ranged from 78.3%-100%, (mean =
268 89.1%; see Table 2). Quality assessment revealed one experiment high (scores between 61%-
269 80%) and 21 experiments very high (scores between 81%-100%) in methodological quality
270 (Payne et al., 2019) with six experiments achieving a maximum score in methodological
271 quality (i.e., 100%). Items 1, 2, 4, 5, 8, 11, 14, 15, 16, 17, 18, 20, and 21 were achieved in all

272 experiments within the systematic review. Lowest scoring (i.e., under 80%) items included
 273 item nine (recording precise probability values), 12 (intended sample representing the general
 274 population), 13 (actual sample representing the represented the general population), 22 (the
 275 relevance of findings to the eligible population), and 23 (the relevance of findings to other
 276 relevant populations).

277 **Study Characteristics**

278 *Sample Characteristics, Sport Type and Design*

279 The main information extracted from the experiments is presented in Table 3. The
 280 total number of participants in the reviewed experiments was 696 with an age range of 14.60-
 281 38.00 years (mean = 23.44 ± 2.82 years). Sample size varied between experiments with
 282 sample sizes ranging from 3-95 (mean = 31.64 ± 20.51). Gender information was reported in
 283 18 of 22 experiments. Representation from female participants ranged from 0-100% (mean =
 284 48.42 ± 32.60). The examined sports included: soccer ($n = 5$), volleyball ($n = 2$), basketball
 285 ($n = 1$), gymnastics ($n = 1$), tennis ($n = 3$), badminton ($n = 1$), shooting ($n = 1$), golf ($n = 1$),
 286 table tennis ($n = 1$), multiple sports ($n = 5$), and non-athletes ($n = 1$). Six sports were
 287 classified as open-sports while three could be classed as closed-sports (Singer, 2000). Sport
 288 type could be further broken down into static ($n = 3$), interceptive ($n = 4$), and strategic ($n =$
 289 2; see Krenn et al., 2018, for full definitions). Fourteen experiments used a between-subjects
 290 design, six used a within-subjects design, and two applied a mixed between- and within-
 291 subjects design (Brimmell et al., 2021; van Maarseveen et al., 2018a). Substantial variation in
 292 the labelling of expertise groups was found across the experiments (see Table 3).

293 **INSERT TABLE 3 ABOUT HERE**

294 *Executive Function*

295 Table 3 shows a full breakdown of EF results. Ten experiments (45.45%) examined
 296 higher-order EF and 12 experiments (54.55%) examined lower-order EF. Higher-order EF

297 experiments examined decision-making ($n = 5$), anticipation ($n = 4$), and decision-making,
298 anticipation, and pattern recall ($n = 1$). Lower-order EF experiments had a somewhat even
299 split between inhibition ($n = 5$) and working memory ($n = 6$) with only one experiment
300 examining multiple lower-order EFs (i.e., inhibition, shifting, and updating; Brimmell et al.,
301 2021). Ten different tasks were used to assess EF including: sport-specific video tasks ($n =$
302 8), sport-specific photo tasks ($n = 1$), visual search tasks ($n = 2$), Go/No-Go Task ($n = 1$),
303 Flanker Task ($n = 1$), N -back Task ($n = 3$), Operation Span Task (OSPAN; $n = 3$), Change
304 Detection Task ($n = 1$), Structural Dimension Analysis of Mental Representation Task ($n =$
305 1), and in-situ manipulation tasks ($n = 7$). Five experiments used a combination of tasks (e.g.,
306 Brimmell et al., 2021). Higher-order EFs were more often measured with sport-specific
307 media (video and photo) while lower-order EFs tended to be assessed using computerised
308 cognitive tasks in manipulation designs.

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

318 ***Visual Attention***

319 Table 3 shows a full breakdown of VA results. There was considerable variation in
320 the eye-trackers used across experiments. Six eye-tracking brands were used across the 22
321 experiments including: Applied Science Laboratories (ASL; $n = 8$), SR Research ($n = 4$),

322 SensoMotoric Instruments (SMI; $n = 4$), EyeSeeCam ($n = 3$), Tobii ($n = 2$), and Pupil Labs (n
 323 $= 1$). Twenty-four different outcome measures were reported. Three experiments used one
 324 outcome measure while 19 used at least two outcome measures (range 2-7). Outcome
 325 measures included: number of fixations ($n = 11$), fixation duration ($n = 10$), percentage time
 326 spent viewing key locations ($n = 10$), quiet eye duration ($n = 8$), search rate ($n = 7$), quiet eye
 327 onset ($n = 4$), quiet eye offset ($n = 4$), saccadic latency ($n = 4$), number of fixation locations
 328 ($n = 2$), fixation order ($n = 2$), first fixation time ($n = 2$), percentage of incorrect saccades ($n =$
 329 2), percentage dwell time ($n = 1$), saccadic amplitude ($n = 1$), entropy ($n = 1$), scan paths ($n =$
 330 1), peak saccadic velocity ($n = 1$), quiet eye location ($n = 1$), visual search time ($n = 1$), first
 331 fixation on selection ($n = 1$), final fixation on selection ($n = 1$), number of fixations to correct
 332 option when incorrect ($n = 1$), and inter-fixation rate ($n = 1$).

333 *Executive Function and Visual Attention*

334 All 22 of the included experiments allowed for a direct or inferred (i.e., indirect) EF
 335 and VA comparison. Whether the EF and VA relationship was direct or inferred, the
 336 analytical method used, and key analytical result(s) are presented in Table 4. In sum, nine
 337 experiments allowed direct comments and 13 allowed for indirect comments only. The
 338 analytical methods of experiments allowing for direct comments were ANOVA ($n = 1$),
 339 regression ($n = 2$), mediation ($n = 1$), correlation ($n = 4$), and correlation plus descriptive ($n =$
 340 1). For experiments allowing only indirect comments, the analytical methods included
 341 ANOVA ($n = 10$) and t-tests ($n = 3$). Such techniques were often used as the experimental
 342 design involved comparing groups. More specifically, the indirect experiments involved
 343 comparing participants split based on EF performance ($n = 6$), training vs. control groups (n
 344 $= 4$), and across tasks where demands were differentially manipulated ($n = 3$). Only one
 345 experiment that examined EF and VA found no significant association (i.e., Savelsbergh et
 346 al., 2002). Overall, there appears to be an association between EF and VA (21/22

347 experiments reported significance between at least one measure of EF and VA). Although the
348 type of effect size calculated, the effect direction, and the size of the effect varied across
349 experiments better task performance on one is often associated with better outcomes on the
350 other (see Table 4, for full details).

351 INSERT TABLE 4 ABOUT HERE

352 Discussion

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

367 Quality Assessment

368 The quality assessment check raised a number of issues within the included
369 experiments. Reporting actual p values (item 9) rather than whether a value is greater or
370 lesser than a standardised alpha value (e.g., $p < .05$) was low. Including specific values
371 allows for greater transparency and for readers to interpret the findings themselves (Payne et

372 al., 2019). However, in instances where the p value is less than .001, reporting $p < .001$ is
373 suitable. Though exact p values are important, research has noted that best practice may be to
374 prioritise effect sizes, rather than p values, given that large sample sizes can lead to a
375 significant p value though statistical effects may actually be arbitrary (Sullivan & Feinn,
376 2012). Therefore, it is recommended that future work reports exact p values and the effect
377 size in all relevant statistical analyses.

378 Various experiments were deemed to not meet item 12 (i.e., have a targeted sample
379 that is fully representative of the larger population) nor item 13 (i.e., have an actual sample
380 that is fully representative of the larger population). This was typically due to issues around
381 generalising results of low sample size experiments (average sample size = 31.64) and in
382 experiments examining athletes from a single sport (e.g., an experiment on basketball players
383 is not likely representative of all athletes/sports; van Maarseveen et al., 2018b). It is
384 recommended that future experiments opt for larger samples where possible, as we appreciate
385 recruiting larger numbers, especially large professional/world class samples, is difficult, to
386 allow more definitive inferences. Perhaps more important is to include power calculations
387 that justify sample size to help avoid missing real effects (i.e., underpowered experiments) or
388 over-spending on experimental resources (i.e., overpowered experiments; Green & MacLeod,
389 2015). Recommended methods for power calculations include G*Power (Faul et al., 2009) or
390 using R (e.g., the “simr” package; Green & MacLeod, 2015).

391 Item 22 and Item 23 assessed whether the results could be applied to the eligible and
392 other relevant populations, respectively. As the present review outlined that results were not
393 applicable to all individuals within the target sport, they are therefore unlikely to represent all
394 eligible athletes, or other relevant populations, as a whole. It is important to consider that a
395 number of experiments used lab-settings where ecological validity can be low and
396 transferring results to the “real-world” is difficult. When using a lab-setting we recommend

397 that researchers consider ways to boost ecological validity. For example, in a soccer task
398 Roca et al. (2011) placed cameras at a height and angle reflective of a typical point of view
399 for soccer players. Also, virtual reality environments may provide a useful avenue for
400 increasing task validity (Wood et al., 2021). Some experiments utilised in-situ tasks which
401 may yield higher ecological validity and show that the design is possible. Only higher-order
402 EF experiments considered outcome measures within in-situ tasks. Whereas lower-order EF
403 experiments opted instead to manipulate task demands and not use an outcome measure (e.g.,
404 Klostermann, 2020).

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

419 **Discussion of Findings**

420 *Sample Characteristics, Sport Type, and Design*

421 Age, sample size, and gender provided some interesting points of discussion. Age
422 varied across studies. Given that EF develops with age (Diamond, 2013) caution should be
423 taken when reconciling findings using samples with different ages and therefore, disparate
424 cognitive development. Sample size was generally small so future works are encouraged to
425 use larger samples (to produce more generalisable results) and utilise a priori power
426 calculators (e.g., G*Power or R) to ensure confidence in effects. Indeed, Abt et al. (2020)
427 note that many papers submitted to the Journal of Sport Sciences were without sample size
428 justification and recommend future work includes such calculations. Though it is
429 acknowledged that when working with elite groups obtaining a larger sample can be difficult
430 (Koch & Krenn, 2021). Female representation was around 50% which appears acceptable.
431 However, numerous experiments failed to provide gender information. Increased female
432 representation in high-quality experiments will only help alleviate issues around the
433 misapplication of previous findings from male samples to female samples (Emmonds et al.,
434 2019) and act as a response to recent research calling for greater female specific research
435 (Kryger et al., 2021).

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

445 thus, suggesting an interaction effect. This suggestion, however, remains hypothetical and yet
446 to be tested.

447 *Expertise*

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

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

470 class conclusions must be cautious. This simple reporting method may help future researchers
471 make more informed choices.

472 *Executive Function, Tasks and Outcomes*

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

486 Higher-order EFs are predominately examined using sport-specific video tasks
487 whereas lower-order EFs are often assessed with domain-general cognitive tasks or through
488 task manipulation. The ecological validity and transferability to real word sport contexts has
489 been questioned, though (van der Kamp et al., 2008). Specifically, sport-specific videos are
490 sport-relevant but often lack haptic feedback while domain-general cognitive tasks assess the
491 underlying cognitive procedures but lack sport-specificity. Future work may wish to focus on
492 how performance on EF tasks that include haptic feedback, are sport-relevant, and assess how
493 the underlying cognitive processes can influence subsequent sport performance. Though
494 numerous lower-order EFs were examined, they were often not considered in the same

495 experiment (see Brimmell et al., 2021, for an exception). This is surprising giving the
496 proposed interplay between inhibition, shifting, and updating (Miyake et al., 2000). Also,
497 Miyake et al. (2000), and the present review, note that experiments examining lower-order
498 EFs often utilise a single task which may only allow researchers to comment on task-specific
499 performance. Therefore, we call for more studies to examine multiple EFs in the same
500 experiment and use multiple measures of the same EF to better understand the latent
501 construct over task-specific performance.

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

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

520 (2020) then assessed VA (quiet eye duration) differences across the conditions and assumed
521 differences were due to varying inhibitory demands across conditions. However, this task
522 also placed demands on peripheral attention (participants were asked to fixate centrally) and
523 working memory (targets were shown only for a short time-period). Without any specific
524 outcome measure of inhibition, it is difficult to understand the individual contribution to
525 performance. It is suggested for future work to first include a direct outcome measure when
526 examining lower-order EF.

527 *Visual Attention*

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

542 Rather than explicitly state the advantages of certain VA outcomes, the present review
543 suggests that the importance of VA variables may fluctuate across sports and tasks. For
544 example, Brimmell et al. (2021) found better soccer penalty performance was associated with

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

557 *Executive Function and Visual Attention*

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

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

586 Bishop et al. (2014) reported that an earlier first fixation to the soccer ball predicted
587 greater decision-making efficiency. In this situation, early first soccer ball fixations may
588 support the processing of such visual stimuli (i.e., individual assessment of how to interact
589 with the object) at a certain time while suppressing the want/need to fixate other stimuli (e.g.,
590 upper body; Bishop et al., 2014). The ability to attend to this key visual stimulus then
591 positively influence decision-making efficiency (i.e., faster and more accurate assessments of
592 player movement direction). Interestingly, whether this effect is mono-directional (and if so,
593 which way) or bi-directional remains unclear from the present review (i.e., does VA facilitate
594 EF, vice versa, or do they influence one another). Brimmell et al. (2021) showed that

595 inhibition (a lower-order EF located within the pre-frontal cortex) predicted soccer penalty
596 performance through the mediator of quiet eye duration. This finding may suggest cognitive
597 attentional processes like inhibition influence an individual's soccer penalty performance
598 through their VA while the opposite could be said for Bishop et al. (2014). Though the
599 direction is unclear, the present review shows how neuroscientific theory on EF and VA may
600 extend to sport.

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

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

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

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

641 Together the direct and indirect experiments provide a strong argument that EF and
642 VA relate in a sporting context, though more research is needed. Given the vast number of
643 divergent EF tasks and variables, VA variables, and study designs a meta-analytical approach
644 is beyond the scope of the literature at this time. Though we hope that this systematic review

645 provides future researchers with a starting point to run targeted meta-analyses on more
646 homogenous samples. Such an approach would further our understanding of the strength of
647 the association between EF and VA. It is important to note that, so far, the focus has been on
648 significant relationships between EF and VA. Attention to non-significant effects is also
649 important for understanding the EF and VA relationship given their ability to further inform
650 intervention work.

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

667 Quiet eye variables are very popular in this research area. This could be because
668 lengthened quiet eye durations can facilitate information processing in sport aiming tasks
669 (Lebeau et al., 2016). Despite the popularity of duration, other quiet eye variables were

670 examined by experiments and showed mixed results. Quiet eye offset results were mixed, but
671 most often non-significant. Specifically, Klostermann (2019) and Klostermann (2020
672 experiment 2) showed that when inhibition demands were high, quiet eye offset was not
673 significantly impacted while quiet eye duration was longer and onset was earlier. This may
674 suggest that an enhanced ability to inhibit irrelevant stimuli (perhaps stemming from
675 improved ventral/dorsal suppression; Itti & Koch, 2001) allows earlier quiet eye onset and
676 longer quiet eye durations. In lay terms, helping athletes block distracting visual stimuli may
677 allow the individual to begin selecting and performing the optimal motor action earlier.
678 Caution is paramount here given the reported non-linear relationship between quiet eye
679 duration and performance. Specifically, research from Harris et al. (2021b) showed that
680 simply elongating the quiet eye duration doesn't always lead to performance improvements
681 when target location is known. Also, an increased time internally focusing on upcoming
682 motor action can negatively impact subsequent performance (Beilock et al., 2002).

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

695 **Implications**

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

712 The present review found that there is generally a lack of research examining EFs and
713 VA together. Lower-order EFs comprise the fundamental processes used in perceptual-
714 cognition and likely underpin more complex higher-order EFs (e.g., decision-making). Tasks
715 designed to assess lower-order EFs are also more likely to tap only the targeted function
716 providing a more sensitive examination of the underlying processes at work during gaze. The
717 present review recommends that future work should deploy EF tasks that, where possible,
718 assess both response time and accuracy together (i.e., efficiency scores) and VA tasks that
719 assess some or all of fixation number and duration, fixation percentage to key locations, and

720 quiet eye (despite concerns from Klostermann & Moeinirad, 2020). The key may be deciding
721 on the relevance of certain outcome variables based on the sport and task being examined.
722 The present review also highlights that theoretical accounts from neuroscience may be
723 relevant and transferable to sport. Moreover, cognitive attentional processes that are housed
724 within the fronto-parietal areas of the brain (i.e., EF) relate to VA when considered in a
725 sporting context.

726 **Limitations**

727 Though the present review is an informative resource for understanding the current
728 state of EF and VA literature in sport, it has some weaknesses. Despite following PRISMA
729 guidelines (Moher et al., 2009) and adopting similar criteria to previous reviews (e.g., Payne
730 et al., 2019) the items used for quality assessment were not specific to all the identified
731 studies. Items were adapted from relevant previous works (Downs & Black, 1998; DuRant,
732 1994; Genaidy et al., 2007; Payne et al., 2019) yet the lack of general agreement in how to
733 assess experiment quality can lead to differences in opinion (Payne et al., 2019). Until a list is
734 psychometrically tested criteria may be considered somewhat hypothetical. Further, the
735 review included many experiments covering a variety of sports, EFs, VA measures, and
736 sample characteristics, and this may raise questions around comparing and drawing
737 conclusions from very different works. However, we hope that our review provides a critique
738 of the necessary ‘ingredients’ for future studies and becomes the catalyst for further work in
739 EF and VA in sport.

740 **Conclusion**

741 The examination of EF and VA in sport is an exciting and growing area for
742 researchers and sport practitioners alike. Overall, there appears to be a positive link between
743 EF and VA that may suggest some interplay between the two for sports performance. Though
744 the exact relationship, and between which variables the relationship is strongest or weakest,

745 remains unclear. Moreover, it is likely that this relationship is more nuanced and dependent
746 on the design used, such as type of task, as reported in the neuroscientific literature. The
747 present review highlighted differences in tasks with sport-specific video tasks utilised for
748 examining higher-order EFs and domain-general or manipulation tasks used for investigating
749 lower-order EFs. A number of experiments examining lower-order EFs were limited by their
750 outcome variables (i.e., some including no outcome measures and not all measured both
751 effectiveness and efficiency) and the representation of EFs in relation to VA in the literature
752 was limited (especially shifting). For athletic expertise there is an issue around definition
753 with large discrepancies in how labels are used and a unified method of operationalising
754 expertise is required. In sum, despite very limited direct research, it seems that EF and VA
755 are positively associated and more focus on how this relationship impacts sport performance
756 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).

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
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, 1 st 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 1 st fixate the ball	Overall participants were highly accurate (88.70 ± 0.10%)
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
	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		SR Research	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		SR Research	Time to 1 st 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.

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	Condition was significant, showing that first target fixation was significantly earlier in the high-pressure compared to low-pressure
					Nback and change detection task		Average level of difficulty in the nback and hits and false alarms in CDT		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
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	EyeSeeC am	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	EyeSeeC am	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	EyeSeeC am	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	Tobii T120	Latency of 1 st correct saccade, % incorrect saccades	Working-memory significantly affected the latency of 1 st 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	Tobii T120	Latency of 1 st correct saccade, % incorrect saccades	Working-memory trained group showed improvements in similar OSPAN task and also shorter latency of the 1 st 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
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
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
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	Response accuracy and anticipatory recall score	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
van Maarseveen et al. (2018b)	13 skilled players (16.90 ± 1.30)	Basketball	W-S	100	Decision-making	Response accuracy and response time	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

								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	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	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
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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 1 st 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 1 st 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 1 st saccade latency	$\eta\rho^2 = .19$
Luo et al. (2017) exp 2	Inferred	ANOVA	Working memory trained group had significantly shorter 1 st 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 - $\beta = -.32$ and shoulders - $\beta = -.90$. No. of fixations: ball - $\beta = .45$ and head - $\beta = -.36$
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	$\omega^2 = .23$ 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).

