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[Vyacheslav Romanenko](#) , [Wojciech J. Cynarski](#) , [Yrui Tropin](#) , [Yuliya Kovalenko](#) , [Georgiy Korobeynikov](#) ^{*} ,
[Svitlana Piatysotska](#) , [Volodymyr Mikhalsky](#) , [Valerii Holokha](#) , Shukurjon Gazyev

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Article

Methodology for Assessing Spatial Perception in Martial Arts

Vyacheslav Romanenko ¹, Wojciech J. Cynarski ², Yrui Tropin ¹, Yuliya Kovalenko ¹, Georgiy Korobeynikov ^{3,4}, Svitlana Piatysotska ¹, Volodymyr Mikhalskyi ¹, Valerii Holokha ¹ and Shukurjon Gaziyeu ⁴

¹ Kharkiv State Academy of Physical Culture, 61058, Kharkiv, Ukraine

² University of Rzeszow, Faculty of Physical Culture Sciences, 35-310, Rzeszow, Poland

³ National University of Ukraine on Physical Education and Sport, 02000 Kyiv, Ukraine

⁴ Uzbek State University of Physical Education and Sports, 100173 Tashkent, Uzbekistan

* Correspondence: k.george.65.w@gmail.com

Abstract: The study of mechanisms underlying the perception of visual information, the speed and adequacy of its processing, is of practical interest to martial artists. The study aims to develop and validate a methodology for assessing spatial perception in martial arts. It involved 57 participants practising Taekwon-Do, representing various age groups and skill levels (age: 18.6 years, SD=3.52; qualifications: 8th Gup to 1st Dan). At the first stage of the research, the newly developed “Spatial Perception” application was preliminarily tested to determine its reliability and validity. In the second stage, the specific features of spatial perception among martial artists of different ages and qualifications were examined. The findings indicate the rotation of objects provides additional information for object recognition, which reduces reaction time and the number of errors in response selection. The speed of processing dynamic visual cues reflects athlete’s psychophysiological capabilities, which are crucial during competitive bouts. Experienced martial artists possess a larger repertoire of visual samples and images, enabling them to formulate effective responses to unexpected situations during combat. Athletes at this level can maintain focus on objects and are less affected by distracting visual stimuli. The results obtained may assist martial arts coaches in improving the monitoring of athletes’ functional states and optimizing training processes.

Keywords: cognitive abilities; martial arts; mobile application; mobile devices; psychophysiological parameters; spatial perception

1. Introduction

The study of psychophysiological parameters has garnered significant interest among scientists from numerous countries [1,2]. Experts indicate that psychophysiological traits are more predictable, genetically more conservative, and less dynamic in ontogenesis [3,4]. Assessing the psychophysiological functions of athletes provides critical information regarding their functional state. A thorough analysis of this information enables specialists to address tasks related to monitoring and adjusting the training process [5,6].

Psychophysiological parameters vary depending on the research focus, objectives, measurement methods, and the athletes’ qualifications and ages. It has been shown that the same respondent may exhibit different reaction times depending on the type of reaction measured [7–9]. Studies have demonstrated that athletes generally exhibit shorter reaction times compared to non-athletes in tasks involving perceptual-cognitive skills [10–13]. An increase in reaction time can be associated with the complexity of test tasks, which engage additional psychophysiological processes influencing decision-making speed [14–16]. It has been established that combat sports athletes are better at anticipating opponents’ actions based on information perceived before and during an attack [17,18].

Considering the high speed and short duration of strikes in combat sports (e.g., the duration of a karate strike is 242 ms), the demands on reaction time increase significantly [19]. It is important to

note that at the elite level of combat sports, the cognitive abilities required—such as memory, attention, perception, and information processing—become increasingly crucial. Competitive activities in combat sports demand athletes to rapidly evaluate situations, make complex decisions under time constraints, and respond promptly to stimuli and stressors [20,21]. Cognitive traits, including spatial perception, play a significant role in combat sports athletes. Individual-typological characteristics shape an athlete's unique combat style, which impacts competitive outcomes [22,23].

Spatial skills refer to the ability to create, remember, reproduce, and transform well-organized visual images. Spatial abilities are evaluated as both a component of intelligence and an area where specific talents are expressed. A significant correlation has been established between spatial abilities and academic performance in mathematics [24]. Recent research highlights the connection between spatial abilities and achievements in STEM fields (science, technology, engineering, and mathematics) [25,26].

When observing the environment, individuals may feel they are aware of everything, but in reality, they perceive very little. However, with eye movements, they can quickly access any visual information as needed. Observers acquire relevant information precisely when it is useful. Information unrelated to the current task is deemed unimportant and may fall outside the focus of attention [27,28]. Vision is not a passive registration of information. Visual perception is determined by two types of processes: those guided by visual information (light striking the retina) and those directed by attentional demands, which are dictated by task requirements [29].

Experimental studies suggest that space can be conceptualized in terms of three dimensions or planes: height (vertical), width (horizontal), and depth (sagittal). Humans do not perceive binocular space (separate visual worlds from each eye) but instead perceive a “cyclopean space,” where images merge to create a unified field of vision. Environmental information is perceived only to the extent that it relates to the individual's goals, needs, or physiological state at the time [30].

Research into the mechanisms of visual information perception and the speed and accuracy of its processing is of practical interest for combat sports athletes. Understanding these processes allows the identification of key parameters for evaluating spatial perception and the quality of visual information processing. This is crucial for determining the individual-typological characteristics of athletes. Consequently, this study aims to develop and validate a methodology for assessing the spatial perception of combat sports athletes.

2. Materials and Methods

2.1. Participants

The study involved 57 ITF Taekwon-Do athletes of various ages and skill levels (mean age: 18.6 years, SD = 3.52; qualification: 8th Gup to 1st Dan). All participants provided informed consent for their involvement in the study. They were briefed about the study's objectives, testing procedures, and their right to withdraw at any time and for any reason. Parental consent was obtained for underage participants, and parents were present during the measurements. At the time of the study, all participants were in good health. The study adhered to the fundamental principles of bioethics, including the Council of Europe's Convention on Human Rights and Biomedicine (04.04.1997), the World Medical Association's Declaration of Helsinki on ethical principles for medical research involving human subjects (1964–2008), and the Ministry of Health of Ukraine's Order No. 690 (23.09.2009).

2.2. Procedure

The research was conducted in several stages. At the Preliminary Stage twenty Taekwon-Do athletes (mean age: 11.4 years, SD = 2.48; qualification: 6th–4th Gup) participated in the initial testing of the developed “Spatial Perception” application to assess its reliability and validity. Two measurements were conducted three weeks apart. At the Main Stage the study aimed to further validate the application and analyze spatial perception differences among athletes of varying ages

and skill levels. Participants were divided into two groups: group 1– 33 athletes (mean age: 11.5 years, SD = 2.02; qualification: 8th–3rd Gup); group 2 – 24 athletes (mean age: 18.2 years, SD = 2.40; qualification: 2nd Gup–1st Dan). Before testing at each stage, a warm-up session was conducted using tennis balls to activate visual and motor coordination mechanisms. The warm-up included throwing and catching the ball from the floor, in pairs, and against a wall. Each exercise lasted 2 minutes.

A mobile application called “Spatial Perception” was developed for iOS devices using Swift programming language and libraries such as UIKit, CoreData, AVFoundation, UniformTypeIdentifiers, and SceneKit. The visual stimuli (2D and 3D geometric shapes) were created using the 3D modeling software Blender (version 4.0.2). The application includes four stages of tasks requiring participants to compare geometric shapes. Stage 1– comparison of 2D shapes (e.g., Square, Rhombus, Hexagon, Circle, Triangle). Each shape is randomly rotated before display. Stage 2– comparison of 3D shapes (e.g., Cube, Cylinder, Sphere, Hexagonal Prism, Octahedron). Shapes are displayed in random positions within a three-dimensional space (Figure 1). At the 3rd Stage, shapes begin rotating for 300 ms before stopping, after which the comparison task is performed, and Stage 4 – Similar to Stage 3, but with additional distracting visual stimuli in the background (Figure 2). Participants responded by selecting the appropriate field: “Same” (green field) if the shapes were identical or “Different” (red field) if the shapes were different.

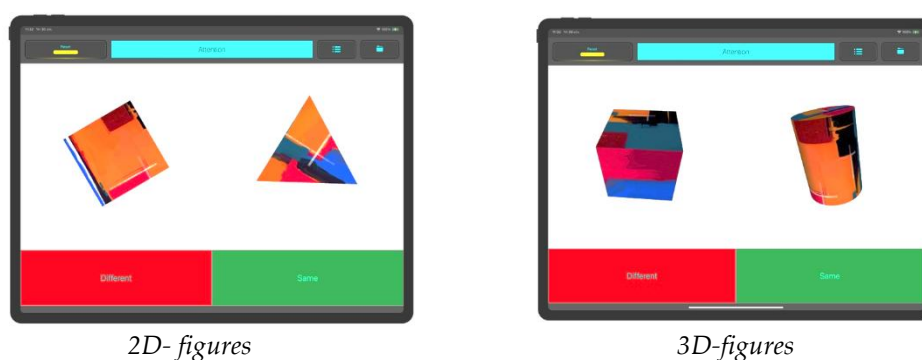


Figure 1. Main interface of the “Spatial Perception” application.

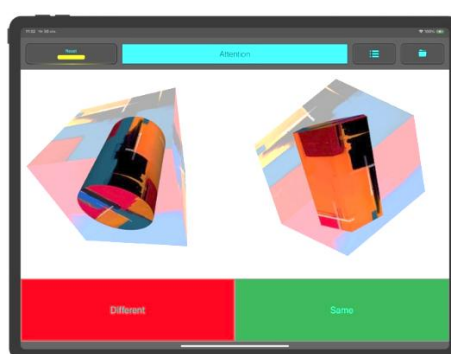


Figure 2. Test task of the fourth stage of the application “Spatial Perception”.

The mobile application includes settings that allow users to familiarize themselves with the geometric shapes presented in the test tasks, customize their textures, select the number of stages, and set the number of attempts. Selecting the “2D Shapes” option enables users to view the two-dimensional shapes included in the test. The “3D Shapes” option provides an interactive display of three-dimensional shapes, allowing rotation in any direction to give users a spatial understanding of these figures. The application also features a “Demo” mode, which offers a shortened version of the test exercise (5 attempts per stage). Additionally, users can choose the texture of the shapes from three available options, which can be configured in the application settings (Figure 3). Texture selection is tailored based on the age and athletic qualifications of the participants. The application

allows users to specify the number of attempts per stage, ranging from 10 to 40. For the study’s test tasks across all stages, the “Color Abstraction” texture was selected, with 20 attempts per stage. The duration of a test exercise with 20 attempts per stage is approximately 2.5 minutes.



Figure 3. Textures.

In the “Settings” section, users can manage measurement data with several options: “Save backup” to save a backup of measurements in JSON format; “Add backup” to merge measurement data from another device running iPadOS; to overwrite existing measurement data with new ones – “Replace backup”, and “Delete all data” to erase all saved data.

2.3. Statistical Analysis

The mathematical and statistical analysis was conducted using the licensed program RStudio (version 2023.12.1+40). Descriptive statistics were presented as mean, standard deviation, 1st and 3rd quartiles, and median. To determine the statistical relationship between the first and second measurements in the first stage of the study, a non-parametric statistical method – the Spearman rank correlation coefficient (r) – was used. The strength of the correlation was interpreted as follows: 0.80–1.0 “Very strong”, 0.60–0.79 “Strong”, 0.40–0.59 “Moderate”, 0.20–0.39 “Weak”, and 0.00–0.19 “Very weak” [31].

The internal consistency of the measurements (test-retest reliability) was evaluated using Cronbach’s alpha coefficient. The metrics included: Alpha (r) – unstandardized correlation; Std. alpha (r) – standardized correlation; Average (r) – average correlation. The strength of consistency was categorized as follows:> 0.9 “Excellent”, 0.8–0.9 “Good”, 0.7–0.8 “Acceptable”, <0.7: “Low” [32]. A Bland-Altman plot [33] was created to visualize the consistency analysis between the two measurements. To identify test-retest differences for paired comparisons of dependent sample results, the Wilcoxon signed-rank test was employed. For independent samples, the Mann-Whitney U test was used.

Statistical significance was set at a confidence level of $p < 0.05$.

3. Results

The results of the first and second measurements of the first stage of the study are presented in Table 1.

A comparison of the results from the first and second measurements indicates no statistically significant differences ($p > 0.05$) in reaction time across all test stages. A very strong correlation ($r \geq 0.80$) was observed between the measurements for reaction time during the second and fourth stages of the test. A strong correlation ($r \geq 0.60$) was noted for the first and third stages (Table 1).

Table 1. Results of the First and Second Measurements of the First Stage of the Study (n=20).

Measurement	The whole test	1st stage	2nd stage	3rd stage	4th stage
1st measurement (ms)	901.2±157.9	883.2±190.8	892.1±210.0	886.9±147.0	960.1±155.8
2nd measurement (ms)	898.7±166.5	876.5±203.0	901.9±206.6	877.9±174.0	938.6±169.4
Wilcoxon tests	V=121	V=102	V=189	V= 123	V=135

	p=0.571	p=0.925	p=0.779	p=0.522	p=0.277
Correlation (r-Spearman)	0.87	0.73	0.80	0.75	0.82

To assess the internal consistency and reliability of the results between the first and second measurements, Cronbach’s alpha coefficient was calculated (Table 2), and a Bland-Altman plot was constructed (Figure 4).

Table 2. Assessment of Consistency and Reliability of Measurement Results (Cronbach’s Alpha Coefficient).

Stages	Alpha (r)	Std. alpha (r)	Average (r)	Mean (ms)	SD (ms)
Stage 1	0.89	0.89	0.81	871	187
Stage 2	0.91	0.91	0.84	897	200
Stage 3	0.91	0.92	0.85	882	155
Stage 4	0.90	0.90	0.82	949	155
For the entire test	0.96	0.96	0.92	900	159

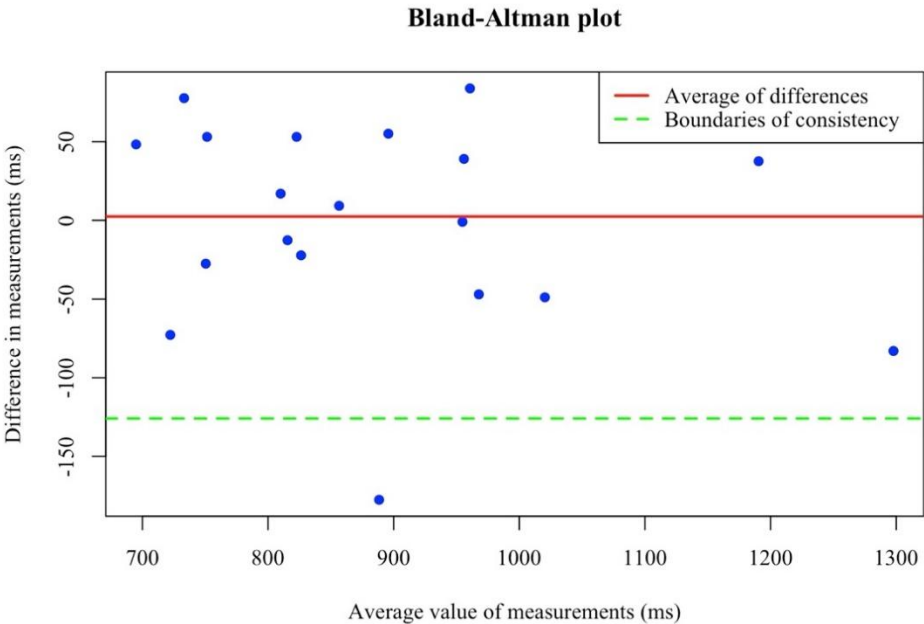


Figure 4. Assessment of Reaction Time Consistency Across the Entire Test for the First and Second Measurements.

A high α value of 0.96 was observed according to Cronbach’s alpha (Table 2). The analysis of the Bland-Altman plot (Figure 4) indicates that most of the values lie within the limits of agreement.

The results of the spatial perception assessment of martial artists in the second stage of the study are presented in Tables 3 and 4.

Table 3. Results of the Measurements of Martial Arts in the First Group (n=33).

Characteristics	The whole test	1st stage	2nd stage	3rd stage	4th stage
Mean (ms)	908.0	882.2	916.0	893.5	940.2
SD (ms)	149.4	160.8	183.0	150.8	173.9
1st Quarter (ms)	782.8	750.8	794.8	775.7	828.0
Median (ms)	875.6	847.3	853.1	862.8	925.1
3rd Quarter (ms)	995.9	1002.9	1008.2	994.7	1075.8
Errors (%)	9.6	8.6	9.2	8.0	12.4

Table 4. Results of the Measurements of Martial Arts in the Second Group (n=24).

Characteristics	The whole test	1st stage	2nd stage	3rd stage	4th stage
Mean (ms)	795.0	747.9	813.6	802.5	816.0
SD (ms)	94.6	123.0	128.0	88.5	99.2
1st Quarter (ms)	716.7	672.8	710.4	724.5	737.4
Median (ms)	779.5	711.4	801.5	792.2	777.6
3rd Quarter (ms)	877.0	782.7	910.4	881.9	909.1
Errors (%)	4.7	3.8	6.5	4.0	4.8

As previously noted, each stage of the test differs in the complexity of the impact of visual stimuli. To determine this effect, a comparison of reaction times across the test stages was conducted (Table 5).

Table 5. Differences in Reaction Time of Martial Arts Across Different Test Stages (Wilcoxon tests).

Stages	First group (n=33)	Second group (n=24)
S1 and S2	V=168, p=0.044	V=54, p=0.005
S2 and S3	V=343, p=0.271	V=173, p=0.527
S3 and S4	V=175, p= 0.060	V=101, p=0.169

The analysis of the differences in reaction time between martial artists at different stages of the test shows a statistically significant correlation only between the first and second stages (p<0.05).

Given that the athletes in the second group are older and have a higher qualification than those in the first group, a comparison of reaction time results between the two groups was conducted (Table 6).

Table 6. Differences in Reaction Time between Martial Arts of the Studied Groups.

Stages	First group (n=33)	Second group (n=24)	Mann-Whitney test
S1	882.2±160.8	747.9±123.0	W=604.5, p < 0.001
S2	916.0±183.0	813.6±128.0	W=519, p=0.047
S3	893.5±150.8	802.5±88.5	W=542, p=0.019
S4	940.2±173.9	816.0±99.2	W=572, p=0.004
The whole test	908.0±149.4	795.0±94.6	W=580, p=0.002

The differences in reaction time between qualified martial artists and beginner martial artists across all stages of the test exercise are statistically significant (p<0.05).

A correlation analysis of these relationships was conducted to determine the influence of the result shown at each stage of the test on the overall reaction time for the entire test. (Fig. 5).

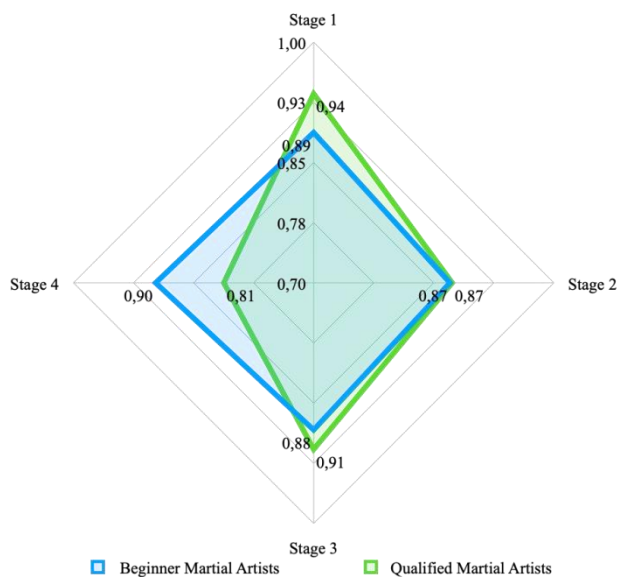


Figure 5. Relationship between the Result at Each Stage of the Test and the Overall Reaction Time for the Entire Test.

The results of the analysis of the relationships between reaction times at each stage of the test and the overall reaction time indicate that the final result of qualified martial artists is least influenced by the outcome shown at the fourth stage of the test, where visual stimuli that interfere are present (Fig. 5).

4. Discussion

This study aimed to develop and validate a method for assessing spatial perception in martial artists. Spatial perception refers to the ability to determine the position or direction of objects or points in space [34,35]. Various methods are available for assessing spatial perception, such as tasks where participants are asked to determine whether a rotated figure corresponds to a stimulus figure [36]. Similar computerized versions of such tasks have also been developed [37,38].

Visual characteristics of objects, such as color and shape, affect observers in different ways. Studies investigating the impact of visual information, specifically shape and color, on human attention have shown that figures with appealing or prominent attributes (bright colors, large sizes) tend to capture attention more effectively than those with less distinctive attributes. Colors can be effective in enhancing attention, while simple and clear shapes reduce cognitive load and improve object recognition speed [29,39].

The choice of simple 2D and 3D geometric shapes for the “Spatial Perception” application’s test tasks was motivated by the fact that these shapes possess distinctive, familiar features that allow for differentiation. The terrestrial environment consists of objects with clearly defined surfaces, textures, colors, and a variety of shapes. Given the properties of the everyday world, it can be assumed that humans develop similar visual systems, regardless of cultural context. Everyone probably sees in essentially the same way. Visualization represents a physical process that enables individuals, when detailed forms are not visible, to identify an object in three-dimensional space [29].

The first phase of the study focused on the validation of the developed application and the assessment of its reliability and measurement accuracy. According to recommendations [40], the second measurement of spatial perception in martial artists was conducted after three weeks (test-retest). A comparative analysis of the first and second measurements showed no statistically significant differences ($p>0.05$) between them and a strong correlation across all stages of the test ($r\geq0.70$) (Table 1). The high Cronbach’s alpha score ($\alpha=0.96$) (Table 2) for the reaction time over the entire test and the distribution of values on the Bland-Altman plot (Figure 4) indicate that most of

these values lie within the consistency range. Therefore, it can be concluded that the test for assessing spatial perception demonstrates sufficient reliability, which also suggests the possibility of reproducing test results over a set time.

Regarding the reliability and usability of the “Spatial Perception” application, the validation showed that athletes of varying ages and qualifications easily understand its working algorithm, and the “Demo test” mode allows users to practice the test task beforehand.

Determining the validity of any tests is a complex process that requires considering multiple factors. Kane [41] provides an overview of validity theory and argues that the focus of validation lies in the interpretation and use of test scores. The argument-based approach to validity can be simplified. It can be made more accessible to practitioners by removing the need to develop an argument for interpretation and use. The author believes that instead of requiring practitioners to provide complex reasoning, the validation process should be adapted to their needs and ensure the practical value of the test. Validity should be oriented toward practical benefit, not just formal justification. If test developers appropriately articulate the intended goals of test tasks, there is no need for an interpretative argument. Tests should be designed to accomplish one or more predetermined goals [42]. The test tasks in the “Spatial Perception” application for assessing spatial perception are clearly formulated. In Stage 1 – “quickly recognize 2D shapes,” and in Stages 2-4 – “quickly recognize 3D shapes.” Spatial abilities are essential for interpreting and understanding the geometric world [43]. Spatial skills include understanding the characteristics of two-dimensional and three-dimensional forms and recognizing the relationships between figures [44]. The test tasks provided in the “Spatial Perception” application indeed assess the ability to quickly recognize figures of different shapes in both two-dimensional and three-dimensional spaces, thus confirming the validity of the proposed methodology for evaluating spatial perception.

In the second phase of the study, the features of spatial perception in martial artists of different ages and qualifications were identified (Tables 3, 4). It is important to note that individuals employ different strategies for object recognition in space. In a study by Boucheix and Chevret [45], four main strategies were identified. The first two were categorized as imaginative strategies (mental rotation and perspective), while the other two were classified as analytical strategies. It was also noted that some participants may use a combination of strategies. Similarly, in martial arts, athletes use various strategies to recognize the movements of their opponents. Based on interviews with experienced athletes, it was observed that they typically focus on the center of the opponent’s chest and, through peripheral vision, detect changes in the position of the hands or legs. Peripheral vision plays a crucial role in martial arts [46]. Human perception requires more time to detect stimuli that are farther from the fixation point. The decline in peripheral vision function is explained by the physiological properties of the retina, as visual acuity rapidly decreases starting from 5° of the visual angle from the fixation point [47].

Research [1,2,48] has shown that athletes are not distinguished from non-athletes by visual function, but rather by visual “software,” meaning their ability to efficiently process and interpret visual information using various strategies acquired through practice. It was noted that during the test exercise presented by the application, more experienced martial artists focused on the center of the tablet screen. With this strategy, peripheral vision was sufficient to recognize simple shapes. However, when more complex visual stimuli were presented, athletes shifted their gaze to one of the shapes for more detailed recognition. Beginner martial artists, on the other hand, used a different strategy. They initially looked at one shape, then at another, and only after that, they decided on their response. The choice of one or another object recognition strategy in space is determined by the athlete’s perception level and the speed at which visual information is processed. Similar results were obtained previously [13].

The dynamics of reaction time changes in martial artists from the studied groups throughout the test show similar trends. The best reaction time was observed during the first stage of the test in both groups (reaction to 2D figures). This can be explained by the fact that recognizing simple two-dimensional shapes, which do not require additional cognitive effort, occurs faster than recognizing

static 3D figures. In the second stage of the test, a deterioration in reaction time was observed in both groups (reaction to static 3D figures), and this was statistically significant ($p < 0.05$) (Table 5). This can be explained by the fact that reacting to static 3D figures requires significant cognitive abilities, demanding more attention from the performer and the use of strategies to review each figure separately. In the third stage of the test, an improvement in reaction time was observed, but the differences were not statistically significant ($p > 0.05$) (Table 5). The reaction time at the third stage (rotation of 3D figures) was better than at the second stage (static 3D figures) in both groups. The rotation of 3D figures at this stage of the test provides visual information about the third dimension of three-dimensional space, namely depth, which provides additional information for recognition. The duration of rotation was chosen based on the duration of striking actions in martial artists as studied by Vences Brito et al. [19]. When an object moves, the brain receives more information about its geometry, improving the ability to quickly identify it when it stops. Research [17] shows that dynamic cues enhance perceptual integration, leading to more accurate object perception. Our findings confirm this statement. The reduction in the number of errors also indicates improved object recognition at this stage. The effect of additional visual stimuli for quick recognition of objects in three-dimensional space is also reflected in the sports duel, where it relates to the tactical informativeness of offensive or defensive actions. Any additional information regarding an opponent's potential tactical actions is a foundation for effective counterattacks. This has been confirmed in previous research [49].

At the fourth stage of the test, there are discrepancies in the dynamics of reaction time changes between the studied groups. This stage is characterized by the introduction of distracting visual stimuli (Figure 2). Such stimuli create additional false signals. The intensity of these signals was experimentally determined and set in the mobile application at $\alpha = 0.3$, which constitutes 30% of the original image. Increasing this parameter would impair object recognition capabilities while decreasing it would improve them. The results of our study, specifically the reaction time at the fourth stage of the test, where the visual stimuli that interfere are present, show that more experienced martial artists, who have more competitive experience, are less affected by these visual stimuli. This is also supported by the correlation analysis between the results at each stage of the test and the overall reaction time (Figure 5). Therefore, the final result for qualified martial artists is least influenced by the outcome shown at the fourth stage of the test, where distracting visual stimuli are present (Figure 5). This statement is also corroborated by the findings of previous studies [16,18].

In martial arts, particularly during training or competitive bouts, situations arise where the athlete must instantly determine many parameters regarding the circumstances. During the match, a skilled athlete simultaneously processes a lot of visual information, such as the color of the floor (wrestling mat, ring, dojang, or tatami), the color of protective gear, the opponent's position, and the positions of their individual body parts, among other things. All actions in the duel occur under the constant influence of distracting visual stimuli [50]. Naturally, athletes with more competitive experience possess a larger set of visual patterns and images, which can help form appropriate responses to situations that arise during the bout. According to the results of our research, the outcomes of qualified martial artists are statistically significantly ($p < 0.05$) better than those of beginner martial artists (Table 6).

The application allows users to select the texture under which the figures in the test will be presented. According to research [29,39] on color and shape perception, the mobile application "Spatial Perception" offers several textures for the test tasks. To increase the difficulty of the task, a complex, bright texture called "Color Abstraction" is available. This texture creates a high level of visual stimulation, which enhances attention and alertness. This figure presentation mode for assessing spatial perception is recommended for experienced athletes who are accustomed to intensive visual and physical loads. The "Chess Texture" provides moderate visual stimulation compared to the first, colorful texture. The presence of visual details helps maintain attention and stimulates the development of recognition skills under moderate distraction conditions. This mode can be recommended for athletes of medium qualification. The "Gray Wood" texture helps easily

recognize shapes, being the most homogeneous and neutral, with minimal distracting details, and does not overload with visual information. This mode is recommended for beginner athletes.

It can be concluded that using modern technologies, such as mobile devices (smartphones, tablets) with specialized software, allows for optimizing the process of data acquisition, storage, and analysis in scientific research [51,52].

5. Conclusions

This study developed and tested the mobile application “Spatial Perception” for assessing spatial perception in martial artists, and experimentally confirmed its reliability and validity. The study results indicate that prior rotation of objects provides additional information for their recognition. This reduces reaction time and the number of errors in selecting responses. The speed with which the athlete processes dynamic cues reflects their psychophysiological abilities, which can be crucial in competitive bouts. Adult martial artists with relevant competitive experience possess a greater repertoire of visual patterns and images, which can assist in forming adequate responses to situations that suddenly arise in a fight. Athletes of this level are able to maintain focus on the necessary object and are less affected by interfering visual stimuli. The results obtained may assist martial arts coaches in improving functional state control and adjusting training processes.

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