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Review

FUNCIONES EJECUTIVAS Y AGENTES DEPORTIVOS

EXECUTIVE FUNCTIONS AND SPORT AGENTS

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RESUMEN

El objetivo de la presente revisión es investigar la producción científica de artículos que relacionen a los agentes deportivos (deportistas, entrenadores, árbitros) con las funciones ejecutivas (FE). Para ello, se realizó una búsqueda en WoS que arrojó 703 resultados. Un cribado de las referencias siguiendo las directrices PRISMA dejó 94 artículos con los que se llevó a cabo un análisis bibliométrico y revisión de los temas subyacentes que son FE de dominio general y específico en relación con el deportista, FE y tipo de deporte, detección de talentos, relación entre FE y habilidades específicas en el deporte, FE y posición en el terreno de juego, paradigma del experto/deportista de élite y las FE, FE y otros agentes deportivos y deportistas de élite con discapacidad y FE. En vista de los resultados, si bien parece haber un consenso sobre la importancia de las FE en el deporte, se requieren más estudios longitudinales que certifiquen su valor. Estudios recientes parecen indicar que no es trascendental en la detección de talentos. De la misma manera, existen indicios sobre su rol en deportistas que practican disciplinas abiertas y de oposición y sobre las diferencias existentes entre deportistas y no deportistas o expertos y noveles. Junto con lo expuesto anteriormente, se requieren pruebas que evalúen las FE con validez ecológica y de constructo y es necesario que el valor de las FE se traslade a la investigación con otros agentes deportivos como entrenadores o árbitros.

Palabras clave: funciones ejecutivas, deportista, jugador, entrenador, árbitro, deporte.

ABSTRACT

The present review aims at investigating the scientific production with respect to the link between executive functions (EF) and sport agents (athletes, players, coaches, umpires). For that purpose, a series of searches were carried out on WoS that yielded 703 references. Upon a screening process following the PRISMA guidelines, a total of 94 papers were used to complete a bibliometric analysis together with a scoping review. Some underlying themes were detected, namely, domain-general vs domain-specific EF tests in sport, EF and type of sport, talent detection, EF and sport-specific skills, EF and position on the field/court, expert/elite paradigm and EF, EF and other sport agents and high-performance athletes with disabilities and the role of EF. In light of results, more longitudinal studies are required to confirm their value in athlete´s development, albeit the consensus with regard to their importance. Recent studies indicate the lack of predictive value of EF in talent detection. Likewise, there some indicators that point out to their role in open-skills, strategic sports as well as in the difference found between athletes and non-athletes and experts versus amateurs. In addition, domain-specific tasks are required to assess EF with both ecological and construct validity and EF should also be used to test other sport agents, such as coaches and referees/umpires.

Keywords: executive functions, athlete, player, coach, umpire, sport

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INTRODUCTION

Executive functions (EF) is a term utilized to describe cognitive processes that regulate thinking and action, enabling the concretion of more complex forms of thinking, such as problem resolution, planning decision making or even creativity (Friedman et al. 2006; Friedman & Miyake, 2017; Diamond, 2013, 2014). Researchers seems to agree in regard to the existence of both core EF (CEF), that include inhibition, working memory and cognitive flexibility; and high EF (HEF), such as planning, reasoning, problem solving and metacognition (Vestberg et al., 2017,2020, 2021; Diamond, 2013; Lehto et al, 2003; Huijgen et al., 2015; Miyake et al., 2000). Other authors would also add the affective decision making and the monitoring of behavior with respect to certain emotional states (Kerr & Zelazo, 2004; Zelazo & Müller, 2002; Damasio, 1994; Petrides, 1996). Inhibitory control can be defined as the suppression of dominant but irrelevant response tendencies (Benedek et al., 2014). In turn, working memory consists of the monitoring and coding of incoming information for relevance that leads to a constant revision and replacement of old data stored temporarily with new and more relevant information (Miyake et al., 2000). Lastly, cognitive flexibility refers to the ability to consider simultaneously multiple conflicting representations of a single object or event or quickly adapt to new demands and rules (Jacques & Zelazo, 2005; Huijgen et al., 2015).

Decision making is a high-order mental process that is not only embedded in every athlete´s behavior, whether in practice or competition, but is also present in the rationale of coaches and officials alike. Both the nature of every sport and its internal logic help configure the conditions under which decision-making occurs as well as the mechanisms on which such cognitive process is supported. Beyond skill level, age or expertise, every sport agent needs a certain capacity to perceive and interpret the bits of information coming from the environment, enabling an efficient rapport toward purposeful behavior (Lezak,1995). Sometimes, temporal constraints, uncertainty and opposition pose novel decisional contexts that favor the creation of new options and the ulterior attainment of outcomes (Shallice, 1990). As a consequence, reasoning, problem resolution or planning are complex thinking functions that ensure the process to be adequate and fulfill the goals built upon an optimal cognitive level of development (Collins & Koechlin, 2012; Lunt et al. 2012; Garon et al., 2008). As sport, in all competitional and formative levels, relies more and more on cognitive efficiency to peak when it counts, it seems evident a need for delving deep into the power of EF in sport agents´ performance.

The frequency of scientific publishing on this topic provides information about both the degree of knowledge development and its level of maturity so contributing to dynamiting the scientific community (García-Angulo & Ortega, 2015). Such process makes possible the emergence of collaborations between researchers which, in turn, set the stage for original ideas to arise (Valenciano et al., 2010). Unfortunately, the attempts to examine the incidence of production that relates EF to sport are scant. Thus, Lindahl et al. (2015) carried out a bibliometric study with the purpose of analyzing the different topics in sport psychology from 2008 to 2011. They pinpointed motivation, exercise and health, perceptual and cognitive training and motor skills as the major topics of research in this regard. Within the last topic, some mention is made to the sub-themes attention or anticipation as well as perception and action which, to some extent, may be connected to the concepts of cognitive performance or cognitive functioning. In any case, there is no mention to the executive functions as such in the study. Something similar occurs with Barker's study case analysis in sport psychology (Barker et al., 2013), Clancy's exploration on motivation in sport (Clancy et al., 2017) or Rangeon's inquiry on coaching science (Rangeon et al., 2012). Concurrently, a number of reviews on EF and sport have helped summarize the strength of the effect of these mechanisms on the attainment of athletes´ outcomes (Kalen et al., 2021; Scharfen & Memmert, 2019; Voss et al., 2009; Ivarsson et al., 2020; Sakalidis et al., 2021).

The purpose of the present study is two-fold, as is also its approach. On one hand, it aims at analyzing the scientific production that connects EF to any of the sport agents (whether it is athletes, coaches or officials). Together with this bibliometric exploration, a scoping review will help us analyze the information obtained by detecting recurrent topics on which we will base a subsequent discussion.

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METHODS

As a first step, a process of identification and collection of bibliographic records was carried out through a series of exploratory searches on the Web of Science (WoS) database, without limiting any edition or adding a time frame. Then, a succession of search queries was made, and each step helped refine the final set of descriptors, so avoiding an unnecessary number of references. The search that was used contained the descriptors Executive function* or executive process* or cognitive function or cognitive performance, searched by title and sport* or athlete or player or coach or referee or umpire, search by abstract (see table 1). The final query returned 691 results.

Table 1. Description of the search process

Search steps	Boolean search	Results
Query #1	Sport*AND athlete or player or coach or referee or umpire **AND** executive function* or executive process* or executive control or cognitive function* or cognitive performance **(Title)**	86714
Query #2	Sport*AND athlete or player or coach or referee or umpire or executive function* or executive process* or executive control or cognitive function* or cognitive performance (**Title)** AND Sport*AND athlete or player or coach or referee or umpire **(Abstract)**	31288
Query #3	Sport*AND athlete or player or coach or referee or umpire **(Title) AND** executive function* or executive process* or executive control or cognitive function* or cognitive performance (All Fields)	3140
Query #4 (Final)	**Executive function* or executive process* or cognitive function or cognitive performance (Title)** AND **sport* or athlete or player or coach or referee or umpire (Abstract)**	691

A defined set of inclusion criteria was established by which only papers or book chapters describing research on EF and their link to any sport agent included in the initial search (athletes, players, coaches or officiating personnel) were accepted. Specifically, researchers had to assess EF to compare the cognitive performance of either groups of athletes of distinctive level of achievement or expertise (elite versus sub-elite, expert versus novice) or a group of athletes with sedentary controls. In addition, articles whose topic was children´s involvement in sport with EF and participants were classified as athletes or players were also incorporated. By contrast, papers about the effects of physical activity on children´s EF, the effects of aging on cognitive performance, mental effort, mental fatigue or dual tasks involved in exercise, e-sports and cognitive function, concussion protocols in sport and other topics on EF that were not sport-related were excluded (table 2).

Table 2. Inclusion/exclusion criteria in the present study.

Included	Criteria	Excluded
X	Papers/Book chapters retrievable	
	Conference abstracts	X
X	EF & sport agents (athletes, players, coaches, referees, umpires)	
X	EF levels amongst elite, semi-elite, pro, semi-pro, amateur and/or novice athletes	
X	EF levels within the expert/novice paradigm in sport	
X	EF and talent detection	
	Cognitive training (NT, biofeedback, etc)/electric stimulation effects on athletes´ EF	X
	Athletes´ cognitive performance/cognitive function	X
	Physical activity in children and EF	X
	EF, sport and aging	X
	Exercise and cognitive effort or dual task or mental fatigue	X
	Sport, concussion and cognitive protocols	X
	EF and e-sports	X
	Mindfulness and its effects on athletes	X
	Other topics on EF not sport-related (learning disability, clinical psychology, development disorders, bilingualism, leadership, management, business, law/criminology…)	X

A PRISMA 2020 (Preferred Reporting Items for Systematic Reviews and Meta-analysis) protocol was followed to discard records that were repeated or did not match the demands of the study. This approach incorporates innovative conceptual and methodological aspects associated with systematic reviews (Page et al., 2021). The search yielded a total of 691 references to which an additional 12 from other sources were also included. From the initial 703, 4 were discarded, as no author appeared in the reference. A reading of the titles left aside 394, since topics were not related to the search criteria. Upon

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the reading of the abstract a total of 299 papers remained. An in-depth screening process that entailed the reading of the aims and participants helped discard 205 additional records. A total of 94 articles were included in the analysis. The search was conducted in May 2022.

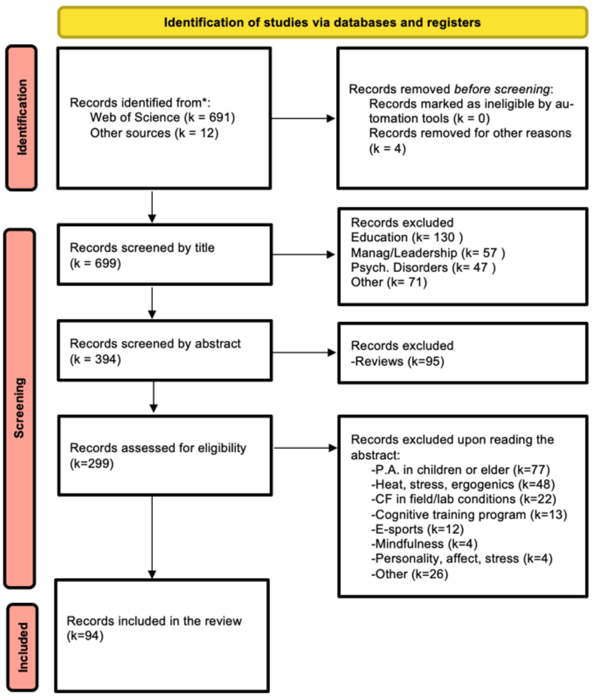

Figure 1: PRISMA flow chart of the literature search.

The total amount of papers included was used to perform an analysis that incorporated the following variables: a) evolution of the research production on the topic of EF and sport agents over the years; b) sports of choice in studies; c) exploration of journal production and the disciplines that represent; d) analysis of research production by gender; and, e) rank of production per country.

RESULTS

Evolution of scientific production

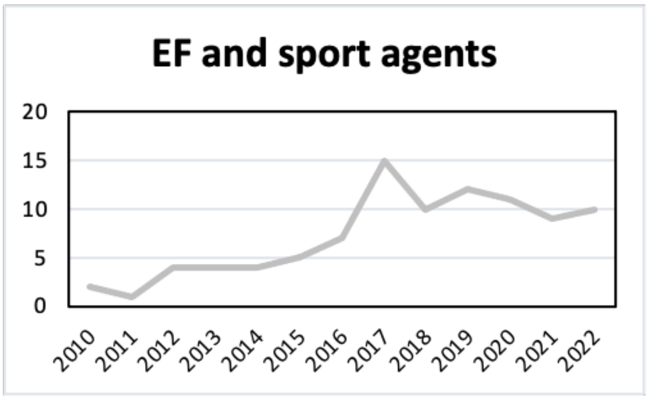

Figure 2: Evolution of the scientific production linking EF and sport agents.

The scientific production that aims at investigating the role of EF in athletes´ development has been increasing over the last ten years with a steep peak in 2017 that has stabilized later on above the 10-paper/year mark over the last five years. Such increase is probably due to the fact that previous studies, which either highlighted EF predictive value as a talent detection tool or helped investigate what part of the variance between sport experts and novices was due to EF, set the stage for other research avenues to crop up. In the year in which that increment took place, several topics were addressed, namely differences between pros and amateurs, lab studies on several EF between experts and novices, the cognitive secrets of the elite athletes and EF power for talent detection. Five years later, a part of the research bulk on EF and sport aims at challenging some of these assumptions (Fig.2)

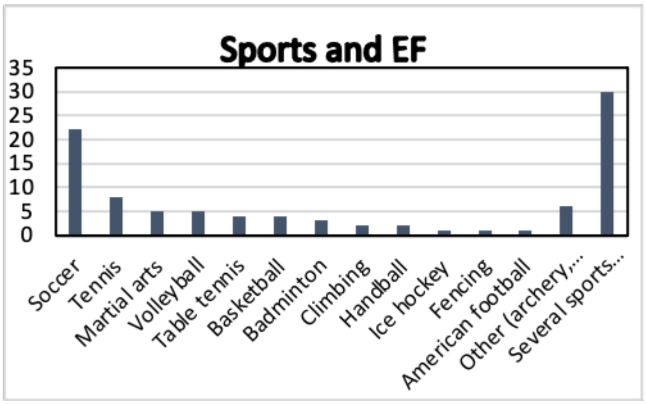

Figure 3. Sports involved in the sample of studies.

Sports involved

A good number of sports have been studied in connection with EF and sport agents. Of them, the most researched is soccer (24.4%) followed in the

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distance by tennis (7.78%), volleyball and martial arts (5.32% each), table tennis and basketball (4.26%) and badminton (3.19%). Not only did soccer triple its pursuers but also some of the work that involves several sports included it (an additional 5.32% shared with other disciplines). One of the reasons why soccer is frequently used is sample size. It is not unusual for soccer teams to have rosters of more than 20 players, and this makes it easier for researchers to collect data compared with individual sports. Another reason might be accessibility to sampling in return for information about the results. There is no doubt that valuable data related to players´ cognitive performance may be of help for elite teams as training enhancers and for talent detection. In addition, the part of the sample that appears as "several sports" in a vast number of cases implies the cognitive assessment of two groups of athletes participating in opposite sport types.

Type of Journals

The journals where the articles included in this study were accepted for publication mostly belong within the realm of psychology. Interestingly, though, only a small portion of the sample was published by sport psychology journals (21.3%), of which Psychology of Sport and Exercise, Journal of Sport & Exercise Psychology and Perceptual and Motor Skills accounted for approximately a 70%. General psychology journals, such as Plos One and Frontiers in Psychology, brought to light a higher number of papers in conjunction than all the sport psychology-related journals. Overall, the percentage of articles belonging to general psychology journals (and other disciplines) represents a 60% of the sample whereas the percentage of articles that fall into the sport sciences´ category lies below 20% (Table 3).

Sample by gender

Sample distribution by gender represents male and female athletes in almost a 50% of the sample. However, when researchers chose only one gender, male samples (39.4%) were significantly prevalent compared to that of female athletes (7.4%). Remarkably, as sports and sample gender are confronted, in soccer studies in which EF are tested in athletes, an overwhelming percentage contains a male-only sample (81.8%, 18 of 22 studies). Moreover, only one study linking soccer and EF is characterized by selecting female players as participants. Lastly, a small number of articles did not specify the gender of participants (6.4%).

Table 3. Summary of journal production per disciplines.

Discipline	Publication	#	%
Sport Psychology (21.27%)	Psychology of Sport and Exercise	6	6.4
	Journal of Sport & Exercise	4	4.3
	Psychology	4	4.3
	Perceptual and Motor Skills	2	2.1
	International Journal of Sport and		
	Exercise Psychology	2	2.1
	Journal of Motor Behavior	1	1.0
	Journal of Clinical Sport Psychology	1	1.0
	Revista de Psicologia del Deporte		
(Other) Sport Sciences (18.08%)	Journal of Human Kinetics	3	3.2
	European Journal of Sport Science	2	2.1
	Journal of Human Sport and	2	2.1
	Exercise	2	2.1
	Journal of Sports Sciences	1	1.0
	Journal of Strength and		1.0
	Conditioning Research	1	
	Acta Gymnica	1	1.0
	International Journal of Sports	1	1.0
	Science & Coaching		
	Journal of Sports Medicine and	1	1.0
	Physical Fitness		
	Human Movement Science	1	1.0
	Physical Activity Review	1	1.0
	Adapted Physical Activity Quarterly	1	1.0
	Journal of Sport and Health Science		
Psychology and other disciplines (60.63%)	Plos One	12	12.8
	Frontiers in Psychology	10	10.6
	PEERJ	4	4.3
	Brain Sciences	3	3.2
	IJERPH	3	3.2
	Sustainability	2	2.1
	Neuroscience	2	2.1
	Neuroimage	1	1.0
	Scientific Reports	1	1.0
	Frontiers in Physiology	1	1.0
	Psychiatry Investigation	1	1.0
	Journal of Neurotrauma	1	1.0
	Acta Psychologica	1	1.0
	Applied Cognitive Psychology	1	1.0
	Cognition & Emotion	1	1.0
	Children-Basel	1	1.0
	Neural Plasticity	1	1.0
	Developmental Science	1	1.0
	Advances in Cognitive Psychology	1	1.0
	Behavioral Brain Research	1	1.0
	Journal of Intellectual Disabilities	1	1.0
	Research in Developmental	1	1.0
	Disabilities	1	1.0
	Intelligence	1	1.0
	Acta Medica Mediterranea	1	1.0
	Journal of Experimental Child		

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Psychology	3	3.2
Other		

Production per Country

Europe is the continent in which research on EF and sport agents is mostly located. Almost two thirds (65%) of the literary production took place in that continent. More precisely, scholars in German academic institutions produce a fifth of the studies included in this analysis (19.1%) followed by their colleagues in Italy (10.6%), Belgium (7.4%) and The Netherlands (5.3%). At a great distance, Asia produces slightly over a fourth (26.6%), especially in Taiwan (12.8%) but also in China and Japan (5.3% each). America and Oceania add the remaining percentage (8.5%).

DISCUSSION

After analyzing the bulk of papers comprising the sample, some recurrent themes underlie, namely domain-general and domain-specific EF in sport, findings regarding athletes´ involvement and the nature of the sport, talent detection and EF, the link between EF and sport-specific skills, players positions and EF, EF and the expert/elite paradigms, and EF in other sport agents.

Domain-general and domain-specific EF

An issue that stands out concerning the assessment of EF in sport is the use of tools measuring a variety of components. One task can be utilized to assess, say, the levels of cognitive flexibility in a group of athletes in a study and the metacognition or the levels of cognitive shifting in other. In addition, it also occurs that two tasks with different protocols may be measuring similar constructs and, while one obtains a large effect, the other does not. Together with that, there is also a conflict with respect to the use of different measures for the same task. For example, data gathered with the TMT A-B to measure CF by researchers from two studies may be analyzed in cm/s, subtracting the time invested in finishing A from the one obtained after doing B or, simply, using A and B as two separate criteria. Consequently, comparisons among studies and generalization of results is far from possible (Table 4). The following sub-sections address the topic of domain-general and domain-specific tasks, as well as the efforts from researchers to ensure both construct and ecological validity.

Domain-general tasks

A wide variety of domain-general tasks has been utilized to assess both athletes´ Core EFs (CEF) and Hot EFs (HEF). The most common tools used to test inhibition involved the Stroop task both in a manual or computerized version (Vesterberg et al., 2012, 2020; Alarcón et al. 2017; Heilmann et al., 2021; Parkin et al., 2017; Faro et al., 2020) as well as the Flanker task (Heilmann et al., 2022; Trecroci et al., 2021; Chiu et al., 2017; Koch & Krenn, 2021; Krenn et al., 2018; Wang et al., 2020, 2017; Yongtawee et al., 2022; Yu & Liu, 2021 Alves et al., 2013; Formenti et al., 2022; Holfelder et al., 2020; Van Biessen et al., 2022, 2017; Musculus et al., 2022) , Go/No-go (Wang et al., 2017; Yu et al., 2018; Faro et al, 2020; Sanchez-Lopez et al., 2014; Bianco et al., 2017), ANT (Verburgh et al., 2014; Huertas et al., 2019; Spanou et al., 2022; Rahimi et al., 2022; Wang et al., 2016) or Stop-Signal (Wang et al., 2013; Verburgh et al., 2014, 2016; Liao et al., 2017; Meng et al., 2019; Brevers et al., 2018; Hagyard et al., 2021; Heppe & Zentgraf, 2019; Huijgen et al., 2015 Beavan et al., 2020, 2022) paradigms. Every protocol is comprised of at least a congruent and an incongruent condition and can also appear in a combined fashion. RT and errors on each condition are normally registered.

Working memory tasks are contingent on the type of construct that is being assessed. On one hand, working memory capacity refers to the storing of transient pieces of information (Engle, 2002) while working memory control is responsible for the handling of information and related processes, such as updating (Baddeley, 2003; Miyake et al., 2000). Team sport athletes, for example, need to manipulate incoming as much information from the environment as possible (capacity) while constantly replacing the old one when the situation require it (updating). Updating is commonly assessed with a digital format of the n-back task, which consists of detecting a series of stimuli (letters, words, images, etc) that have previously appeared on a screen n-times before, responding as fast as possible by pressing a specific key on a keyboard. Thus, Holfelder et al. (2019) used the n-back task to compare the working memory

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levels in a sample of athletes assigned to an elite or amateur group, finding a significant influence of training experience on this task (p= .044) among participants. Also, Vestberg et al. (2017) used a similar paradigm contained in the CogStateSports (CS) to compare top youth soccer players with norms. Not only did players score higher than norms, but they also found that there was a positive correlation between the player´s results on demanding working memory (dWM) and the number of goals made (r=.550, p=.001). Similarly, varied span protocols (digit backward span, spatial span task or operation span task) are utilized to test working memory capacity (Vaughan & Laborde, 2020; Scharfen & Memmert, 2019; Furley & Memmert, 2010, 2012, 2015; Hujgen et al., 2015; Verburgh et al., 2016; Lagner et al., 2015).

A working memory modality that has been submitted to study is visuospatial/visuomotor working memory, or the ability to track or detect pieces of information from the environment. Researchers in the studies included here utilized mainly MOT (multiple object tracking) and UFOV (Use of Field of View) devices to test this ability. For the MOT task, participants are asked to track a varying number of target circles of a certain color (red) moving around on a computer screen together with circles of a different color (green) and indicate their location as soon as the color of the target circles changes (green) (Scharfen & Memmert, 2019). Similarly, UFOV task requires to follow a geometric figure and identify its location on the screen as soon as a black mask that has been previously displayed disappears. Different levels of difficulty are presented (Alves et al. 2013; Berti et al., 2019). On both tasks, accuracy in the detection is measured.

Lastly, a series of tasks have been used to test cognitive flexibility (also known as set-shifting or switching), the ability to tend to different tasks or adapt to environmental fluctuating conditions. Although not limited to them, the D-KEFS Design Fluency Test (DFT) and Trail Making Test A-B (TMT) are the most frequently tests to gather data on this construct. Firstly, the DFT usually comes in a paper-and-pencil format with time constrain and three conditions (60 sec each). In condition 1, participants are asked to complete as many different designs as possible by using four lines to connect five filled dots contained in a cell. In condition 2, each cell has five filled dots and five blank dots. Participants are asked to follow the same rules (five dots, four lines) but now connecting the blank dots and avoiding contact with the filled dots. In condition 3, participants are asked to create as many patterns as possible but alternating filled and blank dots. Repetitions and errors penalize. Correct designs in all three conditions are counted and scaled scores are provided. This task has been used to predict domain-specific expertise in basketball players (Alarcón et al., 2017), soccer (Sartori et al. 2020) and tennis (Ishihara et al., 2019). The TMT, in turn, has been presented in both a digital or paper-and-pencil version. The most common type is the one with A-B conditions (Han et al., 2011; Rincon-Campos et al., 2019; Turner et al., 2022; Heilmann et al., 2021, Ishihara et al., 2018, Holfelder et al., 2020) although other derivations have also been used (Vestberg et al., 2017; Koch & Krenn, 2021; Elferink-Gemser et al. 2018; Lundgren et al., 2016; Heilman, 2021). In TMT-A, twenty-five numbered circles are dispersed on the screen. Subjects are asked to connect the numbered circles starting from 1 as fast as possible. In TMT-B (switching), in turn, numbered circles (from 1 to 13) and circles containing letters (from A to L) on them are scattered on the screen. Participants are encouraged to connect numbers and letters in order starting from one (1-A-2-B and so forth). One aspect that is worth highlighting is diversity in scoring, which is often contingent on the authors´ interests. Thus, time taken to complete both separate components (Turner et al., 2022), time invested and number of errors (Han et al., 2011), the number of correct answers per test (numbers/letters correctly connected in ascending order), error types such as omissions (number or letter), order (number or letter), errors of perseverance, and error corrections (Rincon-Campos et al., 2019), speed (cm/s) and time difference between TMT-A and TMT-B (Holfeder et al., 2020) are representative of the difficulty to compare results from different investigations.

Some authors chose the abovementioned two tasks to gather data in such a way that the TMT measured general features of cognitive flexibility whereas the DFT did it in a more integrative approach. For example, Vestberg et al. (2012, 2017, 2020) and Lundgren et al. (2016) used the DFT as a primary test measuring creativity, response inhibition and cognitive flexibility together with working memory update while also employing the Color-Word interference Stroop test and the TMT as a measure of general executive functions. In addition, these tasks have been also used concurrently to measure two separate constructs, namely cognitive flexibility as a component of the core EF and metacognition as a representation of high-level cognitive functions (Huijgen et al., 2015; Elferink-Gemser et al., 2018). Further studies include both tasks to assess similar components but then are analyzed separately (Yongtawee et al., 2021; Koch & Krenn, 2021).

As highlighted earlier, research on cognitive flexibility was not limited to the DFT and TMT. Additional tools thought to be administered in a digital fashion such as the Task-Switching task (Yu et al., 2017, 2019), the Global-Local task (Ishihara et al, 2018; Berti et al., 2019), and the Letter-Number task (Heilmann et al., 2022) were implemented as well.

Lastly, more comprehensive tasks measuring cognitive flexibility levels in young athletes have been applied, mainly the How many/What number test (Spanou et al., 2022) or the Odd One Out task (De Waelle et al., 2021).

Domain-specific tasks in the lab or on the field

Some interesting attempts have been made to ensure the appropriate assessment of athletes´ EF that extend beyond the traditional realm of cognitive testing. Whether in the lab or on the field, these tools have aimed at fusing sport-specific features with standardized domain-general EF protocols whose purpose is to accurately capture athletes´ EF levels within a valid context (Van der Water et al. 2017, Beavan et al., 2020a, 2022; Wang et al., 2017).

In the lab

Wang et al. (2017) utilized a modified sport-specific attentional cueing paradigm to test both badminton players´ and controls´ anticipatory attention. The task consisted of two conditions, valid and invalid with three types of cues – low shot, backswing and neutral cues. In a valid condition, the cues correctly indicated the position of an upcoming shuttlecock whereas in the invalid condition cues did the opposite. As expected, badminton players´ reaction times were significantly lower in all conditions (valid, invalid and neutral; $p<.05$) compared to those of the controls. A similar approach was followed by Van der Water et al. (2017) who tested the validity and reproducibility of a Stop-Signal based protocol Badminton Reaction Inhibition Test (BRIT) comprised of four components (domain-general reaction time, badminton-specific reaction time, domain-general inhibitory control and badminton-specific inhibitory control) with a group of elite and non-elite badminton players. Good construct validity was shown for badminton-specific reaction time together with concurrent validity but not for inhibitory control. Reproducibility was acceptable for both badminton-specific reaction time and inhibitory control.

Also, in a study by Beavan et al. (2020a) youth soccer players´ visuospatial working memory was tested implementing the Helix, a multiple object tracking device in which participants are asked to detect the position of an increasing number of male soccer players who run around a virtual soccer field on a 7x2m 180º curved screen and found that domain-general and domain-specific EF significantly developed between 10 and 15 years old to slow down during adolescence and accelerate again during early adulthood.

Montuori et al. (2019) used a task-switching protocol between two different tasks that had to be carried out in a random sequence with elite volleyball players. In task A, participants had to judge whether the action showed on a screen was attack-or-defense related while in task B were required to indicate the color of the player´ shirt. Every image was pre-cued, with a rhombus for task A and a square for task B. To assess differences between groups of players (strikers, defenders and mixed) switch trials, repetition trials, switch costs and errors were computed.

Research based on the cognitive component skills approach (Nougier et al., 1991) and the expert performance approach (Ericsson, 2003) encourages scholars to test cognitive skills adopting a naturalistic perspective. Recently, Musculus et al. (2022) set to develop and validate cognitive tasks to measure inhibition and cognitive flexibility in a soccer-specific setting. First, a sample consisting of 77 youth soccer players (M_{age}=15.7) completed a computerized version of the flanker task as well as the number-letter task together with a soccer-specific test requiring the same cognitive skills. Results showed an acceptable convergent validity for the soccer-specific number-letter for response time and accuracy but only for response time (not accuracy) for the soccer-specific flanker task.

On the field

Despite the efforts to find adequate cognitive testing for each sport, very few studies are carried out in domain-specific settings. To examine the relationship between domain-specific cognitive skills and EF, Heilmann et al. (2021) a group of climbers was asked to predict the moves they would have to make to complete a climbing route and remember those moves at the wall. Route difficulty equaled the average of the reported skill level. Together with it, some general cognitive testing was completed (Stroop Color-Word and TMT A-B). Results showed no relation between EF and domain-specific cognitive skills.

Type of sport and EF

Another topic that emerges from the scholarly work included in the present analysis is concerned about EF and the type of sport performed. Four sport-type classifications have been utilized, namely externally-paced versus internally-paced sports (Singer, 2000), interceptive versus strategic or static sports (Mann et al., 2007), open-skills sports versus closed-skilled sports (Knapp, 1967) and team versus individual sports (Cratty, 1973).

Externally paced versus self-paced

Only two studies were included in which externally and self-paced athletes were compared to one another and, again, results are ambiguous and dependent upon the type of task used to measure each EF component. Thus, Jacobson & Matthaeus (2014) found that self-paced athletes scored higher in an inhibition task and externally paced athletes outperformed self-paced athletes on a problem-solving task and decision-making accuracy. These results are likely to be caused by the nature of each sport, for externally paced athletes must deal with situations requiring decision-making under time constraints. In this setting, errors are part of the learning process and frequently forced by the opponents´ pressure. Hence, the urge to take risks in order to gain advantage. Contrary to this assumption, Ballester et al. (2019) found that externally-paced athletes accumulated less errors than their self-paced counterparts ($p<.001$) on the oddball task, a test that measures inhibitory control.

Interceptive versus strategic or, static

A classification of sport types by Mann et al (2007) have been frequently used to examine the role of EF in them. Interceptive sports are any sports that requires coordination between a participant´s body, parts of the body and an object in the environment whereas strategic sports are characterized by a those that involves multiple teammates, make use of tactical configurations on defense or offense and emphasize the importance of focusing on both a projectile and an array of participants. In turn, static sports could be closed, self-paced, and aiming at a target. In this matter, the nature of each sport type and its internal logic renders the allocation of cognitive resources different in intensity and amount. Consequently, it is likely that the cognitive requirements needed for a basketball player to face uncertainty during a game be higher than those in a runner.

When comparing athletes involved in interceptive sports to their static or strategic sports colleagues, the former perform better than latter in rapid visual processing and reaction time. Thus, in a study with university athletes divided into two groups, badminton and track & field, badminton players outperformed track & field athletes on a flanker task, making faster and less variable decisions under congruent ($p<.001$) and incongruent conditions ($p=.015$) (Wang et al., 2017a). Similar results were obtained on the go/no-go paradigm in a study also with badminton players and athletic controls in which the former responded faster (Wang et al., 2017b) and again with similar populations also on the flanker task (Wang et al., 2020), suggesting that differences in motor expertise may be related to different ways in which information is processed and integrated. Recently, Yongtawee et al (2022) found that a group of boxers displayed better visuospatial functioning on the mental rotation task and processing speed on the simple and choice RT compared to both strategic and static sports.

In turn, strategic sport athletes obtain higher scores in core and hot executive functions, the ones that require an integrated effort of the three components. Accordingly, when compared to practitioners of either static or interceptive sports, athletes involved in strategic sports showed significantly higher performance in cognitive flexibility and working memory measures on the DFT and on the TMT A-B (Yongtawee et al., 2022), working memory on the 2-back task and adapted flanker task (Krenn et al., 2018), and executive control with faster RT and higher accuracy in different conditions of the flanker task (Yu & Liu, 2021; Rahimi et al., 2022)

Open-skills versus closed skills sports

Open and closed motor skills sports depend upon the stability or predictability of the environment. While actions in closed motor skill sports are stable and predictable, in open motor skill sports are subject to certain degrees of unpredictability and require a constant adaption. It is speculated that participation in open motor skill sports would enhance the cognitive mechanisms that support decision-making, for athletes are expected to find successful solutions to everchanging tactical problems. Therefore, closed and open motor skills sports would differ in EF measures. Studies showed that tennis players had faster RT compared to swimmers on stop-signal tasks but not on go-no go tasks (Wang et al., 2013a, 2013b). In a related study with badminton players and track & field athletes, the former had low switch cost of RT on a task-switching task although simple RT were similar in both groups. Lower switch cost was present in both the 100% valid and the 50% valid conditions, requiring, respectively, proactive and retroactive control (Yu et al., 2017). In a subsequent query, the same authors also reported shorter switch cost in the 100% and 50% valid conditions in badminton players compared to track and field athletes (Yu et al., 2019).

When the chosen open-skills sports participants are team players, results remain similar. For example, Chiu et al. (2017) compared volleyball players with a group of runners and swimmers and found that volleyball players RT were shorter and responses more accurate in both congruent and incongruent conditions on the flanker task. Similarly, in a study with a group of elite athletes (N=70; M_{age}=23.0), the open-skills sports group showed significantly higher performance in working memory on the 2-back task and cognitive flexibility on the flanker task-switching test in comparison with participants of closed-skills sports group. Author also controlled for past involvement in either closed or open skills sport and found that extensive time spent in open-skills sport practice until the age of 18 was beneficial for faster and more accurate performance on working memory, and cognitive flexibility tasks in elite closed-skills sport athletes (Koch & Krenn, 2021). Likewise, differences between athletes from a different sport modality are present even in studies with samples comprised of women. Pacesova et al (2020) found higher levels of cognitive functions in open-skills sports female athletes compared to closed-skills sports colleagues but no differences between the latter and non-athletes. These results could be partially replicated in young male athletes (M_{age}=22.7), as differences were in favor of the open-skills sports athletes although not in a significant way. Nevertheless, an important finding was the strong negative correlation between the level of cognitive functions and psychological traits, such as impulsivity and neuroticism (Pacesova, 2021).

In a recent study on young athletes involved in either open-skills and closed-skills sports (M_{age}=10.6), authors reported no differences in inhibition and updating between groups but lower switch cost in open-skills sport athletes than their closed-skills counterparts, thus suggesting that the unpredictable nature of open-skill sports may have an effect on the development of EF components, such as cognitive flexibility (Mohring et al., 2022). By contrast, other studies with young athletes (M_{age}=13.9) showed an overall effect for expertise but not for type of sport or the interaction of the two variables (Holfelder et al., 2020).

Team versus individual sports

Four papers confront the effect of EF and the type of sport depending on whether athletes carry it out in group or on their own. With respect to the studies devoted to young populations of athletes are

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conflicting. Whereas some studies highlight the benefits of team sport practice, others point out to the benefits of individual sports. For example, De Waelle et al (2021) reported that team sports´ participation in young athletes (M_{age}=10.4) showed superior EF than self-paced practitioners. Conversely, Giordano et al. (2021) divided a group of athletes by age (7 to 11 and 12 to 15) and sport (martial arts, team sports and sedentary) who completed a series of cognitive tests. Results showed that the martial arts group outperformed the team sports group in WM (p=.029), inhibition (p<.000), distributed attention (p=.002), auditory distributed attention (p=.008) and on the Iowa good play (p=.044). In addition, Spanou et al. (2022) compared both the motor competence and EF of a group of boys and girls (8-12 years old) recruited in Greek sport clubs and participating in either team, individual open-skill or individual closed-skill sports and found that children´s involvement in different sport types (closed-skills sports) discriminated the level of motor competence but not the level of EF. Also, no gender variance was found but age seemed to modulate motor competence as well as EF.

In a study with elite badminton and volleyball players and controls (M_{age}=22.7), Meng et al (2019) found that team sport expertise showed superior motor inhibition (p<.05) and alertness (p<.001) compared to individual open-skills athletes.

Talent detection and EF

Talent detection

A significant corpus of research included in the search devotes to assess EF as a predictor of sport performance and a tool for talent detection (Alarcón et al., 2017; Bisagno & Morra, 2018; Beavan et al., 2020a, 2020b, 2022; Huertas et al., 2019; Ishihara et al., 2019; Lovecchio et al., 2021; Sabarit et al., 2020; Sakamoto et al., 2018; Schumacher et al., 2018; Trecroci et al., 2021; Turner et al., 2021; Vestberg et al., 2017; Balakova et al., 2015; Verburgh et al., 2014). Results are contradictory, though. While some authors underline the predictive power of EF in future performance and encourage its use as a necessary asset for talent detection, others cast some doubts on its usefulness. For example, Verburgh et al. (2014) reported higher levels of motor inhibition on the Stop-Signal task were observed and a larger alerting effect on the ANT test in a highly talented group of youth soccer compared to an amateur youth soccer group with EF measures predicting both groups in and 89%. Similarly, Schumacher et al. (2018) also described significant correlations regarding age and correct responses and percentage of error on a sustained attention task. In addition, Vestberg et al. (2017) found that young elite soccer players (14.9 years old) performed better than the norm on both a demanding WM task and the DFT. Both tests positively correlated with the number of goals the players scored over the season with a strong combined effect (r=.550) still present when controlled for intelligence and age. Moreover, Sakamoto et al (2018) significant differences were obtained on some conditions of the Stroop tests (incongruent tasks) and the DFT (correct responses) in a group of young soccer players (8-11 years old) who were admitted into the program compared to those who were not, even though the determination on admittance was based on technical-tactical aspects of the game. Lastly, in a somehow seminal study, Ishihara et al (2019) showed that the DFT significantly predicted the future ranking of a group of junior tennis players (9-15 years old), so suggesting that EF might play an important role in success years after.

Recent research production, however, challenges the assumption with respect to the predictive value of EF for performance in sport. Thus, Huijgen et al. (2015) in a cross-sectional study compared the cognitive functions of a group of adolescent soccer players (M_{age}=15.4), dividing them into two groups, elite and sub-elite. Elite players obtained higher scores only on the DFT as a measure of metacognition. When controlling for training hours and academic level, only scores in inhibitory control and cognitive flexibility jutted over on the side of elite players. A call for longitudinal work had a response from Beavan et al (2020a, 2020b) whose series of studies aimed at testing the validity of EF as a talent diagnostic tool and found that the developmental trajectories of soccer players´ EF follow patterns similar to that of the general population with an increase during childhood and adolescence (10-15) and a plateau once the players reach the adulthood. In turn, domain-specific abilities run an analogous path with a rather late development in pre-adolescent years (12-15) to achieve little and isolated improvements during early adulthood. Consequently, these authors question the relationship between EF and soccer performance and the inclusion of EF in talent identification since there is not difference between EF in young soccer players and general population. In a similar study with high-performing female soccer players, age explained low to moderate proportions of the variance in cognitive performance. EF performance appeared to increase rapidly during adolescence (12-17) and into the initial stages of adulthood (18-21) but improvements began to diminish further into adulthood. As the authors suggest, female soccer players might only need a reasonable level of EF ability to perform at the highest level (Beavan et al., 2022). The limited impact of sport on cognitive function from the adolescence to the adult stages is not reduced to soccer. Comparable results have also been obtained in a study with junior-beginner to intermediate tennis players (12.6), in which positive correlations between cognitive performance and tennis were stronger only in the younger portion of the sample (Turner et al., 2021).

Relative Age Effect

The topic of relative age effect (RAE) or the consequences generated by the difference between individuals of the same age group (Musch & Grondin, 2001) has also come up in regard to the cognitive functions. In a cross-sectional study, Huertas et al. (2019) submitted a group of young soccer players (n=105, M_{age}=11.8) from two elite youth academies to an array of physical fitness and attentional ANTI-Vea) tasks and divided them into birth quarters (BQ). In addition, expert staff members evaluated their game intelligence from 1 (very weak) to 5 (very good). Results showed that whereas the RAE was statistically significant ($p<.001$), neither attentional measures, game intelligence, anthropometrics or even physical fitness were affected by BQ. Similar results were obtained by Heilmann et al. (2022), who concluded that performance in EF scores could not be ascribed to sports experience, physical maturity, or RAE. Only inhibition measures (RT) on the flanker test were moderated by calendar age.

EF and sport-specific skills

Further studies set to associate EF with domain-specific skills. In this regard, research also reflects some ambiguity. Thus, Scharfen & Memmert (2019) investigated the interplay between sport-specific skills in soccer were associated with cognitive function. Results shown the association of attention breadth and WMC with dribbling skills (respectively, r=.656, r=.562) and the latter with ball control (r=0.669) and ball juggling (r=0.727). Moreover, composite cognitive scores correlated with motor tests scores (r=.614). Also, attention, measured by the D2 task, has been positively correlated with decision-making during the game, skill execution and game performance in youth soccer players (Sabarit et al., 2020) and Stroop scores were positively correlated with a soccer agility task, so discriminating between elite and low-division youth players (Lovecchio et al., 2021). Additionally, a large positive correlation was found between composite EF and the sport-specific scores (r=.41) in young volleyball players (Trecroci et al., 2021). Also in this population, working memory highly predicted the efficiency of attacking skills (Bisagno & Morra, 2018). By contrast, Balakova et al. (2015), after testing the cognitive functions a group of promising adolescent soccer players divided into two groups (more talented and less talented), reported that the talented group was only significantly better on the anticipation task.

Player´s positions and EF

Soccer

Beyond the extant differences between sport types, a handful of papers have also focused on studying whether players occupying different roles on the field or on the court could differ regarding EF requirements. As Vestberg et al. (2017) speculated, different positions are likely to demand specific cognitive profiles and this tendency could also be present in other sports.

However, results are far from elucidating. In soccer, for example, Vestberg et al. (2012) found that DFT scores were not mediated by playing position. Likewise, in a study with elite female players, playing position did not seem to be a strong contributor to the variance associated with most cognitive measures (Beavan et al., 2022). Contrarily, when comparing high-level male soccer players, field players -specially, midfielders but also defenders- scored higher than goalkeepers on the stop-signal task (Beavan et al., 2020a). Similar results were obtained by Schumacher et al (2018) when compared to other roles on the field. Midfielders obtained higher scores in visual RT than strikers (p=.002) and acoustic RT compared to defenders (p=.002), even though sustained attention and anticipation levels were similar. Concurrently, Beavan et al. (2020b) found that forwards had a lower number of correct responses and slower RT on the determination test compared to other positions whereas goalkeepers obtained faster and more accurate responses than defenders.

As the selection process filters young players into their most suitable roles, EF may also help place each player in their right position. Forwards may find helpful being impulsive, so they are able to anticipate to the defenders´ actions. Hence, those findings suggesting a rather precipitous cognitive behavior. On the same note, midfielders must show their poise by pacing their teams´ tempos and constantly look for connection between lines when controlling the ball. Contrary to the assumption, domain-specific experience in a certain playing position could also moderate gains in a variety of EF measures. Thus, adding experience, response inhibition had a noticeable effect with forwards (p<.060) and midfielders (p<.060 and p<.001, respectively) compared to defenders (Beavan et al., 2020b). Consequently, playing positions in soccer might have a limited role in the development of EF over the years.

Other sports

Other researchers have also developed similar studies looking into other sports. For example, Lundgren et al. (2016) set to compare the EF of level A and level B ice hockey players and reported higher scores on DFT on the part of center forwards compared to players in other positions. Like the midfielder in soccer, the center forward is the link between defense and offense being required to make fast decisions based on the location and moves of their teammates and the opponents. These features are likely to demand the ability to efficiently adapt to a changing environment and respond to pressure constraints with accuracy. Like midfielders in soccer or center forward in ice hockey, guards in basketball are expected to select the most appropriate attacking speed, analyze a variety of passing options and refrain from making rush decisions. The cognitive load this role entails sets the stage for highly developed levels of EF. However, compared to forwards, guards exhibited similar results in RT and accuracy rate on a go/no-go task (Chiu et al., 2020). Interestingly, in other sports such as volleyball, EF scores mirror the skills need to perform a role. Strikers must be ready to react quickly after receiving a pass from the setter focusing on the free spaces available on the opponent´s side of the court. Thus, after performing a domain-specific task-switching task, not only did strikers react faster but also had less switch cost than the group of defenders and outside hitters (p<.05). Perhaps because of the need to execute fast, strikers -and defenders- incurred more errors (p<.05) than the outside hitters (Montuori et al., 2019).

Expert/Elite paradigms and EF

As we set to discuss and analyze every academic article included in the present review with regard to the expert/elite/pro paradigm, one of the characteristics that stands out is that of the diversity in the conceptualization (table 5). Thus, elite athletes in different studies vary in age range (from 9.5 to 35), competition scope (national to Olympics) and sport achievement (Olympic medalist versus youth soccer league). In addition, As one tries to match experts´ involvement, variance goes from 5 (Wang et al., 2017a, 2017b) to 10 years (Furley & Memmert, 2010) and the condition of expert is so lax that an athlete with not enough experience in her sport may become an expert only based on skill level (Heilmann et al., 2021). Similarly, an even wider terminology is used for the term pro, which should be used to refer an athlete that makes a living out of sport but is looks only related to sport experience (Berti et al., 2019; Bianco et al., 2017). In the sections that follow, we summarize the findings reported in the papers included in this review with regards to expert versus novices, elite versus sub-elite or amateur athletes and athletes versus non-athletes. In addition, we also comment on research published associating EF with other sport agents.

Experts versus novices

Expertise in sports is associated with proficient modulation of brain activity during cognitive and motor preparation as well as response execution when performing a task related to an individual´s specific sport domain (Wang et al. 2017b). In addition, it modulates unconscious executive control in a way that allows trained athletes to trigger neural correlates associated with visuospatial working memory and attention while keeping the default mode network activated (Meng et al., 2019a; Seo et al., 2012). Compared to novices, expert athletes are characterized by being able to exhibit higher accuracy, shorter RT, and a more precise mental representation of the sport gesture (Kim et al., 2019). In addition, proficient athletes possess a heightened reactive and proactive response inhibition (Brevers et al., 2018; Liao et al., 2017; Hagyard et al., 2021) and a developed capacity to attend to tactical decisions while ignoring irrelevant auditory stimuli together with an ability to successfully tailor their tactical decision making to the internal logic of each situation instead of relying on prepotent inadequate decisions (Furley & Memmert, 2012). Also, super-expert athletes possess higher attention processes that result in greater working memory (Vaughan & Laborde, 2020).

Interestingly, the choice of certain domain-general tasks that measure cognitive abilities may hide actual differences between expert and novices. Thus, Faro et al. (2020) did not find any discordance between black and white belts performance on a Stroop color-word test.

Table 5. Conceptualization of the terms elite, pro and expert in the articles included in the review

Elite	Pro	Expert
-Basketball players competing at the University Basketball Association in Taiwan (Chiu et al. ,2017) -Volleyball players playing in the Italian National Championship (Montuori et al., 2019) -Participants in European and World championships and Olympic Games (Koch & Krenn, 2021; Kren et al., 2018) - Volleyball players recruited at a Sport Development Center in Brazil (Alves et al. 2013) -Top 100 world-class badminton players playing first division in Taiwan (Liao et al., 2017) -Athletes competing @ the Olympics and internationally (Parkin et al., 2017) -Table tennis players (M_{age}=16) selected from the Netherlands table tennis association (Elferink-Gemser et al., 2018) -Athletes from externally-paced and self-paced sports meeting Swann et al.(2015) standards on sport class(Vaughn & Laborde, 2020; Hagyard et al., 2021) -Professional soccer players playing in the Swedish first division (Vestberg et al., 2020) -Youth soccer players (M_{age}=12.7) from a pro youth academy playing at their top division league (Scharfen & Memmert, 2019) -Elite Sport School students with more than 600h/week of extensive training (M_{age}=9.5) (Granacher & Borde, 2017) -Adolescents (M_{age}=14.0) team handball players and track and field athletes from D-national squad (Holfelder et al., 2020).	-Basketball players competing in the ACB league (Spanish 1st division) (Alarcón et al., 2017) -Athletes competing at the National Intercollegiate Athletic Games, with more than 7 years of experience (Yongtawee et al., 2022) -Experienced black belt karateka with more than 4 years of experience (M_{exp}=14±6 8) (Berti et al., 2019). -Boxers and fencers with more approximately 11 years of experience (Bianco et al., 2017).	-Collegiate badminton players with professional training for more than 5 years (Wang et al., 2017a, Wang et al., 2017b) -Basketball players playing for a minimum of 10 years and no less than 4th division in Germany (Furley & Memmert, 2010). -Climbers assigned to the expert group based on self-reported climbing skill level (Heilmann et al., 2021). -Archers from Korean University Archery Association members and part of the National archery team (Seo et al., 2012). -Professional handball players playing in the second league in Germany (Heppe & Zentgraf, 2019).

Elite versus sub-elite, amateur

Young elite athletes are reported to possess higher inhibitory control and cognitive flexibility (Huijgen et al., 2015). Inhibitory response -together with short term memory, working memory and sustained attention- might be related to time spent in sports and outdoors play during childhood (Verburgh et al., 2016). In addition, heterogeneity with regards to sport participation during the first eighteen years of life may be beneficial to increase working memory and cognitive flexibility levels in elite close-skills sports athletes (Koch & Krenn, 2021)

As young elite athletes make their way into adulthood, they seem to preserve similar levels of cognitive performance. Thus, adult elite athletes still displayed higher inhibitory control compared to sub-elite athletes (Elferink-Gemser et al., 2018; Hagyard et al., 2021), even under physical pressure (Parkin et al., 2017). In addition, this section of the sport´s population reacted faster on a stop-signal task (Alves et al. 2013) and also had faster and more accurate responses with the hands on the same modified task in which hand/feet performance was put to test (Heppe & Zentgraf, 2019). Elite competitors obtained higher scores on sustained attention tasks, albeit no differences were found on the mental rotation or 2-choice RT tasks when compared to recreational athletes (Heppe et al., 2016), Interestingly, elite athletes´ levels in some EF components may be contingent on the position on court in team sports (Montuori et al., 2019).

Athletes vs non-athletes

Overall, results indicate a superior performance on the part of the athletes compared to non-athletes. Athletes respond faster than non-athletes on the go/no-go task although there are no differences in response accuracy (You et al., 2018). Other studies using the same paradigm reported similar effects in inhibitory control together with a shorter RT in conditions in which uncertainty is high and time to react is limited but only in open-skills sports, not in closed-skills sports athletes (Wang et al., 2013b). Interestingly, further research reports analogous results for the flanker task paradigm (Chiu et al., 2017), stop-signal task (Wang et al., 2013a; Meng et al., 2019), visual search and across sport disciplines (tennis, table tennis, volleyball). In addition, a significant amount of research provides consistent evidence to support athletes´ ability to deal with a changing environment, which would highlight higher levels of cognitive flexibility. Thus, athletes displayed less switch cost on the task switching task (Alves et al. 2013) not only when conditions were stable (100% valid condition) but also when tasks were loaded with high uncertainty levels (50% valid conditions (Yu et al., 2017, 2019) and only in open-skills (sports (Yu et al., 2019; Meng et al., 2019b; Pacesova, 2021). Moreover, athletes showed more elevated levels of executive control network activation -which denotes higher ability to monitor and resolve conflict- but no differences for alert or orientation networks (Wang et al., 2016). No gender-related differences were found (Pacesova et al., 2020). Contrarily, Furley & Memmert (2010) reported no significant differences between experienced basketball players and college students on the Corsi Blocks Tapping Task.

When young and prepared athletes are compared with non-athletes, results are mixed. While some studies reported better inhibitory control, cognitive flexibility and working memory in young athletes compared with non-athletes (Giordano et al., 2021; Sartori et al., 2020), in a longitudinal study, Granacher & Borde (2017) found no differences in cognitive performance between pre-adolescent athletes from an elite sport school (M_{age}=9.5) and an age-match group from a regular class, even as there was a significant variance in training volume per week among groups (620min/week versus 155 min/week).

EF and athletes with disabilities

Research included in the search focused on three aspects: characteristics of athletes with disabilities (Van Biesen et al., 2016a, 2016b, 2017), differences between athletes with disabilities and non-athletes (Di Russo et al., 2010) and between the former and athletes without disabilities (Van Biesen et al., 2022, 2016b). Results indicated that athletes with physical disabilities respond slower to go/no-go protocols, even though intra-individual differences showed that wheelchair athletes´ scores -not just on RT but also on switch cost and errors- were comparable to those of non-athletes (Di Russo et al., 2010). Similar findings were reported in studies with athletes with intellectual disabilities, for RT was also slower and scored lower compared to athletes without disabilities on EF and cognitive abilities, albeit some obtained higher scores than average norm values (Van Biessen et al., 2016b). As expected, differences in EF were found between athletes with intellectual disabilities and without disabilities. In this matter, inhibition and working memory seem to be strongly associated with IQ and fluid intelligence (Van Biesen et al., 2022). Lastly, tactical proficiency in this population is also affected as a part of its variance was attributed to simple reaction time and spatial visualization (Van Biesen et al., 2016a).

Other sport agents

A final section is devoted to the link between the role of EF with other sport agents, namely referees and coaches. Pietraszewski et al. (2014) sought out to explore the executive attention of a group (N=53; M_{age}=32.7) of top soccer referees and assistants referees with different levels of expertise (International FIFA, Extra-class, First league level). Significant differences were found between assistant referees and referees. Not only did the former did better for the precision index of the Toulouse-Pieron test but they also made less mistakes. When comparing groups according to the level of expertise, no significant differences stood out between extra-class and international referees for number of errors whereas extra-class and international referees differed from first league referees significantly (p<.001, p=.01, respectively). Similar results were obtained when controlling for precision. Assistant referees are likely to possess higher levels of executive attention due to domain-specific attributions, such as assessing the offside line, follow both the in-game and off-game sequence of actions, etc., while referees are more focused on in-game play.

As for coaches, no study has addressed the link between coaches´ decision making and the role of EF in them. However, some research did ask coaches to rate the player´ game intelligence so as to associate it to cognitive functions (Huertas et al., 2019; Vestberg et al., 2012, 2017,2020; Scharfen & Memmert, 2021; Lundgren et al., 2016). For example, Vestberg et al. (2020) asked professional coaches to rate the game intelligence of a group of Swedish First Division soccer players who were divided into those who played for their national team and the ones who did not. As expected, the first group scored significantly higher than the second. Moreover, a positive - although moderate- correlation was found between the DFT scores and game intelligence (r=.37, p=.008). Interestingly, coaches were able to use their knowledge base and expertise to distinguish between players with high and low EF profile. In the same vein, coaches´ rates were used in a study with youth soccer players in which the RAE was investigated (Huertas et al., 2019). Similar to cognitive functions, game intelligence scores were not related to birth quartiles. Conclusions are important because they highlight the role of scouts in talent detection and also pave the way for an indirect way for coaches and researchers to assess the ability to recognize in-game patterns and display flexibility in dealing with the environment (Lundgren et al., 2016). Finally, coaches´ ratings of sport performance were also positively correlated to better inhibition control (Hagyard et al., 2021), albeit not in other studies, in which this component was not correlated with that same rating and showed small to moderate effects on WMC and CF (Scharfen & Memmert, 2021).

CONCLUSIONS AND FUTURE DIRECTIONS

The role high-order thinking plays in sport demands a deeper study of how cognitive constraints affect not only decision-making competence and problem resolution but also forward planning, at all levels of performance. Executive functions are the pillars on which high-order thinking is sustained and yet, although some interest in the topic has stirred research production significantly for the last five years, there is still a vast area that remains unexplored. A part of the scientific groundwork is focused on comparing how cognitive skills work in specific populations in regard to experience, sport excellence or type of sport and how much EF contribute to such inter-group variance. Different focal points of research lie on either assessing how different EF are affected by long-term treatments or how a variety of experimental conditions normally developed in a lab have an impact on them. Some EF are even highlighted to predict future performance levels in athletes.

Some lines of research have a wide margin for enquiry, tough. For example, although there has been interesting attempts in a form of longitudinal studies that help the scientific community to shed some light on how EF evolve over the time and if the latter may be helpful to actually predict athlete´s success, whether in an individual or team setting, data is far from concluding. In addition, more research should also be devoted to the study of how other sport agents´ EF levels, such a referees, coaches or even administrators, not just athletes, may influence their decisions and guarantee their success. Accordingly, research on how coaches´ cognitive functions may effect a positive momentum -or avoid a negative one- on their athletes that ensure a successful performance should provide valuable information on the importance of implementing cognitive enhancing programs for coaches to boost their capabilities. Likewise, the sport community could benefit from research that sets out to know whether different levels of EF and a similar degree of excellence among coaches could impact either their win-loss records or their ability to lead young athletes to a high-performance status. Finally, this analysis has also set the stage for claiming the creation of a sport-specific array of tools measuring EF that make data more reliable.

Additionally, the authors of this research acknowledge some limitations. For example, although the present review has sought to include all the current literary references regarding EF and their link to a variety of sport stakeholders, the use of supplementary databases such as Scopus could have also been helpful to add further scientific work that might have been overlooked due to the rather restricted use of a single database. Therefore, it is recommended that future research on the topic consider using more than one database so as to reduce such issue.

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