UNIVERSIDAD DE COSTA RICA
CIMOHU
EDUFI
Escuela de Educación Física y Deportes

Descriptive, Correlational and Qualitative studies
Volume 22, issue 2, pp. 1-18
Opens July 1st, closes December 31st, 2024
ISSN: 1659-4436

Pensar en Movimiento
Revista de Ciencias del Ejercicio y la Salud

Cognitive functions and their relation to balance and agility in athletes from different sports branches

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Original submission: 2023-09-05 | Resubmitted: 2024-03-13, 2024-07-26 | Accepted: 2024-07-30
Published: 2024-09-18*

Doi: https://doi.org/10.15517/pensarmov.v22i2.56481

Associate editor in charge: Ph.D Judith Jiménez Díaz

This manuscript was submitted to a mixed review. We thank to Ph.D. Rafael Martínez Gallego, Ph.D. Miguel Crespo and the double-blind reviewer for their reviews.

¿How to cite this paper?

Özen Oruk, D., Bayar, K., Saygın, Ö., & Bayar, B. (2024). Cognitive functions and their relation to balance and agility in athletes from different sports branches. *Pensar en Movimiento: Revista de Ciencias del Ejercicio y la Salud,* 22(2), e56481. https://doi.org/10.15517/pensarmov.v22i2.56481

* This article has a Spanish version. Available: Özen Oruk, D., Bayar, K., Saygın, Ö., y Bayar, B. (2024). Funciones cognitivas y su relación con el equilibrio y la agilidad en atletas de diferentes ramas deportivas. Pensar en Movimiento: Revista de Ciencias del Ejercicio y la Salud, 22(2), e62707. https://doi.org/10.15517/pensarmov.v22i2.62707

Cognitive functions and their relation to balance and agility in athletes from different sports branches

Las funciones cognitivas y su relación con el equilibrio y la agilidad en atletas de diferentes ramas deportivas

Funções cognitivas e sua relação com equilíbrio e agilidade em atletas de diferentes modalidades esportivas

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Abstract: Successful performance in each sport requires high ability in various features, including motor and perceptual-cognitive skills. The aim of this study was to compare balance and agility in athletes from several sports branches in order to find out how cognitive functions relate to these parameters. Seventy-three individuals aged 18-30 were included in this prospective-descriptive study. In the assessment of cognition, Montreal Cognitive Assessment Scale, d2 Test of Attention, and a Bassin Anticipation Timer Device were used. While Prokin-TecnoBody was used to measure the balance skills, Illinois Agility Test (IAT) was used for agility. IAT times showed positive weak correlations with both the absolute error-score (AES) at 8mph (r=0.260, p=0.040) and mediolateral balance score (ML)(r=0.255, p=0.043). While there was a negative weak correlation between AES at 3mph and anteroposterior score of balance (r=-0.267, p=0.035), we found positive weak correlation between AES at 8mph and ML of balance (r=0.253, p=0.046). It was found that the IAT scores of the sedentary group were significantly lower than those of athletes (p=0.000). According to AES at 3mph, there were significant differences between tennis players and both sedentary and volleyball players (p=0.008, p=0.002, respectively). When the AES at 8mph was compared, the only statistically significant difference was between tennis players and sedentary (p=0.008). In conclusion, this study shows how cognitive functions, particularly coincidence anticipation timing (CAT), correlate with essential physical performance factors like agility and balance across different sport branches, suggesting that improving cognitive skills could enhance overall athletic performance and inform mental training strategies in sports. It is recommended that future sports science research focus on enhancing CAT through targeted training programs.

Keywords: motor ability, performance, cognition, balance.

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Resumen: El rendimiento exitoso en cada deporte requiere una alta capacidad en diversas características, incluidas las habilidades motoras y perceptivo-cognitivas. Este estudio tuvo como objetivo comparar el equilibrio y la agilidad en atletas de varias ramas deportivas, para descubrir cómo se relacionan las funciones cognitivas con estos parámetros. En este estudio prospectivo-descriptivo se incluyeron setenta y tres individuos con edades comprendidas entre los 18 y los 30 años. En la evaluación de la cognición se utilizaron la Escala de Evaluación Cognitiva de Montreal, la Prueba d2 de Atención y un Dispositivo Temporizador de Anticipación de Bassin. Por su parte, el Prokin-TecnoBody se utilizó para medir las habilidades de equilibrio y el Test de Agilidad de Illinois (IAT) se utilizó para la agilidad. Los tiempos de IAT mostraron correlaciones débiles positivas tanto con la puntuación de error absoluto (AES) a 8mph (r = 0.260, p = .040) como con la puntuación de equilibrio mediolateral (ML [r = 0.255, p = .043]). Si bien hubo una correlación débil negativa entre AES a 3 mph y la puntuación anteroposterior del equilibrio (r = -0.267, p = .035), se encontró una correlación débil positiva entre AES a 8 mph y ML del equilibrio (r = 0.253, p = .046). Se encontró que los puntajes del IAT del grupo sedentario fueron significativamente más bajos que los de los atletas (p = .000). Según AES a 3 mph, había diferencias significativas entre los tenistas, por una parte, y los sedentarios y los jugadores de voleibol, por otra (p = .008, p = .002, respectivamente). Cuando se comparó el AES a 8 mph, la única diferencia estadísticamente significativa fue entre tenistas y sedentarios (p = .008). En conclusión, este estudio muestra cómo las funciones cognitivas, en particular el tiempo de anticipación de coincidencias, se correlacionan con factores esenciales del rendimiento físico como la agilidad y el equilibrio en diferentes ramas deportivas, lo que sugiere que al mejorar las habilidades cognitivas, también lo haría el rendimiento atlético general e informar las estrategias de entrenamiento mental en los deportes. Se recomienda que las futuras investigaciones en ciencias del deporte se centren en mejorar el tiempo de anticipación de coincidencias mediante programas de entrenamiento específicos.

Palabras clave: habilidad motora, rendimiento, cognición, equilibrio.

Resumo: O desempenho bem-sucedido em cada esporte requer alta habilidade em diversas características, incluindo habilidades motoras e perceptivo-cognitivas. Este estudo teve como objetivo comparar o equilíbrio e a agilidade em atletas de diversas modalidades esportivas, para descobrir como as funções cognitivas estão relacionadas com esses parâmetros. Neste estudo prospectivo-descritivo foram incluídos setenta e três indivíduos com idade entre 18 e 30 anos. Foram utilizados para avaliar a cognição a Escala de Avaliação Cognitiva de Montreal, o Teste de Atenção d2 e um Dispositivo Temporizador de Antecipação Bassin. Por sua vez, o Prokin-TecnoBody foi utilizado para medir as habilidades de equilíbrio e o Teste de Agilidade de Illinois (IAT) foi utilizado para agilidade. Os tempos do IAT mostraram correlações positivas fracas tanto com o escore de erro absoluto (AES) a 8mph (r = 0,260, p = 0,040) quanto com o escore de equilíbrio médio-lateral (ML [r = 0,255, p = 0,043]). Embora tenha havido uma correlação negativa fraca entre AES a 3 mph e pontuação de equilíbrio anteroposterior (r = -0,267, p = 0,035), uma correlação positiva fraca foi encontrada entre AES a 8 mph e equilíbrio ML (r = 0,253, p = 0,046). As pontuações do IAT do grupo sedentário foram significativamente inferiores às dos atletas (p = 0,000). Segundo a AES, a 3 mph, houve diferenças significativas entre tenistas, por um lado, e sedentários e jogadores de voleibol, por outro (*p* = 0,008, p = 0,002, respectivamente). Quando o AES foi comparado a 8 mph, a única diferença estatisticamente significativa foi entre tenistas e sedentários (*p* = 0,008). Em conclusão, este estudo mostra como as funções cognitivas, em particular o tempo de antecipação-coincidência, estão relacionadas com fatores essenciais do desempenho físico, como agilidade e equilíbrio em diferentes modalidades esportivas, sugerindo que, ao melhorar as capacidades cognitivas, também melhoraria o desempenho atlético global e informaria as estratégias de treinamento mental nos esportes. Recomenda-se que futuras pesquisas em ciências do esporte se concentrem na melhoria do tempo de antecipação-coincidência através de programas de treinamento específicos.

Palavras-chave: habilidade motora, desempenho, cognição, equilíbrio.

1. Introduction

High performance in sports requires not only physical and motor skills, but also perceptual-cognitive ability (Broadbent et al., 2015). Cognition, which is defined as the general process of all mental functions, is the name given to the perception of stimuli coming from the environment and their arrival to the cortex, processing and regulating with our behaviors and movements. In addition, cognition includes the processes of concentration, executive functions, attention, memory, language, visualization skills, abstract thinking, calculation, and orientation; it plays an important role in emotions and behavior. Some of our basic cognitive functions are attention, memory, perception, language, motor ability, executive functions, visual and spatial processing. These functions are also very important for us to be able to carry on our activities of daily living independently (Conti, 2017; Çetin et al., 2017).

Attention, which is a basic but complex cognitive process, in its most general definition; is the focus of mental activity. It includes the mental state of stimulation and the selection process (Novikova, 2021). The sensory system is constantly stimulated by the myriad stimuli generated by the natural environment. In order to function effectively in this environment, there have been a number of neural mechanisms for the extraction of sensory inputs that are most relevant to current goals. These systems that form our attention is highly flexible and can be used to select information based on various factors, such as sensory modality, within-modality features, spatial location, object identity, and temporal properties (Gomez-Ramirez et al., 2016). Selective attention, on the other hand, is focusing attention on a particular stimulus by ignoring other stimuli, distinguishing the relevant stimulus from the irrelevant, and responding only to the relevant stimulus (Yaycı, 2013). In other words, selective attention refers to the goal-directed focus on specific aspects of the environment, while disregarding other irrelevant aspects (Ku, 2018). Sports have been an area where studies on selective attention have been frequently made (Vaughan & Laborde, 2021). Based on the fact that humans have limited information processing capacity at a given time, high selective attention helps athletes to decide which stimuli to pay attention to, (e.g., coach instruction) and/or which stimuli to ignore (e.g., crowd shouts) (Diamond, 2013). Knowing what to focus on, how to shift attention to another area, and how to concentrate attention are important elements for high sportive performance (Çağlar & Koruç, 2006). A particular aspect of cognition skills related to sportive performance is coincidence anticipation timing (CAT). CAT is the ability to predict the arrival of a moving object at a specific point in space and coordinate a motion response for that arrival. A successful CAT performance hinges on the prediction of a rapidly moving object on time, appropriate body motions towards it, and the location of the object after the response is completed (Ceylan & Günay, 2020). In most sports, accurate and precise anticipation is vital to excellent performance. An athlete with good CAT can anticipate and react to the target quickly and dynamically at the right time (Akbulut et al., 2015).

Balance is an important component of motor skills ranging from maintaining posture to performing complex sports skills. Static balance is the ability to maintain the base of support with minimal movement, while the dynamic balance is the ability to perform a task while maintaining a stable position or to achieve and maintain balance with minimal movement on an unstable surface (Yoo et al., 2018). Both static and dynamic balance; requires integrating sensory information from the visual, vestibular and somatosensory systems (Ricotti, 2011). There are many studies stating that balance ability is related to performance measures in sports. Findings from prospective studies support the idea that balance training may be beneficial in addition to regular training for non-elite athletes to improve some motor skills (Ricotti, 2011; Yoo et al., 2018). Some sports branches require a highly improved balance performance for maximum efficiency, on the other hand, for some sports branches, it may not be the first priority. That's why the need for balance ability of each sport is different from each other (Çelenk et al., 2018).

Although there are many definitions of agility in the literature, it can generally be defined as the ability to maintain a controlled body position and change direction rapidly without loss of balance, body control or speed. Thus, it is very important for sports such as football, volleyball, and tennis, which require the ability to change direction quickly in all planes/axes. The benefits of enhanced agility include; increase in body control during fast movements, increase in intramuscular coordination, and decrease in the risk of injury (Sheppard & Young, 2006; Bin Shamshuddin et al., 2020).

Optimal development of cognitive skills is important for successful motor learning, performance of movements and elite sports skills in every sport. It is known that cognitive abilities are important determinants of athletic performance in various sports and especially affect the athletic progress of the individuals. It is stated that elite athletes demonstrate better cognitive functions, balance, and agility than non-athletes, also differences in athletes' dominant features depend on the sport (Yongtawee et al., 2022).

Sedentary behavior, defined by low levels of physical activity, is linked to increased health risks such as obesity and cardiovascular disease (Hamilton et al., 2007). Compared to athletes who participate in regular physical activity, sedentary individuals are generally expected to exhibit poorer cognitive functions, reduced agility, and impaired balance abilities. Understanding these differences may highlight the importance of promoting physical activity to improve cognitive and motor skills necessary not only for physical fitness but also for optimal sports performance and overall well-being (Ludyga et al., 2020).

When it was performed a literature search in the databases "PubMed", "Google Scholar" and "Web of Science", most of the studies were related to the relationship of balance and agility with age, gender, sports experience, team, or individual sports (Boutios et al., 2021; Mocanu et al., 2022; Tulchin-Francis & Ulman, 2021; Zwierko et al., 2022). Just a few studies were emphasize the relationship of these parameters with cognitive functions and the differences between athletes from different sports branches and sedentary individuals. High performance in sports requires multiple cognitive functions such as attention, decision making and working memory to function optimally in stressful and challenging environments (Chiracu et al., 2017; Walton et al., 2018). However, there are few studies in the literature examining whether the improvement of cognitive abilities leads to increased performance in sports. Therefore, we think that the relationship between cognitive functions and parameters such as sensing time, balance and coordination, which are important for high performance in sports, should be determined. Based on these, the aim of this research was to determine the relationships between balance, agility, and cognitive skills such as attention and anticipation time, primarily. The second purpose was to compare these parameters according to different sports branches and sedentary individuals.

2. Methods

Signed informed consent was obtained from all participants prior to data collection and after the study protocol was reviewed by Human Research Ethics Committee of Muğla Sıtkı Koçman University and approved on 01.18.2020 (Protocol number: 190247/9) according to document 1.

Participants

Participants signed the Informed Consent Form before the assessments, and their physical characteristics such as height, weight, and body mass index (BMI), sports experience, and sports branches were recorded. Participants have been divided into four groups: volleyball players, soccer players, tennis players, and sedentary. The sedentary group was determined according to Physical Activity Level (PAL) values (Gerrior et al., 2006).

A total of 63 participants between the aged 18-30 studying at Muğla Sıtkı Koçman University, including male athletes licensed for at least two years from different sports branches and sedentary individuals, were included in this study. Exclusion criteria from the study were as follows: Any pathologies that might affect the participation in the study, history of lower extremity trauma requiring any treatment in the last six months, consumption of alcohol, and pharmaceuticals up to 24 hours before the assessment.

Measures

Body Weight, Height and BMI: The body weight and height of the participants (± 0.1kg, ± 1mm precision) were measured with a weighing instrument. BMI was calculated from the formula of body weight(kg)/height(m)^2.

Cognitive Functions

Montreal Cognitive Assessment Scale (MOCA): It is a scale that evaluates eight different cognitive domains such as concentration, executive functions, attention, memory, language, visualization skills, abstract thinking, calculation, and orientation. In this scale, an evaluation is made over a total of 30 points, and a higher score indicates better cognition. Values below 26 points are considered cognitive dysfunction (Rossetti et al., 2011).

Selective Attention: The D2 Test of Attention (d2), that was developed by Brickenkamp, is a cancellation test to measure selective attention and concentration (Brickenkamp & Zillmer, 1998). Turkish adaptation of this was made by Çağlar and Koruç (Çağlar & Koruç, 2006). The test sheet comprises 14 lines, and each line has 47 characters. These characters are "p" and "d" letters with from one to four small marks. During the test, “d” letters with two marks should be found by subjects. The time given for each line is 20 seconds (Brickenkamp & Zillmer, 1998; Çağlar & Koruç, 2006; Yaycı, 2013).

Coincidence Anticipation Timing (CAT): The Bassin Anticipation Timer Device (Lafayette Instrument Company, model35575) was used to assess coincidence anticipation timing of participants. This device consists of a total of three parts: the control console, the response button and a runway where 49 LED lights move in a linear (Lafayette Instrument Company, 2008). The CAT at different stimuli speeds (3mph and 8mph) were measured randomly and the target was set as the 49th light of the device. Measurements were recorded in milliseconds and raw data of the CAT were converted to absolute error scores (AES). Participants were taken one by one to the laboratory during the CAT assessment (Duncan et al., 2013; Saygın et al., 2016).

Dynamic Balance: The dynamic balance performance was measured by the Prokin TecnoBody (PKW 200 PL,Italy). During the evaluation, the participant was asked to stand bipedal on the moving platform (medium difficulty) and maintain his balance for 30 seconds with eyes open. Firstly, a 10-second trial was carried out. After the test was completed, perimeter length (PL), medium equilibrium center - Anterior Posterior (AP), and medium equilibrium center – Medial Lateral (ML) were recorded for analysis. While a high PL score means weak balance performance, increases in AP and ML values indicate leg muscle weakness and reduced neuromuscular control of these (Tecnobody, 2024).

Agility: Illinois Agility Test (IAT) was used to assess agility in participants. For this test which includes spins, slaloms, and sprint run, in a 10 by 5 meters court; the cones on the horizontal lines are placed 2.5 meters in between, and on the vertical lines are positioned 3.3 meters apart. Each performance was recorded using a chronometer and the best performance of the two trials was used for analyses (Miller et al., 2006).

Procedures

All measurements were taken in the Faculty of Sport Sciences. On different days, the same person evaluated each group. During the CAT assessment, participants were taken individually to the laboratory.

Analysis

The sample size was determined by using G-Power (Windows version: 3.1) statistical program. The calculation was made on four different groups according to α = 0.05, β = 0.20 (80% power value), and F = 0.39. It was found that the study requires a total sample size of 76 participants (19 cases for each group). Collected data were analyzed using the Statistical Package for the Social Science (version 22.0). Quantitative variables were described as mean±standard deviation, and descriptive variables as numbers and percentages (%). Kolmogorov Smirnov and Skewness Kurtosis tests were used to determine whether data were normally distributed. The relationship between continuous variables was analyzed by Pearson’s correlation coefficient, and the one-way analysis of variance (ANOVA) was used to determine whether there are any statistically significant differences between the means of the four groups. Pairwise comparisons with Bonferroni correction were used when any differences were detected. Statistical significance was set at 95% confidence interval.

3. Results

A sample of 63 participants (20 volleyball players, 17 soccer players, 16 tennis players, and 10 sedentary) were included in this study. As a result of normality tests, it was found that the variables were normally distributed. According to the one-way analysis of variance, the physical properties of the groups were found to be similar except for sport experience (p>0.05). Sport experience was also similar in the different sport branches. Physical characteristics of the participants are given in Table 1 (Özen Oruk et al., 2024).

Table 1.
Physical characteristics of the participants

Variables	Volleyball (n= 20) Mean±SD	Soccer (n= 17) Mean±SD	Tennis (n= 16) Mean±SD	Sedentary (n= 10) Mean±SD	Total (n= 63) Mean±SD	F	p
Age (year)	22.85±3.79	22.24±1.56	21.44±1.67	22.00±2.97	22.19±2.71	0.817	0.490
Height (cm)	180.85±7.04	177.35±6.85	180.06±7.35	177.04±3.67	179.10±6.72	1.274	0.291
Weight (kg)	77.68±11.16	71.27±7.43	71.3±8.61	72.60±8.92	73.52±9.5	2.011	0.122
BMI (kg/m2)	23.67±2.37	22.68±2.26	21.96±1.87	23.15±2.57	22.89±2.3	1.804	0.156
SE (year)	6.75±4.08	6.88±3.74	7.13±5.06	-	5.81 ±4.62	8.573	**0.000***

Note. SE: Sport Experience, SD: Standard Deviation, BMI: Body Mass Index, F: one way ANOVA, *p<0.05. Source: the authors.

As a result of the correlation analysis between IAT times and other parameters, positive weak correlations were found with AES at 8 mph (r = 0.260, p = 0.040) and ML values of balance (r = 0.255, p = 0.043). While there was a negative weak correlation between AES at 3mph and AP values of balance (r = -0.267, p = 0.035), we found positive weak correlation between AES at 8mph and ML values of balance (r = 0.253, p = 0.046). In addition, there was a positive moderate correlation between both AES scores, as expected (r = 0.495, p = 0.000). Relationships between other measurements were insignificant (p>0.05). All correlations between parameters are shown in Table 2.

Table 2.
Correlations between parameters of participants

N= 63		MOCA	IAT	3mph	8mph	d2	PL	AP	ML
MOCA	r	1	-	-	-	-	-	-	-
	p		-	-	-	-	-	-	-
IAT	r	0.195	1	-	-	-	-	-	-
	p	0.125		-	-	-	-	-	-
3mph	r	-0.133	0.096	1	-	-	-	-	-
	p	0.300	0.453		-	-	-	-	-
8mph	r	0.041	0.239	**0.479***	1	-	-	-	-
	p	0.749	0.059	0.000		-	-	-	-
d2	r	0.142	0.014	-0.063	-0.006	1	-	-	-
	p	0.270	0.914	0.627	0.964		-	-	-
PL	r	0.070	-0.134	-0.073	-0.147	0.009	1	-	-
	p	0.588	0.295	0.570	0.250	0.947		-	-
AP	r	-0.002	0.040	**-0.273***	-0.191	-0.001	-0.051	1	-
	p	0.989	0.761	0.034	0.140	0.993	0.698		-
ML	r	0.062	**0.303***	0.050	**0.264***	-0.086	-0.191	0.180	1
	p	0.632	0.018	0.702	0.040	0.514	0.141	0.164	

Note. MOCA: Montreal Cognitive Assessment, IAT: Illinois Agility Test, 3mph: Slow speed stimulus at coincidence anticipation timing, 8mph: Fast speed stimulus at coincidence anticipation timing, d2: D2 test of attention, PL: Parameter length, AP: medium equilibrium center – Anterior Posterior, ML: medium equilibrium center – Medial Lateral; *p<0.05. Source: the authors.

When compared with the athletes, the IAT scores of the sedentary group were found to be significantly lower (p = 0.000). Results of the one way analysis of variance according to AES at slow stimulus speed (3mph) indicated a significant difference between tennis players and both volleyball players and sedentary (p = 0.002 and p = 0.008, respectively). When the AES at fast stimulus speed (8mph) of participants were compared according to their group, the only statistically significant difference was found between tennis players and sedentary (p = 0.008). There weren't any significant differences between MOCA, d2, and balance scores when comparing groups (p>0.008). All comparisons according to groups were presented in Table 3.

Table 3.
Comparisons of parameters according to groups of participants

	Sports Branches	n	Mean±SD	One-way ANOVA	Post-hoc comparison Groups	p
MOCA	Volleyball	20	25.50±2.33	$F_{3,59}$=0.188 p=0.904	-	
	Soccer	17	25.47±2.07			
	Tennis	16	25.75±2.84			
	Sedentary	10	26.10±2.13			
IAT	Volleyball	20	17.34±.0.96	$F_{3,59}$=13.061 p=0.000	Volleyball > Sedentary	0.000
	Soccer	17	17.42±.0.87		Soccer> Sedentary	0.000
	Tennis	16	17.48±0.77		Tennis > Sedentary	0.000
	Sedentary	10	19.38±1.11			
3mph	Volleyball	20	37.73±19.46	$F_{3,59}$=5.889 p=0.001	Tennis > Volleyball	0.002
	Soccer	17	30.86±18.73		Tennis > Sedentary	0.008
	Tennis	16	15.19±9.09			
	Sedentary	10	39.37±22.63			
8mph	Volleyball	20	23.70±12.29	$F_{3,59}$=4.287 p=0.008	Tennis > Sedentary	0.006
	Soccer	17	20.49±10.40			
	Tennis	16	14.92±7.36			
	Sedentary	10	30.43±14.70			
d2	Volleyball	20	560.20±64.45	$F_{3,59}$=0.390 p=0.761	-	
	Soccer	17	560.29±45.06			
	Tennis	16	559.81±67.44			
	Sedentary	10	582.20±55.47			
PL	Volleyball	20	461.94±89.88	$F_{3,59}$=1.250 p=0.300	-	
	Soccer	17	514.88±124.49			
	Tennis	16	473.44±104.09			
	Sedentary	10	445.96±71.47			
AP	Volleyball	20	0.21±2.75	$F_{3,59}$=0.765 p=0.518	-	
	Soccer	17	-0.12±1.11			
	Tennis	16	0.85±1.32			
	Sedentary	10	0.65±2.14			
ML	Volleyball	20	0.24±1.62	$F_{3,59}$=1.185 p=0.323	-	
	Soccer	17	0.62±1.37			
	Tennis	16	0.42±1.94			
	Sedentary	10	1.45±2.04			

Note. MOCA: Montreal Cognitive Assessment, IAT: Illinois Agility Test, 3mph: Slow speed stimulus at coincidence anticipation timing, 8mph: Fast speed stimulus at coincidence anticipation timing, d2: D2 test of attention, PL: Parameter length, AP: medium equilibrium center - Anterior Posterior, ML: medium equilibrium center - Medial Lateral; F: One way ANOVA, *p<0.05, **p<0.008 (Bonferroni correction was applied). Source: the authors.

4. Discussion

Successful performance in each sport requires high ability in different features. This is also true for perceptual-cognitive skills, such as the difference in motor skill requirements. Therefore, it is expected that they will have advantages over each other in various parameters that will affect the performance.

Our findings indicated that the IAT scores of the sedentary group were significantly lower than athletes. While there was a significant difference between tennis players and both volleyball players and sedentary in AES at slow stimulus speed (3mph), only tennis players and sedentary in AES at fast stimulus speed (8mph). There weren't any significant differences between MOCA, d2, and balance scores when comparing groups. In addition, a positive moderate correlation was found between IAT times and ML values of balance.

One of the most important physical characteristics necessary to attain high sports performance is agility. This skill has a critical value for many sports branches. Although there are various models of main factors determining agility in the literature, they all include motor and cognitive skills such as strength, speed, power, technique, anticipation and visual scanning (Sheppard & Young, 2006; Young et al., 2015). These features also affect agility performance. Therefore, agility is expected to be higher in athletes than in sedentary individuals. In our study, similar to the literature, while agility scores were higher in athletes, it was lower in sedentary individuals. Demirhan et al. (2017) reported that agility skills vary according to sports branches. Zemková & Havar (2014) conducted a study to compare agility times of athletes from different sport branches and they stated that the best agility times are in athletes of racquet sports, followed by players of ball sports. In another study by Šimonek (2017), it was reported that agility of soccer players is better than volleyballers. In line with these studies, we also compare volleyball, soccer and tennis players but did not find any significant differences between the sports branches.

From another point of view, there are studies comparing individual and team athletes according to agility. Lots of studies indicated that individual athletes have better agility performance than team athletes (Mackala et al., 2020). It is possible to see different results on this subject in the literature. In recent years, sport-specific agility tests have come to the fore (Lima et al., 2021; Sinkovic et al., 2022; Altmann et al., 2022). Because in order to evaluate the parameters of agility skills related to a particular sport, the test closest to the pattern used during training/competition should be preferred. According to our results, the reason why there was no difference between athletes from different sports may be due to the sport-specific tests weren't used for the evaluation.

Performances on some CAT tasks may vary between different sports branches. Sports like tennis require precise catching or hitting. CAT could be a key factor that contributes to high performance in these sports. CAT is the ability to track the movement of an object, estimate its arrival at a specific location, and precisely coordinate movement with the stimulus when it arrives at that target position. The detection and evaluation of moving stimuli is complex and relies on different processes depending on the duration of the subject's movement and the size and duration of the stimulus exposure. In addition, the evaluation of some features of the moving stimulus is altered by the nature of the motor task. The contact position of both the ball and the racket and the timing of stroke are two factors that determine the ball's direction in tennis (Akpınar et al., 2012; Kim et al., 2013; Kim, 2023). In the present study, there was a difference between the groups in both slow and fast speed of CAT. In addition, this difference was in favor of the tennis players. Similar to our study, Kim (2023) reported that the absolute errors of tennis players showed better accuracy and consistency than controls and other athletes (volleyball, and football) (Kim, 2023). This may be due to the fact that tennis players had more experience than athletes from other sport branches in the current study. Also, it might result from the use of different equipment, movements, reaction times, the different size of balls, playing surface etc.

To the best of our knowledge, there are not many studies evaluating the relationship between agility and CAT in the literature. In the light of the information in the literature, it can be said that CAT performance is affected not only by perceptual but also by motor processes. (Kim et al., 2013). One of the main factors determine the agility is the cognitive components including decision making and speed accuracy. Anticipation, visual scanning, pattern recognition and knowledge of situation are all part of this component (Young et al, 2015). The perceptual-motor training effects on brain neurophysiology and provides more efficient and faster cognitive process including executive functions (Moradi et al, 2020). There are many opinions about the role of neural systems in sports anticipation and agility. A complex cortico-subcortical network has been proposed, involving regions of the mirror neural system, prefrontal cortex, ventral and dorsal visual pathways, and two subcortical structures - the basal ganglia and the cerebellum. Based on this, visual inputs are transformed into motor plans, before the basal ganglia behaviorally bias the best possible motor action, by encoding the difference between anticipated and actual reward of a given course of action eventually leading to action execution (Yarrow et al., 2009). Optimal CAT requires accurate completion of listed as follows: a sensory phase (detection, correction, and guiding the motor actions with sensory information), a sensorymotor integration phase (determining the motor response and time and place of incoming stimuli), and a motor phase (also known as the execution phase) (Duncan et al., 2013). In fact, especially the motor phase can clarify its relationship with agility. An athlete with good CAT can anticipate and react to the target quickly and dynamically at the right on time if has high agility skills. In this context, high agility and more accurate anticipation may provide a better performance. Our study found a significant positive correlation (r=0.25, p=0.046) between agility and CAT scores at fast stimulus speed.

Not only in sports, but every activity of daily living also requires less or more balance. As stated in the definition of agility, balance is known to be a component of it and maintaining balance is crucial for better agility performance (Bin Shamshuddin et al., 2020). It is known that balance plays a key role in maintaining the optimal posture necessary for high performance in sports. Thus, it is likely that there is a relationship between them. Ionescu and Ionescu (2022) was conducted a study to examine the association between agility and balance in skaters. They evaulated the agility by hexagon test and balance by stork test and found that there is a significant correlation between the agility and balance with opened eyes. In a descriptive cross-sectional study by Rokaya et al (2021), 44 university male soccer players were evaluated. The Y Balance Test and modified T-Test were used for measurements and they found that the balance measures were significantly related to agility performance. Our current study was similar with previous outcomes, resulting in a relationship between balance and agility scores.

We found that slow and fast speed stimulus at coincidence anticipation timing are related to each other in our study. We think that this is an expected result because both parameters evaluate different speeds of the same skill.

In the previous studies, it was shown that cognitive functions and sport-specific physical performances are closely related in different sports branches. Lots of studies indicated that the highest sports performance requires cognitive skills especially attention, making decision and working-memory to function optimally in changing situations, and also reported that cognitive skills influenced sport performance (Vaughan & Laborde, 2021; Walton et al., 2018). For open skill sports such as volleyball, soccer and tennis cognitive functions were essential. Verburgh et al. (2014) compared 84 elite and 42 non-elite soccer players and found that high-level players demonstrated better cognitive abilities than amateurs. Similarly, Alves et al. (2013) studied in 87 volleyball players and 67 control to investigate the relationship between sport expertise and perceptual and cognitive skills. And their results indicated that elite volleyballers have better cognition than non-athletes. In a study conducted by Vaughan and Laborde (2021) aimed to determine the association between attention, working-memory, and sport performance and evaluated 359 athletes by using a battery of neurocognitive tasks. They reported that attention and the working-memory interact to predict performance, and found that performance is correlated with each of these parameters. In contrast, Kalén et al. (2021) researched the relationship between cognitive functions, skills, and sports performance in a meta-analysis. They screened 9,433 records and included 142 studies and found that there was insufficient evidence to determine whether cognitive functions are related to the sport performance (Kalén et al., 2021). Our results indicated that there was no relationship between cognitive function indicators such as MOCA and d2 with agility and balance scores. One potential reason for this finding is that our sample consisted of non-elite athletes rather than elite athletes.

Several limitations of this study are as follows: The inability to reach the sample size recommended by G-power, which caused a lower statistical power than expected; and the most of the sample was non-elite athletes rather than elite (mean year of sport experiences was 5.81 ±4.62). Also, although we included different sports branches in the study, sport-specific tests were not used in the evaluation. Despite these limitations, this study has its strengths. To the best of our knowledge, this is the first study to evaluate the agility, balance, and cognitive functions (including CAT and attention) together and compare them among sports branches.

5. Conclusion

In conclusion, this study highlights the relationship between cognitive functions, specifically coincidence anticipation timing, and critical physical performance indicators like agility and balance across various sports branches. Cognitive and physical abilities are closely linked in shaping athletic performance, and interventions to enhance cognitive skills could potentially improve sports performance and our understanding of mental training in athletics. It is recommended that future research in sports science should prioritize activities aimed at enhancing CAT among athletes when designing training programs. Given the correlation found between CAT and both agility and balance in this study, focusing on improving these perceptual skills could potentially enhance overall sports performance across different branches. Sports scientists may benefit from incorporating specific CAT training protocols tailored to the demands of individual sports, thereby optimizing athletes' ability to anticipate and react to dynamic stimuli effectively. Moreover, longitudinal studies investigating the long-term effects of CAT training on sports performance could provide valuable insights into the long-term benefits of enhancing cognitive functions in athletes.

Contributions: Dilara Özen Oruk (A-B-C-D-E), Kılıçhan Bayar (B-D-E), Özcan Saygin (B-C-E), Banu Bayar (C-D-E)

A-Financing, **B-**Study design, **C-**Data collection, **D-**Statistical analysis and interpretation of results, **E-**Manuscript preparation

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