



CATÓLICA

FACULDADE DE CIÊNCIAS DA SAÚDE E ENFERMAGEM

LISBOA · PORTO

ESPECIFICIDADE DOS BENEFÍCIOS COGNITIVOS EM ATLETAS DE RUGBY

Dissertação apresentada à Universidade Católica Portuguesa para obtenção do grau de
mestre em Neuropsicologia

Por

Mónica Lança de Morais

Lisboa 2023



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Sob a orientação de Professora Doutora Ana Maria Abreu

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Resumo

Introdução: O nosso objetivo é explorar a forma como a prática desportiva influencia o funcionamento cognitivo, analisando as possíveis diferenças entre atletas profissionais, amadores e não atletas em diferentes domínios cognitivos. Embora já se saiba que o exercício físico influencia positivamente a cognição, existe pouca investigação sobre a forma como os desportos de contacto podem prejudicar a relação positiva entre desporto e cognição. Neste estudo, investigamos se os diferentes níveis de prática desportiva podem provocar alterações no desempenho cognitivo e de que forma é se manifestam em desportos de contacto como o rugby.

Métodos: Foram utilizadas tarefas neuropsicológicas para avaliar três funções cognitivas: Memória de trabalho Visuoespacial (Tabuleiro de Corsi), Atenção (teste de atenção $d2$) e Controlo Inibitório (tarefa Go/No-go). Recrutámos 67 participantes com idades compreendidas entre os 19 e os 31 anos, distribuídos por três grupos: Grupo 1, constituído por jogadores profissionais de rugby que integram a seleção nacional portuguesa ($n=23$); Grupo 2, constituído por jogadores amadores de rugby de um clube de rugby amador ($n=22$); e Grupo 3, constituído por não atletas que não praticam atividades desportivas regulares ($n=22$).

Resultados: Não se verificaram diferenças entre atletas profissionais, atletas amadores e não atletas no domínio da atenção. No entanto, registaram-se diferenças na memória de trabalho visuoespacial. Os atletas profissionais e amadores obtiveram pontuações superiores em comparação com os não atletas. No que diz respeito ao controlo inibitório, o Inverse Efficiency Score (IES) não revelou diferenças entre grupos. No entanto, houve diferenças nas pontuações do d' prime que surpreendentemente sugerem que os não atletas revelaram maior sensibilidade na deteção do sinal em comparação com os atletas amadores e profissionais.

Conclusão: Neste estudo, explorámos o impacto do rugby no funcionamento cognitivo de atletas profissionais e amadores. Se por um lado, não encontramos diferenças significativas no desempenho cognitivo entre os grupos de atletas (profissionais e amadores). Por outro lado, constatámos diferenças entre o grupo de atletas e de não atletas em determinados domínios cognitivos, que podem estar relacionados com o desporto em estudo. A memória de trabalho visuoespacial revelou ser melhor nos jogadores de rugby do que nos não atletas. Note-se que, esta relação entre desporto e cognição é complexa pelo que é necessário continuar a investigar para uma melhor compreensão das alterações cognitivas provocadas pela prática de um desporto de contacto.

Palavras-chave: cognição, funções executivas, exercício físico, desporto

Abstract

Introduction: Here we aim to explore how sports expertise affects cognitive functioning by examining the putative differences between professional athletes, amateur athletes, and non-athletes in different cognitive tasks. Whilst it is well known that physical exercise benefits cognition, there is scant research concerning how contact sports might hinder the positive sports-cognition relationship. Here we delve deeper into whether different levels of sports expertise might lead to variations in cognitive performance and how these are manifest in rugby – a contact sport.

Methods: Neuropsychological tasks were employed to assess three cognitive functions: Visuospatial Memory (Corsi block task), Attention (d2 test of attention), and Inhibitory Control (Go/No-go Task). We recruited 67 participants aged 19 to 31 years, distributed across three groups: Group 1, comprising professional rugby players from the Portuguese national team (n=23); Group 2, consisting of amateur rugby players from Portuguese rugby clubs (n=22); and Group 3, composed of non-athletes who did not engage in regular sports activities (n=22).

Results: There were no differences between professional athletes, amateur athletes, and non-athletes in the attention domain... However, there were differences in visuospatial working memory. Professional and amateur athletes had higher scores compared to non-athletes. Regarding inhibitory control, the inverse efficiency score (IES) revealed no group differences. However, there were variations in d' prime scores, surprisingly suggesting that non-athletes were more sensitive to the signal than both amateur and professional athletes. There were no differences, in inhibitory control observed between professional and amateur athletes.

Conclusion: In this study, we explored the impact of sports expertise, particularly in professional and amateur rugby players, on cognitive functions. We found no significant differences in cognitive performance between these athlete groups but observed differences when comparing athletes with non-athletes, in specific cognitive domains affected by rugby sports expertise. While visuospatial memory was improved in rugby players, other cognitive domains such as attention and inhibitory control, remained unaffected. This complex relationship needs further research to optimize sports-specific cognitive deficits and safeguard athletes from potential cognitive impacts derived from contact sports.

Key words: cognition, executive functions, physical exercise, sports

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Index

<i>1. Introduction</i>	1
<i>2. Literature Review</i>	3
2.1 Physical Exercise and Cognition	3
2.2 Executive Functioning	3
2.2.1 Visuospatial Working Memory	4
2.2.2 Inhibitory Control	5
2.2.3 Attention	5
2.3 Rugby and contact sports	6
<i>3. Research question and hypothesis</i>	7
<i>4. Methods</i>	8
4.1 Participants	8
4.2. Measures	10
4.2.1 Sociodemographic questionnaire	10
4.2.2 The international Physical Activity Questionnaire (IPAQ).....	10
4.2.3 <i>d2</i> Test of Attention	10
4.2.4 Go/ No-go Task	11
4.2.5 Corsi Task.....	12
<i>5. Experimental procedure</i>	12
<i>6. Data Analysis</i>	13
<i>7. Results</i>	15
7.1 <i>d2</i> Test of Attention	16
7.1.1 General Efficiency Score	16
7.1.2 Concentration Index	17
7.1.3 Variability Index	17
7.1.4 Error percentage	18
7.2 Corsi Task.....	19
7.2.1. Corsi total	19
7.3 Go/ No- Go task.....	20

7.3.1 Inverse Efficiency Score (IES)	20
7.3.2 d' prime.....	21
8. Discussion.....	23
8.1 Limitations and future research	26
9. Conclusion	27
References.....	29
Appendices.....	41
Appendix 1. Table for test of Normality and variance's Homogeneity for Total MET min/ week	41
Appendix 2. Table for Post-hoc analyses for MET min/week	41
Appendix 3. Table for Multivariate Tests	41
Appendix 4. Table for test of Normality and variance's Homogeneity for assessed .	42
Appendix 5. Table for the differences between groups for each variable of <i>d2</i> test of Attention – One Way ANOVA	42
Appendix 6. Table for the differences between groups for each variable of Corsi Block Test– One Way ANOVA.....	42
Appendix 7. Table for the differences between groups for each variable of Go/ No go – One Way ANOVA.....	43
Appendix 8. Table for Post- hoc analyses for Corsi Block test.....	43
Appendix 9. Table for Post- hoc analyses for Go/ No-go	43
Appendix A. Informed Consent.....	44
Appendix B. Sociodemographic Questionnaire	47
Appendix C. Manuscript submitted to the Psychology of Sports and Exercise	48

1. Introduction

In an era wherein both mental and physical well-being are highly valued, there has been a growing interest and debate concerning the connection between the benefits of exercise on cognition. Here we aim to explore the relationship between exercise, sports expertise and cognitive functioning. In other words, is amateur training and non-exercise practice different from professional practice and is amateur practice different from non-exercise practice in terms of cognitive benefits? Numerous studies have emphasized the impact of activity on cognitive function especially in tasks that demand a high level of mental control (Colcombe and Kramer, 2003; Hillman et al., 2008; Ludyga et al., 2020). This relationship is especially relevant for high-level athletes, who often need a harmonious blend of motor control, perception and cognitive skills to excel in their respective sports (Scharfen, 2019). Based on previous studies, Scharfen (2019) suggests that professional athletes demonstrate better executive functioning in comparison to amateurs. However, there is some disagreement, among researchers when it comes to the relationship between expertise and cognitive functioning. Some studies suggest that being skilled in sports enhances cognition (Huijgen et al., 2015; Lundgren et al., 2016) while others do not find any advantage in professionalization (Heppe et al., 2016).

Abreu et al. (2012) suggest that sports expertise leads to neuronal alterations, that could potentially be linked to cognitive advantages. Other studies have pinpointed the physiological and neurobiological alterations of exercise leading to cognitive benefits (e.g., Abreu & Frade, 2020; Maeneja et al., 2022; Maeneja et al., 2023).

Here we explore different cognitive functioning domains amongst which is executive functioning. Executive functions involve controlling impulses, working memory and being adaptable to manage emotions, thoughts and behaviors effectively (Gioia et al., 2000; McCloskey et al., 2009; Miyake & Friedman 2012). These cognitive processes are crucial in self-regulation and impact aspects of everyday life (Mischel et al., 2011; Moffitt et al., 2011).

Working memory is one such executive function which deals with spatial information and is essential for remembering and locating objects in our everyday lives (Arce & McMullen, 2021). Athletes who participate in sports like soccer or basketball where there is a lot of ball movement, often show enhanced visuospatial abilities based on the use of spatial strategies to interact with the balls' trajectory (Kruger et al., 2009). However, a recent study by Millard et al. (2021) revealed that athletes may not perform

as well as non-athletes when it comes to visual memory with the potential explanation of this might not be a crucial domain in the visuospatial intelligence to differentiate athletes from non-athletes.

Inhibitory control, on the other hand, is a component of executive functioning that plays a role in managing attention, behavior, thoughts, and emotions in a rational manner (Diamond, 2013). Studies have shown that athletes demonstrate better performance compared to controls, in tasks related to inhibitory control, exhibiting a faster response time and fewer errors in Go/No Go tasks (Di Russo, 2006; Nakamoto, 2008; Chan, 2011), denoting the athletes improved capacity to resist impulsive reactions.

Alternatively, attention serves as a selective mechanism that prevents information overload in the human brain (Desimone & Duncan, 1995; Chun et al., 2011; Rosenberg et al., 2017). In particular, selective attention has been shown to be amenable to improvement through physical exercise (Maeneja et al., 2022; 2023; Tomporowski, 2003; Brisswalter et al., 2002), making it a pertinent topic for investigation in the realm of sports, where decision-making under pressure is pivotal.

This research explores rugby as a contact sport known for its high impact nature. Contact sports offer a rich context to investigate the connection between activity and cognitive abilities. While some studies suggest detrimental effects on cognitive function due to contact sports (Hume et al., 2017) others have proposed cognitive benefits, specifically in visuospatial working memory (Furley & Memmert, 2010). These inconsistencies highlight the complex connection between physical activity, contact sports and cognitive abilities.

In summary, our research explores the connection between exercise, sports expertise and cognitive abilities. We aim to gain an understanding of how these factors interplay. We investigate inhibitory control, working memory and attention in high level athletes, amateur athletes and non-athletes. According to the FluentRugby (n.d) website, amateur individuals who play rugby usually participate in training sessions about 2- 3 times per week with each session lasting around 1.5 to 2 hours. On the other hand, professional rugby players tend to dedicate themselves to training 5- 6 times a week and occasionally have multiple sessions, mainly during the pre-season. With this, our aim is to acquire knowledge regarding the benefits associated with different degrees of physical exercise. By shedding light on the nature of this relationship we hope to contribute to the discussion about the advantages of engaging in exercise and developing expertise in sports.

2. Literature Review

2.1 Physical Exercise and Cognition

Over the past decade, there has been growing interest in the role of physical exercise in cognitive functioning, particularly in tasks that require significant cognitive control (Colcombe and Kramer, 2003; Hillman et al., 2008; Ludyga et al., 2020). This relationship is especially relevant for high-level athletes, who often require a combination of motor control, perception, and cognitive skills in order to perform at their best (Scharfen, 2019). A meta-analysis by Scharfen (2019) found that elite athletes have superior executive functioning compared to amateurs. However, research on the relationship between athletic expertise and cognitive functioning is mixed, with some studies supporting the hypothesis that expertise benefits cognition (Huijgen et al., 2015; Lundgren et al., 2016) and others finding no such benefit (Heppe et al., 2016).

One study by Abreu et al. (2012) found that sports expertise leads to neuronal changes that may be associated with cognitive benefits. Given the ambiguity of the existing research, here we aim to investigate the effect of expertise in sports on cognitive functioning by assessing three cognitive domains in high-level athletes, amateur athletes, and non-athletes.

2.2 Executive Functioning

Executive functioning is a cognitive process that plays a fundamental role in tasks requiring sustained concentration and attention (Burgess & Simons, 2005; Espy, 2004; Miller & Cohen, 2001). This set of top-down cognitive processes enables individuals to manage their emotions, thoughts and behaviors effectively (Gioia et al., 2000; McCloskey et al., 2009; Miyake & Friedman, 2012), thus allowing them to navigate the challenges of daily life. The three core components of executive functions are inhibitory control, working memory, and cognitive flexibility (Diamond, 2016; Finegood & Blair, 2017). These cognitive processes play a crucial role in self-control and self-regulation, exerting a profound impact on various aspects of our daily lives (Mischel et al., 2011; Moffitt et al., 2011). It is widely acknowledged that executive functions can be enhanced or optimized at any stage of life. Notably, increased engagement in physical exercise has been shown to yield notably positive outcomes in stimulating executive functions, particularly among older adults (Erickson & Kramer, 2009; Voss et al., 2011).

2.2.1 Visuospatial Working Memory

Working memory is one of the key executive functions that retains and processes information for brief periods through a mental process which allows the manipulation of the information without the need of perceptualize previous auditory or visual stimulus (Baddeley & Hitch, 1994; Smith & Jonides, 1999). According to Baddeley and Hitch's model (1974), working memory is directly related to short-term memory, involving a system that operates by manipulating information held in short-term memory for demanding tasks such as learning, comprehension, and reasoning (Baddeley, 1998). It is essential to observe that working memory can be categorized into two forms: verbal working memory and non-verbal working memory, the latter commonly known as visuospatial working memory (Diamond, 2013). According to the framework proposed by Baddeley & Hitch (1974), an attentional control system operates concurrently with two primary systems, namely the phonological loop and the visuospatial sketchpad. Visuospatial memory, a specific subtype of memory, enables the recall and localization of objects, individuals, and various elements, endowing it with considerable significance in daily life (Arce & McMullen, 2021).

Remarkably, athletes who participate in sports involving the dynamic movement of a ball, such as soccer or basketball, tend to exhibit more developed visuospatial abilities (Kruger et al., 2009). This enhanced capability is attributed to the intricate interplay between the ball's trajectory and the athletes' need to formulate and adapt spatial strategies to enhance their performance (Kruger et al., 2009). Furthermore, a comparative study conducted by Gao et al. (2015) concluded that athletes possess superior visual skills when compared to the general population. In a separate study by Millard et al. (2021), which compared rugby players with non-athletes, five domains of visuospatial ability were evaluated. Millard's findings indicated that rugby players generally outperformed the non-athlete population in this regard. However, upon closer examination of the results within each domain, it was observed that rugby players displayed relatively weaker performance in the domain of visual memory when compared to non-athletes, explained by the eventuality of this specific domain does not play crucial role in the visuospatial intelligence to differentiate athletes from non-athletes. (Millard et al., 2021).

The extant literature reveals the exploration of various methodologies to assess this domain of working memory, including the Corsi Block-Tapping Test (Arce & McMullen, 2021).

2.2.2 Inhibitory Control

Inhibitory control is the function responsible for the rational control of factors such as attention, behavior, thoughts, and emotions (Diamond, 2013). Additionally, the attention given to one stimulus over another is linearly related to inhibitory control of attention (Diamond, 2013). Auditory or visual stimuli easily capture attention on their own, making them considered exogenous, bottom-up, or even involuntary attention (Posner & DiGirolamo 1998, Theeuwes 1991). Moreover, other mechanisms allow voluntary ignoring of stimuli that are not relevant to the individual's intention. Thus, this process is not only referred to as selective or focused attention but is also considered attentional control, endogenous attention, and top-down attention (Posner & DiGirolamo 1998, Theeuwes 2010).

Another component of inhibitory control is self-control, which plays a significant role in regulating behavior and emotions, involving the ability to resist external stimuli considered unimportant and avoid acting impulsively (Diamond, 2013). According to Vestberg et al. (2012), inhibitory control emerges as a critical factor in the success of sports performance, suggesting that this executive function is more finely honed in athletes compared to non-athletes. Substantiating this notion, various studies have undertaken comparisons of inhibitory control between athletes across different sports and non-athletes, consistently revealing athletes' superior performance in Go/No-Go tasks, whether through faster response times or fewer errors (Di Russo, 2006; Nakamoto, 2008; Chan, 2011). In recent years, specialized tools, notably Go/No-Go tasks (Cragg & Nation, 2008), have been developed for the assessment and quantification of inhibitory control.

2.2.3 Attention

Attention, a fundamental cognitive function, it serves as a selection mechanism that prevents the human brain from becoming overwhelmed by excessive information, playing an indispensable role in daily life (Desimone & Duncan, 1995; Chun et al., 2011; Rosenberg et al., 2017). It is well-established that attention maintains a strong relationship with other cognitive dimensions, including executive functions (Logue and Gould, 2014; Bialystok, 2015; Campillo et al., 2018), being the focus of extensive studies across various contexts, including the realm of sports (Reigal et al., 2019).

While attention is often regarded as a unified concept, it is central to recognize its distinct components, encompassing alternating attention, sustained/maintained attention, divided attention, and selective/focused attention (Posner and Petersen, 1990; Estévez-

González et al., 1997). Among these subtypes, selective attention stands out, as it underpins the ability to choose one stimulus over others and also holds an important role in the effectiveness of adapting to diverse tasks and performing well in different contexts like education or sports (Estévez-González et al., 1997; Bar-Eli et al., 2011; Giuliano et al., 2014). Several authors suggest that attentional processes, especially selective attention, can be enhanced through physical exercise (Tomporowski, 2003; Brisswalter et al., 2002). In the context of soccer, this becomes particularly relevant, as players must continually make decisions about which teammate they should pass the ball to, while also being acutely aware of the positions and movements of other players during the game (Romeas et al., 2016; Gonçalves et al., 2017).

The measurement of attention relies on various assessment tools tailored to the specific subtype of attention under investigation. For the evaluation of selective attention, the *d2* test is a widely adopted instrument (Izquierdo et al., 2007).

2.3 Rugby and contact sports

Rugby is a team sport renowned for its robust physical nature, characterized by high-impact collisions. The game is played with an oval-shaped ball that can be carried, kicked, or passed among players. According to the World Rugby website (2020), rugby features two teams competing to score points by either carrying the oval ball across a designated line or accurately kicking it between the opposing team's goalposts and over the crossbar. A defining element of the sport is the act of tackling, where defenders endeavor to impede the ball carrier's progress, a fundamental aspect of the game (Patricios & Kemp, 2013). During a typical match, there are approximately 450 instances of tackles or contact events, with nearly 200 of them involving tackles (Cross et al., 2019). It is imperative to acknowledge that rugby players face a heightened risk of injury when compared to participants in more mainstream team sports (Williams et al., 2013). Notably, many concussions in rugby arise from head-to-head collisions and contact with the ground, underscoring the physical demands and risks associated with the sport (Patricios and Kemp, 2013).

Indeed, the nature of the sport can impact the presence of cognitive benefits. For instance, a comparative study conducted by Hume et al. (2017) revealed that former rugby union players displayed diminished cognitive function when compared to individuals from non-contact sports, especially on assessments related to complex attention, processing speed, executive functioning, and cognitive flexibility. However, Furley and

Memmert's (2010) study highlighted a significant association between expertise in team sports and visuospatial working memory, suggesting that proficiency in team sports is linked to enhanced performance in tasks assessing visuospatial memory. In a research study conducted by Guskiewicz and his colleagues (2002), they found no evidence of cognitive impairments in collegiate soccer players despite the sport's concussion risk.

The relationship between exercise and cognition is not straightforward, and its effects may vary depending on the type of sport and can be influenced by the specific characteristics of each activity. This debate surrounding the cognitive advantages of exercise and the potential risks associated with contact sports underscores the intricate nature of this connection.

3. Research question and hypothesis

Research question: Here we aim to investigate if the number of hours of physical exercise practice have an impact on cognitive functioning, specifically on inhibitory control, visuospatial working memory, and attention. In other words, is amateur training distinguished from professional practice, and is amateur practice distinguished from non-exercise practice in terms of cognitive benefits?

Study hypothesis:

Hypothesis 1: High-performance rugby practitioners should show better results on some cognitive functioning compared to the amateur rugby athletes and non-athletes.

H1a: High-performance rugby practitioners should show better results on attention tasks compared to the amateur rugby athletes and non-athletes.

H1b: High-performance rugby practitioners should show better results on visuospatial working memory tasks than amateur rugby athletes and non-athletes.

H1c: High-performance rugby practitioners should show better results on inhibitory control tasks compared to the amateur rugby athletes and non-athletes.

Hypothesis 2: Amateur rugby practitioners should show better results on cognitive functioning compared to non-athletes.

H2a: Amateur rugby practitioners should show better results on attention tasks compared to non-athletes.

H2b: Amateur rugby practitioners should show better results on visuospatial working memory tasks compared to non-athletes.

H2c: Amateur rugby practitioners should show better results on inhibitory control tasks compared to non-athletes.

4. Methods

4.1 Participants

The sample size was determined with an a priori power analysis using G*Power 3 software (Düsseldorf, Germany) (Faul et al., 2007) for the F tests family and the corresponding approaches (ANOVA One-Way). Based on the criteria, a sample size of 66 participants was calculated to provide 95.0% power for detecting an effect related to the condition. A total of 67 participants (all males) took part in the study. They were divided into three groups: 23 professional athletes (PA), 22 amateur athletes (AA) and 22 non-athletes (NA). They were all aged between 19 and 31 years old ($M_{PA}= 24.57$, $SD_{PA}= 3.287$; $M_{AA}= 24.23$, $SD_{AA}= 4.353$; $M_{NA}= 23.05$, $SD_{NA}= 2.299$). The professional athletes were recruited from the Portuguese National Rugby Team, while the amateur athletes were recruited from a Portuguese rugby club (Belas Rugby Club). The non-athlete participants were recruited through social networks. Regarding our recruitment approach we opted for convenience sampling when selecting participants, for both professional and amateur groups. However, for the control group (non-athletes) we utilized snowball sampling.

According to the International Physical Activity Questionnaire (IPAQ), the group of professional and amateur athletes practiced physical activity at a high level ($M_{PA}= 10874.22$ MET min/week, $SD_{PA}= 16248.08$ MET min/week¹; $M_{AA}= 4342.20$ MET min/week, $SD_{AA}= 3783.81$ MET min/week) while the control group (non-athletes)

¹ METs (Metabolic Equivalent of Task) per minute per week. MET is a ratio that compares the working metabolic rate to the resting metabolic rate, and it serves as a measure of physical activity intensity

displayed a moderate level of physical activity ($M_{NA}= 1327.68$ MET min/week, $SD_{NA}= 765.31$ MET min/week). All the descriptive data concerning age, education, number of reported losses of consciousness, and physical activity of the participants are reported in Table 1.

A One-Way ANOVA was computed to assess differences of physical exercise between the groups. The MET min/week did not meet the assumption of normal distribution in Professional and Amateur groups. However, Monte Carlo simulations with different sample sizes and other conditions have shown that F-test is robust with non-normal data (Blanca et al., 2017; Blanca et al., 2023). Here we report Welch’s F-test [$F(2, 29.865) = 10.34, p < .001$], because the Levene’s test of homogeneity of variances showed statistically significant differences [$F(2,64) = 12,2101, p < .001$]. Although the sample sizes were practically identical, the Welch test can provide more guarantees regarding significance. Post-hoc comparisons using Tamhane’s T^2 tests revealed statistically significant differences between professional athletes and non-athletes ($p= .03$) and between amateur athletes and non-athletes ($p= .004$), but not between professional and amateur athletes ($p= .203$). In summary, professional athletes did not differ from professional athletes in terms of quantity of exercise, but both groups differed from non-athletes. (Appendix 1 and 2)

None of the participants had any physical injury in their hands and arms or any significant visual uncorrected problems. All participants gave written informed consent to the study following the procedure approved by the Ethics Committee of the local University.

Table 1
Descriptive data of the three groups of participants

Group	Age	Education	Number of Loss of Consciousness	MET - min/week
Professional (N=23)	M= 24.57 (3.287)	Bachelor	2	M= 10874.22 (16248.08)
Amateur (N= 22)	M= 24.23 (4.353)	Bachelor	1	M= 4342.21(3783.81)
Non- athletes (N= 22)	M= 23.05 (2.299)	Bachelor	0	M= 1327.68 (765.31)

4.2. Measures

In this study, we used a sociodemographic questionnaire, the International Physical Activity Questionnaire (*IPAQ*), the Corsi block Test, the *d2* Test of Attention and a Go/ No-Go task.

4.2.1 Sociodemographic questionnaire

We created a sociodemographic questionnaire to collect, for each participant, important information, such as age, education, if a player reported any loss of consciousness in the past year or any other injury.

4.2.2 The international Physical Activity Questionnaire (*IPAQ*)

The study employed the short form of the International Physical Activity Questionnaire (*IPAQ*) to evaluate each participant's level of physical activity (Booth M., 2000 & Lee, et al., 2011). This self-reported questionnaire consists of 7 questions and typically takes about 10 minutes to complete (Lavelle, et al., 2020). The data obtained from the *IPAQ* was treated as parametric, with the focus on METs (Metabolic Equivalent of Task) per minute per week. MET is a ratio that compares the working metabolic rate to the resting metabolic rate, and it serves as a measure of physical activity intensity. According to the American Heart Association, a minimum of 500 METs per minute per week is recommended for maintaining a healthy lifestyle, equivalent to at least 75 minutes of vigorous physical activity or 150 minutes of moderate physical activity per week (Abreu, et al., 2022 & Úbeda-Colomber, J et al., 2019).

4.2.3 *d2* Test of Attention

The *d2* Test of Attention is a widely used paper-and-pencil assessment tool designed to measure attention, visual scanning, and processing speed. This test involves presenting 14 lines of characters, including the letters "p" and "d," which are arranged adjacent to each other. Its primary objective is to evaluate an individual's attention and concentration, both of which are closely associated with cognitive functions in the brain. The typical duration of the *d2* Test of Attention is 4 minutes and 40 seconds.

The test provides valuable insights into cognitive performance, and the assessment includes several performance indices such as the General Efficiency Score (TC-E), which is a comprehensive measure of attention control and the balance between speed and

accuracy in task performance. It is calculated by subtracting the total number of errors from the total number of characters processed. Also, the Concentration Index (CI) indicates an individual's concentration ability, considering both the speed and precision of their responses. It is computed by subtracting the total omission errors from the total hits. The Error Percentage (E%) is a metric that evaluates the qualitative aspects of performance. It represents the percentage of total errors made during the test, including both commission errors related to inhibitory control and omission errors related to attention control. Finally, the Variability Index (VI) which quantifies the consistency and stability of an individual's task performance. It is determined by measuring the difference between the maximum and minimum numbers of characters processed, indicating temporal persistency throughout the task.

The d2 Test of Attention was chosen for this study due to its effectiveness in assessing attention and concentration. Additionally, physical activity has been associated with positive effects on attention and concentration capacity.

4.2.4 Go/ No-go Task

The go-no go task, designed to assess inhibitory control, was conducted using the [testable.org](https://www.testable.org/) platform (<https://www.testable.org/>), where participants were presented with a five-minute computer-based cognitive test. In this task, participants were required to press the space bar on their keyboard whenever an orange square (the "go stimulus") appeared on the screen. However, when a blue square (the "no-go stimulus") was presented, they were instructed to refrain from pressing any key. Each stimulus, whether "go" or "no-go," was displayed on the screen for 1000 milliseconds, testing the participant's ability to quickly and accurately respond to specific visual cues while inhibiting responses to others. This task was administered through the [testable.org](https://www.testable.org/) website and is commonly employed in psychology and neuroscience research to measure inhibitory control.

The results and information collected through this task on the [testable.org](https://www.testable.org/) platform, afforded several key performance metrics that were computed to gain insights into the participants' cognitive abilities. These metrics allowed us to calculate inverse efficiency scores (IES), which provide a measure of the efficiency of the participants' responses, d' prime derived from the theory of signal detection, which assesses the participants' sensitivity to discriminate between "go" and "no-go" stimuli. Each of these scores offered valuable information about the participants' performance.

The concept of the inverse efficiency score (IES) was first introduced by Townsend and Ashby in 1983 to address how speed-accuracy tradeoffs can affect performance. This score combines both accuracy and reaction times providing a measure where in higher scores indicate worse overall performance. To calculate the IES we divide the correct reaction times by the percentage of correct responses, for each condition and subject. This calculation enables us to obtain a performance index, which has been used in studies, like Rach et al. (2010) and Throne (2006).

4.2.5 Corsi Task

Visuospatial working memory was assessed using the Corsi Block-Tapping Test from the Wechsler Memory Scale (WMS-III). This test consists of a board with 10 cubes arranged in a random pattern. The assessment was administered in two different ways, both forward and backward (Wechsler, 1997). Prior to the actual test, two practical examples were given to ensure participants' understanding of the task. In these examples, two sequences of cubes were presented, and participants were asked to repeat the touched cubes in the same order. The first example consisted of two cubes, and the second, three cubes. Following the examples, the actual test began, where participants were required to successfully repeat as many cube sequences as possible.

The test comprised 8 items, with each item representing a different level of difficulty. Each item included 2 trials with the same number of cubes. The test finished when a participant consistently failed both trials of a specific item. One point was awarded for each correctly repeated sequence, allowing for a maximum score of 16. Here we investigate the total Corsi score comprised of the sum of scores of the forward and backward trials.

5. Experimental procedure

After reading and signing the informed consent (that had previously been shared online), the participants filled in the Sociodemographic questionnaire wherein they shared sociodemographic data (age and education), some information about sports practice (player at the Portuguese national team, player in an amateur rugby club or did not practice regular sports activities), information about any physical injuries and loss of consciousness (Appendices A and B). The participants also filled in the International

Physical Activity Questionnaire (*IPAQ*), which allowed us to assess the MET min/ week of each group to distinguish the groups who practiced sports from the non-athletes group. Subsequently, the participants engaged in the three tasks (*d2* test of attention, Go/ No-go and Corsi block test) that afforded the evaluation of cognitive performance in different domains across the three distinct groups. Together, the experimental procedures took \approx 30-35 minutes (Figure 1).

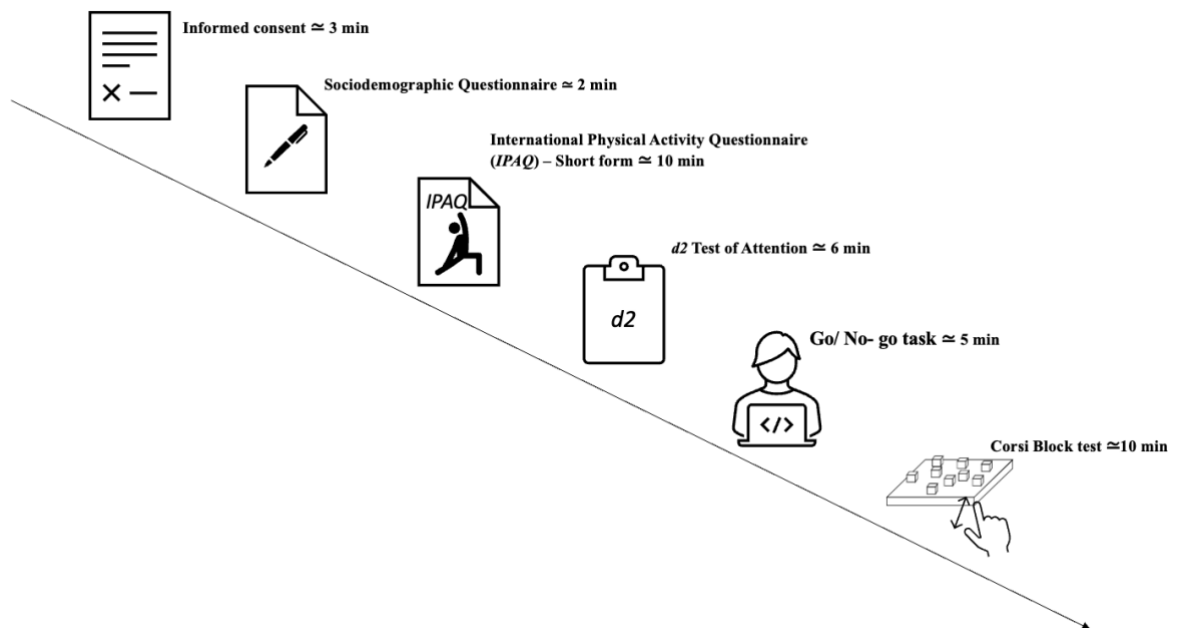


Fig 1. Task timeline

6. Data Analysis

A One-Way Multivariate Analysis of Variance (MANOVA) was computed since we measured several response variables. Compared to univariate analyses, multivariate analysis has the advantage of showing the effect of the independent variable, when it exists. It does not always happen if univariate analyses are carried out for each dependent variable separately. Furthermore, MANOVA controls type for I errors without having to perform any correction (Tabachnick & Fidell, 2013).

The independent variable considered in the analysis was the type of participant, i.e., being a professional athlete, being an amateur or not being an athlete. The dependent variables were the following: *d2* performance indices (General Efficiency, Concentration Index, Variability Index and Error Percentage), Go/No-go indices (IES and *d'* prime) and Corsi block indice (Total Corsi).

After multivariate analysis, separate univariate ANOVAs were performed for each dependent variable when multivariate analysis revealed statistically significant differences. Also, when an univariate ANOVA showed statistic differences between, at least two means, subsequent post-hoc tests were performed.

MANOVA assumptions were verified. In particular, the absence of multivariate outliers, normality, the absence of multicollinearity, the linearity and homogeneity of the variance-covariance matrices between groups. Further, the independence of observations was assumed.

Mahalanobis distances were performed through multivariate linear regression using the response variables as predictors. Four observations were identified as multivariate outliers. Nevertheless, all the Leverage influence measures were less than .06, Cook distances were also very low, and all values were less than 1 (Marôco, 2023). Univariate normality was tested with and without the multivariate outliers, and Shapiro-Wilk tests revealed non-normal data for several dependent variables and groups. When multivariate outliers were eliminated, the results of Shapiro-Wilk only improved in three tests. The definitive elimination of those observations would make the groups more unequal, which could subsequently reduce robustness of the multivariate analysis test and the univariate F tests. Considering the above, we decided to keep all observations. (Appendices 3 and 4)

With respect to linearity, matrix scatter plots were performed for the three groups. Due to the high number of dependent variables, scatter plots with all variables did not allow observing the distribution of the data. For this reason, we created graphs for each index subset (d2 performance indices, go/ no-go indices and corsi block indices). The dots plotted in the graphs allowed to discern a linear trend in the data for most variables and groups. Although in some graphs the linear pattern was not consistently clear, but no signs of non-linearity were observed.

To assess the potential multicollinearity of the response variables, bivariate correlations were calculated. According to Tabachnick and Fidell (2013), MANOVA works well with moderate correlations about .60. We found a high correlation between Concentration Index and General Efficiency Score ($r=.747$, $p<.001$). So, we performed MANOVA with all the variables, without the General Efficiency Score or the Concentration Index. We verified that the results of multivariate test were not affected by those high correlations. This test was used to assess the last assumption, i.e., the homogeneity of the variance-covariance matrices across the groups. Results showed that

this assumption was not fulfilled [Box's $M = 533.520$; $F(90, 11183, 116) = 4.719$, $p < .001$). Nevertheless, it is known that Box's M is very sensitive to departure from multivariate normality (Cohen, 2008) and that MANOVA is robust to violation of this assumption when sample sizes are equal (Tabachnick & Fidell, 2013).

7. Results

One-Way MANOVA showed an effect of the type of participants on the dependent variables [Pillai's Trace = .998; $F(20, 112) = 5.577$, $p < .001$; partial $\eta^2 = .499$] Pillai's Trace is more robust when the observed covariance matrices of the dependent variables are unequal across groups (Appendix 3).

The homogeneity of variances was rigorously examined for each variable using Levene's Test for Equality of Error Variances. The results indicate that for several variables, the variances are approximately equal, suggesting homogeneity. Specifically, for "General Efficiency Score" ($F(2,64) = 0.456$, $p = 0.630$), "Concentration Index" ($F(2,64) = 1.497$, $p = 0.231$), "Variability Index" ($F(2,64) = 2.774$, $p = 0.07$), "Error Percentage" ($F(2,64) = 2.433$, $p = 0.096$), "Corsi_direct" ($F(2,64) = 2.050$, $p = 0.137$) and "Go/No-Go Inverse Efficiency Score" ($F(2,64) = 0.007$, $p = 0.993$) the p -values obtained from Levene's tests exceeded the conventional significance level of 0.05, thus affirming the presence of homogeneity. Conversely, for "Corsi_total" ($F(2,64) = 4.128$, $p = 0.021$) and "Go/No-Go d' prime" ($F(2,64) = 3.902$, $p = 0.025$) the p -values were less than 0.05, implying the absence of homogeneity in these variables. This indicates that the variances of these variables significantly differ among the groups. Overall, these results provide valuable insights into the equality of variances for each variable, which is crucial in subsequent statistical analyses (Appendix 4).

Once the assumption of homoscedasticity was not verified in every variable, we used Tamhane's T^2 test, which is more conservative, to compare the means between the groups. The partial η^2 indicates the existence of a strong association between the type of participant and each dependent variable presenting significant results.

7.1 *d2* Test of Attention

7.1.1 General Efficiency Score

We computed a One-Way Analysis of Variance (ANOVA) and found that there were no significant differences among the study groups in terms of the General Efficiency Score variable ($F(2,64) = 0.255, p = 0.755$). This empirical finding highlights that there are no variations in the General Efficiency Score, across the study groups (Fig 2. and Appendix 5).

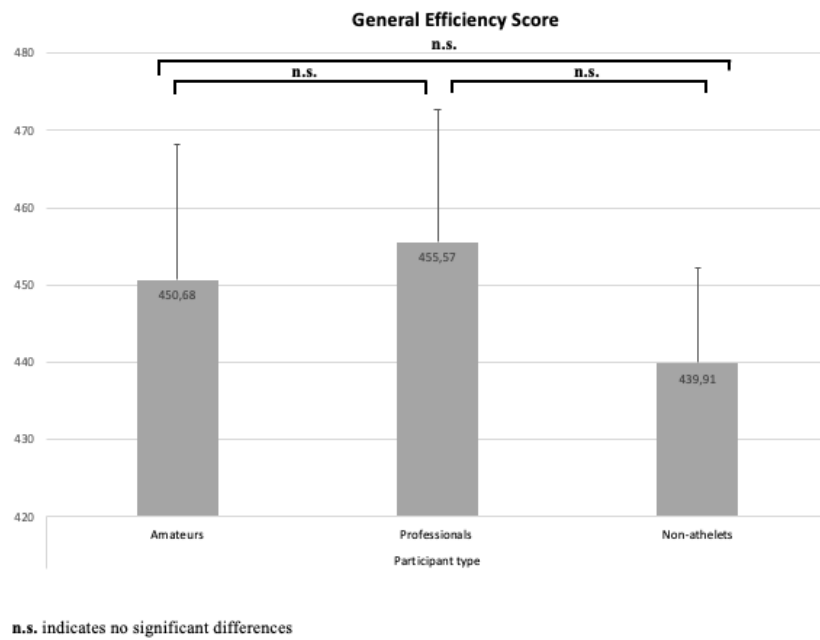


Fig 2. Participants groups mean for General Efficiency score. Error bars represent standard deviation.

7.1.2 Concentration Index

We computed a One-Way Analysis of Variance (ANOVA) and determined that there were no significant differences between the different groups studied ($F(2, 64) = 0.442$, $p = 0.645$) (Fig 3. and Appendix 5)

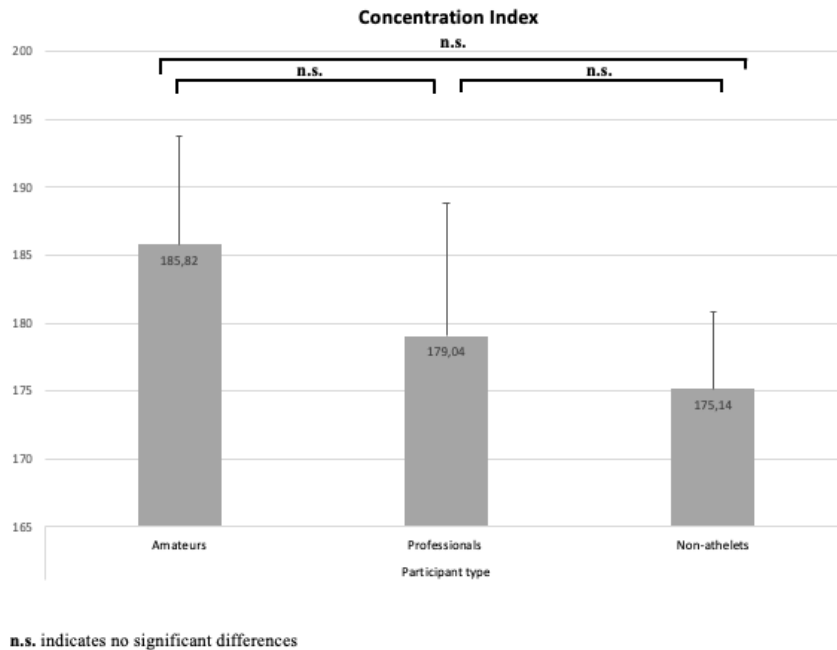
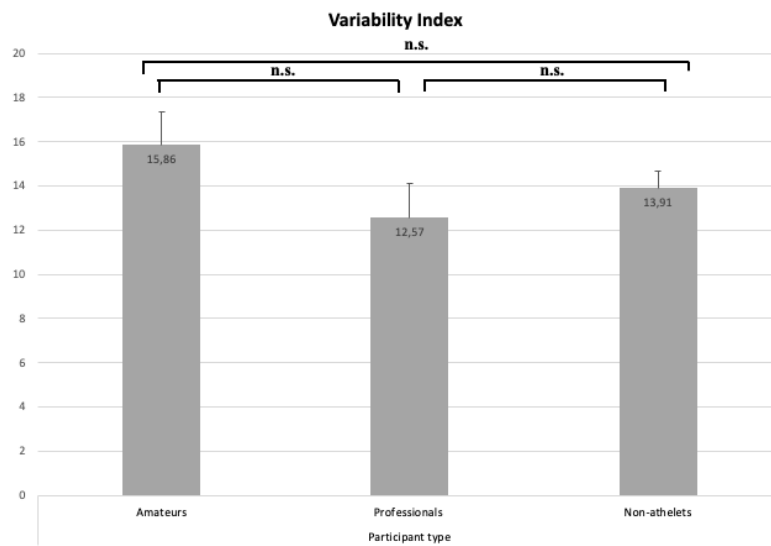


Fig 3. Participants groups mean for Concentration Index. Error bars represent standard deviation

7.1.3 Variability Index

We computed a One-Way Analysis of Variance (ANOVA) and determined that there were no significant differences, between the study groups ($F(2,64) = 1.583$, $p = 0.213$) (Fig 4. and Appendix 5).

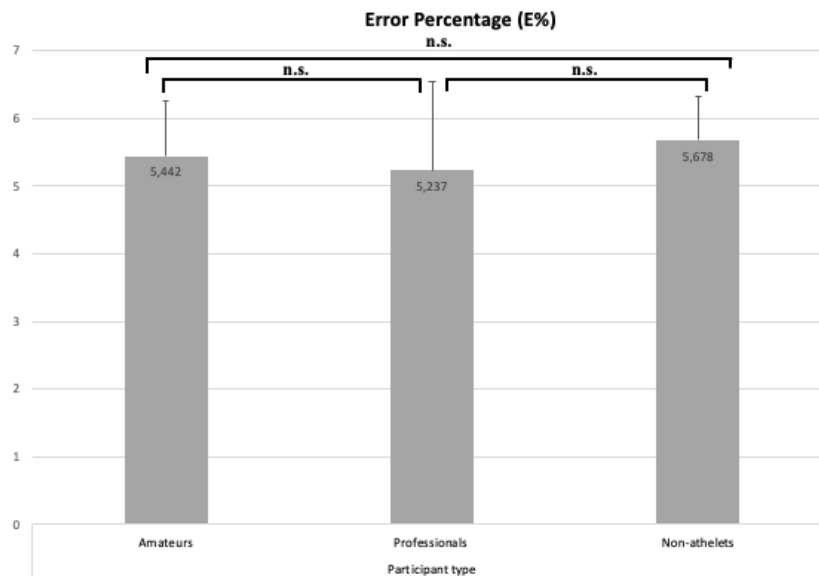


n.s. indicates no significant differences

Fig 4. Participants groups mean for Variability Index. Error bars represent standard deviation

7.1.4 Error percentage

We computed a One-Way Analysis of Variance (ANOVA) applied to the Error Percentage variable, we ascertained that there were no statistically significant differences amongst the study groups ($F(2,64) = 0.051, p = 0.950$). This empirical finding underscores the absence of meaningful distinctions within the Error Percentage variable across the diverse study groups (Fig 5. and Appendix 5).



n.s. indicates no significant differences

Fig 5. Participants groups mean for Error Percentage. Error bars represent standard deviation

7.2 Corsi Task

7.2.1. Corsi total

The data related to this variable was analyzed using One Way Analysis of Variance (ANOVA). The results showed that there were differences, among the groups ($F(2,64) = 9.447, p < 0.001, \eta^2 = 0.228$).

We examined the multiple comparisons through the Tamhane's T^2 post hoc test to see the differences between the groups of participants. The p-values were used systematically to assess significance and determine any differences among the groups.

The comparison between "Professional" and "Non athlete" participants yielded a p-value < 0.001 . This indicates that there are differences between these two participant groups meeting the conventional threshold for statistical significance ($p \leq 0.05$).

Moreover, when comparing "Non athlete" and "Amateur" participants, we found a p-value of 0.001 highlighting differences between these groups.

However, when comparing participants labeled as "Professional" and "Amateur" the obtained p-value of 0.937 suggests that there are no significant differences.

To sum up, the multiple comparisons analysis clearly establishes a difference, between "Professional" and "Non-Athlete" participants ($p < 0.001$). It is worth mentioning that the "Professional" individuals exhibited a score ($M = 19.13, SD = 3.520$) in comparison to the "Non athlete" participants ($M = 15.64, SD = 2.237$). Additionally, a significant difference was observed between the "Amateur" and "Non athlete" participants ($p = 0.001$) with means of $M = 18.64$ and $M = 15.64$, alongside their corresponding standard deviations ($SD = 2.770$ and $SD = 2.237$), respectively (Fig 5. And Appendices 6 and 8).

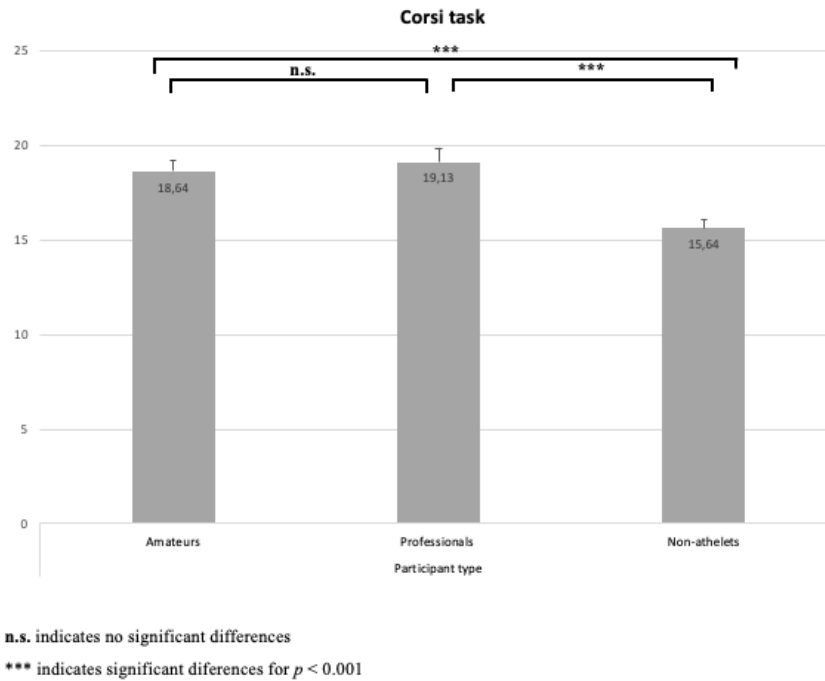


Fig 6. Participants groups mean for Corsi Task. Error bars represent standard deviation

7.3 Go/ No- Go task

7.3.1 Inverse Efficiency Score (IES)

The data obtained from the Inverse Efficiency Score (IES) was carefully analyzed using One Way Analysis of Variance (ANOVA). The results showed that there was no difference ($F(2,64) = 1.247, p = 0.294$), among the study groups indicating that the groups being investigated were similar. This further highlights the consistency and similarity of the groups (Fig 7. and Appendix 7).

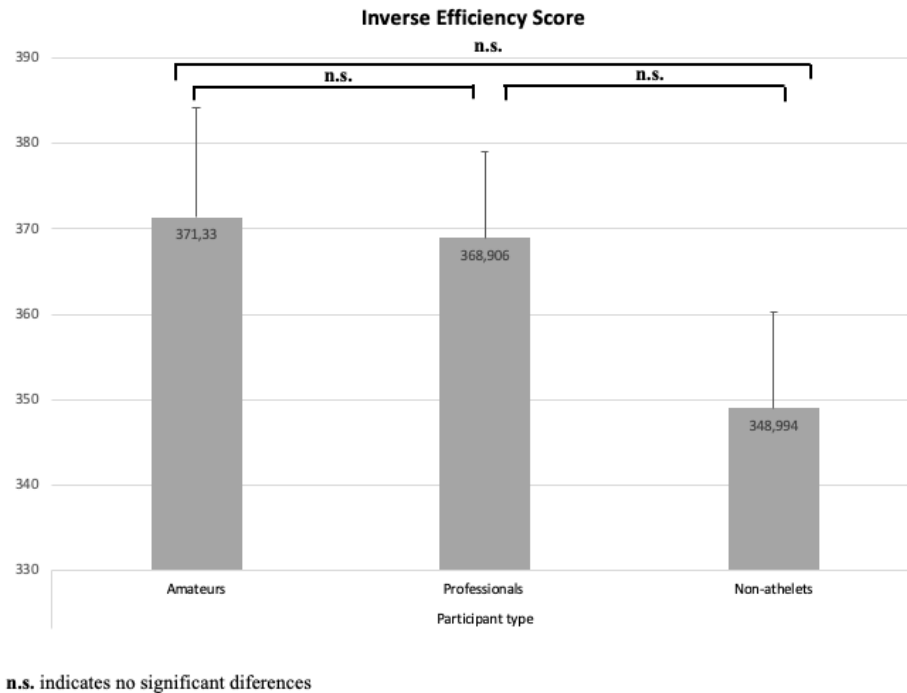


Fig 7. Participants groups mean for Inverse Efficiency Score. Error bars represent standard deviation

7.3.2 *d'* prime

The data related to this variable was analyzed extensively using One Way Analysis of Variance (ANOVA). The results showed that there were differences, among the groups ($F(2,64) = 10.829, p < 0.001, \eta^2 = 0.253$).

We examined the multiple comparisons through the Tamhane's T^2 post hoc test to see the differences between the groups of participants. The p-values were used systematically to assess significance and determine any differences among the groups.

The comparison between "Professional" and "Non athlete" participants yielded a p-value < 0.001 . This indicates that there are differences between these two participant groups meeting the conventional threshold for statistical significance ($p \leq 0.05$).

Moreover, when comparing "Non athlete" and "Amateur" participants we found a p-value of 0.008 highlighting differences, between these groups.

However, when comparing participants labeled as "Professional" and "Amateur" the obtained p-value of 0.572 suggests that there is no significance

To sum up the multiple comparisons analysis clearly establishes a difference, between participants categorized as "Professional" and those classified as "Non-Athlete" ($p < 0.001$). It is worth mentioning that the "Professional" individuals exhibited a score ($M = 0.866, SD = 1.654$) in comparison to the "Non athlete" participants ($M = 3.324, SD = 2.193$). Additionally, a significant difference was observed between the "Amateur" and "Non athlete" participants ($p = 0.008$) with means of $M = 1.444$ and $M = 3.324$, alongside their corresponding standard deviations ($SD = 1.639$ and $SD = 2.193$), respectively (Fig 8. and Appendix 7 and 9).

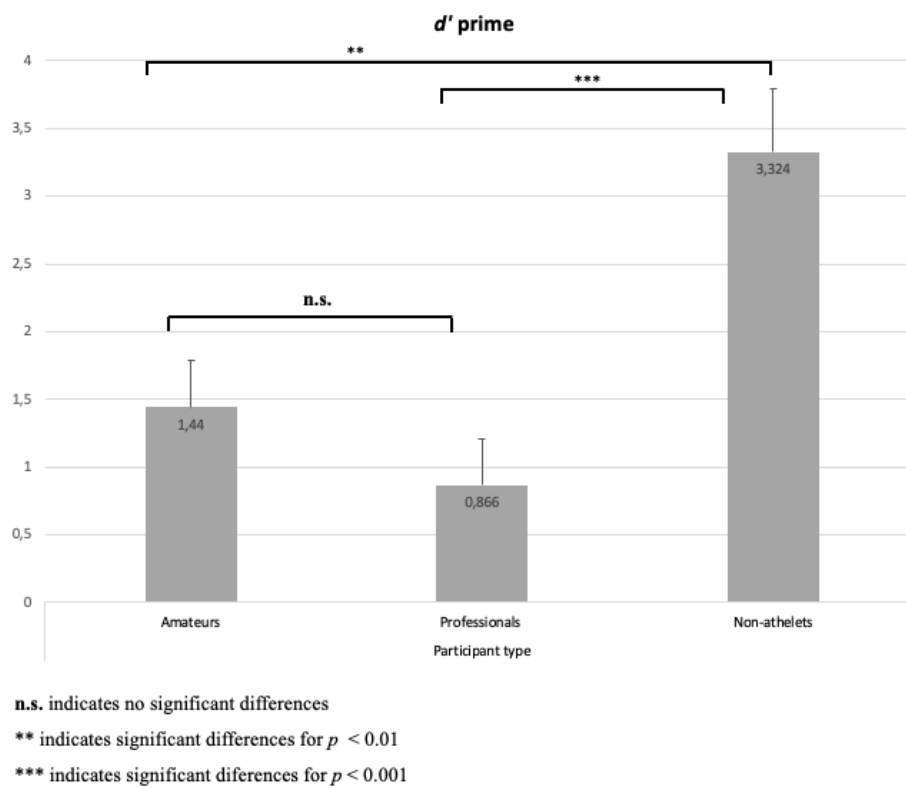


Fig 8. Participants groups mean for d' prime. Error bars represent standard deviation

8. Discussion

The present study investigated the relationship between sports expertise and cognitive functioning, specifically focusing on the performance of professional rugby players, amateur rugby players, and non-athletes in the domains of visuospatial working memory, inhibitory control, and attention. As highlighted in the introduction, our research aimed to address the ambiguity surrounding the effect of expertise in sports on different cognitive performance domains. Our study sheds light on the complex relationship between sports participation and cognitive performance. Regarding the hypothesis 1: high-performance rugby practitioners should show better results on cognitive functioning compared to the amateur rugby athletes and non-athletes, the results of our study suggest that rugby may have differential effects on cognitive function, depending on the specific cognitive domain being assessed. Specifically, professional and amateur rugby players showed better performance on the Corsi block task, which assesses visuospatial memory, compared to non-athletes. The evaluation of visuospatial working memory is particularly relevant in sports that involve ball movement, as it plays a vital role in recalling and locating objects and individuals (Arce & McMullen, 2021). Kruger et al. (2009) suggested that the visual skills of athletes participating in ball sports are superior to those of the general population. However, there was no difference between the groups on the *d2* Test of Attention, which assesses sustained attention, and on the performance in the Go/No go task which assesses inhibitory control. Surprisingly, we verified that the non-athletes had more sensitivity, given by the d' prime measure, to detect and distinguish stimulus when compared with professional and amateur athletes. It is possible that these findings result from the putative competition between the cognitive benefits of exercise and the potential negative effects of contact sports on cognition.

One common theme in the existing literature is the potential cognitive benefits of regular exercise. Numerous studies have suggested that young adults engaged in physical activity tend to exhibit superior cognitive functioning compared to their sedentary counterparts (Colcombe & Kramer, 2003; Hillman et al., 2008). This was partly corroborated by our study, as both professional and amateur rugby players demonstrated improved visuospatial memory performance, as assessed by the Corsi block task. These findings align with the study by Gao et al. (2015) in which rugby players had better visual skills than non-athletes, prevailing the notion that physical exercise can positively influence cognitive abilities (Erickson et al., 2011). One possible explanation for these benefits is that exercise increases blood flow to the brain, stimulates the growth of new

neurons and strengthens connections between neurons (Cotman & Engesser-Cesar, 2002). These changes in the brain's structure and function may contribute to the cognitive benefits of exercise (Hilman et al., 2008).

The lack of differences between the amateur and professional athletes in our study can be understood based on the findings we obtained from the International Physical Activity Questionnaire (*IPAQ*). Surprisingly, the results from *IPAQ* showed that there were no differences in the total METs minutes per week between professional and amateur athletes, which means the professional amateurs participants cannot be distinguished by the time dispended in physical activity. Previous research had suggested that professionals tend to spend more time exercising compared to amateurs assuming that professionals engage in more frequent and intense training sessions. Naturally, we expected to see outcomes within the *IPAQ* assessments. However, it is important to consider the context of our research, which was conducted in Portugal—where rugby hasn't been fully professionalized yet and the Rugby National Team players have their own jobs and do not play rugby for living. This unique scenario might explain why there is such a similarity in exercise time dispended between amateur and professional athletes providing insights.

However, the data also introduced a nuanced perspective. In our study, the participants engaged in a contact sport - rugby. Interestingly, some studies have shown that athletes involved in contact sports, may not exhibit the same cognitive advantages as athletes participating in a non-contact sport (Hume et al., 2017). This observation challenges the conventional wisdom that sports automatically enhance cognitive functioning. Our findings, suggesting superior visuospatial memory in rugby athletes, contribute to this ongoing debate by showing that not all cognitive functions are adversely affected by contact sports. Regarding our hypothesis 1b and 2b, which suggests that high-performance rugby practitioners would demonstrate superior performance on visuospatial working memory tasks compared to amateur rugby athletes and non-athletes (1b) and amateurs demonstrate superior performance on visuospatial working memory task compared to non-athletes (2b), our findings partially confirm this hypothesis. We observed no significant differences between professional and amateur athletes. However, significant differences were found between professional athletes and non-athletes, as well as between amateur athletes and non-athletes.

The results related to attention are intriguing. Attention is another key cognitive function and it is vital for selecting relevant information in the presence of an information

overload (Desimone & Duncan, 1995). Previous research has indicated that attentional processes can be enhanced by physical exercise (Tompsonski, 2003). Contrary to our initial expectations proposed in the hypothesis 1a and 2a, we found no significant differences in attention between the three groups, highlighting that the impact of sports on attention may be influenced by various factors, such as the specific sport and the cognitive domain under investigation. This finding aligns with studies suggesting that the cognitive benefits of exercise might not uniformly extend to all cognitive domains. In the context of contact sports like rugby, it is also possible that the potential cognitive advantages are offset by the physical impacts and potential head injuries associated with the sport (Hume et al., 2017). Thus, while exercise may offer cognitive advantages in certain domains, it might not protect against attention-related deficits caused by contact sports. Although the number of reported cases of losing consciousness is relatively low it is important to recognize that the nature of the sport suggests that many individuals may have experienced head impacts during both games and training sessions. These head impacts even if they do not immediately cause loss of consciousness can still have effects on cognitive abilities (Guskiewicz et al., 2005). The cumulative impact of repeated concussive impacts, which often go unnoticed is a cause for concern as studies have shown that they can contribute to long term cognitive impairments (Broglio et al., 2012).

One particularly significant observation from our study pertains to inhibitory control. Several studies have suggested that athletes exhibit superior inhibitory control (Di Russo, 2006; Nakamoto, 2008). Despite the inexistence of differences between the groups in the Inverse Efficiency Score (IES), the non-athletes demonstrated greater sensitivity in stimulus detection compared to professional and amateur rugby athletes. Furthermore, our study did not detect significant differences in inhibitory control between professional rugby players, amateur rugby players, and non-athletes, challenging our hypotheses 1c and 2c and the assumption that inhibitory control is enhanced in athletes. This result highlights the eventual negative effects of contact sports on inhibitory control, a cognitive function crucial for impulse regulation (Diamond, 2013). Existing literature supports this finding by suggesting that individuals engaged in rugby and similar contact sports may exhibit higher levels of aggression (Maxwell et al., 2009), which can compromise inhibitory control. Our study's results align with these findings, emphasizing the complex interplay between sport, cognitive functions, and emotional regulation.

The inconsistency in results may be attributed to the specific cognitive functions assessed and the nature of the sport. While executive functions play a crucial role in sports

that require concentration and attention (Burgess & Simons, 2005), the manifestation of these functions may vary across sports. In our study, we explored visuospatial working memory, inhibitory control, and attention. These functions were selected based on their relevance to daily life and sports performance (Gioia et al., 2000; Vestberg et al., 2012).

This study and previous research suggest that rugby participation has a complex and multifaceted relationship with cognitive function. Rugby players may have both positive and negative effects on cognitive function, depending on the specific cognitive function being assessed. Finally, in contrast to our initial hypothesis our study did not find substantial evidence to support the notion that sports, particularly rugby, leads to significant cognitive advantages. However, it is worth highlighting that rugby is a sport that requires understanding ball trajectories, field awareness and the positioning of teammates (Romeas et al., 2016; Gonçalves et al., 2017). This could potentially explain why there is a superior performance in working memory in rugby players (Kruger et al., 2009). Our findings emphasize the intricate and multifaceted nature of the relationship between sports and cognitive functioning.

Further research is needed to unravel the complexities of this relationship and its implications for sports training to develop strategies to protect rugby players from the potential negative effects of this contact sport on cognitive function.

8.1 Limitations and future research

There are a few limitations and suggestions to be aware of when interpreting the findings of this study.

First of all, the non-professional status of rugby in Portugal does not allow the national team players to make their living from rugby thus, the differences between amateur and professional players are further nuanced. However, it is essential to note that these athletes despite the fact they are not professionals they usually engage in intensive training depending on the competition, tournament or cup, such as the Rugby World Cup 2023.

Crucially, there was a time variability of the interviews. With some of the interviews before training but after a workday, others after training and others in the morning before work or training. We believe this introduces a potential fatigue factor that could influence the quality and depth of the participants' responses, potentially affecting the accuracy of the data. Unfortunately, we had to adapt to the teams' and

players' individual availabilities to be able to collect the data. These limitations should be considered when assessing the study's outcomes and considering their transferability to different rugby contexts. Moreover, it is worth highlighting that our study utilized a blend of snowball sampling and convenience sampling to collect data. While these methods were appropriate for our research it is crucial to recognize that they may restrict the applicability of the data beyond the specific sample and context studied.

Finally, for future research it is essential to investigate approaches for monitoring concussions and head impacts that extend beyond relying on athletes self-reporting. Although self-reporting is valuable for gathering data it has limitations such as recall bias, underreporting or players not recognizing the true severity of head impacts. In future research, exploring the cognitive functioning disparities, particularly in decision-making and cognitive flexibility between rugby's forward and back positions could yield valuable insights.

9. Conclusion

In conclusion, this study investigated how sports in professional and amateur rugby players affects cognitive functions, such as visuospatial working memory, inhibitory control, and attention. The findings revealed that the impact of rugby expertise on cognitive functioning is variable. Indeed, in our study, we found that there were no significant differences in cognitive performance between the professional and amateur athletes. However, notable differences in working memory did emerge when comparing the combined group of athletes (professional and amateurs) with non-athletes. This observation highlights that the impact of sports expertise, regardless of the level, differs from that of non-athletes in certain cognitive domains such as visuospatial memory that can be seriously promoted because of the constant awareness in the field and ball.

Both professional and amateur rugby players displayed improved visuospatial working memory, aligning with the positive influence of physical exercise on this domain. However, no differences were observed in attention across the groups, suggesting that the benefits of exercise might not extend uniformly. Inhibitory control also did not significantly differ, challenging the assumption of uniform cognitive enhancement across domains in athletes. The intricate relationship between sports and cognitive functioning requires further comprehensive research to understand these complexities.

In summary, expertise in rugby may have both positive and negative effects on cognitive function, depending on the specific cognitive domain. While rugby players showed improved visuospatial working memory, this does not necessarily apply to other domains like attention and inhibitory control. The intricate nature of this relationship emphasizes the need for in-depth research to develop strategies for safeguarding athletes, particularly rugby players, from potential cognitive effects associated with their sport.

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Appendices

Appendix 1. Table for test of Normality and variance's Homogeneity for Total MET min/week

Tests of Normality and variances' Homogeneity

	Shapiro-Wilk						Levene	
	Professional		Amateur		Non-Athlete		S.T	p
	S.T.	p	S.T.	p	S.T.	p		
Total MET min/ week	.504	<.001	.606	<.001	.947	.271	12.201	<.001

Appendix 2. Table for Post-hoc analyses for MET min/week

Variable	Groups	Mean Differences	p
Total MET min/ week	Tamhane Professional- Amateur	= 6532.013	.203
	Professional - Non Athlete	3014.523	.030*
	Non- Athlete- Amateur	= 3014.523	<004*

* The mean difference is significant at the 0.05 level.

Appendix 3. Table for Multivariate Tests

Multivariate tests

		Value	F	df		p	h ²
				Hypotesis	Error		
Intercept	Pillai's Trace	.996	1264.895	10.000	55.000	<.001	0.996
	Wilks Lambda	.004	1264.896	10.000	55.000	<.001	0.996
	Hotelling's Trace	229.981	1264.897	10.000	55.000	<.001	0.996
	Roy's Largest Root	229.981	1264.898	10.000	55.000	<.001	0.996
Participant Type	Pillai's Trace	.998	5.557	20.000	112.000	<.001	.499
	Wilks Lambda	.180	6.468	20.001	110.000	<.001	.576
	Hotelling's Trace	3.571	9.642	20.002	108.000	<.001	.641
	Roy's Largest Root	3.269	18.305	20.003	56.000	<.011	.766

Appendix 4. Table for test of Normality and variance's Homogeneity for assessed variable

Tests of Normality and variances' Homogeneity

	Shapiro-Wilk						Levene	
	Professional		Amateur		Non-Athlete		S.T	p
	S.T.	p	S.T.	p	S.T.	p		
d2 Test of Attention								
General Efficiency Score	.981	.919	.956	.421	.915	.061	.465	.630
Concentration Index	.965	.564	.966	.623	.949	.303	1.497	.231
Variability Index	.729	<.001	.849	.003	.733	<.001	2.774	.070
Error Percentage	.604	<.001	.905	.038	.688	<.001	2.083	.133
Corsi Block Test								
Corsi total	.939	.173	.964	.581	.871	.008	4.128	.021
Go/ No-go								
Inverse Efficient Score (IES)	.906	.033	.842	.002	.970	.711	.007	.993
d' prime	.887	.014	.702	<.001	.681	<.001	3.902	.025

Appendix 5. Table for the differences between groups for each variable of d2 test of Attention – One Way ANOVA

Differences between groups in d2 test of Attention

	Professional (n=23)		Amateur (n=22)		Non-athletes (n=22)		F	p	η^2
	M	SD	M	SD	M	SD			
General Efficiency Score	455.57	82.458	450.68	81.786	439.91	57.592	.255	.0775	.008
Concentration Index	179.04	47.242	185.82	37.075	175.14	26.920	.442	.645	.014
Variability Index	12.57	7.335	15.86	7.019	13.91	3.624	1.583	.213	.047
Error Percentatge	5.237	6.3178	5.075	5.144	5.678	3.005	.051	.950	.002

Appendix 6. Table for the differences between groups for each variable of Corsi Block Test– One Way ANOVA

Differences between groups in Corsi Block Test

	Professional (n=23)		Amateur (n=22)		Non-athletes (n=22)		F	p	η^2
	M	SD	M	SD	M	SD			
Corsi Total	19.13	3.520	18.64	2.770	15.64	.447	9.447	<.001*	.228

* The mean difference is significant at the 0.05 level.

Appendix 7. Table for the differences between groups for each variable of Go/ No go –
One Way ANOVA

Differences between groups in Go/ No-go Task

	Professional (n=23)		Amateur (n=22)		Non-athletes (n=22)		F	p	η^2
	M	SD	M	SD	M	SD			
Inverse Efficiency Score	368.906	48.479	371.330	60.627	348.479	48.765	1.247	.294	.038
<i>d'</i> prime	0.866	1.654	1.444	1.639	3.324	2.193	10.829	<.001*	0.253

* The mean difference is significant at the 0.05 level.

Appendix 8. Table for Post- hoc analyses for Corsi Block test

Variable	Groups	Mean Differences	p
Corsi Total	Tamhane Professional- Amateur	.49	.937
	Professional - Non Athlete	3.49	<.001*
	Non- Athlete- Amateur	-3.00	<.001*

* The mean difference is significant at the 0.05 level.

Appendix 9. Table for Post- hoc analyses for Go/ No-go

Variable	Groups	Mean Differences	p
Inverse Efficiency Score	Tamhane Professional- Amateur	-2.424	.998
	Professional - Non Athlete	20.427	.420
	Non- Athlete- Amateur	-22.851	0.440
<i>d'</i> prime	Tamhane Professional- Amateur	-.577	.572
	Professional - Non Athlete	-2.457	<.001*
	Non- Athlete- Amateur	1.880	.008*

* The mean difference is significant at the 0.05 level.

CONSENTIMENTO INFORMADO PARA EFEITOS DE INVESTIGAÇÃO

Este estudo tem como investigador principal a estudante de Mestrado em Neuropsicologia Clínica do Instituto de Ciências da Saúde da Universidade Católica Portuguesa **Mónica Lança de Moraes**. A sua participação neste estudo é inteiramente voluntária. Deve ler a informação que se segue e colocar questões sobre aquilo que não entender antes de decidir se participa ou não neste estudo.

Solicitamos a sua participação num estudo que tem como objetivo explorar a perícia no desporto no funcionamento cognitivo em jogadores de *rugby* com idades compreendidas entre os 18 e os 31 anos.

O que implica a sua participação?

A sua participação consiste em desempenhar 3 tarefas: Uma tarefa de memória visuoespacial que consiste na identificação de estímulos dispostos num tabuleiro; uma tarefa de atenção que consiste no cancelamento de itens; uma tarefa de controlo inibitório que consiste na resposta motora oferecida consoante o estímulo proposto. Além disso, requer-se o preenchimento de 2 formulários para aferir a média semanal do nº de horas despendidas em atividade física e para recolher informação sociodemográfica.

Prevê-se que a recolha de todos os dados, tanto os das provas como os dos questionários, tenha uma duração de aproximadamente 30 a 40 minutos. Os participantes podem desistir a qualquer momento (sem necessidade de apresentar razões para a sua desistência) sem qualquer consequência.

Tratamento dos Dados

Os dados recolhidos serão processados em conjunto e de forma anónima, sendo atribuído um código a cada participante. Não serão analisados dados individuais, mas de grupo e os resultados serão exclusivamente utilizados para as estatísticas do estudo proposto, com fins unicamente académicos. Os dados serão armazenados em computador, de acesso exclusivo ao aluno e ao responsável da unidade curricular. Após a análise dos resultados

obtidos, todos os dados serão apagados. O estudo terá a duração de 4 meses (entre Março e Junho de 2023).

Benefícios

Com este estudo pretendemos conhecer melhor as especificidades cognitivas da perícia no desporto. Não se preveem benefícios diretos para o participante, mas indiretamente, através do aumento do conhecimento, poderemos melhorar as indicações de treino e otimizar os seus benefícios.

Identificação dos investigadores

Caso tenha alguma questão adicional ou necessite de entrar em contacto connosco, poderá fazê-lo para:

Mónica Lança de Moraes (Investigadora) monicalancamorais@gmail.com ou pelo telemóvel +351 910969353

Ana Maria Abreu (Orientadora) anelas@ucp.pt

O Encarregado da Proteção de Dados (DPO) no Instituto de Ciências da Saúde da Universidade Católica Portuguesa é Dra. Frederica Campos de Carvalho. compliance.rgpd@ucp.pt ou para o telefone +351 217214179

Agradecemos desde já a disponibilidade.

Assinatura do participante na investigação

Declaro que eu, _____ (nome do participante) com o número de identificação _____ li e compreendi a informação relativa ao projeto de investigação acima. Foi-me dada a oportunidade de colocar questões, as quais foram devidamente esclarecidas. Foi-me dada uma cópia deste documento.

AO ASSINAR ESTE DOCUMENTO ASSUMO ACEITAR PARTICIPAR VOLUNTARIAMENTE NO ESTUDO NELE DESCRITO.

Assinatura _____

Data: _____

Assinatura do investigador

Expliquei o estudo ao participante e respondi a todas as suas questões. Considero que compreende a informação apresentada neste documento e consente livremente participar neste estudo.

_____ (nome do investigador)

Assinatura: _____

Data: _____

Questionário Sociodemográfico

Código de identificação: _____

Sexo: _____

Idade: _____

Data de Nascimento: _____

Escolaridade: _____

No caso de ser jogador de *rugby*: **CLUBE** _____ **SELEÇÃO** _____

Posição em que joga: _____

Usa óculos: **SIM** _____ **NÃO** _____. Se sim, tem-nos consigo? **SIM** ____ **NÃO** _____

Lesão: **SIM** ____ **NÃO** _____. Se sim, o quê? _____

Teve alguma perda de consciência nos últimos meses? **SIM** ____ **NÃO** _____. Se sim, quando? _____

Nº treinos por semana: _____

Nº de horas por treino: _____

Data: ____/____/2023

Appendix C. Manuscript submitted to the Psychology of Sports and Exercise

Psychology of Sport & Exercise

Domain-specific cognitive benefits in rugby athletes

--Manuscript Draft--

Manuscript Number:	
Article Type:	Research Paper
Section/Category:	Exercise & Health
Keywords:	cognition, executive functions, physical exercise, sports.
Corresponding Author:	Ana Maria Abreu, Ph.D. Center for Interdisciplinary Research in Health, Institute of Health Sciences, Catholic University of Portugal Lisboa, Lisboa PORTUGAL
First Author:	Mónica Lança de Morais
Order of Authors:	Mónica Lança de Morais Belén Rando, PhD Ana Maria Abreu, Ph.D.
Abstract:	This study investigates the influence of sports expertise on cognitive functioning, focusing on professional athletes, amateur athletes, and non-athletes, within the context of rugby as a contact sport. Neuropsychological tasks assessed visuospatial memory, attention, and inhibitory control in 67 participants across the three groups. While no differences were observed in the attention domain, both professional and amateur athletes outperformed non-athletes in visuospatial working memory. Inhibitory control, as measured by the inverse efficiency score, showed no group disparities, although non-athletes exhibited greater sensitivity to signals (d' prime scores) compared to athletes. Notably, professional, and amateur athletes demonstrated similar inhibitory control. This study underscores that rugby sports expertise impacts specific cognitive domains, enhancing visuospatial memory but not affecting attention or inhibitory control. The intricate relationship between contact sports and cognitive performance necessitates further research to address sports-specific cognitive deficits and ensure the cognitive well-being of athletes. Understanding these cognitive differences can inform athlete training programs and potentially mitigate any negative cognitive effects associated with contact sports.
Suggested Reviewers:	Philip D. Tomporowski ptomporo@uga.edu has worked in similar issues Joanne L. Park joanne.park3@stir.ac.uk Has worked on similar issues Erik Lundkvist erik.lundkvist@umu.se Works in the area of Sports performance

Abstract

This study investigates the influence of sports expertise on cognitive functioning, focusing on professional athletes, amateur athletes, and non-athletes, within the context of rugby as a contact sport. Neuropsychological tasks assessed visuospatial memory, attention, and inhibitory control in 67 participants across the three groups. While no differences were observed in the attention domain, both professional and amateur athletes outperformed non-athletes in visuospatial working memory. Inhibitory control, as measured by the inverse efficiency score, showed no group disparities, although non-athletes exhibited greater sensitivity to signals (d' prime scores) compared to athletes. Notably, professional, and amateur athletes demonstrated similar inhibitory control. This study underscores that rugby sports expertise impacts specific cognitive domains, enhancing visuospatial memory but not affecting attention or inhibitory control. The intricate relationship between contact sports and cognitive performance necessitates further research to address sports-specific cognitive deficits and ensure the cognitive well-being of athletes. Understanding these cognitive differences can inform athlete training programs and potentially mitigate any negative cognitive effects associated with contact sports.

Keywords: cognition, executive functions, physical exercise, sports.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Subject: Manuscript submission

Lisbon, November 9, 2023

Dear Editors-in-Chief at *Psychology of Sport and Exercise*,

Professor Markus Raab and Professor Katherine Tamminen,

Please find enclosed the manuscript entitled “**Domain-specific cognitive benefits in rugby athletes**”, by Morais, Rando, and Abreu, which we would like to submit for consideration for publication in *Psychology of Sport and Exercise*.

Here, we aimed to investigate the putative competition between the cognitive benefits of exercise and sports and the detrimental hindrance of contact sports on cognition. We also aimed to investigate how this complex relationship might be expressed across different competition levels in rugby: non-athletes, amateur athletes, and professional athletes; and across different cognitive domains (visuospatial memory, inhibitory control, and attention). While both professional and amateur rugby players demonstrated improved visuospatial memory, the absence of significant differences in attention and inhibitory control could result from the competitive interplay between the cognitive advantages of physical activity and the potential cognitive challenges associated with contact sports. Notably, in the assessment of inhibitory control, no significant group differences were found. However, an intriguing discovery emerged, as non-athletes displayed greater sensitivity, as assessed by the d' prime scores, compared to professional and amateur athletes. Crucially we demonstrate that cognitive benefits of sports are not clearcut and might vary across cognitive domains and that the specificity of the benefits is linked to the practiced sport.

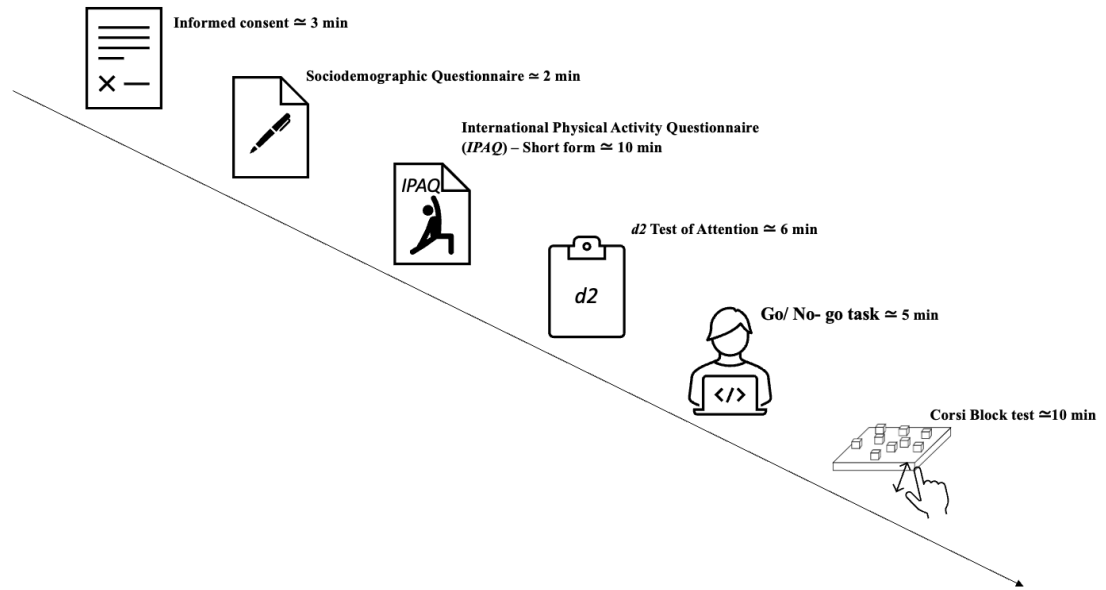
Our research contributes to elucidating the complex dynamics between sports benefits and hindrances on cognition. It contributes to developing strategies that safeguard athletes from potential cognitive consequences in contact sports.

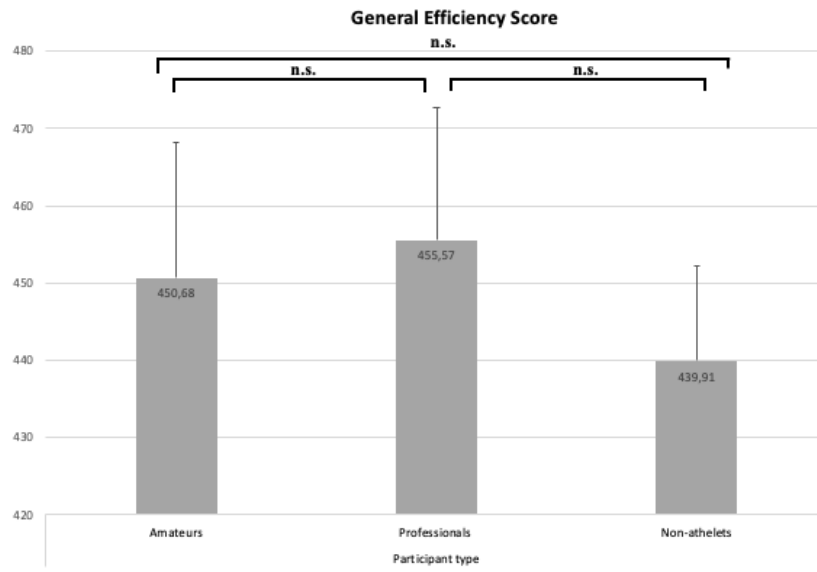
All co-authors reviewed this manuscript. None of this material has been published or is under consideration elsewhere, including the Internet. None of the co-authors have any financial or other conflicts of interest.

We thank you very much for your consideration and look forward to hearing from you.

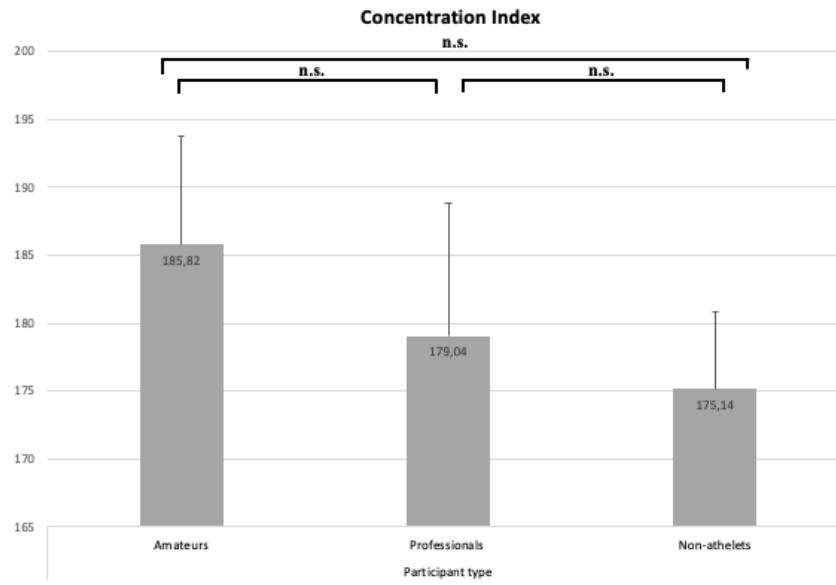
Sincerely yours,

Mónica Morais
Belén Rando
Ana Maria Abreu

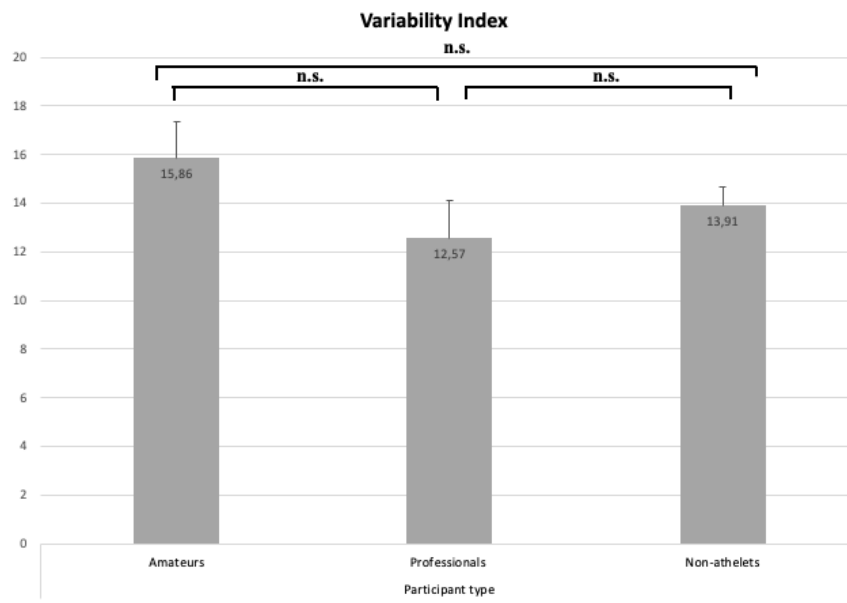




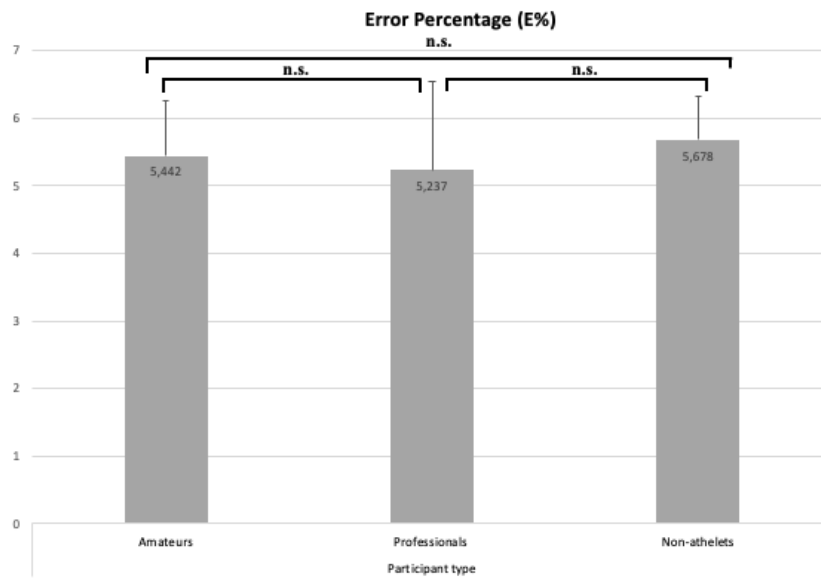
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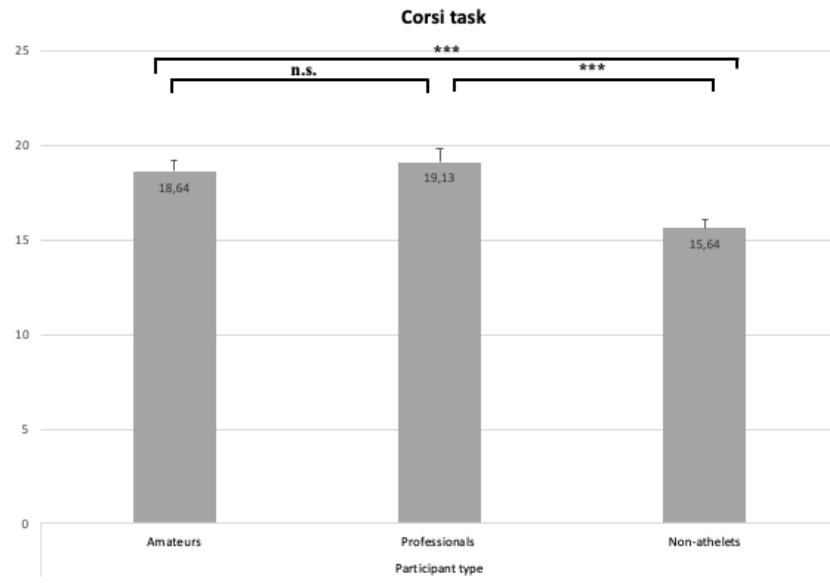
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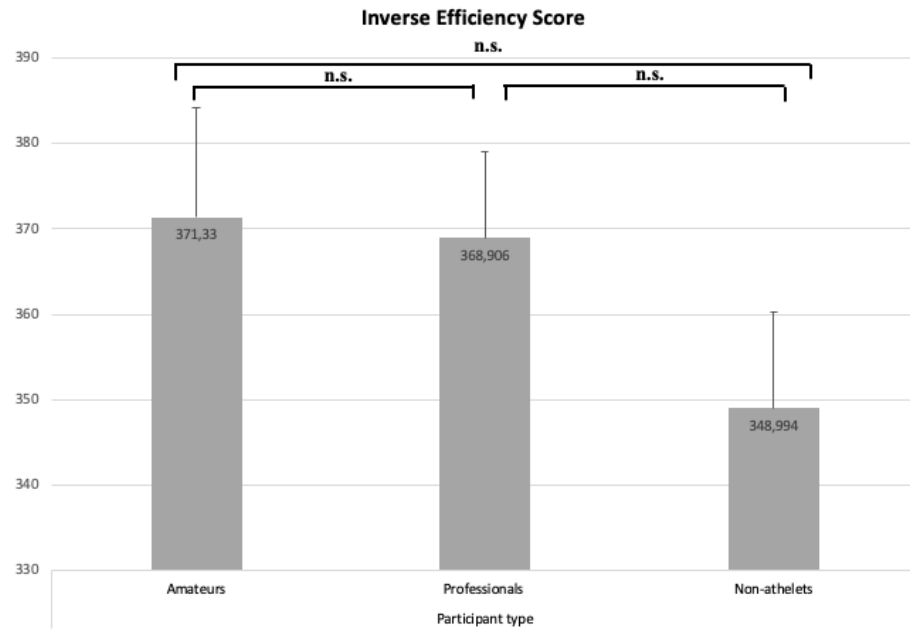


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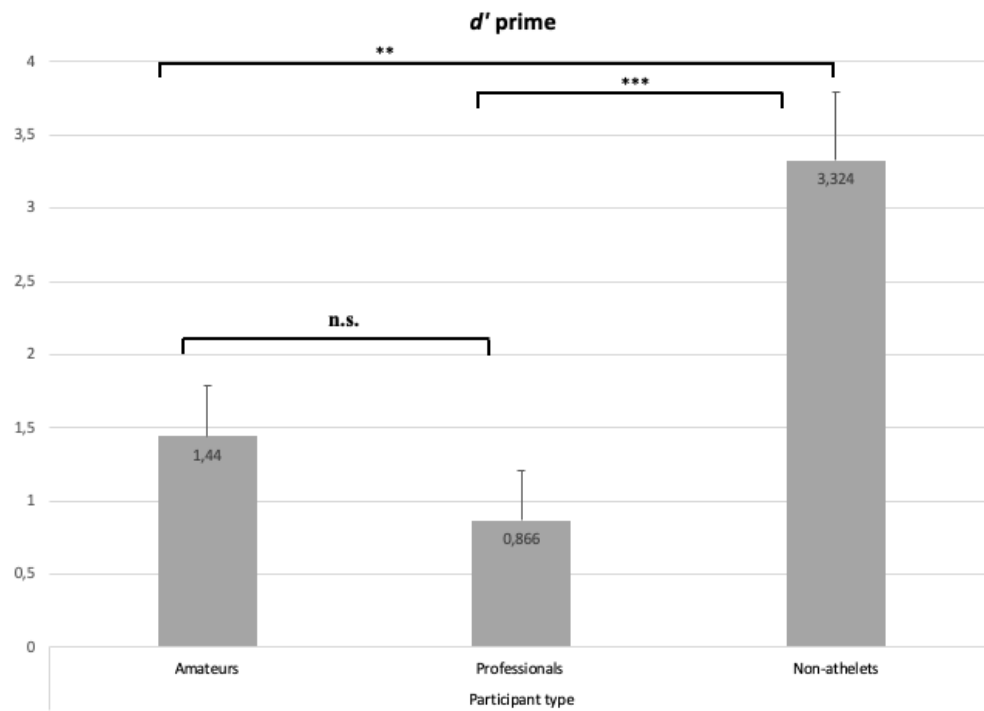


n.s. indicates no significant differences

******* indicates significant differences for $p < 0.001$



n.s. indicates no significant differences



n.s. indicates no significant differences

****** indicates significant differences for $p < 0.01$

******* indicates significant differences for $p < 0.001$

DOMAIN-SPECIFIC COGNITIVE BENEFITS IN RUGBY ATHLETES

This study investigates the influence of sports expertise on cognitive functioning, focusing on professional athletes, amateur athletes, and non-athletes, within the context of rugby as a contact sport. Neuropsychological tasks assessed visuospatial memory, attention, and inhibitory control in 67 participants across the three groups. While no differences were observed in the attention domain, both professional and amateur athletes outperformed non-athletes in visuospatial working memory. Inhibitory control, as measured by the inverse efficiency score, showed no group disparities, although non-athletes exhibited greater sensitivity to signals (d' prime scores) compared to athletes. Notably, professional and amateur athletes demonstrated similar inhibitory control. This study underscores that rugby sports expertise impacts specific cognitive domains, enhancing visuospatial memory but not affecting attention or inhibitory control. The intricate relationship between contact sports and cognitive performance necessitates further research to address sports-specific cognitive deficits and ensure the cognitive well-being of athletes. Understanding these cognitive differences can inform athlete training programs and potentially mitigate any negative cognitive effects associated with contact sports.

Keywords: cognition, executive functions, physical exercise, sports.

Introduction

In an era wherein both mental and physical well-being are highly valued, there has been a growing interest and debate concerning the connection between the benefits of exercise on cognition. Here we aim to explore the relationship between exercise, sports expertise and cognitive functioning. In other words, is amateur training and non-exercise practice different from professional practice and is amateur practice different from non-exercise practice in terms of cognitive benefits? Numerous studies have emphasized the impact of activity on cognitive function especially in tasks that demand a high level of mental control (Colcombe and Kramer, 2003; Hillman et al., 2008; Ludyga et al., 2020). This

1 relationship is especially relevant for high-level athletes, who often need a harmonious
2 blend of motor control, perception and cognitive skills to excel in their respective sports
3
4 (Scharfen, 2019). Based on previous studies, Scharfen (2019) suggests that professional
5 athletes demonstrate better executive functioning in comparison to amateurs. However,
6
7 there is some disagreement, among researchers when it comes to the relationship between
8
9 expertise and cognitive functioning. Some studies suggest that being skilled in sports
10
11 enhances cognition (Huijgen et al., 2015; Lundgren et al., 2016) while others do not find
12
13 any advantage in professionalization (Heppe et al., 2016).
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19 Abreu et al. (2012) suggest that sports expertise leads to neuronal alterations, that
20
21 could potentially be linked to cognitive advantages. Other studies have pinpointed the
22
23 physiological and neurobiological alterations of exercise leading to cognitive benefits
24
25 (e.g., Abreu & Frade, 2020; Maeneja et al., 2022; Maeneja et al., 2023).
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29 Here we explore different cognitive functioning domains amongst which is
30
31 executive functioning. Executive functions involve controlling impulses, working
32
33 memory and being adaptable to manage emotions, thoughts and behaviors effectively
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35 (Gioia et al., 2000; McCloskey et al., 2009; Miyake & Friedman 2012). These cognitive
36
37 processes are crucial in self-regulation and impact aspects of everyday life (Mischel et
38
39 al., 2011; Moffitt et al., 2011).
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43 Working memory is one such executive function which deals with spatial
44
45 information and is essential for remembering and locating objects in our everyday lives
46
47 (Arce & McMullen, 2021). Athletes who participate in sports like soccer or basketball
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49 where there is a lot of ball movement, often show enhanced visuospatial abilities based
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51 on the use of spatial strategies to interact with the balls' trajectory (Kruger et al., 2009).
52
53 However, a recent study by Millard et al. (2021) revealed that athletes may not perform
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55 as well as non-athletes when it comes to visual memory with the potential explanation of
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1 this might not be a crucial domain in the visuospatial intelligence to differentiate athletes
2 from non-athletes.
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4 Inhibitory control, on the other hand, is a component of executive functioning that
5 plays a role in managing attention, behavior, thoughts, and emotions in a rational manner
6 (Diamond, 2013). Studies have shown that athletes demonstrate better performance
7 compared to controls, in tasks related to inhibitory control, exhibiting a faster response
8 time and fewer errors in Go/No Go tasks (Di Russo, 2006; Nakamoto, 2008; Chan, 2011),
9 denoting the athletes improved capacity to resist impulsive reactions.
10

11 Alternatively, attention serves as a selective mechanism that prevents information
12 overload in the human brain (Desimone & Duncan, 1995; Chun et al., 2011; Rosenberg
13 et al., 2017). In particular, selective attention has been shown to be amenable to
14 improvement through physical exercise (Maeneja et al., 2022; 2023; Tomporowski, 2003;
15 Brisswalter et al., 2002), making it a pertinent topic for investigation in the realm of
16 sports, where decision-making under pressure is pivotal.
17

18 This research explores rugby as a contact sport known for its high impact nature.
19 Contact sports offer a rich context to investigate the connection between activity and
20 cognitive abilities. While some studies suggest detrimental effects on cognitive function
21 due to contact sports (Hume et al., 2017) others have proposed cognitive benefits,
22 specifically in visuospatial working memory (Furley & Memmert, 2010). These
23 inconsistencies highlight the complex connection between physical activity, contact
24 sports and cognitive abilities.
25

26 In summary, our research explores the connection between exercise, sports
27 expertise and cognitive abilities. We aim to gain an understanding of how these factors
28 interplay. We investigate inhibitory control, working memory and attention in high level
29 athletes, amateur athletes and non-athletes. According to the FluentRugby (n.d) website,
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1 amateur individuals who play rugby usually participate in training sessions about 2- 3
2 times per week with each session lasting around 1.5 to 2 hours. On the other hand,
3
4 professional rugby players tend to dedicate themselves to training 5- 6 times a week and
5
6 occasionally have multiple sessions, mainly during the pre-season. With this, our aim is
7
8 to acquire knowledge regarding the benefits associated with different degrees of physical
9
10 exercise. By shedding light on the nature of this relationship we hope to contribute to the
11
12 discussion about the advantages of engaging in exercise and developing expertise in
13
14 sports.
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21 **Material and Methods**

22 *Participants*

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24 We conducted an a priori power analysis utilizing G*Power 3 software (Faul et al., 2007)
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26 for the F tests family and corresponding approaches (MANOVA repeated measures). The
27
28 input parameters included a medium effect size ($d = 0.05$) as per Cohen (1988) and
29
30 Bakker et al. (2019), a significance level of $\alpha = 0.05$, and a power value of 80%, following
31
32 the approach of Abraham and Russell (2008). Based on the criteria, a sample size of 66
33
34 participants was calculated to provide 95.0% power for detecting an effect related to the
35
36 condition. A total of 67 participants (all males) took part in the study. They were divided
37
38 into three groups: 23 professional athletes (PA), 22 amateur athletes (AA) and 22 non-
39
40 athletes (NA). They were all aged between 19 and 31 years old ($M_{PA} = 24.57$, $SD_{PA} =$
41
42 3.287 ; $M_{AA} = 24.23$, $SD_{AA} = 4.353$; $M_{NA} = 23.05$, $SD_{NA} = 2.299$). The professional athletes
43
44 were recruited from the Portuguese National Rugby Team, while the amateur athletes
45
46 were recruited from a Portuguese rugby club (Belas Rugby Club). The non-athlete
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48 participants were recruited through social networks. Regarding our recruitment approach
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50 we opted for convenience sampling when selecting participants, for both professional and
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1 amateur groups. However, for the control group (non-athletes) we utilized snowball
2 sampling.
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4 According to the International Physical Activity Questionnaire (IPAQ), the group of
5 professional and amateur athletes practiced physical activity at a high level ($M_{PA} =$
6 10874.22 MET min/week, $SD_{PA} = 16248.08$ MET min/week; $M_{AA} = 4342.20$ MET
7 min/week, $SD_{AA} = 3783.81$ MET min/week) while the control group (non-athletes)
8 displayed a moderate level of physical activity ($M_{NA} = 1327.68$ MET min/week, $SD_{NA} =$
9 765.31 MET min/week). All the descriptive data concerning age, education, number of
10 reported losses of consciousness, and physical activity of the participants are reported in
11 Table 1. A One-Way ANOVA was computed to assess differences of physical exercise
12 between the groups. The MET min/week did not meet the assumption of normal
13 distribution in Professional and Amateur groups. However, Monte Carlo simulations with
14 different sample sizes and other conditions have shown that F-test is robust with non-
15 normal data (Blanca et al., 2017; Blanca et al., 2023). Here we report Welch's F-test [F
16 $(2, 29.865) = 10.34, p < .001$], because the Levene's test of homogeneity of variances
17 showed statistically significant differences [$F(2,64) = 12,2101, p < .001$]. Although the
18 sample sizes were practically identical, the Welch test can provide more guarantees
19 regarding significance. Post-hoc comparisons using Tamhane's T^2 tests revealed
20 statistically significant differences between professional athletes and non-athletes ($p =$
21 $.03$) and between amateur athletes and non-athletes ($p = .004$), but not between
22 professional and amateur athletes ($p = .203$). In summary, professional athletes did not
23 differ from professional athletes in terms of quantity of exercise, but both groups differed
24 from non-athletes. None of the participants had any physical injury in their hands and
25 arms or any significant visual uncorrected problems. All participants gave written
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1 informed consent to the study following the procedure approved by the Ethics Committee
2 of the local University.
3

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6 [Please insert Table 1 around here]
7

8
9 Table 1. Descriptive data of the three groups of participants
10

11 12 13 **Measures**

14 In this study, we used a sociodemographic questionnaire, the International Physical
15 Activity Questionnaire (IPAQ), the Corsi block Test, the d2 Test of Attention and a Go/
16 No-Go task.
17
18

19 20 21 **Sociodemographic questionnaire**

22 We created a sociodemographic questionnaire to collect, for each participant, important
23 information, such as age, education, if a player reported any loss of consciousness in the
24 past year or any other injury.
25

26 27 28 **The international Physical Activity Questionnaire (IPAQ)**

29 The study employed the short form of the International Physical Activity Questionnaire
30 (*IPAQ*) to evaluate each participant's level of physical activity (Booth M., 2000 & Lee, et
31 al., 2011). This self-reported questionnaire consists of 7 questions and typically takes
32 about 10 minutes to complete (Lavelle, et al., 2020). The data obtained from the IPAQ
33 was treated as parametric, with the focus on METs (Metabolic Equivalent of Task) per
34 minute per week. MET is a ratio that compares the working metabolic rate to the resting
35 metabolic rate, and it serves as a measure of physical activity intensity. According to the
36 American Heart Association, a minimum of 500 METs per minute per week is
37 recommended for maintaining a healthy lifestyle, equivalent to at least 75 minutes of
38 vigorous physical activity or 150 minutes of moderate physical activity per week (Abreu,
39 et al., 2022 & Úbeda-Colomber, J et al., 2019).
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d2 Test of Attention

The d2 Test of Attention is a widely used paper-and-pencil assessment tool designed to measure attention, visual scanning, and processing speed. This test involves presenting 14 lines of characters, including the letters "p" and "d," which are arranged adjacent to each other. Its primary objective is to evaluate an individual's attention and concentration, both of which are closely associated with cognitive functions in the brain. The typical duration of the d2 Test of Attention is 4 minutes and 40 seconds.

The test provides valuable insights into cognitive performance, and the assessment includes several performance indices such as the General Efficiency Score (TC-E), which is a comprehensive measure of attention control and the balance between speed and accuracy in task performance. It is calculated by subtracting the total number of errors from the total number of characters processed. Also, the Concentration Index (CI) indicates an individual's concentration ability, considering both the speed and precision of their responses. It is computed by subtracting the total omission errors from the total hits. The Error Percentage (E%) is a metric that evaluates the qualitative aspects of performance. It represents the percentage of total errors made during the test, including both commission errors related to inhibitory control and omission errors related to attention control. Finally, the Variability Index (VI) which quantifies the consistency and stability of an individual's task performance. It is determined by measuring the difference between the maximum and minimum numbers of characters processed, indicating temporal persistency throughout the task.

The d2 Test of Attention was chosen for this study due to its effectiveness in assessing attention and concentration. Additionally, physical activity has been associated with positive effects on attention and concentration capacity.

4.2.4 Go/ No-go Task

1 The go-no go task, designed to assess inhibitory control, was conducted using the
2 testable.org platform (<https://www.testable.org/>), where participants were presented with
3
4 a five-minute computer-based cognitive test. In this task, participants were required to
5
6 press the space bar on their keyboard whenever an orange square (the "go stimulus")
7
8 appeared on the screen. However, when a blue square (the "no-go stimulus") was
9
10 presented, they were instructed to refrain from pressing any key. Each stimulus, whether
11
12 "go" or "no-go," was displayed on the screen for 1000 milliseconds, testing the
13
14 participant's ability to quickly and accurately respond to specific visual cues while
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16 inhibiting responses to others. This task was administered through the testable.org
17
18 website and is commonly employed in psychology and neuroscience research to measure
19
20 inhibitory control.
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26 The results and information collected through this task on the testable.org platform,
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28 afforded several key performance metrics that were computed to gain insights into the
29
30 participants' cognitive abilities. These metrics allowed us to calculate inverse efficiency
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32 scores (IES), which provide a measure of the efficiency of the participants' responses, d'
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34 prime derived from the theory of signal detection, which assesses the participants'
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36 sensitivity to discriminate between "go" and "no-go" stimuli. Each of these scores offered
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38 valuable information about the participants' performance.
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48 The concept of the inverse efficiency score (IES) was first introduced by Townsend and
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50 Ashby in 1983 to address how speed-accuracy tradeoffs can affect performance. This
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52 score combines both accuracy and reaction times providing a measure where in higher
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54 scores indicate worse overall performance. To calculate the IES we divide the correct
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56 reaction times by the percentage of correct responses, for each condition and subject. This
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1 calculation enables us to obtain a performance index, which has been used in studies, like
2 Rach et al. (2010) and Throne (2006).
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4 **4.2.5 Corsi Task**

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7 Visuospatial working memory was assessed using the Corsi Block-Tapping Test from the
8
9 Wechsler Memory Scale (WMS-III). This test consists of a board with 10 cubes arranged
10
11 in a random pattern. The assessment was administered in two different ways, both forward
12
13 and backward (Wechsler, 1997). Prior to the actual test, two practical examples were
14
15 given to ensure participants' understanding of the task. In these examples, two sequences
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17 of cubes were presented, and participants were asked to repeat the touched cubes in the
18
19 same order. The first example consisted of two cubes, and the second, three cubes.
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21 Following the examples, the actual test began, where participants were required to
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23 successfully repeat as many cube sequences as possible.
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29 The test comprised 8 items, with each item representing a different level of difficulty.
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31 Each item included 2 trials with the same number of cubes. The test finished when a
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33 participant consistently failed both trials of a specific item. One point was awarded for
34
35 each correctly repeated sequence, allowing for a maximum score of 16. Here we
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37 investigate the total Corsi score comprised of the sum of scores of the forward and
38
39 backward trials.
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48 **Experimental procedure**

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51 After reading and signing the informed consent (that had previously been shared online),
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53 the participants filled in the Sociodemographic questionnaire wherein they shared
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55 sociodemographic data (age and education), some information about sports practice
56
57 (player at the Portuguese national team, player in an amateur rugby club or did not practice
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1 regular sports activities), information about any physical injuries and loss of
2 consciousness (Appendices A and B). The participants also filled in the International
3 Physical Activity Questionnaire (IPAQ), which allowed us to assess the MET min/ week
4 of each group to distinguish the groups who practiced sports from the non-athletes group.
5 Subsequently, the participants engaged in the three tasks (d2 test of attention, Go/ No-go
6 and Corsi block test) that afforded the evaluation of cognitive performance in different
7 domains across the three distinct groups. Together, the experimental procedures took \approx
8 30-35 minutes (Figure 1).
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21 [Please insert Figure 1 around here]
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23 Figure 1. Task timeline
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30 *Statistical analysis*

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32 A One-Way Multivariate Analysis of Variance (MANOVA) was computed since we
33 measured several response variables. Compared to univariate analyses, multivariate
34 analysis has the advantage of showing the effect of the independent variable, when it
35 exists. It does not always happen if univariate analyses are carried out for each dependent
36 variable separately. Furthermore, MANOVA controls type for I errors without having to
37 perform any correction (Tabachnick & Fidell, 2013).
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46 The independent variable considered in the analysis was the type of participant, i.e., being
47 a professional athlete, being an amateur, or not being an athlete. The dependent variables
48 were the following: d2 performance indices (General Efficiency, Concentration Index,
49 Variability Index and Error Percentage), Go/No-go indices (IES and d' prime) and Corsi
50 block indice (Total Corsi). After multivariate analysis, separate univariate ANOVAs were
51 performed for each dependent variable when multivariate analysis revealed statistically
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1 significant differences. Also, when an univariate ANOVA showed statistic differences
2 between, at least two means, subsequent post-hoc tests were performed. MANOVA
3 assumptions were verified. In particular, the absence of multivariate outliers, normality,
4 the absence of multicollinearity, the linearity and homogeneity of the variance-covariance
5 matrices between groups. Further, the independence of observations was assumed.
6
7 Mahalanobis distances were performed through multivariate linear regression using the
8 response variables as predictors. Four observations were identified as multivariate
9 outliers. Nevertheless, all the Leverage influence measures were less than .06, Cook
10 distances were also very low, and all values were less than 1 (Marôco, 2023). Univariate
11 normality was tested with and without the multivariate outliers, and Shapiro- Wilk tests
12 revealed non-normal data for several dependent variables and groups. When multivariate
13 outliers were eliminated, the results of Shapiro-Wilk only improved in three tests. The
14 definitive elimination of those observations would make the groups more unequal, which
15 could subsequently reduce robustness of the multivariate analysis test and the univariate
16 F tests. Considering the above, we decided to keep all observations.

17
18 With respect to linearity, matrix scatter plots were performed for the three groups. Due to
19 the high number of dependent variables, scatter plots with all variables did not allow
20 observing the distribution of the data. For this reason, we created graphs for each index
21 subset (d2 performance indices, go/ no-go indices and corsi block indices). The dots
22 plotted in the graphs allowed to discern a linear trend in the data for most variables and
23 groups. Although in some graphs the linear pattern was not consistently clear, but no signs
24 of non-linearity were observed.

25
26 To assess the potential multicollinearity of the response variables, bivariate correlations
27 were calculated. According to Tabachnick and Fidell (2013), MANOVA works well with
28 moderate correlations about .60. We found a high correlation between Concentration
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Index and General Efficiency Score ($r=.747, p<.001$). So, we performed MANOVA with all the variables, without the General Efficiency Score or the Concentration Index. We verified that the results of multivariate test were not affected by those high correlations. This test was used to assess the last assumption, i.e., the homogeneity of the variance-covariance matrices across the groups. Results showed that this assumption was not fulfilled [Box's $M= 533.520$; $F(90, 11183,116) = 4.719, p<.001$). Nevertheless, it is known that Box's M is very sensitive to departure from multivariate normality (Cohen, 2008) and that MANOVA is robust to violation of this assumption when sample sizes are equal (Tabachnick & Fidell, 2013).

23 Results

25 One-Way MANOVA showed an effect of the type of participants on the dependent
26 variables [Pillai's Trace= .998; $F(20, 112) = 5.577, p<.001$; partial $\eta^2= .499$] Pillai's
27 Trace is more robust when the observed covariance matrices of the dependent variables
28 are unequal across groups. The homogeneity of variances was rigorously examined for
29 each variable using Levene's Test for Equality of Error Variances. The results indicate
30 that for several variables, the variances are approximately equal, suggesting homogeneity.
31 Specifically, for "General Efficiency Score" ($F(2,64)=0.456, p=0.630$), "Concentration
32 Index" ($F(2,64)=1.497, p=0.231$), "Variability Index" ($F(2,64)=2.774, p=0.07$), "Error
33 Percentage" ($F(2,64)=2.433, p=0.096$), "Corsi_direct" ($F(2,64)=2.050, p=0.137$) and
34 "Go/No-Go Inverse Efficiency Score" ($F(2,64)=0.007, p=0.993$) the p-values obtained
35 from Levene's tests exceeded the conventional significance level of 0.05, thus affirming
36 the presence of homogeneity. Conversely, for "Corsi_total" ($F(2,64) =4.128, p=0.021$)
37 and "Go/No-Go d' prime" ($F(2,64) = 3.902, p=0.025$) the p-values were less than 0.05,
38 implying the absence of homogeneity in these variables. This indicates that the variances
39 of these variables significantly differ among the groups. Overall, these results provide

1 valuable insights into the equality of variances for each variable, which is crucial in
2 subsequent statistical analyses. Once the assumption of homoscedasticity was not verified
3
4 in every variable, we used Tamhane's T^2 test, which is more conservative, to compare the
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6 means between the groups. The partial η^2 indicates the existence of a strong association
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8 between the type of participant and each dependent variable presenting significant results.
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11 *d2 Test of Attention*

12 **General Efficiency Score**

13 We computed a One-Way Analysis of Variance (ANOVA) and found that there were no
14
15 significant differences among the study groups in terms of the General Efficiency Score
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17 variable ($F(2,64) = 0.255, p = 0.755$). This empirical finding highlights that there are no
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19 variations in the General Efficiency Score, across the study groups (Figure 2).
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34 Figure 1. Participants groups mean for General Efficiency score. Error bars represent
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36 standard deviation.
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48 **Concentration Index**

49 We computed a One-Way Analysis of Variance (ANOVA) and determined that there
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51 were no significant differences between the different groups studied ($F(2, 64) = 0.442, p$
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53 $= 0.645$) (Figure 3).
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Figure 3. Participants groups mean for Concentration Index. Error bars represent standard deviation.

Variability Index

We computed a One-Way Analysis of Variance (ANOVA) and determined that there were no significant differences, between the study groups ($F(2,64) = 1.583, p = 0.213$) (Figure 4).

[Please insert Figure 4 around here]

Figure 4. Participants groups mean for Variability Index. Error bars represent standard deviation.

Error percentage

We computed a One-Way Analysis of Variance (ANOVA) applied to the Error Percentage variable, we ascertained that there were no statistically significant differences amongst the study groups ($F(2,64) = 0.051, p = 0.950$). This empirical finding underscores the absence of meaningful distinctions within the Error Percentage variable across the diverse study groups (Figure 5).

[Please insert Figure 5 around here]

Figure 5. Participants groups mean for Percentage Error . Error bars represent standard deviation.

Corsi Task

Corsi total

1 The data related to this variable was analyzed using One Way Analysis of Variance
2 (ANOVA). The results showed that there were differences, among the groups ($F(2,64) =$
3
4 $9.447, p < 0.001, \eta^2 = 0.228$).
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7 We examined the multiple comparisons through the Tamhane's T^2 post hoc test to see the
8 differences between the groups of participants. The p-values were used systematically to
9 assess significance and determine any differences among the groups.
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12 The comparison between "Professional" and "Non athlete" participants yielded a p- value
13 < 0.001 . This indicates that there are differences between these two participant groups
14 meeting the conventional threshold for statistical significance ($p \leq 0.05$).
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17 Moreover, when comparing "Non athlete" and "Amateur" participants, we found a p-
18 value of 0.001 highlighting differences between these groups.
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21 However, when comparing participants labeled as "Professional" and "Amateur" the
22 obtained p-value of 0.937 suggests that there are no significant differences.
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25 To sum up, the multiple comparisons analysis clearly establishes a difference, between
26 "Professional" and "Non-Athlete" participants ($p < 0.001$). It is worth mentioning that the
27 "Professional" individuals exhibited a score ($M = 19.13, SD = 3.520$) in comparison to the
28 "Non athlete" participants ($M = 15.64, SD = 2.237$). Additionally, a significant difference
29 was observed between the "Amateur" and "Non athlete" participants ($p = 0.001$) with
30 means of $M = 18.64$ and $M = 15.64$, alongside their corresponding standard deviations
31 ($SD = 2.770$ and $SD = 2.237$), respectively (Figure 6).
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57 Figure 6. Participants groups mean for Corsi Task. Error bars represent standard
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2 ***Go/ No- go task***
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4 **Inverse Efficiency Score (IES)**
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7 The data obtained from the Inverse Efficiency Score (IES) was carefully analyzed using
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9 One Way Analysis of Variance (ANOVA). The results showed that there was no
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11 difference ($F(2,64) = 1.247, p = 0.294$), among the study groups indicating that the groups
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13 being investigated were similar. This further highlights the consistency and similarity of
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15 the groups (Figure 7).
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23 Figure 7. Participants groups mean for Corsi Task. Error bars represent standard
24 deviation.
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29 ***d' prime***
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32 The data related to this variable was analyzed extensively using One Way
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34 Analysis of Variance (ANOVA). The results showed that there were differences, among
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36 the groups ($F(2,64) = 10.829, p < 0.001, \eta^2 = 0.253$). We examined the multiple
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38 comparisons through the Tamhane's T^2 post hoc test to see the differences between the
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40 groups of participants. The p-values were used systematically to assess significance and
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42 determine any differences among the groups.
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46 The comparison between "Professional" and "Non athlete" participants yielded a p- value
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48 < 0.001 . This indicates that there are differences between these two participant groups
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50 meeting the conventional threshold for statistical significance ($p \leq 0.05$).
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54 Moreover, when comparing "Non athlete" and "Amateur" participants we found a p-value
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56 of 0.008 highlighting differences, between these groups.
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2 However, when comparing participants labeled as "Professional" and "Amateur" the
3 obtained p-value of 0.572 suggests that there is no significance.

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5 To sum up the multiple comparisons analysis clearly establishes a difference, between
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7 participants categorized as "Professional" and those classified as "Non-Athlete" ($p <$
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9 0.001). It is worth mentioning that the "Professional" individuals exhibited a score ($M =$
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11 0.866, $SD = 1.654$) in comparison to the "Non athlete" participants ($M = 3.324$, $SD =$
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13 2.193). Additionally, a significant difference was observed between the "Amateur" and
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15 "Non athlete" participants ($p = 0.008$) with means of $M = 1.444$ and $M = 3.324$, alongside
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17 their corresponding standard deviations ($SD = 1.639$ and $SD = 2.193$), respectively
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21 (Figure 8).

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28 Figure 8. Participants groups mean for d' prime. Error bars represent standard deviation.

29 30 31 32 33 **Discussion**

34
35 The present study investigated the relationship between sports expertise and cognitive
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37 functioning, specifically focusing on the performance of professional rugby players,
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39 amateur rugby players, and non-athletes in the domains of visuospatial working memory,
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41 inhibitory control, and attention. As highlighted in the introduction, our research aimed
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43 to address the ambiguity surrounding the effect of expertise in sports on different
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45 cognitive performance domains. Our study sheds light on the complex relationship
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47 between sports participation and cognitive performance. Regarding the hypothesis 1:
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49 high-performance rugby practitioners should show better results on cognitive functioning
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51 compared to the amateur rugby athletes and non-athletes, the results of our study suggest
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53 that rugby may have differential effects on cognitive function, depending on the specific
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55 cognitive domain being assessed. Specifically, professional and amateur rugby players
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1 showed better performance on the Corsi block task, which assesses visuospatial memory,
2 compared to non-athletes. The evaluation of visuospatial working memory is particularly
3 relevant in sports that involve ball movement, as it plays a vital role in recalling and
4 locating objects and individuals (Arce & McMullen, 2021). Kruger et al. (2009)
5 suggested that the visual skills of athletes participating in ball sports are superior to those
6 of the general population. However, there was no difference between the groups on the
7 *d2* Test of Attention, which assesses sustained attention, and on the performance in the
8 Go/No go task which assesses inhibitory control. Surprisingly, we verified that the non-
9 athletes had more sensitivity, given by the *d'* prime measure, to detect and distinguish
10 stimulus when compared with professional and amateur athletes. It is possible that these
11 findings result from the putative competition between the cognitive benefits of exercise
12 and the potential negative effects of contact sports on cognition.

13 One common theme in the existing literature is the potential cognitive benefits of regular
14 exercise. Numerous studies have suggested that young adults engaged in physical activity
15 tend to exhibit superior cognitive functioning compared to their sedentary counterparts
16 (Colcombe & Kramer, 2003; Hillman et al., 2008). This was partly corroborated by our
17 study, as both professional and amateur rugby players demonstrated improved
18 visuospatial memory performance, as assessed by the Corsi block task. These findings
19 align with the study by Gao et al. (2015) in which rugby players had better visual skills
20 than non-athletes, prevailing the notion that physical exercise can positively influence
21 cognitive abilities (Erickson et al., 2011). One possible explanation for these benefits is
22 that exercise increases blood flow to the brain, stimulates the growth of new neurons and
23 strengthens connections between neurons (Cotman & Engesser-Cesar, 2002). These
24 changes in the brain's structure and function may contribute to the cognitive benefits of
25 exercise (Hilman et al., 2008).

1 The lack of differences between the amateur and professional athletes in our study can be
2 understood based on the findings we obtained from the International Physical Activity
3 Questionnaire (*IPAQ*). Surprisingly, the results from *IPAQ* showed that there were no
4 differences in the total METs minutes per week between professional and amateur
5 athletes, which means the professional amateurs participants cannot be distinguished by
6 the time dispended in physical activity. Previous research had suggested that
7 professionals tend to spend more time exercising compared to amateurs assuming that
8 professionals engage in more frequent and intense training sessions. Naturally, we
9 expected to see outcomes within the *IPAQ* assessments. However, it is important to
10 consider the context of our research, which was conducted in Portugal—where rugby
11 hasn't been fully professionalized yet and the Rugby National Team players have their
12 own jobs and do not play rugby for living. This unique scenario might explain why there
13 is such a similarity in exercise time dispended between amateur and professional athletes
14 providing insights.

15 However, the data also introduced a nuanced perspective. In our study, the participants
16 engaged in a contact sport - rugby. Interestingly, some studies have shown that athletes
17 involved in contact sports, may not exhibit the same cognitive advantages as athletes
18 participating in a non-contact sport (Hume et al., 2017). This observation challenges the
19 conventional wisdom that sports automatically enhance cognitive functioning. Our
20 findings, suggesting superior visuospatial memory in rugby athletes, contribute to this
21 ongoing debate by showing that not all cognitive functions are adversely affected by
22 contact sports. Regarding our hypothesis 1b and 2b, which suggests that high-
23 performance rugby practitioners would demonstrate superior performance on
24 visuospatial working memory tasks compared to amateur rugby athletes and non-
25 athletes (1b) and amateurs demonstrate superior performance on visuospatial working

1 memory task compared to non-athletes (2b), our findings partially confirm this
2 hypothesis. We observed no significant differences between professional and amateur
3 athletes. However, significant differences were found between professional athletes and
4 non-athletes, as well as between amateur athletes and non-athletes.
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9 The results related to attention are intriguing. Attention is another key cognitive function
10 and it is vital for selecting relevant information in the presence of an information overload
11 (Desimone & Duncan, 1995). Previous research has indicated that attentional processes
12 can be enhanced by physical exercise (Tomporowski, 2003). Contrary to our initial
13 expectations proposed in the hypothesis 1a and 2a, we found no significant differences in
14 attention between the three groups, highlighting that the impact of sports on attention may
15 be influenced by various factors, such as the specific sport and the cognitive domain under
16 investigation. This finding aligns with studies suggesting that the cognitive benefits of
17 exercise might not uniformly extend to all cognitive domains. In the context of contact
18 sports like rugby, it is also possible that the potential cognitive advantages are offset by
19 the physical impacts and potential head injuries associated with the sport (Hume et al.,
20 2017). Thus, while exercise may offer cognitive advantages in certain domains, it might
21 not protect against attention-related deficits caused by contact sports. Although the
22 number of reported cases of losing consciousness is relatively low it is important to
23 recognize that the nature of the sport suggests that many individuals may have
24 experienced head impacts during both games and training sessions. These head impacts
25 even if they do not immediately cause loss of consciousness can still have effects on
26 cognitive abilities (Guskiewicz et al., 2005). The cumulative impact of repeated
27 concussive impacts, which often go unnoticed is a cause for concern as studies have
28 shown that they can contribute to long term cognitive impairments (Broglio et al., 2012).
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1 One particularly significant observation from our study pertains to inhibitory control.

2 Several studies have suggested that athletes exhibit superior inhibitory control (Di
3 Russo, 2006; Nakamoto, 2008). Despite the inexistence of differences between the
4 groups in the Inverse Efficiency Score (IES), the non-athletes demonstrated greater
5 sensitivity in stimulus detection compared to professional and amateur rugby athletes.
6

7 Furthermore, our study did not detect significant differences in inhibitory control
8 between professional rugby players, amateur rugby players, and non-athletes,
9 challenging our hypotheses 1c and 2c and the assumption that inhibitory control is
10 enhanced in athletes. This result highlights the eventual negative effects of contact
11 sports on inhibitory control, a cognitive function crucial for impulse regulation
12 (Diamond, 2013). Existing literature supports this finding by suggesting that individuals
13 engaged in rugby and similar contact sports may exhibit higher levels of aggression
14 (Maxwell et al., 2009), which can compromise inhibitory control. Our study's results
15 align with these findings, emphasizing the complex interplay between sport, cognitive
16 functions, and emotional regulation.
17

18 The inconsistency in results may be attributed to the specific cognitive functions
19 assessed and the nature of the sport. While executive functions play a crucial role in
20 sports that require concentration and attention (Burgess & Simons, 2005), the
21 manifestation of these functions may vary across sports. In our study, we explored
22 visuospatial working memory, inhibitory control, and attention. These functions were
23 selected based on their relevance to daily life and sports performance (Gioia et al., 2000;
24 Vestberg et al., 2012).
25

26 This study and previous research suggest that rugby participation has a complex and
27 multifaceted relationship with cognitive function. Rugby players may have both positive
28 and negative effects on cognitive function, depending on the specific cognitive function
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1 being assessed. Finally, in contrast to our initial hypothesis our study did not find
2 substantial evidence to support the notion that sports, particularly rugby, leads to
3 significant cognitive advantages. However, it is worth highlighting that rugby is a sport
4 that requires understanding ball trajectories, field awareness and the positioning of
5 teammates (Romeas et al., 2016; Gonçalves et al., 2017). This could potentially explain
6 why there is a superior performance in working memory in rugby players (Kruger et al.,
7 2009). Our findings emphasize the intricate and multifaceted nature of the relationship
8 between sports and cognitive functioning.

9 Further research is needed to unravel the complexities of this relationship and its
10 implications for sports training to develop strategies to protect rugby players from the
11 potential negative effects of this contact sport on cognitive function.

12 **Limitations and future research**

13 There are a few limitations and suggestions to be aware of when interpreting the
14 findings of this study.

15 First of all, the non-professional status of rugby in Portugal does not allow the national
16 team players to make their living from rugby thus, the differences between amateur and
17 professional players are further nuanced. However, it is essential to note that these
18 athletes despite the fact they are not professionals they usually engage in intensive
19 training depending on the competition, tournament or cup, such as the Rugby World
20 Cup 2023.

21 Crucially, there was a time variability of the interviews. With some of the interviews
22 before training but after a workday, others after training and others in the morning
23 before work or training. We believe this introduces a potential fatigue factor that could
24 influence the quality and depth of the participants' responses, potentially affecting the
25 accuracy of the data. Unfortunately, we had to adapt to the teams' and players'

1 individual availabilities to be able to collect the data. These limitations should be
2 considered when assessing the study's outcomes and considering their transferability to
3 different rugby contexts. Moreover, it is worth highlighting that our study utilized a
4 blend of snowball sampling and convenience sampling to collect data. While these
5 methods were appropriate for our research it is crucial to recognize that they may
6 restrict the applicability of the data beyond the specific sample and context studied.
7 Finally, for future research it is essential to investigate approaches for monitoring
8 concussions and head impacts that extend beyond relying on athletes self-reporting.
9 Although self-reporting is valuable for gathering data it has limitations such as recall
10 bias, underreporting or players not recognizing the true severity of head impacts. In
11 future research, exploring the cognitive functioning disparities, particularly in decision-
12 making and cognitive flexibility between rugby's forward and back positions could yield
13 valuable insights.

34 **Conclusion**

35 In conclusion, this study investigated how sports in professional and amateur rugby
36 players affects cognitive functions, such as visuospatial working memory, inhibitory
37 control, and attention. The findings revealed that the impact of rugby expertise on
38 cognitive functioning is variable. Indeed, in our study, we found that there were no
39 significant differences in cognitive performance between the professional and amateur
40 athletes. However, notable differences in working memory did emerge when comparing
41 the combined group of athletes (professional and amateurs) with non-athletes. This
42 observation highlights that the impact of sports expertise, regardless of the level, differs
43 from that of non-athletes in certain cognitive domains such as visuospatial memory that
44 can be seriously promoted because of the constant awareness in the field and ball. Both
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1 professional and amateur rugby players displayed improved visuospatial working
2 memory, aligning with the positive influence of physical exercise on this domain.
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4 However, no differences were observed in attention across the groups, suggesting that
5 the benefits of exercise might not extend uniformly. Inhibitory control also did not
6 significantly differ, challenging the assumption of uniform cognitive enhancement
7 across domains in athletes. The intricate relationship between sports and cognitive
8 functioning requires further comprehensive research to understand these complexities.
9

10 In summary, expertise in rugby may have both positive and negative effects on
11 cognitive function, depending on the specific cognitive domain. While rugby players
12 showed improved visuospatial working memory, this does not necessarily apply to other
13 domains like attention and inhibitory control. The intricate nature of this relationship
14 emphasizes the need for in-depth research to develop strategies for safeguarding
15 athletes, particularly rugby players, from potential cognitive effects associated with their
16 sport.
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Highlights

- We show that professional and amateur rugby teams, but not non-athletes, present visuospatial cognitive benefits.
- Although exercise and sports have been shown to benefit the attention cognitive domain, professional and amateur rugby players do not present enhanced attention compared to non-athletes.
- Professional and amateur athletes are also not showing enhanced performance in inhibitory control compared to non-athletes. Indeed, non-athletes show greater sensitivity to detecting stimuli over noise compared to the athlete groups.
- We suggest a putative competition between the benefits of exercise and sports and the detrimental hindrance of contact sports on cognition.
- The putative cognitive benefits seem to be sports-specific and cognitive-domain-specific.

Table 1

Descriptive data of the three groups of participants

Group	Age	Education	Number of Loss of Consciousness	MET - min/week
Professional (N=23)	M= 24.57 (3.287)	Bachelor	2	M= 10874.22 (16248.08)
Amateur (N= 22)	M= 24.23 (4.353)	Bachelor	1	M= 4342.21(3783.81)
Non- athletes (N= 22)	M= 23.05 (2.299)	Bachelor	0	M= 1327.68 (765.31)

DOMAIN-SPECIFIC COGNITIVE BENEFITS IN RUGBY ATHLETES

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