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Evaluation of Traumatic Brain Injury Risk in Athletes: A Neuropsychological Investigation in Active Boxers

Sporcularda Travmatik Beyin Hasarı Riskinin Değerlendirilmesi: Aktif Boksörlerde Nöropsikolojik Bir İnceleme

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ABSTRACT: This study aims to evaluate the risk of traumatic brain injury by comparing data obtained from elite active boxers and healthy individuals through the application of the Symbol Digit Modalities Test and the Trail Making Test, which are sensitive to brain damage, as well as the Verbal and Nonverbal Cancellation Test, which is sensitive to the right parietal lobe. The study is conducted with eight male boxers with an average age of 19.3±2.60 years, who had an average of 7.25±3.41 years of active boxing experience, and ten healthy males with an average age of 19.7±1.05 years, who had no involvement in any combat sport. The Kruskal-Wallis Test was employed to investigate the difference between the groups based on the data obtained from the Symbol Digit Modalities Test and the Trail Making Test, while the Mann-Whitney U test was used to evaluate the difference between the groups in the data from the Verbal and Nonverbal Cancellation Test. Upon evaluating the results of the Symbol Digit Modalities Test, the control group scored significantly higher on the SDMT-1, SDMT-2, and SDMT-3 than the boxers. The results of the Trail Making Test showed that the control group completed the TMT1-A, TMT1-B, TMT2-A, and TMT2-B forms faster than the boxers, but the differences in these times were not statistically significant. In the context of neuropsychological tests, active boxers exhibited lower neurocognitive performance compared to healthy individuals.

Keywords: boxing, traumatic brain injury, neuropsychology.

ÖZ: Bu araştırmanın amacı beyin hasarına duyarlı Symbol Digit Modalities Test ve Trail Making Test ile sağ parietal lob üzerinde duyarlı Verbal and Nonverbal Cancellation Test dahilinde elit aktif boksörlerden elde edilecek olan verilerin sağlıklı bireyler ile karşılaştırılması sonucu travmatik beyin hasarı açısından değerlendirmeye çalışmaktır. Çalışmaya yaş ortalaması 19,3±2,60 yıl olan, ortalama 7,25±3,41 yıl aktif boks yaşam süresine sahip 8 erkek boksör ile yaş ortalaması 19,7±1,05 yıl olan ve herhangi bir mücadele sporu ile ilgilenmemiş 10 sağlıklı erkek dahil edilmiştir. Symbol Digit Modalities Test ve Trail Making Test kapsamında elde edilen verilerde, gruplar arasında oluşan farkı incelemek için Kruskal-Wallis Testi, Verbal and Nonverbal Cancellation Test verilerinde ise gruplar arasındaki farkı değerlendirmek amacıyla Mann-Whitney U testi uygulanmıştır. Symbol Digit Modalities Test sonuçları değerlendirildiğinde kontrollerin; SDMT-1, SDMT-2 ve SDMT-3 başarı puanlarının boksörlerden anlamlı düzeyde daha yüksek olduğu belirlenmiştir. Trail Making Test sonuçları değerlendirildiğinde kontrollerin; TMT1-A, TMT1-B, TMT2-A ve TMT2-B formlarını boksörlerden daha kısa sürede tamamladığı, fakat oluşan bu süre farklarının istatistiksel olarak anlamlı düzeyde olmadığı tespit edilmiştir. Verbal and Nonverbal Cancellation Test sonuçları değerlendirildiğinde ise kontrol grubunun; genel itibariyle boksörlerden daha fazla başarı gösterdiği, fakat oluşan bu başarı düzeylerinin istatistiksel olarak anlamlı seviyede olmadığı tespit edilmiştir. Nöropsikolojik testler kapsamında aktif boksörler, sağlıklı bireylere göre daha düşük nörobilişsel performans sergilemiştir. Bu durum nörobilişsel işleyiş açısından bir eksiklik olarak değerlendirilebilir.

Anahtar Kelimeler: boks, travmatik beyin hasarı, nöropsikoloji.

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1. INTRODUCTION

Boxing is a physical activity involving two athletes, equipped with special gloves, who mutually exchange punches over a predetermined period and within defined rules (*Varlık, 1982*). Sports of this nature can lead to diverse forms of injuries and fatalities. Traumatic brain injury, causing impairment in standard brain functions, can be defined as the impact, concussion, or penetrating head injuries (*Önal et al., 2013*). Athletes participating in boxing are at risk of acute and long-term neurological damage due to the opponent's primary target being the head (*Ryan, 1998*). Despite substantial debates concerning the ethics of boxing, a prominent medical concern is the risk of a boxer developing chronic traumatic encephalopathy during or after their boxing career (*McCrory, 2002*). In light of the evidence of acute and chronic injuries associated with boxing, the British Medical Association (BMA) has called for a ban on boxing. Their most recent reports express their position on banning boxing (both amateur and professional) outright due to allegations of cumulative brain damage (chronic traumatic brain injury) (*British Medical Association, 1993; British Medical Association, 2007*).

Despite humans' ability to effectively utilize both hemispheres of the brain, there exists a prevailing dominance of one hemisphere over the other in terms of privileged usage and skills, as suggested by Gabbard and Hart (*1996*). Functional activities necessitating the coordinated use of hand, foot, eye, and auditory functions exhibit a unilateral preference. This phenomenon is termed laterality (*Nissan et al., 2004*). Generally, individuals tend to favor one side over the other when employing hands or feet. The underpinnings of this inclination are rooted in anatomical and social factors (*Şen, 1998*). Those with a right-hand preference predominantly engage the left hemisphere, whereas individuals favoring their left hand predominantly employ the right hemisphere while also partly utilizing the left hemisphere (*Özsu, 2006*).

Neuropsychological tests have been observed to be sensitive in detecting cognitive impairments resulting from contact and collision sports (*Jordan et al., 1996; Matser et al., 1992; Matser et al., 1998*). The Symbol Digit Modalities Test (SDMT) is a psychometrically reliable screening measure sensitive to brain injury (*Smith, 1968; Spreen & Strauss, 1998*). The SDMT is a widely used screening tool in clinical and research settings for assessing neurological disorders (*Smith, 2007*). SDMT test performance is determined by attention, perceptual speed, motor speed, and visual scanning. Although the SDMT cannot distinguish specific disorders, it is sensitive to various neurological conditions and therefore has applications in many clinical populations. For example, poor performance detected in the test has been associated with traumatic brain injury, sports-related brain trauma, multiple sclerosis, Huntington's disease, Parkinson's disease, and stroke (*Strauss et al., 2006*). Development of the test began in the early 1900s (*Healy & Fernald, 1911*) and was later updated for use in the Army Beta (*Pintner & Paterson, 1917*). Subsequently, it was used as a Digit Symbol subtest, a subscale of Wechsler tests (*Wechsler, 1955*). In the Wechsler version, the matching of numbers with symbols is requested, whereas, in Smith's version, the matching of symbols with numbers is requested (*Landrø et al., 2004*).

The Trail Making Test, initially featured in the "Army Individual Test Battery" in 1944 for use by the United States Army, was later updated by Reitan (*Reitan, 1955; Reitan, 1971*). This test, consisting of two distinct forms, A and B (*Lezak et al., 2012*), is used to evaluate a range of neurocognitive abilities, including psychomotor speed, complex attention, visual scanning, and cognitive flexibility. Its sensitivity to brain damage in adults has been demonstrated repeatedly (*Boll et al., 1977; Jaffe et al., 1993; Reitan, 1955; Reitan, 1971*). According to Reynolds, the Trail Making Test can be specifically used to detect frontal lobe deficiencies; problems related to psychomotor speed, visual scanning, sequencing, and attention (*Reynolds, 2002*).

The Verbal and Nonverbal Cancellation Test was developed by Weintraub and Mesulam in 1985. This test, accepted to identify visual-motor skill, visual selectivity, and sustained attention (*Lezak, 1995*), is also sensitive to the functional state of the right parietal lobe (*İnce, 2011*). The importance of visual motor speed and coordination in test performance should be acknowledged (*Matier et al., 1994*). It has been reported that the test incorporates executive functions such as keeping the symbol or letter to be marked in memory, acting strategically, proceeding in order with planned responses, and maintaining these. The Verbal and Nonverbal Cancellation Test was adapted into the Turkish version as the Marking Test by Karakaş et al. (*1996*).

In light of this information, this study sets out to evaluate the risk of traumatic brain injury by comparing data obtained from elite active boxers and healthy individuals through the application of the Symbol Digit Modalities Test and the Trail Making

Test, which are sensitive to brain damage, as well as the Verbal and Nonverbal Cancellation Test, which is sensitive to the right parietal lobe.

2. METHOD

This study embraces a quantitative research approach by utilizing a general survey model.

2.1. Participant Characteristics

The research was conducted with participants who were right-hand dominant and had at least a high school level education. The study included eight male boxers with an average age of 19.3 ± 2.60 years and an average active boxing experience of 7.25 ± 3.41 years, as well as ten healthy males with an average age of 19.7 ± 1.05 years who had not previously engaged in any combat sports. Participants were provided with information about the tests. When including participants in the study, attention was paid to ensure that they did not have any chronic or acute diseases and that they had not used any medications or stimulants that could affect the functions of the central nervous system or cognitive performance. Participants were requested to refrain from alcohol, tobacco, and caffeine consumption 24 hours prior to the tests.

The tests were implemented in the Neuropsychology Laboratory of the Ataturk University Sports Sciences Application and Research Center in accordance with the current version of the Declaration of Helsinki. The tests were conducted in a 21 Celsius degree and 15 Db room with optimal humidity. Environmental conditions were uniformly determined, and the tests were conducted in the same setting for all participants, ensuring they were dressed comfortably and without hunger or fatigue.

Table 1. Data Collection Procedure

Day	Hour	Test
Day 1	12:00	Hand Preference Survey Symbol Digit Modalities Test 1
Day 2		Symbol Digit Modalities Test 2
Day 3		Symbol Digit Modalities Test 3
Day 4		Trail Making Test 1 A-B
Day 5		Trail Making Test 2 A-B
Day 6		Verbal and Nonverbal Cancellation Test

2.2. Data Collection Tools

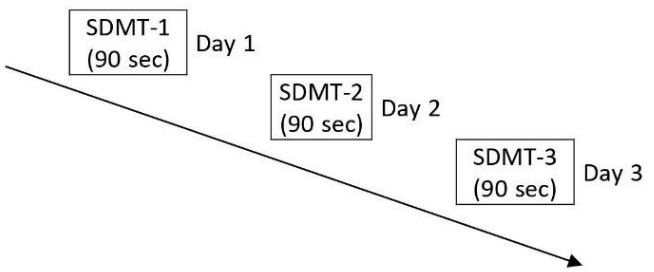
2.2.1. Edinburgh Inventory Hand Preference Survey

Given that the current investigation is structured as a neuropsychological assessment, a prerequisite for ensuring parity among the participants was upheld by the researchers. This necessitated confirming that all participants exhibited homogeneity in terms of their dominant cerebral hemisphere. To determine the participants' hand preferences, the "Edinburgh Inventory Hand Preference Survey" (*Oldfield, 1971*) was administered. Participants were asked to answer the questions in the survey in relation to their hand preferences. The responses were evaluated according to the Geschwind score and hand preference scores were summed. As a result, the levels of individuals being left-handed, ambidextrous, and right-handed were determined by this method.

2.2.2. Symbol Digit Modalities Test

The Symbol Digit Modalities Test was administered with a one-day interval on three different occasions. Before the test, participants were given a practice section consisting of boxes in which numbers from 1 to 9 were matched with symbols, with symbols on the top and numbers on the bottom. Participants were asked to match the symbols in the top boxes with the numbers by looking at them. After the practice, participants were asked to match as quickly as possible without skipping any boxes within 90 seconds while being timed with a stopwatch. The number of correct responses within was calculated. Averages were taken from the three different forms of Symbol Digit Modalities Tests completed by the participants. The participants' time during the application was taken with an electronic hand stopwatch (Casio Hs-70w-1DF, JP) with 0.01-second precision.

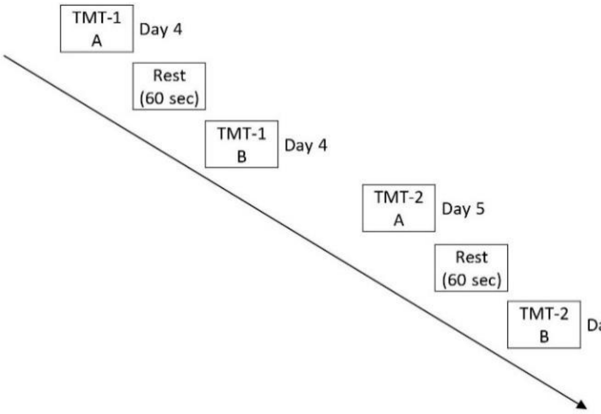
Figure 1. Symbol Digit Modalities Test Paradigm Series



2.2.3. Trail-Making Test

The Trail Making Test was administered with a one-day interval on two different occasions. Each Trail Making Test form consists of two subtests, A and B. Before the test, practice sections were administered without any time restriction. In section A, the participants were asked to draw lines connecting scattered circles containing numbers from 1 to 25 using a pencil. In section B, participants were asked to quickly connect circles containing both numbers and letters, in a way that alternates between a number and a letter. The participants' mistakes were corrected during the application. Averages were taken from the two separate Trail Making Tests completed by the participants based on the completion time for forms A and B. The participants' time during the application was recorded with an electronic hand stopwatch (Casio Hs-70w-1DF, JP) with 0.01-second precision.

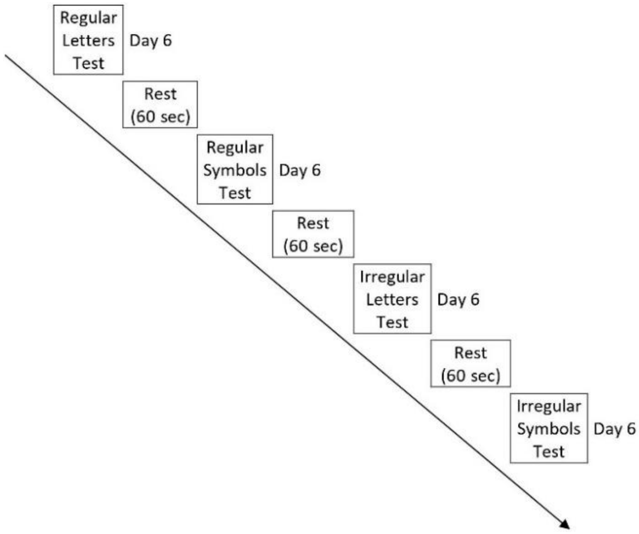
Figure 2. Trail Making Test Paradigm Series



2.2.4. Verbal and Nonverbal Cancellation Test

Participants were asked to complete four subtests consisting of Regular Letters, Regular Symbols, Irregular Letters, and Irregular Symbols. 60 second breaks were given between the tests. The application time averaged 20 minutes. Each test contained 60 target stimuli (A) (☼) positioned among 300 stimuli. In the Regular Letters and Irregular Letters subtests, the "A" stimulus was used, and in the Regular Symbols and Irregular Symbols subtests, the " ☼" stimulus was used. Participants were asked to encircle the target stimuli (A) (☼) with the aid of a pencil. During marking, pencils in black, blue, red, green, brown, and pink colors were given to the participant after every 10 marks and they were asked to continue marking with the new colored pencil provided. For each subtest, five different scores were obtained, consisting of the number of marked targets, number of skipped targets, number of marked incorrect letters-symbols, total error count, and scanning time. The total error score was obtained from the sum of the scores of the marked incorrect target and skipped target. The participants' time during the application was recorded with an electronic hand stopwatch (Casio Hs-70w-1DF, JP) with 0.01-second precision.

Figure 3. Verbal and Nonverbal Cancellation Test Paradigm Series



2.3. Data Analysis

In the data analysis, standard statistical methods were used to calculate the means and standard deviations. Neuropsychological test data were evaluated using the IBM SPSS Statistics 29.0 software package (IBM Corp., Armonk, NY, USA). Normality analysis were run in order to determine the tests to implement. Results indicated that the data was not normally distributed. Therefore, for the data obtained within the scope of the Symbol Digit Modalities Test and Trail Making Test, the Kruskal-Wallis Test was used to examine the difference formed between the groups. In the Verbal and Nonverbal Cancellation Test data, the Mann-Whitney U test was used to evaluate the difference between the groups. The significance level for the analyses was set as $p < 0.05$.

3. RESULTS

In this section, the results of the statistical analysis regarding the obtained research data will be presented.

Table 2. Statistical comparison of Symbol Digit Modalities Test scores between groups

Test	Group	n	X̄ ± SDs	χ2	p
SDMT 1	Boxers	8	36.50±11.174	8.126	.004*
	Controls	10	52.10±9.871		
SDMT 2	Boxers	8	48.38±9.753	8.135	.004*
	Controls	10	69.60±14.607		
SDMT 3	Boxers	8	50.00±9.040	7.359	.007*
	Controls	10	66.90±13.093		

p<0.05*

The table shows the score differences between the groups obtained from the 3 different Symbol Digit Modalities Tests (SDMT) conducted on the participants. As a result of the statistical analysis, in the SDMT 1, the boxers achieved an average success rate of 36.50±11.174, the controls 52.10±9.871; in the SDMT 2, the boxers achieved an average success rate of 48.38±9.753, the controls 69.60±14.607; and in the SDMT 3, the boxers achieved an average success rate of 50.00±9.040, the controls 66.90±13.093. In all tests, there were statistically significant differences between the two groups ($\chi2$ = 8.126, p = 0.004); ($\chi2$ = 8.135, p = 0.004); ($\chi2$ = 7.359, p = 0.007).

Table 3. Statistical comparison of Trail-Making Test time differences between groups

Test	Group	n	X̄ ± SDs	χ2	p
TMT 1 A	Boxers	8	22.943±6.259	.639	.424
	Controls	10	21.315±5.840		
TMT 1 B	Boxers	8	67.614±36.140	.284	.594
	Controls	10	52.926±13.140		
TMT 2 A	Boxers	8	25.514±10.551	2.558	.110
	Controls	10	19.182±5.351		
TMT 2 B	Boxers	8	64.922±24.894	2.282	.131
	Controls	10	46.820±13.324		

p<0.05*

The table demonstrates the differences between the groups in the completion times of the 2 different Trail Making Test (TMT) inventories by the participants. According to the statistical analysis, for the TMT 1 A, the boxers' average was 22.943±6.259 seconds, while the controls' was 21.315±5.840; for the TMT 1 B, the boxers' average was 67.614±36.140, the controls' was 52.926±13.140; for the TMT 2 A, the boxers' average was 25.514±10.551, the controls' was 19.182±5.351 and for the TMT 2 B, the boxers' average was 64.922±24.894, the controls' was 46.820±13.324. Although there were differences in completion time between the boxers and control group participants in all forms, these differences did not reach a statistically significant level ($\chi2$ = 0.639, p = 0.424); ($\chi2$ = 0.284, p = 0.594); ($\chi2$ = 2.558, p = 0.110); ($\chi2$ = 2.282, p = 0.131).

Table 4. Statistical comparison of Regular Letters Subtest score differences

Test	Data Types	Group	n	X̄ ± SDs	u	z	p
Regular Letters	Marked Target	Boxers	8	59.25±0.886	40.000	.000	1.000
		Controls	10	59.10±1.287			
	Skipped Target	Boxers	8	0.75±0.886	40.000	.000	1.000
		Controls	10	0.90±1.287			
	Incorrectly Marked	Boxers	8	0±0	40.000	.000	1.000
		Controls	10	0±0			
	Total Error	Boxers	8	0.75±0.886	40.000	.000	1.000
		Controls	10	0.90±1.287			
	Completion Time	Boxers	8	113.76±39.33	26.000	-1.244	.214
		Controls	10	89.60±20.81			

p<0.05

As a result of statistical analysis indicated that the average marked target for boxers was 59.25±0.886, and for the controls, it was 59.10±1.287 and the average skipped target for the boxers was 0.75±0.886, for the controls 0.90±1.287. There were no erroneously marked targets by either the boxers or the control group participants. The total error average for the boxers was 0.75±0.886 seconds, and for the controls, it was 0.90±1.287 seconds and the average completion time for the boxers was 113.76±39.33 seconds, and for the controls 89.60±20.81 seconds. Although there were differences in the average marked target, average skipped target, total error average, and average completion time aspects between the two groups, none of the differences reached a statistically significant level. (u = 40.000, z = .000, p = 1.000); (u = 40.000, z = .000, p = 1.000); (u = 40.000, z = .000, p = 1.000); (u = 26.000, z = -1.244, p = .214).

Table 5. Statistical comparison of Regular Symbols Subtest score differences

Test	Data Types	Group	n	X̄ ± SDs	u	z	p
Regular Symbols	Marked Target	Boxers	8	56.63±5.181	32.000	-.762	.446
		Controls	10	59.10±1.287			
	Skipped Target	Boxers	8	3.25±5.203	32.500	-.714	.475
		Controls	10	0.90±1.287			
	Incorrectly Marked	Boxers	8	0.63±1.768	38.000	-.274	.784
		Controls	10	0.20±0.422			
	Total Error	Boxers	8	3.87±6.854	33.500	-.621	.535
		Controls	10	1.10±1.370			
	Completion Time	Boxers	8	102.11±24.40	34.000	-.533	.594
		Controls	10	87.53±33.55			

$p<0.05$*

Following the statistical analysis, it was determined that the average number of targets marked by the boxers was 56.63±5.181, whereas the control group's average was 59.10±1.287; the average number of targets skipped by the boxers was 3.25±5.203, for the control group it was 0.90±1.287; the average number of targets marked incorrectly by the boxers was 0.63±1.768, in the control group it was 0.20±0.422; the average total number of errors made by the boxers was 3.87±6.854, for the control group it was 1.10±1.370 and the average completion time for the boxers was 102.11±24.40 seconds, for the control group it was 87.53±33.55 seconds. Although there are differences in all aspects between the two groups these differences failed to reach statistical significance (u = 32.000, z = -.762, p = .446); (u = 32.500, z = -.714, p = .475); (u = 38.000, z = -.274, p = .784); (u = 33.500, z = -.621, p = .535); (u = 34.000, z = -.533, p = .594).

Table 6. Statistical Comparison of Irregular Letters Subtest Score Differences

Test	Data Types	Group	n	X̄ ± SDs	u	z	p
Irregular Letters	Marked Target	Boxers	8	59.38±1.061	33.500	-.734	.463
		Controls	10	59.60±0.966			
	Skipped Target	Boxers	8	0.63±1.061	33.500	-.734	.463
		Controls	10	0.40±0.966			
	Incorrectly Marked	Boxers	8	0±0	40.000	.000	1.000
		Controls	10	0±0			
	Total Error	Boxers	8	0.63±1.061	33.500	-.734	.463
		Controls	10	0.40±0.966			
	Completion Time	Boxers	8	95.76±42.89	38.000	-.178	.859
		Controls	10	93.43±19.07			

$p<0.05$*

According to the results, the average number of targets marked by the boxers was 59.38±1.061, while for the control group, it was 59.60±0.966 and the average number of targets skipped by the boxers was 0.63±1.061, for the control group it was 0.40±0.966. Neither the boxers nor the control group participants erroneously marked any targets. The average total number of errors made by the boxers was 0.63±1.061, whereas, for the control group, it was 0.40±0.966 and the average completion time for the boxers was 95.76±42.89 seconds, 93.43±19.07 for the control group. There are differences between the two groups in certain aspects, however, none was able to reach a statistically significant level (u = 33.500, z = -.734, p = .463); (u = 33.500, z = -.734, p = .463); (u = 33.500, z = -.734, p = .463); (u = 38.000, z = -.178, p = .859).

Table 7. Statistical Comparison of Irregular Symbols Subtest Score Differences

Test	Data Types	Group	n	X̄ ± SDs	u	z	p
Irregular Symbols	Marked Target	Boxers	8	58.75±2.053	31.000	-1.015	.310
		Controls	10	59.80±0.422			
	Skipped Target	Boxers	8	1.25±2.053	31.000	-1.015	.310
		Controls	10	0.20±0.422			
	Incorrectly Marked	Boxers	8	0.75±1.753	33.500	-.890	.373
		Controls	10	0.10±0.316			

	Total Error	Boxers	8	2.00±3.546	30.500	-1.069	.285
		Controls	10	0.30±0.675			
	Completion Time	Boxers	8	79.43±21.64	29.000	-.977	.328
		Controls	10	70.27±14.57			

p<0.05*

In the final statistical analysis, the average number of targets marked by the boxers was 58.75±2.053, while, for the control group, it was 59.80±0.422; the average number of targets skipped by the boxers was 1.25±2.053, it was 0.20±0.422 for the controls; the average number of targets marked incorrectly by the boxers was 0.75±1.753, it was 0.10±0.316 for the controls; the average total number of errors made by the boxers was 2.00±3.546, it was 0.30±0.675 for the controls and the average completion time for the boxers was 79.43±21.64 seconds, it was 70.27±14.57 seconds for the controls. Again, even if there are differences in all aspects, none was able to be labeled as statistically significant (u = 31.000, z = -1.015, p = .310); (u = 31.000, z = -1.015, p = .310); (u = 33.500, z = -.890, p = .373); (u = 30.500, z = -1.069, p = .285); (u = 29.000, z = -.977, p = .328).

4. DISCUSSION

In this section, the results obtained from the study will be discussed in comparison with the existing literature. This study included eight active right-handed elite boxers and a healthy control group of 10 right-handed individuals. The average age of the boxers was 19.3±2.60 years, and the average age of the healthy individuals was 19.7±1.05 years. Furthermore, the average sports age of the boxers was determined to be 7.25±3.41 years. The left-right hand preference rates of the participants were determined within the framework of the Edinburgh Inventory Hand Preference Survey. The participants were administered 3 Symbol Digit Modalities Tests, and the test parameters were evaluated. Upon examining the results of the Symbol Digit Modalities Test of the participants, the success scores of the controls in SDMT-1, SDMT-2, and SDMT-3 were significantly higher than those of the boxers. In their study on 237 professional boxers in Maryland between 2003 and 2008, Stiller et al. (*2014*) examined the SDMT success performance before and after sparring (training match) and evaluated the SDMT scores with the percentages of sparring performed by the athletes. As a result, the increase in the percentage of sparring was associated with the decrease in the SDMT success performance. Jordan et al. (*1996*) reported a relationship between sparring exposure and low SDMT performance in their research involving 42 professional boxers. Erik et al. (*2000*), in their research aimed at determining whether there is acute traumatic brain injury in boxers, applied the Digit Symbol Test to 38 amateur boxers and 28 control group boxers after a boxing match. The group applying the test before and after the match showed signs of acute traumatic brain injury in areas of planning, attention, and memory capacity compared with the control group. A significant difference was also observed between them regarding Digit Symbol Test success. Despite the use of helmets, it was discovered that concussions could occur in amateur boxing matches, which could reduce neurocognitive processing. Çemç (*2023*), to examine the risk of chronic traumatic brain injury in retired boxers, conducted various measurements and tests on ten boxers who had actively boxed for an average of 13.1±2.46 years and a healthy control group of ten participants. When the data from his three different Symbol Digit Modalities Tests was examined, it was determined that the retired boxers showed a statistically significantly higher level of failure compared to the healthy control group. This may have been caused by the punches to the head area received by the boxers during the match.

Mrazik et al. (*2000*), in their research conducted for college athletes at the University of Georgia, included athletes with a high risk of concussion in their study. As a result, it was determined that the SDMT performances of athletes with a higher number of concussions were poor. Macciocchi et al. (*1996*) prospectively examined neuropsychological functioning in 2300 college football players. The athletes were between the ages of 18-26 and were followed for four years. Impairment was observed in the Digit Symbol Test performance of athletes with head trauma compared to the control group. Brett et al. (*2022*), in their research involving 58 former American football players, about 15 years after retiring from sports, found a decrease in SDMT performance as the active sports period increased. Hinton-Bayre et al. (*1999*), in their research with Australian football players, observed that the SDMT performance of the group who had concussions was significantly lower. Echemendia et al. (*2001*), aimed to examine sports-related traumatic brain injury in college athletes through neuropsychological tests. The study included 29 athletes from male and female American Football, male ice hockey, male and female soccer, and male and female basketball teams at Penn State University and a healthy control group of 20 people.

Neuropsychological test data were recorded for injured athletes and controls before and 2 hours, 48 hours, 1 week, and 1 month after the traumatic brain injury. As a result, when SDMT data were examined, significant differences were detected between injured athletes and controls one week after the concussion. The injured athletes performed significantly worse than the controls.

Collins et al. (*1999*), aimed to evaluate the relationship between concussion history and learning difficulty and the connection of these variables with neuropsychological performance. The research included 393 college football players. Of these, 129 (34%) had previously suffered 1 concussion, and 79 (20%) had suffered 2 or more concussions. In conclusion, a significant correlation was found between multiple concussion histories, learning difficulties, and poor SDMT achievement levels which resulted in poor SDMT performance. Draper and Ponsford (*2008*), aiming to identify impairments 10 years after traumatic brain injury, conducted research involving 60 subjects with a history of traumatic brain injury and a healthy control group of 43 individuals. It was determined that the participants with a history of traumatic brain injury had significantly poorer SDMT achievement levels and cognitive performance. Dymowski et al. (*2015*), aiming to examine the relationship between traumatic brain injury and cognitive performance, evaluated 25 subjects with mild and severe traumatic brain injuries and 25 healthy participants. As a result, it was determined that individuals who had suffered a traumatic brain injury had significantly poorer SDMT performance compared to healthy participants. Bate et al. (*2001*), as part of their research conducted on a group of 35 individuals with severe traumatic brain injuries and a healthy control group of 35 people, found that the group with traumatic brain injury had significantly poorer SDMT performance compared to the healthy group. Ponsford and Kinsella (*1992*), evaluating the relationship between head trauma and attention deficit, studied 47 subjects with a history of head trauma and a control group of 30 individuals with orthopedic injuries resulting from motor accidents. The control group had no history of head trauma. It was observed that subjects with a history of head trauma had significantly poorer SDMT performance compared to the control group. Willmott et al. (*2009*), as part of their research on information processing and attention mechanisms after traumatic brain injury, examined the SDMT performance of a group with traumatic brain injury and a healthy control group. It was determined that the group with traumatic brain injury had significantly poorer SDMT achievement compared to the control group.

Previous literature indicates that athletes with a higher number of concussions and head trauma have poor SDMT test performance and show impairments in Digit Symbol Test performance. Furthermore, a decrease in SDMT performance occurs with the increase in active sports periods in American football players, and the SDMT performance of football players with concussions is significantly lower. This may arise as a result of head traumas occurring in athletes. On the other hand, the existence of a relationship between the history of multiple concussions and poor SDMT performance has been revealed and even observed 10 years after the traumatic brain injury. Furthermore, in the previous research, the decrease in SDMT performance was associated with increased parring (boxing training matches). According to examinations made before and after the boxing match, it was observed that the Digit Symbol Test success dropped despite the use of helmets. As a result of the SDMT that we administered within the scope of our research, boxers showed significantly poorer performance than healthy individuals. This can be evaluated as a deficit in neurocognitive processing. This deficit is thought to arise as a negative effect of the punches received to the head area during boxing matches and can also be referred to as a sign of acute traumatic brain injury. The obtained results are similar to the existing research in the literature.

When the Trail Making Test results of the participants were evaluated between groups, it was observed that the controls completed TMT1-A, TMT1-B, TMT2-A, and TMT2-B forms in a shorter time than the boxers. However, the differences observed were not statistically significant.

In their study, Erik et al. (*2000*) aimed to determine the presence of acute traumatic brain injury in boxers. The research involved implementing the Trail Making Test on 38 amateur boxers pre- and post-match and 28 control group boxers doing sandbag punch training before and after the training. The study found evidence of acute traumatic brain injuries in the group tested before and after the match, in areas of planning, attention, and memory capacity, when compared to the control group. Despite the use of helmets, it was discovered that brain concussions could still occur in amateur boxing matches, which could impair neurocognitive function. However, no significant difference was observed in terms of success in the Trail Making Test. Yongtawee et al. (*2022*) which aimed to investigate differences in athletes' cognitive functions, included 30 boxers, 30 shooters, 30 soccer players, and a control group of 30 individuals. The Trail Making Test was administered to participants, and the results were evaluated. In conclusion, boxers showed lower performance in the TMT Form A compared to shooters and soccer players. Boxers also displayed lower performance in the TMT Form B than shooters. However, these differences were not statistically significant. Neselius et al. (*2014*) examined 30 elite boxers who had participated in at least 45 matches and a healthy control group of 25 individuals from a neuropsychological perspective. To increase the sensitivity of the study, boxers' tests and measurements were performed post-match. The Trail Making Test was administered to all participants. In the end, no significant difference was found between the boxer and control groups.

In a study conducted by Porter and Fricker (*1996*) to determine the relationship between amateur boxing and chronic traumatic encephalopathy, eight neuropsychological tests were performed. The study included 20 active experienced amateur boxers and a healthy control group of 20 individuals. Participants were administered the Trail Making Test, and it was found that boxers significantly outperformed the control group in the Trail Making Test Forms A and B. In his 9-year study conducted in 2003, Porter examined 20 active boxers and a healthy control group of 20 individuals in Dublin and Ireland, aiming to determine the relationship between amateur boxing and chronic traumatic encephalopathy. Measurements and tests were obtained from the participants at the beginning of the study and subsequently at the end of 1.5, 4, 7, and 9 years. The collected data were analyzed. Considering the Trail Making Test data, the boxers performed significantly higher in Forms A and B in all measurements compared to the control group.

Çemç (*2023*) examined the risk of chronic traumatic brain injury in retired boxers, conducting various measurements and tests on 10 boxers who had been active for an average of 13.1±2.46 years and a healthy control group of 10 individuals. When the data from the two different Trail Making Tests included in his tests were analyzed, it was found that retired boxers statistically significantly underperformed in the TMT-B forms compared to the healthy control group. It was suggested that this could be due to the punches to the head area the boxers received during matches. Moser et al. (*2005*) conducted a neuropsychological study among high school-level athletes between 1999-2000 with the objective of understanding the impacts of concussions. The study engaged 40 subjects who had suffered a concussion a week prior to the tests, 45 subjects who had experienced two or more concussions, 56 subjects with one instance of concussion, and 82 participants who had never experienced a concussion. The Trail Making Test was applied to all. The study concluded that those participants who had suffered a concussion a week prior to the test showed poorer performance in the Trail Making Test A and B compared to those who had never experienced a concussion, with the difference in the Trail Making Test B deemed statistically significant. Baker et al. (*2018*) conducted a study to investigate the hypothesis of a mild cognitive impairment difference between retired professional contact sports athletes and non-contact sports retirees. The study incorporated 21 retired National Football League and National Hockey League players and 21 retired athletes. The Trail Making Test was administered, revealing no significant difference between the two groups in the results. Macciocchi et al. (*1996*) prospectively studied neuropsychological functioning in 2,300 college football players. The athletes, aged between 18-26, were tracked over a four-year period. A decline in the Trail Making Test performance was observed among athletes who had experienced head trauma compared to the control group.

Oliaro et al. (*1998*) evaluated 72 college athletes who had experienced a mild head injury by administering three different tests with a two-day interval to study their cognitive abilities. Upon analyzing the Trail Making Test data collected over three different days, a significant increase in test scores was observed from the first to the third day, suggesting a learning effect. Willer et al. (*2018*) examined the executive function and mental health levels of retired professional contact sports athletes and non-contact sports athletes of the same age. In the study, 21 retired National Football League and National Hockey League players and 21 retired athletes were included. Upon reviewing the Trail Making Test data, no significant difference in performance levels was detected between the groups. The study concluded that participation in professional contact sports may not lead to executive dysfunction in later life as suggested by popular media and some research. Prien et al. (*2020*) included 66 retired female soccer players and 45 retired athletes who had not engaged in contact sports in a study designed to examine the long-term neurocognitive and mental health effects of repeated head impacts in women who play football. When evaluating the results of the Trail Making Test conducted on the participants, no significant difference was detected between the groups.

Dymowski et al. (*2015*) evaluated 25 subjects who had experienced mild and severe traumatic brain injury and 25 healthy participants in a study aimed at examining the relationship between traumatic brain injury and cognitive performance. The study concluded that individuals who had suffered a traumatic brain injury exhibited significantly lower performance in the Trail Making Test A and B compared to healthy participants. Brett et al. (*2022*) included 58 former American football players who had been retired for approximately 15 years in a study. They observed a decline in the Trail Making Test B form performance with an increase in active athletic duration. Guskiewicz et al. (*1997*) evaluated 11 college athletes who had experienced mild head trauma and a healthy control group of 11 individuals to assess the impact of mild head trauma on cognitive functions. Upon reviewing the Trail Making Test data, the control group outperformed the group that had experienced mild head trauma, but the difference between the groups was not deemed statistically significant. Guskiewicz et al. (*2001*) examined the process following sports-related concussions by including 36 college athletes who had experienced a concussion and a healthy control group of 36 individuals. The tests were administered on the first, third, and fifth days following the injury. Upon reviewing the data from the Trail Making Test A conducted on the participants, it was observed that the control group outperformed the concussion group on all three days, but the difference was not deemed statistically significant. On the other hand, when the data from the Trail Making Test B were reviewed, the control group was found to significantly outperform the concussion group on all three days.

Literature contains some studies that report no significant differences in terms of Trail Making Test (TMT) success between boxers participating in matches and those who do not. On the other hand, there have been reports suggesting that experienced boxers significantly outperform the healthy control group in terms of TMT performance. Such observed variations may stem from the variability of the sample groups. However, studies have also demonstrated deteriorations in TMT performance in athletes suffering from head trauma. It has been noted that an increase in active athletic duration correlates with a decline in TMT B form performance, and individuals who have suffered traumatic brain injury significantly underperform in terms of TMT A and B forms compared to their healthier counterparts. Furthermore, research has indicated that retired boxers perform significantly worse on TMT B forms compared to a healthy control group. Our research findings indicate that, although not statistically significant, boxers tend to underperform compared to the healthy control group on TMT forms. The obtained data correlate with the empirical studies.

When comparing the results of the Verbal and Nonverbal Cancellation Test between groups, it was determined that boxers had a higher rate of correctly marked targets, lower rates of missed and total errors, and longer completion time than the controls in the Regular Letters test. However, these differences were not significant. No incorrectly marked targets were found in either group. In the Regular Symbols test, it was determined that the controls had higher rates of correctly marked targets, lower rates of missed, incorrectly marked, total errors, and shorter completion time than the boxers. However, these differences were not significant. In the Irregular Letters test, the controls had higher rates of correctly marked targets, lower rates of missed and total errors, and shorter completion time than the boxers. However, these differences were not statistically significant. No incorrectly marked targets were found in either group. The Irregular Symbols test determined that the controls had higher rates of correctly marked targets, lower rates of missed, incorrectly marked, and total errors, and shorter completion time than the boxers. However, these differences were not statistically significant either.

Michael et al. (*2014*) compared the neuropsychological test performance of 18 subjects who had suffered a traumatic brain injury and 21 subjects diagnosed with schizophrenia, alongside a healthy control group of 31 individuals with no history of neurological or psychiatric illness. The Cancellation Test was administered to the participants. The results indicated that when compared with the control group, both patient groups had slower processing speed, lower target processing efficiency, and difficulty distinguishing correct targets from distractor targets. Geldmacher and Hills (*1997*) aimed to examine the effects of stimuli and motor limitations on visual-spatial performance following traumatic brain injury, in their study of 20 subjects with such injuries and 21 healthy controls. The Cancellation Test was again administered to the participants. The results revealed a lower performance on the Cancellation Test for individuals who had suffered a traumatic brain injury when compared to the healthy control group. Hills and Geldmacher (*1998*) used the Cancellation Test on a group of 20 subjects who had suffered a traumatic brain injury and 21 healthy controls, with the aim of assessing visual scanning after traumatic brain injury. The results showed that compared to the control group, the participants who had suffered traumatic brain injuries had significant deficiencies in terms of correctly marking targets and task completion times. Sinopoli et al. (*2011*), in a study evaluating the relationship between ADHD and traumatic brain injury in children and adolescents, found that participants with traumatic brain injuries had lower performance compared to the control group when analyzing the Cancellation Test data. Çemç (*2023*), in a study investigating the risk of chronic traumatic brain injury in retired boxers, conducted various measurements and tests on 10 boxers. When examining the data from the Verbal and Nonverbal Cancellation Test, it was observed that retired boxers generally underperformed on all four forms compared to the healthy control group, albeit not statistically significant.

When reviewing the existing research, it was observed that individuals who had suffered traumatic brain injuries have slower processing speed, lower target processing efficiency, and difficulty distinguishing correct targets from distractor targets. Therefore, it was reported that individuals who had suffered head trauma demonstrated significantly lower performance than healthy individuals, especially in terms of correctly marking targets and task completion times. In our study, it was found that active boxers generally performed at a lower level compared to healthy subjects, although not statistically significant. When examining the research results, it was observed that active boxers displayed cognitive performance deficits compared to healthy individuals.

Considering these results, it is recommended to improve protective equipment used in contact and combat sports to prevent possible traumatic brain injuries, which would be beneficial for athlete health. Additionally, it is suggested that administering neuropsychological tests, especially to contact and combat athletes, would enrich the literature, and contribute to sports science with the obtained data greatly.

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6. ETHICS STATEMENT

For this study, the necessary ethical permissions were obtained from the Ethics Committee of Ataturk University (Number: 050.02.04-2300157958, Dated: 04.07.2023).

7. AUTHOR CONTRIBUTIONS

MSÇ organized the study, established the research design, and collected the data. HHY analyzed the data and prepared the findings. MK participated in the literature review, editing, and composing. The authors read and approved the final version of the article and accepted the order of presentation of the authors. The authors declare that they have no competing interests.

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