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## **Relaciones entre el tipo de deporte practicado y las funciones ejecutivas de control en niños y adolescentes: una revisión sistemática**

### **Relationships between type of sport played and hot and cold executive functions in children and adolescents: a systematic review**

### **Relações entre o tipo de esporte praticado e as funções executivas de controle em crianças e adolescentes: uma revisão sistemática**

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#### **RESUMEN**

En los últimos años, se ha propuesto una división de las funciones ejecutivas en frías y calientes. Las frías se refieren al funcionamiento cognitivo en situaciones descontextualizadas y afectivamente neutras, evaluando dimensiones como la memoria de trabajo, el control inhibitorio y la flexibilidad cognitiva. En cambio, las funciones calientes se refieren a la capacidad de autorregulación en contextos con implicaciones emocionales y motivacionales. Varios estudios han destacado el impacto del deporte en el desarrollo de las funciones ejecutivas, aunque pocos estudios han analizado conjuntamente ambas dimensiones. El objetivo de esta revisión sistemática fue analizar los estudios existentes que analizan conjuntamente el impacto del deporte en ambas dimensiones de las funciones ejecutivas en adolescentes. Se llevó a cabo una revisión sistemática utilizando el método PRISMA para lograr este objetivo. Las bases de datos consultadas fueron Web Of Science (WOS), Scopus, PubMed, PsycInfo e índices del CSIC, entre 2000 y 2023. Finalmente, se incluyeron 8 artículos en la revisión. Los resultados revelaron relaciones significativas entre el deporte y las funciones ejecutivas, especialmente en deportes abiertos como el fútbol o el hockey sobre césped, siendo más relevantes que las modalidades cerradas como el atletismo o las artes marciales. Estos hallazgos son de gran interés ya que podrían ser significativos para promover un tipo particular de deporte como los deportes abiertos durante el desarrollo cognitivo de niños y adolescentes.

**Palabras clave:** Adolescencia; deporte; cognición; función ejecutiva; deportes abiertos.

#### **ABSTRACT**

In recent years a division of executive functions into hot and cold has been proposed. Cold ones refer to cognitive functioning in decontextualized and affectively neutral situations, evaluating dimensions such as working memory, inhibitory control, and cognitive flexibility. Instead, hot ones would refer to the capacity for self-regulation in

contexts with emotional and motivational implications. Several studies have highlighted, the impact of sports on the development of executive functioning, although few studies have jointly analyzed both dimensions. This systematic review aimed to analyze existing studies that jointly analyze the impact of sport on both dimensions of executive functioning in adolescents. A systematic review using the PRISMA method has been carried out to achieve this objective. The databases consulted were Web Of Science (WOS), Scopus, PubMed, PsycINFO, and CSIC indexes, between 2000 and 2023. Finally, 8 articles were included in the review. The results revealed significant relationships between sports and executive functions, especially in open sports such as soccer or field hockey being more relevant than closed modalities such as athletics or martial arts. These findings are of great interest as they could be significant to promoting a particular type of sport like open sports during cognitive development of children and adolescents.

**Keywords:** Adolescence; sport; cognition; executive function; open sports.

## RESUMO

Nos últimos anos, foi proposta uma divisão das funções executivas em quentes e frias. As frias referem-se ao funcionamento cognitivo em situações descontextualizadas e afetivamente neutras, avaliando dimensões como memória de trabalho, controle inibitório e flexibilidade cognitiva. Em vez disso, as quentes referem-se à capacidade de autorregulação em contextos com implicações emocionais e motivacionais. Vários estudos destacaram o impacto dos esportes no desenvolvimento das funções executivas, embora poucos tenham analisado conjuntamente ambas as dimensões. O objetivo desta revisão sistemática foi analisar estudos existentes que investigam o impacto do esporte em ambas as dimensões do funcionamento executivo em adolescentes. Foi realizada uma revisão sistemática utilizando o método PRISMA para atingir esse objetivo. As bases de dados consultadas foram Web Of Science (WOS), Scopus, PubMed, PsycInfo e índices CSIC, entre 2000 e 2023. Finalmente, foram incluídos na revisão 8 artigos. Os resultados revelaram relações significativas entre esportes e funções executivas, especialmente em esportes abertos como futebol ou hóquei de campo, sendo mais relevantes do que modalidades fechadas como atletismo ou artes marciais. Esses achados são de grande interesse, pois podem ser significativos para promover um tipo específico de esporte como esportes abertos durante o desenvolvimento cognitivo de crianças e adolescentes.

**Palavras-chave:** Adolescência; esporte; cognição; função executiva; esportes abertos.

## INTRODUCCIÓN

Diamond (2013) defined Executive Functions (EF) as sets of high-level mental processes that allow controlling, regulating and directing behavior to achieve specific goals. Although there is no consensus on their definition, several authors agree that they are multidimensional constructs (Pino Muñoz & Arán Filippetti, 2019; Reyes et al., 2015) whose function is to respond to a demand from the environment (Rebollo & Montiel, 2006; Rodríguez, 2021). García Bartolomé (2021) and Tirapu Ustarroz & Luna Lario (2008) observed that the efficiency of adaptation to the environment depends on executive functions, since they are responsible for managing information and generating responses to the environment (Braidot, 2008).

Despite this, most theoretical models include dimensions such as planning, cognitive flexibility,

inhibition or working memory (Bull et al., 2004; Soprano, 2003). Traditionally, these variables have been associated with the ability of individuals to perform a task, which is usually decontextualized and performed under laboratory conditions. To differentiate those dimensions of behavior that could be more conditioned by everyday environments, several authors have proposed a division of EF into cold and hot. This division offers a deeper insight into how executive functions operate in daily life by emphasizing the impact of emotions and motivation. "Cold" executive functions involve abstract cognitive skills like planning and organization, independent of emotions. In contrast, "hot" executive functions are tied to emotional regulation and decision-making based on emotional value. This distinction enhances understanding of executive functions in real world scenarios, where cognitive and emotional demands intersect and influence daily task performance (Poon,

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2018; Prencipe et al., 2011; Zelazo et al., 2005; Zelazo & Carlson, 2012; Zelazo & Müller, 2002). To differentiate those dimensions of behavior that could be more conditioned by everyday environments.

Thus, on the one hand, cold EFs would be defined as processes of a cognitive nature that are shown in decontextualized and affectively neutral situations, such as working memory, inhibition and planning when evaluated in a laboratory situation (Marino, 2010; Pesce et al., 2021; Prencipe et al., 2011). On the other hand, hot EFs would refer to the abilities that allow humans to function optimally in specific contexts, such as the capacity for self-regulation in contexts influenced by emotions, behaviors determined by motivational processes, or decision making in natural environments, etc. (Marino, 2010; Pesce et al., 2021; Tsermentseli & Poland, 2016). This division would be motivated by the need to improve the ecological value in the assessment of executive functions and to determine which aspects may determine differences between cold executive assessment and actual behavior occurring in everyday contexts (Pesce et al., 2021).

Cold cognitive abilities are cultivated in relatively abstract and decontextualized conditions, devoid of emotional influences (Graziano, 2009). These skills necessitate a logical and critical approach, encompassing tasks such as planning, verbal reasoning, problem-solving, and working memory. Additionally, they involve capacities such as sustaining attention, behavior monitoring, and inhibition (Martínez & Victoria, 2010). Conversely, hot cognitive abilities emerge within contexts that demand personal interpretation, giving rise to emotions, motivation, or a tension between immediate gratification and long-term rewards (Valencia et al., 2008). These affective skills encompass aspects such as social cognition, emotional regulation, emotion-influenced decision-making, and the ability to defer gratification.

This differentiation is based on neuroanatomical and functional differences. The dorsolateral prefrontal region is associated with "cold" executive functions, while the "hot" functions are linked to the ventral and medial regions. The dorsolateral region is involved in objective tasks such as planning and problem-solving, which are disentangled from emotions (cold

functions) (Aguirre Echeverría, 2020; del Rosario, 2015; Pérez Pichardo et al., 2018). The "hot" executive functions, responsible for emotional regulation, modulate aspects like self-control (Chino Vilca & Zegarra Valdivia, 2019; Pérez Pichardo et al., 2018), whereas the "cold" ones focus on objective thinking (Domínguez González et al., 2018). Both contribute to well-being (Fraile Aranda, 2010; Martín Martínez et al., 2015), integrating emotions into decision-making, in a process that involves evaluation and emotional processing in these brain areas.

In relation to executive functioning and active lifestyles, it has been observed that the practice of physical-sports activity could be relevant for the correct development of EF in adolescence. For example, Domínguez González et al., (2018) found that the regular practice of physical activity was associated with better performance in tasks requiring inhibitory control and cognitive flexibility in adolescents. Likewise, Fraile Aranda (2010) pointed out that physical-sports activity contributes to the development of moral reasoning in young people, since it allows them to acquire values and ethical principles and encourages responsible decision-making. On the other hand, Martín et al. (2015) argue that physical activity can also improve working memory in adolescents, since it requires the integration of sensory, cognitive, and motor information, which can promote the development of more efficient neuronal connections and the optimization of brain networks involved in memory. Research specifically finds that variables such as sports experience in adolescents and children could be a variable that determines better development of EF (Palao Andrés, 2003; Sánchez & Adelantado, 1995; Talpone, 2020).

On the other hand, characteristics such as the open or closed nature of the sport could also condition the evolution of EF at these ages (Talpone, 2020). In relation to this study, Sánchez & Adelantado (1995) made a distinction from motor praxiology about open and closed sport. Motor praxiology is a branch of sports behavior from which sports are classified into two large groups: open sports (or open skill) and closed sports (or closed skill). Open sports are characterized by unpredictable actions that do not depend directly on the actions of the opponent, which

implies a motor communication and counter-communication in praxeological terms (Talpone, 2020). Whereas closed sports are those in which a player's actions are determined by the opponent's actions, which limits the possibility of unpredictability and motor communication. In these sports, strategy and performance depend largely on the player's ability to anticipate and respond to the opponent's actions (Palao Andrés, 2003).

Likewise, the existing literature has highlighted that sports practice in adolescence can have a positive effect on the development of executive functions (EF), especially those involved in decision making and impulse control in emotional situations (Broche Pérez & Cruz López, 2014). Authors such as Kopp & Jekauc (2018) propose that emotions are involved in adolescent sport behavior. During sport, children and adolescent athletes are faced with constant decision making with emotional involvement, so they may develop better EF than children and adolescents who do not practice sport (Mínguez & Ramos, 2016).

On the other hand, Escolano Pérez & Bestué (2021) state that sports training in young people can improve the ability to inhibit automatic responses and reduce reaction time to emotional stimuli. Similarly, González Hernández et al. (2019) found that adolescent athletes have a greater capacity for planning and organization, which is related to a greater development of working memory and cognitive flexibility. On the other hand, Stein et al. (2017) showed that young athletes have a greater capacity for resistance to distraction, which is related to better performance in tasks that require selective and sustained attention. Likewise, sports practice in adolescence can promote the development of social and emotional skills, such as empathy and emotional self-regulation, which are essential for moral reasoning and responsible decision making (Fraile Aranda, 2010).

After an exhaustive review of the current scientific literature, it was found that there are several systematic reviews on the relationship between physical exercise and executive functions in adolescents (Hernández Mendo et al., 2019; Peñalosa et al., 2022; Pérez Romero et al., 2023; Quintero López et al., 2021; Valenzuela et al., 2021). However, it has been observed that these reviews take into consideration jointly the variables type of

sport and the two-dimensional analysis of EF (hot and cold). For this reason, the aim was to fill this information gap and delve into the effects of the type of sport practiced on executive functions in childhood and adolescence, considering the cold and hot dimensions of EF.

This review aims to collect the characteristics of sports programs and the effects they have on executive functions, differentiating between hot and cold executive functions. The purpose of this study was to carry out a systematic review of studies investigating the relationship between sports practice and hot and cold executive functions, also considering the type of sport. Consequently, the aim was to determine whether the type of sport practiced determines a higher level of hot and cold executive functioning. For this purpose, studies analyzing executive functioning in two or more sports disciplines were chosen as fundamental criteria. In this way, we seek to discern whether there are differences between the development of executive functions in adolescents and children based on the sport practiced. One of the strengths of this systematic review is that it focuses on hot and cold executive functions, which allows us to evaluate the impact of sport on both types of executive functions.

In addition, the focus on adolescents and children is relevant, as this is a population in which sport and EF development can have a significant impact on long-term health and well-being. Another strength of this review is the selection of studies that compare the effects of different sports on EFs by attending to their bidimensionality (cool and hot). This search and analysis strategy allow us to identify whether there are differences in the development of hot and cold executive functions based on the sport practiced. The aim was to extract from each article the following data: sample, objective, study design, materials and methods, main variables, time, results, and conclusions. In order to address the study's objective, which was to determine whether the type of sport practiced determines a higher level of executive functioning in both "hot" and "cold" dimensions.

## MATERIAL Y MÉTODOS

The search approach, along with selection criteria and additional details, was previously noted in the prospective registry for PROSPERO systematic

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reviews (CRD42023430663). This systematic review was constructed based on the PRISMA statement (Moher et al., 2014; Page et al., 2020; Tilp et al., 2020). This statement aims to improve the quality of presentation of systematic reviews and meta-analyses by providing a list of 27 items and a flow chart consisting of four phases: identification, selection, eligibility, and inclusion. The purpose of this tool is to facilitate the process of evaluation and selection of relevant studies to be included in the review, ensuring transparency and reproducibility of the search and study selection process. Seven sections detailing the fundamental elements of systematic review methodology are presented. These include terminology, formulation of the research question, identification of studies and data extraction, assessment of study quality and risk of bias, data pooling and consistency analysis, and selective publication bias of studies or results. The purpose of these sections is to provide clear and concise guidance for conducting high-quality systematic reviews and to ensure the reproducibility and transparency of the process. And the PEDro scale was also used as a criteria list for assessing the quality of randomized clinical trials for conducting systematic reviews, developed through Delphi consensus. In this case, for this review, only criterion 1 was met. However, most of the criteria from the PEDro scale were met in the articles included in the present review.

### 2.1. Eligibility criteria:

Inclusion criteria: All the studies included in this project have similar characteristics: 1) The sample is human, healthy and under age (children and adolescents 8-17 years old); 2) The research design, choosing all the studies present an experimental intervention, or quasi-experimental or comparative-associative; 3) The language in which they are written, admitting: English and Spanish; 4) The year of publication of the studies from 2000 to 2023; 5) The type of document, including only articles; 6) That they evaluate executive functions through validated tests tailored to the specific sample type (for example, the Stroop Test is a validated measure of cognitive flexibility); 8) That they compare one or more type of sport with the development of EF.

These variables were chosen as inclusion criteria for the systematic review because they are the variables that have been used as references in other systematic reviews (Fernández García et al., 2021; Holfelder et al., 2020). In addition to being of interest to the authors of the review.

Exclusion criteria were: 1) The type of sample, excluding studies that present samples with cognitive disorders such as ADHD.

### 2.2. Bibliographic search

The databases used in this review were: *Web of Science (WOS)*, *Scopus*, *PubMed*, *PsycInfo*, *ÍnDICES CSIC*. The date of the last search performed was March 14, 2023. As well as the same list of words, but in Spanish. The Boolean command "AND" was used to group the aforementioned terms. In each of the bases the proceeded was similar but not the same way since an adapted search phrase was designed for each base. Before arriving at the construction of the final search phrase for each database, possible combinations were tested with the following list of words: "sport", "Acrobatics", "aquathlon", "Aerobic", "Aikido", "Chess", "mountaineering", "Martial Arts", "athletics", "motor", "athletics", "mountaineering" and "martial arts". athletics, motoring, Badminton, Basketball, handball, Baseball, billiards, bodyboarding, bodyboarding, handball, baseball, basketball, basketball and basketball. bodyboarding", "boxing", "Calisthenics", "Mountain Races", "Hunt", "Cycling", "Circuit Force", "cricket", "Croquet", "Curling", "sport dance", "darts", "horse riding", "fencing", "speleology", "Ski", "Free operation", "soccer", "football", "aussie football", "indoor football", "Gym", "Rhythmic gymnastics", "Golf", "Weightlifting", "equestrian", "ice Hockey", "grass field hockey", "roller field hockey", "throwing", "Judo", "Karate" GO-KARTING, Kendo, Kendo. , "kick boxing" , "lacrosse" , "motorcycling" , "motorboating" , "swimming" , "paddle" , "skydiving" , "paragliding" , "Parkour", "Skating" , "Vasca ball" , "modern pentathlon" , "petanque" , "petanque" , "petanque" , "Canoeing" , "Canoeing" , "pole" , "pole" , "Rowing" , "Rugby" , "Rugby" , "Rugby" , "Rowing" , "Rugby" , "Trekking" , "Trekking" , "snowboarding" , "snowboarding" , "snowboarding" , "snowboarding" , snowboarding , snowboarding ,

*softball* , *softball* , "Sumo" , "superbikes" , "supermotos" , "sailing" , "sailing" , "sailing" , "sailing" , "sailing" , "sailing" , "sailing" , "sailing" , "Sail" , "Sail" , "taekwondo" , "taekwondo" , "Taekwondo" , "Tennis" , "Archery Tennis, archery, Triathlon, Triathlon , UltraTraid , Candle , beach volleyball , "Volleyball" , "Volleyball" , "water polo" , "water polo" , "tennis" , "water polo" , "windsurfing" , "Yoga" , "compare sport" , "compare sport\*") and ("executive function" working memory, set shifting, response inhibition , "multi-tasking" , "attentional control" , "attentional control" , "error detection" , "error detection" , "problem solving" , "performance" , "problem solving" , "performance" , "monitoring" , "cognitive flexibility" , "cognitive flexibility" , "performance" , "performance , cognitive flexibility , fluency emotion , regulation , "regulation" , "self-referential" , "self-referential" , "self-referential" , "self-referential" , "reward processing" , "social" , "reward processing" , "social cognition" , "delay discounting" , "delay discounting" , "delay discounting" , "delay discounting delay discounting, affective decision making.

## RESULTADOS

However, for each database, a particular phrase was chosen since it yielded the most related articles. As mentioned above, five databases were used, and the search strategy in the five databases is shown below.

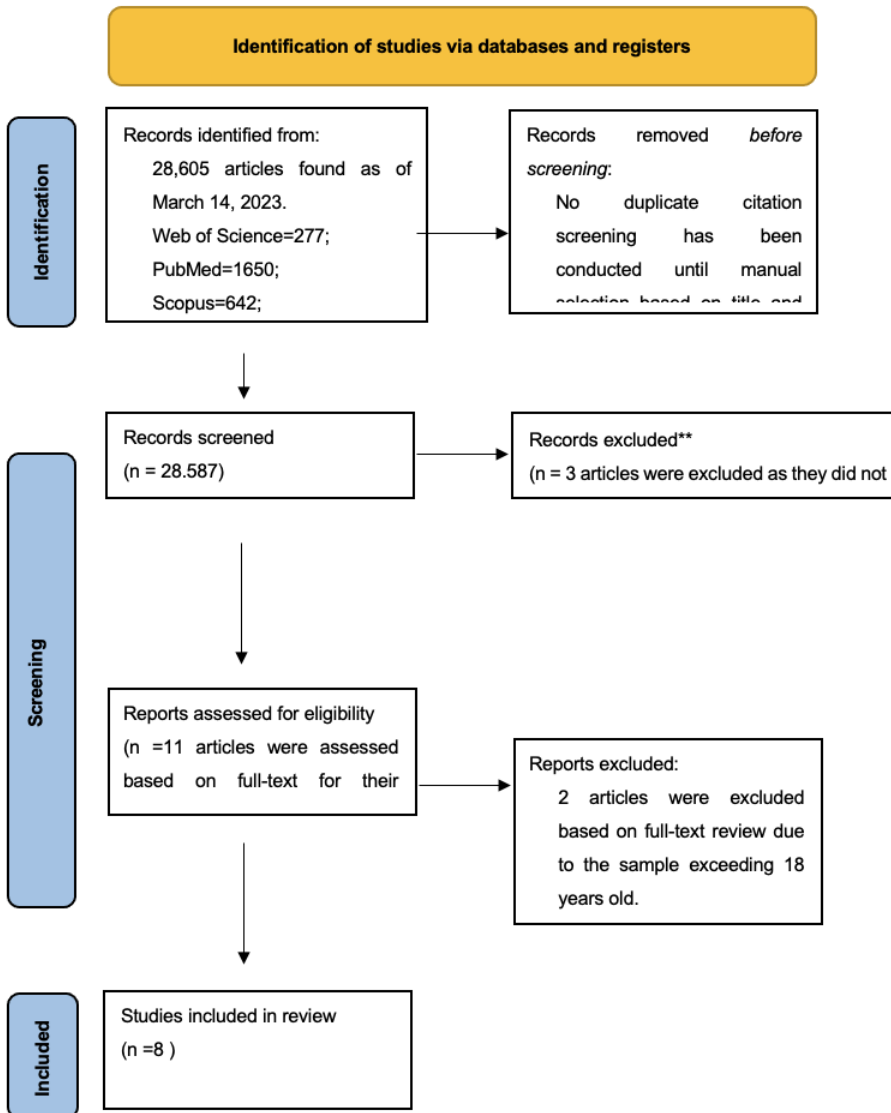
(1) WOS: Topic (compare sports) and (executive function): 277, after applying the open access filter, languages: Spanish and English, remain at: 152 articles, until March 14, 2023. After reading the abstract we selected 10 and after reading the full article we selected 7. (2) PubMed: (sport and

executive function): 1650. Filters applied: Free full text, Humans, English, Spanish, Child: birth-18 years, Child: 6-12 years, Adolescent: 13-18 years, remain at 167 articles until March 14, 2023. After reading the abstract and full text we selected 2. (3) SCOPUS: (sport and executive function): 642. We applied the open Access and English language filters, 338 articles remain until March 14, 2023. Keyword search in title, abstract and keywords. (4) APA PsycInfo: (compare sports) and (executive function): 34 articles until March 14, 2023. When selecting the age birth -17 years, it is reduced to 6 articles. After reading the title and abstract, none are included because they do not fit the inclusion criteria. (5) ÍNDICES CSIC: (compare sports) and (executive function): 2 articles until 14 March 2023. After reading the title, none are included.

After reviewing the articles and considering the inclusion and exclusion criteria, 2605 articles were obtained, including Web of Science = 277; Pubmed = 1650; Scopus = 642; APA PsycInfo = 34; InDICES CSIC = 2. After reading the title and abstract, 2578 articles were eliminated. Of these, 2268 articles did not evaluate EF in a sports context, focusing on other variables such as executive functions in educational contexts, executive functions in an unhealthy sample; 196 of the articles were excluded because they did not meet the established criteria for inclusion in this review, specifically they did not compare two or more sports in relation to the development of executive functions in adolescents. Finally, 114 were excluded due to age criteria. The remaining 11 articles were submitted for full reading. After full reading, 3 articles were eliminated because they did not assess executive functions or did not assess them with validated tests. Finally, the present review had a sample of 8 articles (Figure 1).

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**Figure 1**  
Flow diagram.



First, Table 1 systematically presents the sample, the objective, the type of design and the materials and methods used during the research, the intervention time, the results, the conclusions, and the effect size. Direct contact with the authors was not pertinent, since a large amount of information was available in the databases described above.

The articles collected in the tables pursue a similar objective, to explore the relationship between executive functions (hot and cold) and two or more

types of sports in children and adolescents, considering factors such as type of sport, gender, performance level, metabolic intensity. The sample of each study ranges from 4 (Van der Fels et al., 2015) to 19 years (Sharma et al., 2019). The study by Becker et al., (2018) had the smallest sample with 660 participants and the study by Sharma et al., (2019) had the largest sample with 60 users. Regarding the design of the studies, seven are associative and one manipulative.

As for the tools used in the articles of the present review, the Stroop test, the verbal fluency test, the Trail Making Test and the Batteria di valutazione neuropsicologica per l'età evolutiva (BVN) 5-11 were used in two of them. Then each project used its own tools, such as: Cd-rom de attenzione e concentrazione, the IOWA Game Task, the Lapso digitos, the Game of Dice Task (GDT), the N-Back, the Flanker Task, the UPPS Scale, the Barratt Scale, the Simon Task, the Picture Recall Task and the Bruininks-Oseretsky Motor Competence - Second Edition (BOT-2SF). Tests that measure specific cognitive and motor skills were also used, such as: The Attention Network Test (ANT), the Number Task for cognitive flexibility and the Digits Task for working memory. As well as: The Physical Activity Questionnaire for Older Children (PAQ-C), Tower of Hanoi and the Woodcock-Johnson-Revised (WJ-R) battery.

The variables considered in most of the studies included in the systematic review were age, education and school qualification, executive functions (among them: inhibition, working memory, cognitive flexibility and planning), type of sport practiced, level of experience, hours of sport practiced. Some considered anthropometric measures

such as height and weight, as well as variables related to motor performance, metabolic intensity of the sport and motor capacity.

The intervention time of these studies is between 60 minutes of assessment and 12 weeks of intervention. In two of the studies, the same assessment time is repeated: 2 days (Möhring et al., 2022; Spanou et al., 2022). The results of the various studies suggest that adolescents who practice open skills sports have a better performance of executive functions, specifically improvement in working memory, inhibition, verbal fluency and attention. Experience and time spent playing sports are also related as an advantage in terms of the development of cognitive functions, in addition to better motor skills. However, no clear associations have been demonstrated between motor and cognitive skills, nor the relationship between sport intensity and cognitive skills. The conclusions reached by the present research in a generic way is that regular practice of extracurricular sports, especially open ability/team sports, could significantly improve executive functioning in adolescents and children. Adolescents and children who practice open sports can adapt to changing situations and give a flexible response to the context, since their sports practice demands it.



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**Table 1**

*Summary of studies according to sample, objective, design, materials/method, variables intervention time, results, conclusions and effect size.*

Reference	Sample	Objective	Design	Materials/ Method	Variables	Time	Results Main	Conclusions	Effect size
Giordano et al., (2021)	102; boys = 58; girls = 44; 7-11 years old (43.1%); 12-15 (56.9%); Martial arts athletes (40.2%), team athletes (41.2%) and non-athletes (18.6%).	To analyze differences in executive functions and academic level in adolescent athletes and non-athletes.	Comparative-type associative strategy.	Stroop Test, Attention and Concentration CD-ROM, Tower of London, Iowa Game Task, Verbal Fluency Test, Millisecond Inquisit Software Derivative, Batteria di Valutazione Neuropsicologica (BVN) 5-11, Batteria di Valuation Neuropsicologica (BVN) 12-18, Digit Span.	Age, Education, School Grade, Sex (Family Size, Education and Parental Work), Executive Functioning, Divided Attention, Fluency, Decision Making, Planning, Interference, Sport.	-	Martial arts children obtained better school grades and better performance of executive functions compared to sedentary children and those practicing team sports.	The regular practice of extracurricular sports improves the development of executive functions and, consequently, influences academic performance.	Participants aged 12 to 15 showed higher scores in working memory [F(1,102) = 13.137, p = 0.000, $\eta^2p$ = 0.123], inhibition [F(1,102) = 6.230, p = 0.014, $\eta^2p$ = 0.062], and verbal fluency [F(1,102) = 10.074, p = 0.002, $\eta^2p$ = 0.097]. Children who practiced martial arts performed better in working memory [F(2,102) = 3.680, p = 0.029, $\eta^2p$ = 0.073], inhibition [F(2,102) = 10.891, p = 0.000, $\eta^2p$ = 0.188], and the Iowa test for attention [F(2,102) = 3.232, p = 0.04, $\eta^2p$ = 0.064].
Holfelder et al., (2020)	86 adolescents aged 13 and 15 years (M: 14.0, SD: 0.79); they were further divided into two groups: a) 40 elite athletes and b) 46 amateur athletes (M: 14.0, SD: 0.79).	To examine differences in Executive Functions between closed and open skill sports, performance level and gender.	Associative strategy. Comparative.	-GDT (Game of Dice Task), N-Back, Flanker Task, Trail-Walking Test, Trail-Making Test, UPPS Scale, Barratt Scale	Decision Making, Inhibition, Cognitive Skills, Visual Scanning, Attention, Problem Solving, Impulsivity	60 minutes To collect data	The elite and more experienced athletes obtained better results in the EF tests (such as working memory).	Elite athletes in open ability sports showed better FE performance.	Elite athletes (Wilks' Lambda = 0.61, F(14,69) = 3.19, p = 0.001, $\eta^2p$ = 0.393)
De Waelle et al., (2021)	8-12 years 170 girls. Three groups (1) non-athletes, (2) self-paced sports, (3) team sports.	Refine distinctions in executive function ability among children playing different sports.	Associative strategy. Comparative.	Seven tests from the Cambridge Brain Sciences (CBS) test battery.	Executive functioning, sport	-	Age had a significant effect on executive function. Sports. Different sports groups were found to differ in their performance on executive function.	Individual sports did not have better inhibition. Team sport athletes perform better in executive function.	Cohen (0.004), Effect size moderate

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**Table 1 (continuation)**

*Summary of studies according to sample, objective, design, materials/method, variables intervention time, results, conclusions and effect size.*

Reference	Sample	Objective	Design	Materials/Method	Variables	Time	Results Main	Conclusions	Effect size
Möhring et al., (2022)	138 children aged 8-13 years	Relate the type of sport (open and closed) with executive functions.	Associative strategy. Comparative.	Simon Task, Stroop Task, Image Recall Task	Inhibition, Inhibition, Interference, Working memory, Sports	2 days To collect data	Children in open-skill sports showed better executive functions (as in interference, situation change, flexibility).	Children who played open-skill sports showed a greater ability to cope with interference compared to children who played closed-skill sports.	Inhibition. Age effect $F(1, 103) = 9.90, p < .01, \eta^2p = 0.08$  Switching. Sex effect, $F(1, 103) = 4.19, p < .05, \eta^2p = 0.04$ . sport type, $F(2, 103) = 3.91, p < .05, \eta^2p = 0.07$  Updating. age effect, $F(1, 103) = 16.67, p < .001, \eta^2p = 0.14$ . $\eta^2p$ did not exceed the value of 0.14.
Spanou et al., (2022)	115 adolescents 8-12 years old	To analyze variations in working memory and executive functions among boys and girls who practice different types of sports.	Associative strategy. Comparative.	Bruininks-Oseretsky Motor Proficiency - Second Edition, Attention Network Test, Number Task, Digits Task	Motor competence, Executive functions (inhibitory control, working memory and cognitive flexibility).	2 days of 30 minutes = 1 hour to collect data	The age of the participants was a significant variable.	Children participating in team sports showed significant differences in their motor competence, but not in their executive functions.	
Contreras Osorio et al. (2022)	100 adolescents 10-12 years old	Exploring differences in EF in children engaged in open sports.	Manipulative strategy. Quasi-experimental.	Evaluación Neuropsicológica de las Funciones Ejecutivas en Niños (Enfen), Physical Activity Questionnaire for children (PAQ-C)	Executive functions, Physical fitness, Sports	12 weeks of intervention	Athletes had better EF than handball players. Handball players presented greater cognitive flexibility.	Significant improvements in working memory, cognitive flexibility and inhibitory control. Increased team physical activity is associated with improvements in attention and planning.	Working memory ES $-1.25$ [95% CI $-1.70$ to $-0.79$ ], $p = 0.001$ ; inhibitory control ES $-1.30$ [95% CI $-1.98$ to $-0.63$ ], $p < 0.00001$ ; cognitive flexibility ES $-1.52$ [95% CI $-2.20$ to $-0.83$ ], $p < 0.00001$ .

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**Table 1 (continuation)**

*Summary of studies according to sample, objective, design, materials/method, variables intervention time, results, conclusions and effect size.*

Reference	Sample	Objective	Design	Materials/ Method	Variables	Time	Results Main	Conclusions	Effect size
Becker et al., (2018)	14-16 years n = 660	Investigate associations between open and closed sports, metabolic intensity, and EF.	Associative strategy. Comparative.	Tower of Hanoi, Woodcock-Johnson psychoeducational battery-Revised, Woodcock-Johnson Revised	Sport, Metabolic Intensity, executive functions, Mathematical and literacy achievement	3 phases of data collection.	Positive associations between open sports, mathematical problem-solving ability and executive functions. Positive relationship between metabolic intensity of sport and executive function.	This study has uncovered youth sport-specific connections between intensity, sport complexity, and certain aspects of cognitive development.	The effect size is weak in most of the variables. Sport intensity $\beta = .17$ (executive function model), $\beta = -.13$ (math final model), $\beta = -.03$ (literacy final model). Sport intensity x sport intensity $\beta = -.21$ (executive function model), $\beta = -.19$ (math final model), $\beta = .04$ (literacy final model). Open-skilled sports $\beta = .10$ (executive function model), $\beta = .01$ (math final model), $\beta = -.01$ (literacy final model). Gender $\beta = -.05$ (executive function model), $\beta = .01$ (math final model), $\beta = -.01$ (literacy final model). Family income $\beta = .09$ (executive function model), $\beta = .09$ (math final model), $\beta = .11$ (literacy final model). Maternal education $\beta = .06$ (executive function model), $\beta = .24$ (math final model), $\beta = .24$ (literacy final model). However, it is moderate in the case of sport intensity x sport intensity and maternal education.
Sharma et al., (2019)	10-19 years non-athletes (n = 30) and athletes (n = 30).	Comparing cognition between athletes and non-athletes	Associative strategy. Comparative.	Trail Making Test A and B (TTA and TTb), (RRT), Neuropack M1 EP/EMG MEB-9200 J/K	height (cm) and weight (kg), body mass index. Blood pressure (BP) and heart rate (HR), sport (HR), body mass index.	-	Athletes took less time to solve the Trail Making test. The amplitudes of the evoked potentials in the athletes were higher. A significant decrease in the latency period in athletes.	Athletes demonstrated better executive function compared to non-athletes. Athletic training has a beneficial effect on executive cognitive function in adolescents.	Letter cancellation time d cohen= 0.6193. Trial making test part A d cohen= 0.2916 Trial making test part A d cohen= 1.2183

## DISCUSIÓN

The objective of this study was to conduct a systematic review of research examining the association between sports participation and hot and cold executive functions, incorporating the type of sport as a variable of analysis. Therefore, the goal was to investigate whether the type of sport practiced influenced varying levels of cold and hot executive functioning. As an inclusion criterion, studies analyzing executive functioning across two or more sports were established. This approach aimed to discern potential differences in the development of executive functions among adolescents and children based on their chosen sport. The results obtained could indicate that the type of sport practiced determined the level of executive functioning. In addition, the data analyzed suggest that the practice of open sports (with greater variability in stimulus and decision-making) would be more determinant in the development of hot and cold EF in adolescents and children.

First, in a general sense, the results reviewed highlighted that open sport modalities showed a higher level of EF than closed ones (Giordano et al., 2021; Holfelder et al., 2020; Möhring et al., 2022). This could be due to the fact that more open sport-physical activities with greater variability (e.g., collective sports such as basketball or soccer) would entail greater cognitive involvement, as opposed to semi-open or closed modalities (such as racquet sports or unopposed individual sports), which require less cognitive engagement as they have more closed dynamics in which there is less need to make a decision among a wide set of options (De Waelle et al., 2021; Sharma et al., 2019). It is true that young athletes, whether in individual, team or other sports, are cognitively stimulated from early stages by learning new and complex movement patterns inherent to the sports practiced throughout their training process (Almonacid Fierro et al., 2020). Nevertheless, the inherent characteristics of automated processes may diverge contingent upon the openness of the scrutinized sport. Specifically, within closed modalities of sports, the automatized actions tend to exhibit heightened stability. In contrast, within open or semi-open modalities, the automatized actions demonstrate diminished stability owing to a pronounced elevation in variability. This

heightened variability mandates the amalgamation of pre-established automatisms with spontaneous, less premeditated actions. Therefore, the classification of sports into open or closed modalities could potentially underpin the disparities observed in cognitive function across distinct sports categories.

However, the automatisms generated in more closed sports are more stable as the sport progresses, while in open or semi-open modalities, there is greater variability in the actions, which requires that these automatisms are often combined with spontaneous or less planned actions. Thus, in those modalities in which there is opposition and collaboration, or even only opposition, the actions would also be determined by the decisions made by teammates and opponents (Duran Cespedes, 2019). Therefore, this type of sport would require not only a process of improvement and individual technical understanding but would have to attend to tactical components in which a greater number of variables would be involved (Yáñez Gómez, 2005). This would generate a greater and more prolonged impact on the cognitive functioning of athletes in this type of sport (Moreira et al., 2021).

In the different studies proposed for this review, it is appreciated that open-skill athletes showed better EF performance (Mínguez & Ramos, 2016), which would be congruent with what was previously stated. As an example, Möhring et al., (2022) highlighted that children who participated in open-skill sports activities exhibited a greater ability to cope with interference (cold EF) in contrast to children who engaged in closed-skill sports. For their part, Becker et al., (2018) highlighted positive associations between open sports, mathematical problem-solving ability, and EF. In the same line, the study by De Waelle et al., (2021) accredits similar results to the previous ones, remarking that closed (individual) sports did not have better inhibition than open (group) sports, being team athletes the ones who performed better in EF. Thus, in line with previous studies, the research by Contreras Osorio et al., (2022) shows that athletes (closed sport) had better EF than handball players (open sport) and that, in addition, handball players had greater cognitive flexibility (cold EF).

However, in contrast to the above Spanou et al., (2022) found no differences in working memory

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(cold EF) and executive functions between children practicing different types of sports (open and closed) but did find differences in motor competence. This could be due to the fact that the technical-physical requirements of open sport are not equal to the requirements of closed sport, since open sport, being more variable and context-dependent, has greater physical demands (Smith et al., 2022). For example, an open sport such as soccer has a high variable motor demand. This means that soccer players perform numerous exercises such as running, jumping, shooting, passing the ball, dribbling... while an athlete in a closed sport such as athletics, the only physical requirement of his sport is running (Daulay & Azmi, 2021). For all of the above, athletes in open sports will have greater motor competence than those in closed sports.

However, in the study by Spanou et al., (2022) it was the other way around, the athletes of closed sports were the ones who presented the greatest motor competence, which could be due to the type of tool used to measure motor competence, or to the bias of the sports analyzed. Since rhythmic gymnastics (among others) was evaluated as a sport of closed ability, which is a discipline in which a powerful level of balance is developed, which is a great motor competence. Only the study by Spanou et al., (2022) highlighted the non-existence of different relationships between types of sport and EF, but this may be due to the age of the sample studied (8-12 years), since at that age the structure of sports are usually very similar regardless of the type of sport, since they are usually playful sessions, without so much technical-tactical requirement of the sport itself, i.e. the differences between the physical demands of open or closed sport are barely palpable in these sports categories (Russo et al., 2021).

Giordano et al., (2021) concluded that children who practiced semi-open sports (martial arts) obtained better school performance and better performance in both hot and cold executive functions compared to sedentary children and children practicing team sports. Those who practiced martial arts had better: inhibition, working memory, attention, verbal fluency (all of them cold FE) and decision making (hot FE). This could be due to the fact that in the martial arts discipline, a technical requirement is self-control, therefore, martial arts practitioners have a higher

level of self-regulation, due to the fact that in their habitual sports practice it is necessary (Nanay, 2010). Therefore, the results of Giordano et al., (2021) can be explained by the fact that martial arts users have a higher training in self-regulation, inhibition, selective attention (cold EF) and working memory (hot EF).

Therefore, although most of the research shows that there is a consistent pattern of correspondence of a greater relationship between the practice of open sports and executive functioning, there are some exceptions that would be linked to a greater extent to the technical-tactical requirements of sports (Holfelder et al., 2020). Since depending on the physical and cognitive demands of the sport practiced so will be the development of hot and/or cold EFs (Holfelder et al., 2020). It may also be related to the place where the sport is practiced, this relationship being different in sports practiced outdoors and those not practiced outdoors. Outdoor sports have a greater variability of possible scenarios, since all the variables of that same natural environment are included. While non-outdoor sports have less variability of context. Therefore, the place of practice and the technical-tactical requirements of the sport could be determining factors in the relationship between sport and EF.

Secondly, the analysis of these studies highlighted the scarcity of existing research that differentiates hot and cold performance according to the type of sport practiced. This represents a gap in knowledge that should be filled, especially in light of the multiple investigations that are collecting the need to differentiate both dimensions of EF. Most of the research collected in this review suggests that sports practice contributes to a greater development of EF but focuses to a greater extent on cold executive functions (Contreras Osorio et al., 2022; De Waelle et al., 2021; Holfelder et al., 2020). Thus, multiple studies have collected evidence on the incidence of chronic sports practice in favor of a better development of EF in children and adolescents, highlighting an improvement in cold EF such as: attention and planning, working memory, cognitive flexibility and inhibitory control, especially in the group that practices team sports (Contreras Osorio et al., 2022; De Waelle et al., 2021).

Similarly, it was detected that athletes in open ability sports tended to show better performance, better ability to deal with interference (cold EF), and significant differences in their motor competence, but no significant differences were found in their executive functions (Holfelder et al., 2020; Möhring et al., 2022; Spanou et al., 2022). Consistent with this, a wide spectrum of studies evidenced that sports practice is associated with better hot and cold executive functioning, especially in open sports such as soccer or field hockey versus closed or semi-open sports such as athletics or martial arts (Contreras Osorio et al., 2022; Giordano et al., 2021).

Of all the studies evaluated in the present systematic review, only two of the analyzed studies make the distinction between hot and cold executive functions, the remaining studies discuss executive functions in general. These two studies consider hot executive functions, which in this case is decision-making, as main variables (Giordano et al., 2021 & Holfelder et al., 2020). In this sense, Giordano et al., (2021) and Holfelder et al., (2020) converge in that open-mode athletes with more experience are those who have more developed the executive function of decision making, because in closed-mode sports decision making does not have such a place, due to its lesser relevance. Because in closed-mode sports there is not as much variability of events as in open-skill sports, decision making is not as relevant. Likewise, open sports athletes usually have a better response and adaptation to changing contexts, because the sport practiced requires it (Vázquez Ramos, 2015).

Although the systematic review presents valuable information, it is not without limitations. For example, some studies state that not all the findings are supported, or that the samples used are very small and therefore not representative. To avoid this type of problem, it is advisable to carry out a longitudinal study, since the information collected on a continuous basis is more reliable. Among the limitations is the lack of control of extraneous variables. In addition, in many cases the sport is self-reported, with no monitor or professional to validate the sport. On the one hand, the methodology used in some of these studies is observational and this leads to more errors and biases. Another bias in this type of research is the type of sport practiced, since there can be a great variability of technical, physical and

tactical requirements among several sports of the same category, such as open skills. Finally, one of the most important limitations was that few included studies investigated hot EFs, most of them focusing on the study of cold EFs.

In addition to the limitations, there exist further noteworthy considerations that warrant careful attention when evaluating studies pertaining to sports performance and executive functions. Several of the scrutinized studies adopt an observational nature, lacking the deliberate manipulation and control of variables. This deficiency can potentially impede the establishment of causal relationships between sports performance and executive functions, consequently attenuating the robustness of the outcomes. Moreover, the evaluation of executive functions presents an intricate and subjective endeavor, as it entails delving into internal cognitive processes that aren't always readily observable or quantifiable. The methodologies employed for gauging executive functions may exhibit variation across the span of different studies, thereby complicating both the comparison and generalizability of the findings. An important limitation of this study is the potential for publication bias. Because positive or significant results are more likely to be published than negative or nonsignificant results, it's possible that some studies with less favorable outcomes weren't included in this review. This could affect the representativeness of the gathered evidence and the validity of the conclusions drawn. Athletes are also subject to an array of external factors, encompassing competitive pressure, the sporting milieu, and psychological stress, all of which may exert influence upon their executive functions and, by extension, their performance. While longitudinal studies proffer invaluable insights into the evolutionary trajectory of sports performance and executive functions over time, the execution of protracted investigations demands a substantial investment of time and resources. Consequently, many studies gravitate toward scrutinizing abbreviated time frames, potentially obstructing the identification of overarching long-term trends. In order to surmount these limitations and ameliorate the caliber of research within this domain, a more comprehensive spectrum of methodologies, more representative sample populations, and meticulous vigilance toward variable measurement and control are requisite.

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Through the meticulous consideration of these facets, a more robust and dependable comprehension of the interplay between sports performance and executive functions can be ascertained.

### CONCLUSIONES

In conclusion, the intention is to address the question that initiated this systematic review: Is the type of sports practice related to better development of hot and cold executive functions? Considering the above, it is possible that it could be related, as demonstrated throughout the current research. The relationship between sports practice and the development of executive functions suggests that participation in open sports such as soccer or hockey could offer additional benefits to adolescents in terms of their cognitive and emotional functioning. These sports often involve broader decision-making, motor coordination, and adaptation to changing situations, which exercise and stimulate both "hot" and "cold" executive functions.

Executive functions are crucial for academic success, influencing the ability to concentrate, self-regulate, plan, organize, and problem-solve. By enhancing these skills through sports practice, students may experience improvements in their ability to stay focused on academic tasks, manage their time efficiently, and address academic challenges more effectively. Furthermore, sports can provide a conducive environment for the social and emotional development of adolescents. By participating in sports teams, students learn to collaborate, communicate effectively, and manage their emotions in competitive situations. These social and emotional skills can also positively influence their academic performance and overall well-being. Therefore, considering the importance of executive functions in the learning process and the holistic development of students, incorporating open sports into the school curriculum could be a valuable strategy to improve both academic performance and personal growth in young individuals. Additionally, according to research by Giordano et al., (2021), open sports programs will not only impact the improvement of executive functions but also contribute to better academic performance.

### APLICACIONES PRÁCTICAS

In terms of practical applications, the results of this review suggest that promoting participation in open sports as part of the school curriculum could have significant benefits for both academic performance and personal development of students. Schools may consider integrating open sports programs as a strategy to promote not only physical health but also cognitive and emotional health of their students, which in turn can enhance their academic performance and overall well-being. However, further research is needed to better understand the underlying mechanisms and the magnitude of these effects to support informed decisions in the implementation of sports programs in educational settings.

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