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Article

The impact of strobe visual training on the sports vision abilities of elite clay target shooters

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Abstract: Background: The act of clay target shooting is widely considered to be among the most challenging activities and visual abilities may serve as a limiting factor in shooting performance. Investigating the influence of Stobing visual training on the motor visual ability and special performance of elite clay target shooters. **Method:** The study involved 26 elite athletes from the Chinese national clay target shooting team (11 males, 15 females), divided into experimental group ($n = 13$) and control group ($n = 13$), subjected to eight weeks of general and specialized strobe visual training through experimental methods, utilizing Senaptec testing system to assess the athletes' motor visual ability, utilizing the result of two qualification races to assess the special performance, analyzing the impact of SVT on the motor visual ability and special performance of clay target shooters. Statistical analysis of the results was performed using Mann-Whitney U rank sum test, independent samples *t*-test, Wilcoxon signed-rank test, or paired samples *t*-test. **Results:** There was no statistical difference in any of the sports vision ability indicators between the experimental group and the control group before the intervention ($P > 0.05$). Post intervention, except for visual clarity, contrast sensitivity, and perception depth ($P > 0.05$), all other indicators and the result of special performance showed significant differences ($P < 0.05$). **Conclusion:** Long-term strobe visual training intervention resulted in improved perceptual and motor visual abilities in clay target shooters, displayed as enhanced indices in target capturing, reaction time, decision mechanisms, hand-eye coordination, distance switching, perceptual range, and multi-target tracking ability software indices combined with the special performance. However, the long-term intervention of strobe visual training didn't show notable improvement and promotion on visual system hardware indices.

Keywords: strobe visual training; clay target shooting; intermittent vision; motor perception

1. Introduction

The act of clay target shooting is widely considered to be among the most challenging activities in all of sports. The visual information processing speed of elite clay target athletes at the moment of release is close to the limit of the vestibular eye-tracking system, having only milliseconds to judge and decide on crucial visual information like the clay target [1] , In milliseconds, shooters must see and decipher a clay target, project its trajectory, decide when to hold the gun and coordinate the shotgun movement and timing of shooting to crush the target which the diameter is 110 mm (± 1 mm) the thickness is 25 mm to 26 mm far from athletes 15–20 m that can be moving up to 30 m/s. With such extreme demands placed on vision, it is natural to conclude that visual abilities may serve as a limiting factor in shooting performance.

Ramaja and Hansraj divide the sports vision index into two types: namely software and hardware indicators [2]. Sports vision is classified into hardware and software indicators. Basic visual capacities such as static visual acuity, depth perception, and other fundamental visual functions are hardware indicators that enable athletes to receive information from their environment. In contrast, software indicators encompass athletes' cognitive processes in processing and acting on visual information. These include information processing strategies, memory encoding, perceptual prediction, and decision-making critical skills for high-level performance [2]. A broader framework is provided by Welford's model of visual information processing, with an emphasis on profile within the integrated patterns of perception, decision-making, and action execution that are necessary for optimizing sports performance [3]. For example, Skeet shooters [1] has recently shown that visual, perceptual, and oculomotor skills also greatly affect shooting performance. However, previous research tends to study these skills in isolation without considering the unified ability for visual and cognitive functions in precision sports.

The Senaptec system (formerly the Nike SPARQ Perception Station) is one of the tools being used to evaluate these multifaceted visual and cognitive skills. The system assesses hardware and software aspects of vision and evaluates perception, decision-making, and action execution in athletes [4]. Yet despite its demonstrated capability in baseball [5], hockey [6] and softball [7], its use in precision sports such as clay pigeon shooting remains scarce. This gap is novel because it focuses on how SVT can improve multidimensional visual and cognitive skills in elite shooters, a context that previous studies have not adequately covered. Strobe Visual Training (SVT) is an intermittent visual disruption technique through eyewear that requires athletes to adapt their visual processing and cognitive flexibility in real time. This research has demonstrated that SWAT (special weapons and tactics) improves reaction times, anticipation, and perceptual performance of dynamic sports, such as American football [8], baseball [9], and most recently, hockey [10]. Although SVT has not been well explored in precision sports like clay pigeon shooting. Unlike other sports where rapid movement and reaction time dominate, clay pigeon shooting requires equally important, if not more important, visual and cognitive abilities of precise, high-pressure decision-making, timing, and shot execution [11].

The current literature largely explores training of specific visual abilities such as reaction time or tracking accuracy in static environments [12]. Nevertheless, these studies ignore the dynamic aspect of sight tasks in precision sports. Moreover, SVT has been demonstrated to enhance perceptual skills, but its effects on performance metrics, including shooting accuracy or decision-making speed at competitive events, are yet to be adequately addressed [4]. In particular, this gap is important in precision sports, where athletes must react to dynamic stimuli in high-stakes situations. To address this gap, the study investigates how SVT can enhance multidimensional visual abilities, including reaction time, tracking accuracy, depth perception, anticipation, and decision-making speed in elite clay pigeon shooters. Much of the existing research has treated these skills as isolated, but very few studies have integrated these skills into a medium that simulates real-world competition. Your study is unique in that you examine how improvements in visual processing and cognitive flexibility translate into on-field shooting performance, which is of value to both sports psychology and precision sports training.

Additionally, most previous work on visual training has been methodologically less rigorous, with many using small samples and pseudo-controlled designs. Addressing these concerns, your study uses a pre-registered, randomized, placebo-controlled design to enhance the reliability and validity of SVT transferability to real-world performance. By applying this methodological approach, the literature gains a more robust understanding of how multidimensional visual training improves shooting performance and cognitive control under pressure. This issue has not been sufficiently addressed in the literature. This study is grounded on models like Fitts' law and Perceptual Motor Learning Theory, which assume that precision sports require anticipation, decision-making, and motor control [13]. Combining these models into the way you design your study allows you to develop a more complete training framework that builds not only visual skills but also the cognitive processor needed to succeed at the elite level.

The purpose of this study is to comprehensively evaluate the effect of Strobe Visual Training (SVT) on both visual processing abilities and competitive shooting performance in elite clay pigeon shooters. In particular, the research examines whether SVT improves specific components of visual perception that are essential for precision in shooting, such as reaction time, tracking accuracy and decision-making speed. We hypothesize that SVT will have a significant positive effect on these visual and perceptual abilities, and as such, will translate into better shooting performance during real world competition. The study aims to provide insights into how targeting visual training can improve the cognitive and perceptual functions of athletes to give them a competitive edge in the sport.

2. Materials and methods

2.1. Subjects

Utilizing G*Power3.1 software (Dusseldorf, Germany) to pre-estimate the required sample size for the study, selecting the option "Means: Difference between two dependent means (matched pairs)" during estimation, with the values of power, α, and effect size set at 0.8, 0.05, and 0.8 respectively, based on the sample size selection design for high-level athletes as per [14,15] .Studies indicate that the effect size is sufficiently large to identify significant effects even in small samples [14,15]. After calculations, the minimum sample size was determined to be 15 individuals. To mitigate the impacts of certain dropout rates and other factors, a total of 26 individuals were recruited to satisfy the experimental requirements. All participants were free from injuries, sleep disorders, and did not smoke; they voluntarily participated in this study, signing an informed consent form after being briefed on the testing procedure and potential risks. A total of 26 elite national clay target shooting athletes participated in this study, comprising 11 males and 15 females, with ages ranging from 17 to 35 (24.18 ± 5.12), and none had previously undergone strobe visual training. Participants have been systematically engaged in shooting training for more than 5 years (9.96 ± 4.86). Among them, there are 12 national elite athletes, international elite athletes, 14 Trap athletes, and 12 skeet athletes. (see **Table 1**) Athletes were randomly assigned to the strobe visual experimental group and the control group, and independent samples rank sum test was used to statistically analyze the age and training years of the two groups. The results showed that there was no statistical significance in the difference of age and training years between the two groups ($P > 0.05$). Chi-square test was used for statistical analysis of gender distribution between the two groups, and the results showed that there was no statistical difference in gender distribution between the two groups ($P > 0.05$, **Table 1**).

Table 1. Basic information of subjects.

		Control group	Experimental group	Z/Chi-square value	*P*
Age		23.00(21.26)	21.00(20.31)	0.280	0.797
Gender	Female	6(46.15)	7(53.85)	0.150	0.695
	Male	7(53.85)	6(46.15)		
Training years		9.00(7.11)	9.00(6.15)	−0.150	0.897

2.1.1. Training protocol

In the same exercises, the control group performed the exercises under normal visual conditions while the experimental group wore Senaptec strobe glasses. Both groups outside the experiment followed the national team's regular training program (see **Figure 1**). The training was performed under stable indoor lighting conditions; the same trained professional was always involved in each session to guarantee consistency in the instruction and feedback [16,17] ruled out athletes who had conditions such as migraines or epilepsy that might interfere with strobe visual training. The SVT experimental group's training consisted of two weekly sessions: one general and one specialized. The general training sessions (27 min) improved basic visual skills such as reaction time, tracking, and visual attention. Drills included face-to-face drills, facing wall drills, and turn-and-catch exercises. These were designed to improve basic visual skills necessary for shooting accuracy and reaction time. The sessions were specialized (22 min) to mimic the perceptual demands of clay pigeon shooting. Simulated Firing Practice and Route Tracking were exercises designed to improve decision-making under pressure, tracking moving targets, and motor coordination. These specialized exercises carefully reproduced the real-world challenges of shooting and improved the athlete's capacity to make quick, accurate decisions in a time constraint [18].

As each athlete performed, the training became progressively harder. Athletes went from level 1, where they did basic reaction time and tracking exercises. Athletes made improvements, such as a 20% increase in reaction time, and as they moved to higher levels (level 2 or 3), which involved more complex tasks [19]. The direct approach meant that athletes were consistently pushed just far enough on their progress when ready. All sessions were run under identical conditions so as to ensure training consistency. Sessions were held in a distraction-free environment, and the same lighting was kept throughout. In both cases, the instruction and feedback were provided by the same trained professional in order to maintain consistency in the instruction and feedback [20]. The exercises used were also standardized, based on previously validated protocols [21], as exercises need to be done the same way every time. The exercises were designed to simulate the perceptual-cognitive tasks athletes perform in actual competitions in order to increase the ecological validity of the training. The tasks for gaze control and reaction time (Simulated Firing Practice) and tracking accuracy and decision time (Route Tracking) were designed. Ben Ali et al. replicated the visual and cognitive demands of clay pigeon shooting so that the training had real-world applicability [22]. Reaction time, tracking accuracy, and perceptual processing were measured using the Senaptec sensory training system [23]. For subsequent training sessions, we used this data to adjust the difficulty of each athlete's training to match their progress.

Figure 1. Stroboscopic training.

2.1.2. Testing protocol

The perception and sports vision abilities of athletes were assessed using the Senaptec sensory training station imported from the USA (see **Figure 2**), with a total of 10 indicators conducted in the order predefined by the system, namely visual clarity, contrast sensitivity, depth perception, near/far quickness, perception span, multiple object tracking, reaction time, target capture, eye-hand coordination, and go/no go decision mechanism. Among these, 5 indicators were tested using mobile devices, with one accompanied by a large screen display, while the rest necessitated the use of mobile devices alongside the Senaptec tablet display. Participants stood 3 meters away from the screen for testing, three tests were conducted at a distance of 60 cm from the screen using the tablet display, and 2 were conducted in conjunction with a large screen. This testing design was referenced from related studies [23,24], and the reliability and validity of the evaluation system have been checked [25]. Upon completion of each test, the system automatically provides a score and generates a structural radar chart depicting the athlete's perceptual and sports vision abilities.

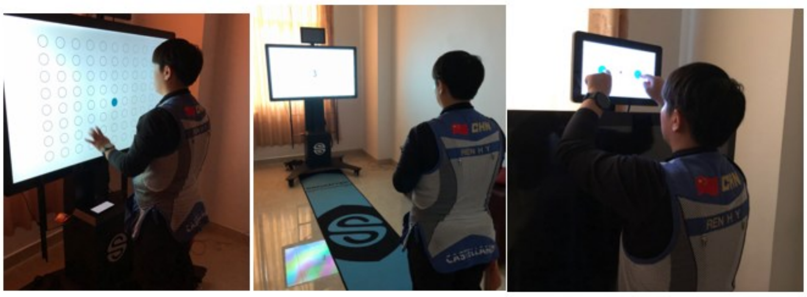


Figure 2. Motor visual test.

2.1.3. Testing procedure and schedule

(1) Sports vision test

The testing schedule is based on the research design of spots vision test [26], with a pre-test conducted before grouping, and a basic information survey administered to participants before testing to ensure their good health and normal participation in the experiment. Through self-set questions in the testing system, it's ensured that athletes do not have migraines, epilepsy, or other neurological diseases, mitigating testing risks. Participants are required to ensure at least 8 h of sleep one day before each test, avoid alcohol and nicotine intake 24 hours before testing, and avoid caffeine intake 12 hours before commencement. On the testing day (especially 3 h before the test), participants should avoid activities like gaming that may induce visual fatigue (**see Tables 2** and **3**). Before each test is officially carried out, athletes watch a demonstration of the test content, followed by a set of practice trials to ensure they are familiar with the testing process and basic requirements. The entire testing process requires a total of 30 min to complete all ten indicators. Athletes' first testing is scheduled for the day before training begins and, on the day, following the last training session of the eight-week training period. To minimize the impact of human biorhythms, the same participant should complete each testing session at approximately the same time (with a deviation of 1 h or less) [26]. Detailed testing information is provided in the table below.

Table 2. Basic training program.

Duration (min)	Training Name	Training content
1	Warm-up exercise	Stroboscopic glasses are stuck on the players' heads or hung around their necks for face-to-face catching-adaptation exercises
10	Face to face catch practice	The strobe glasses start at level1, when the player can catch the ball 5 times in a row, the difficulty is increased, and the strobe level is increased to the highest level
5	Variable speed catch against the wall	The player faces away from the experimenter and faces the wall. The experimenter throws the ball against the wall and the subject catches the ball that bounces off the wall. Starting at level2, the strobe glasses can increase the strobe level to the highest difficulty after the player catches the ball 5 times in a row
5	Turn and catch drills	The player faces away from the experimenter, and when the experimenter throws the ball by Shouting "take", the subject turns to face the experimenter and catches the ball
5	Face to face catch practice	Adjust the strobe glasses level to the highest difficulty and repeat the second item
1	Cooling down exercise	Subjects also practiced face-to-face catching with stroboscopic glasses draped around their necks or on their heads

Table 3. Specific training programs.

Duration (min)	Training Name	Training content
1	Voluntary-hold gun	The strobe glasses are stuck on the athlete's head or hung around the neck, and the athlete performs Voluntary-hold gun exercises
10	Voluntary-hold gun with strobe glasses	Strobe glasses start at level1, and athletes also practice Voluntary-hold gun to adapt.
5	Tracking the line of Infrared ray	Infrared ray is placed in the athlete's gun barrel, the subject faces the target paper with the rice symbol, carries out line tracking control, and continuously accelerates the speed. The stroboscopic level is level1, and the difficulty level is increased after each tracking
5	Tracking simulated the trajectory of the target	The experimental personnel held an infrared device, faced the wall, and simulated the trajectory of the target flight. The athletes quickly responded and simulated the line tracking. The stroboscopic level was set at Level 1, and the difficulty level was increased according to the performance of the athletes
1	Cooling down exercise	The strobe glasses are stuck on the athlete's head or hung around the neck, and the athlete also repeats the Voluntary-hold gun exercise

(2) Special performance test

In order to further explore the impact of stroboscopic training on athletes' sports performance, this study conducted a statistical analysis of the results of Chinese national clay target shooters in the Fujian Putian Province World Cup qualifiers before and after visual training. The environment of the special performance test is the same, and the athletes who want to qualify for the World Cup also have enough motivation to participate in the special test, which can fully reflect the change of their skill level.

2.1.4. Explanation of visual testing indicators

Categorizes sports vision functions into two types of indicators: software and hardware [9]. The first type, hardware indicators, mainly focuses on the reception level of visual information (See **Tables 4** and **5**). Influenced by the ocular features of the athlete's visual system, the hardware includes basic indicators for evaluating sports vision abilities like static visual acuity and depth perception. The second type, software indicators, mainly concern the processing level of visual information. These indicators are influenced by the athlete's experience and strategies. The software aspects of the visual system include information processing strategies, memory encoding and retrieval, perceptual information extraction, and anticipation, which are primarily utilized for processing incoming information [9]. The Senaptec system-related indicators utilized in this paper are classified and elucidated based on this theoretical foundation, as shown in the table below.

Table 4. Description of motor visual test indicators.

Indicator classification	Indicator	Test content	Purpose
Hardware indicators for receiving visual information	Visual clarity	The task tests visual acuity to detail at a certain distance	Reflect the static visual acuity of athletes
	Contrast sensitivity	Measure the minimum resolvable difference in contrast at a given distance	It reflects the ability of visual system of athletes to process related objects and their background space under different brightness conditions
	Depth perception	To assess the speed and accuracy with which subjects can detect depth differences at a distance while using LCD glasses	It reflects the ability of athletes to quickly and accurately judge the distance and spatial position of objects in front of them

Table 4. (*Continued*).

Indicator classification	Indicator	Test content	Purpose
Software indicators for processing visual information	near/far quickness	Test the number of near and far targets that can be correctly judged in the 30 s	The adaptive convergence function, which is the ability to switch sight and focus between far and near, is assessed on the athlete's visual ability
	perception span	Measures the subjects' ability to remember and reconstruct visual patterns	The athlete's visual perception recognition ability is assessed using a dual field of view to measure object recognition, speed, and span
	multiple object tracking	Measure the subject's ability to follow multiple moving objects simultaneously	Reflect the ability of selective attention, distributive attention, continuous attention
	reaction time	Measure the time it takes the subjects to respond to a simple stimulus signal	The simple response time test reflects the athletes' response and response speed to simple visual stimuli
	target capture	The speed at which subjects switched attention and recognized peripheral visual field targets was measured	Reflects the athlete's ability to visual jump tracking
	eye hand coordination	Measure the hand speed of the subject's response to a rapidly changing target through visual orientation	On the basis of acquiring visual information, it processes and integrates visual information to guide and control the body to make actions quickly, coherently and accurately, reflecting the coordination ability of the visual system and the action execution system
	Go/No Go	Measure the level of performing and inhibiting visual orientation and making hand responses under "Go" and "No-Go" stimuli	It reflects the control ability and cognitive flexibility of the athletes to inhibit their own reaction on the basis of finding the target quickly and accurately

Table 5. Detailed description of motor visual test.

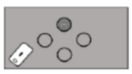
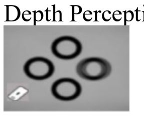
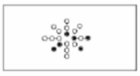
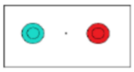
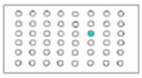
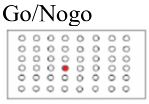
Test indicator	position and location	Specific requirements	Scoring standard
Visual clarity 	Subjects held mobile phones and stood 3 m away from tablet computers	Athletes need to judge the notch direction of the C-shaped pattern on the flat screen and slide in the corresponding direction on the mobile side. The athletes' vision was tested first in both left and right eyes, and then in both eyes.	The more accurate the judgment, the smaller the figure. The unit of the test indicator is LogMAR. The smaller the absolute value, the better
Contrast sensitivity 		Four black circles will appear on the plate, among which concentric circles of different depths will appear inside a circle in a random direction, and the subject will slide to the corresponding direction on the mobile end after finding out.	As the accuracy increases, the contrast within the concentric circles will become less and less obvious. The unit of the test indicator is LogCS. The higher the better
Depth Perception 		Four black circles appear on the screen, and a random one has a sense of stereo vision. The athlete needs to find the circle and slide in the corresponding direction on the mobile end. The athletes were tested first with both eyes, then with their right and left eyes.	With the increase of accuracy, the contrast and three-dimensional sense of the target circle will become less and less obvious. The unit of the test indicator is arcsec. The smaller the better.
Near/far quickness 		During the test, the senaptec flat panel display (remote end) and mobile end (near end) will alternately appear a C-word pattern, and the athlete will switch focus between the remote end and the near end to determine the notch direction within 30 s, and quickly slide to the corresponding direction on the mobile end.	The faster the judgment speed, the more accurate the direction, the better. The evaluation index includes the number of judgments within 30 s, the higher the better

Table 5. (*Continued*).

Test indicator	position and location	Specific requirements	Scoring standard
Perception span 	The athlete stands 60 cm away from the tablet, the eyes level with the center of the screen.	A certain number of circles radiating outward from the center appear on the screen, and some circles will quickly flash black dots in the center, and athletes need to find the circle where the black dots are located.	The number of circles and black dots will continue to increase, the range will continue to expand, and the score is based on the cumulative number of correct judgments, the higher the better.
multi-objects tracking 		After starting the test, several groups of balls appeared on the screen, and each group consisted of two black balls. One of the balls turned red and immediately turned back to black, and then began to rotate continuously in a random clockwise or counterclockwise direction. After stopping the rotation, the subjects were required to find the first red ball in each group.	Evaluation indicators include the number of correctly tracked (number), speed (deg/sec), the higher the better
Reaction time 		The subjects first chose their dominant hand. The screen will first appear two circles, touch the center of the circle with both index fingers, the circle will turn green. Then the two circles randomly turn red and need to quickly raise the corresponding index finger and then put it down.	The test index is the average reaction time of both hands, the unit is ms, and the faster the action speed, the better
target capture 	Subjects held mobile phones and stood 3 m away from tablet computers	Subjects focus on the center point of the large screen, and then a C-word pattern will suddenly appear at random in eight corners of the large screen. Subjects judge the notch direction and draw the corresponding direction on the mobile end.	The unit of the test indicator is ms, and the faster the better
eye-hand coordination 	The athletes stand 60 cm away from the large screen, the center line of the large screen is at arms level or slightly higher.	On the large display screen, 8 rows and 10 rows of hollow rings appear. In the test, one of the rings will randomly turn blue green, and another will appear in a random position after the subject clicks. Ask for more clicks as quickly and accurately as possible within the specified time.	The test indexes include the overall time, average reaction time, central region reaction time and peripheral region reaction time, and the unit is ms, the smaller the better
Go/Nogo 		Eight rows of circles will appear on the big screen with the same eye-hand coordination, and green or red dots will appear randomly on the above. Green dots will appear, and athletes need to touch them quickly; red dots will appear, and athletes should not touch them.	The higher the score for correct clicks, the better.

2.2. Data analysis

The obtained data was analyzed statistically using SPSS 20.0 software. The differences in each indicator before and after training for the participants were calculated, followed by a normal distribution test using the Shapiro-Wilk method and histogram test. For data conforming or approximating to a normal distribution and passing the variance homogeneity test, a paired-sample *t*-test is used, while the Wilcoxon signed-rank test is used for data not conforming. The analysis of between-group differences for the experimental and control groups is conducted by initially subjecting the data to normal distribution testing and variance homogeneity testing. The Mann-Whitney U test method is utilized when the data doesn't conform to normal distribution, and the independent-sample *t*-test is employed when the data conforms to both normal distribution and variance homogeneity.

3. Results

3.1. Between-group comparison results of experimental and control groups

Statistical analysis on various indicators before and after intervention for the control and experimental groups was performed using independent sample *t*-tests and independent sample rank sum tests. The results indicate no statistically significant differences in all indicators between the two groups before the intervention ($P > 0.05$). Post-intervention, statistically significant differences were observed between the experimental group and control group in specialized scores, near/far quickness scores, target capture speed, number of correct judgments in perception span, maximum number in multiple object tracking, highest speed in multiple object tracking, average reaction time in eye-hand coordination, central reaction time in eye-hand coordination, peripheral reaction time in eye-hand coordination, correct click scores in decision-making mechanism, and average value of simple reaction time ($P < 0.05$). Detailed results are shown in **Table 6**.

Table 6. The pro and post-test indicators of experimental group and control group.

		Control group (*N* = 13)	Experiment group (*N* = 13)	t/Z	*P*
The special performance (Target number)	pretest	114.00 ± 5.51	114.62 ± 5.66	−0.270	0.790
	posttest	112.00 ± 4.80	118.23 ± 3.93**	−3.479	0.002
Visual clarity (LogMAR)	pretest	−0.07(−0.07,0.03)	−0.07(−0.19,0.03)	0.560	0.577
	posttest	−0.07(−0.19, −0.07)	−0.07(−0.19, −0.07)	−0.210	0.851
Contrast sensitivity (LogCS)	pretest	2.20(1.90,2.20)	2.20(1.80,2.20)	0.150	0.889
	posttest	2.20(2.00,2.20)	2.20(1.90,2.20)	−0.130	0.904
Depth perception (arcsec)	pretest	41.00(31.00,240.00)	104.00(41.00,240.00)	−0.560	0.581
	posttest	41.00(20.00,72.00)	72.00(41.00,104.00)	−1.460	0.143
Near/far quickness (Score)	pretest	24.77 ± 5.56	23.92 ± 6.38	0.350	0.732
	posttest	28.69 ± 7.15*	40.77 ± 6.20***	−4.420	<0.001
Target capture (ms)	pretest	225.00(200.00,250.00)	200.00(175.00,250.00)	1.100	0.273
	posttest	200.00(275.00,212.50) *	126.00(100.00,161.00) **	4.590	<0.001
Correct judgments in perception span (Number)	pretest	49.00(34.00,56.00)	47.00(46.00,56.00)	−0.440	0.680
	posttest	48.00(34.00,59.00)	70.00（65.00,78.00）**	−6.270	<0.001
Maximum number in multiple object tracking (Number)	pretest	5.00(5.00,5.00)	4.00(4.00,6.00)	0.850	0.380
	posttest	5.00(5.00,5.00)	8.00(8.00,9.00) **	−4.230	<0.001
Highest speed in multiple object tracking (deg/sec)	pretest	503.69 ± 84.98	455.69 ± 155.96	0.940	0.358
	posttest	524.92 ± 94.01	658.92 ± 123.98***	−2.980	0.006
Average reaction time in eye−hand coordination (ms)	pretest	594.61 ± 42.36	604.77 ± 46.02	−0.560	0.579
	posttest	510.15 ± 36.89***	450.33 ± 33.12***	4.180	<0.001
Central reaction time in eye−hand coordination: (ms)	pretest	532.10 ± 48.00	553.62 ± 45.55	−1.130	0.271
	posttest	457.72 ± 35.95***	389.35 ± 34.68***	4.740	<0.001
Peripheral reaction time in eye−hand coordination (ms)	pretest	621.40 ± 41.29	626.69 ± 48.00	−0.290	0.775
	posttest	496.90 ± 39.95***	372.17 ± 34.33***	8.200	<0.001

Table 6. (*Continued*).

		Control group (N = 13)	Experiment group (N = 13)	t/Z	P
Correct click scores in Go/nogo (Number)	pretest	8.38 ± 5.47	5.08 ± 4.38	1.640	0.115
	posttest	12.23 ± 7.28*	17.77 ± 4.26***	−2.270	0.032
Reaction time (ms)	pretest	313.46 ± 26.78	310.77 ± 28.15	0.240	0.812
	posttest	237.77 ± 19.54***	133.00 ± 24.70***	11.520	<0.001

Note: *: The difference was statistically significant compared with pretest ($P < 0.05$); **: ($P < 0.01$); ***: ($P < 0.001$).

Physiological and psychological mechanisms can explain the significant improvements seen in the experimental group on different indicators, including reaction time, tracking speed decision-making, and decision-making accuracy. These improvements are largely due to neuroplasticity for near/far quickness and target capture speed. The more efficient pathways are due to this physiological process that occurs more efficiently. The SVT intervention likely increased the brain's capacity to process visual stimuli quickly and incorporate this stimulus with motor response, leading to faster reaction times and improved eye-hand coordination [27]. Furthermore, changes in the visual stimulus intermittently imposed by SVT perhaps trained athletes to cope with those, enhancing their visual attention and attention Focus on tasks such as tracking moving objects and target capture. From a psychological perspective, SVT likely enhanced cognitive control and mental flexibility. The ability to make these cognitive improvements helped athletes make faster decisions and adjust quicker to changing stimuli, as shown in the significant improvements in decision-making and perception span tasks. Sustaining attention and quick change of focus between multiple targets likely mediated the obtained improvements in multiple objects tracking and reaction time [26].

However, not all indicators improved significantly. As such, the complexity of these visual tasks prevented tasks such as depth perception and contrast sensitivity from changing. For example, depth perception involves spatial processing that requires the brain to interpret three-dimensional visual information that SVT might not have sufficiently targeted. SVT mainly encompasses the control of reaction speed and dynamic visual controls, whereas these tasks differ on static visual cues and also use different cognitive processes. Like SVT, contrast sensitivity requires specialized training beyond what SVT provides [28].

3.2. Within-group comparison results for experimental group and control group

The changes in each indicator before and after intervention for both groups were statistically analyzed using paired-sample *t*-tests and paired-sample rank sum tests. The results indicate that, in the control group, the differences in scores for near/far quickness, target capture speed, average reaction time in eye-hand coordination, central reaction time in eye-hand coordination, peripheral reaction time in eye-hand coordination, correct click scores in decision-making mechanism, and average value of simple reaction time were statistically significant ($P < 0.05$) before and after the intervention. Similarly, in the experimental group, the differences in specialized scores, scores for near/far quickness, target capture speed, number of correct judgments in perception span, maximum number in multiple object tracking, highest speed in multiple object tracking, average reaction time in eye-hand coordination, central reaction time in eye-hand coordination, peripheral reaction time in eye-hand coordination, correct click scores in decision-making mechanism, and average value of simple reaction time were statistically significant ($P < 0.05$) before and after the intervention. The detailed results are shown in **Figures 3–7** below.

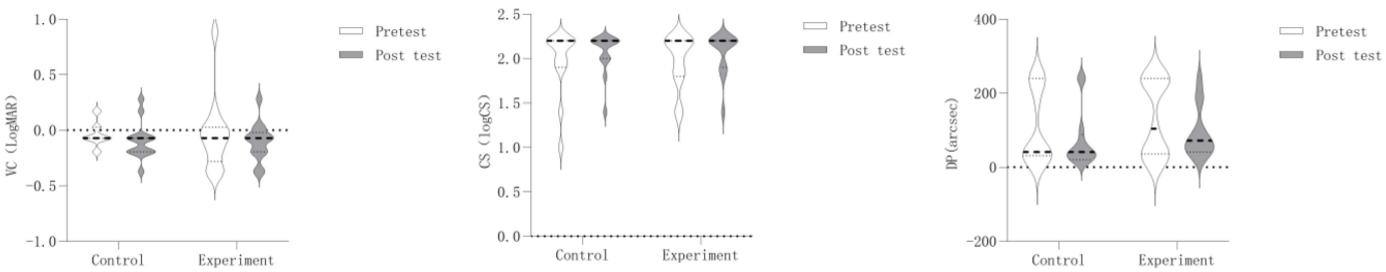


Figure 3. The effect of stroboscopic training on motor visual system hardware indicators.

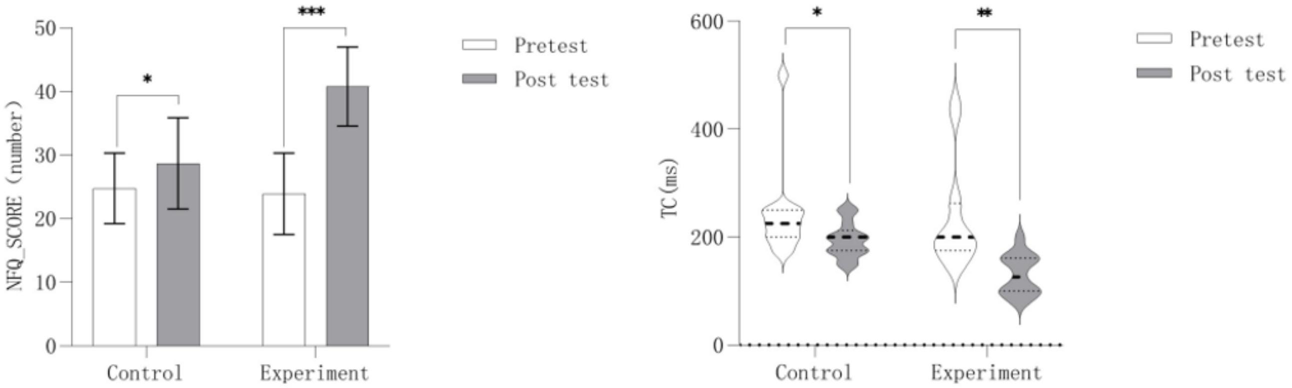


Figure 4. The effect of stroboscopic training on near/far quickness and target capture.

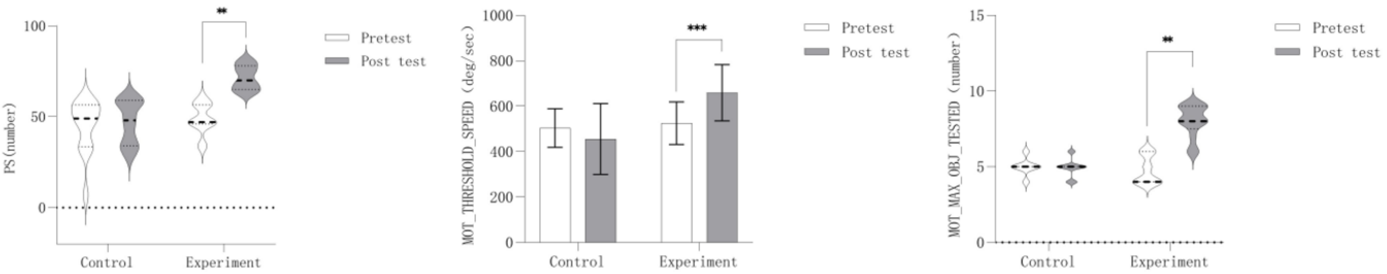


Figure 5. The effect of stroboscopic training on perception span and multiple object tracking.

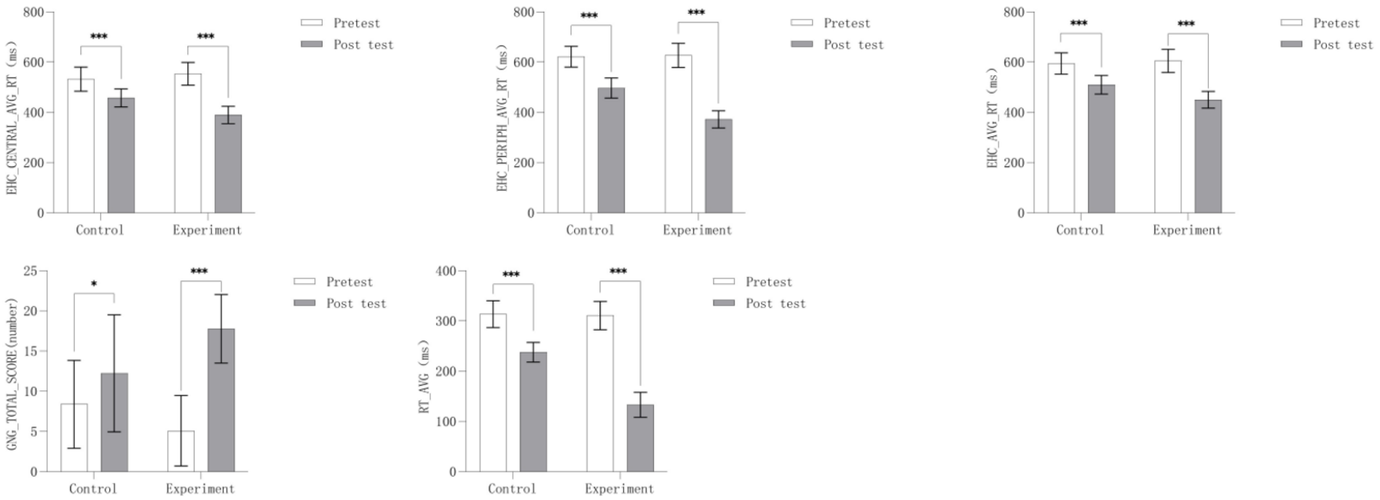


Figure 6. The effect of stroboscopic training on reaction time eye hand coordination and go/no go.

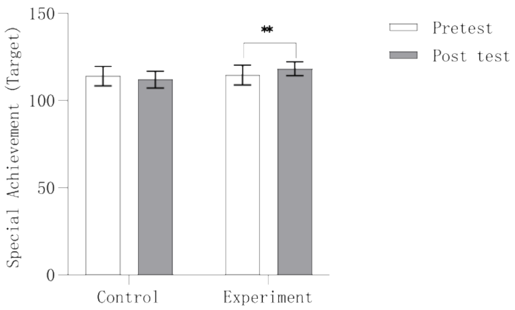


Figure 7. The effect of stroboscopic training on special achievement.

In addition, the within group improvements observed in the experimental group confirm the existence of the SVT as an effective therapy to improve visual processing and cognitive functions. They can be largely attributed to both physiological adaptation and the psychological enhancement that accompany the SVT intervention. SVT did improve the ability of athletes to perform basic visual processing as well as cognitive flexibility and mental focus in complex tasks like multiple object tracking, decision making and reaction time and the athletes in the experimental group had greater gains in these tasks than the control group.

It's likely that neural adaptations enabled athletes to respond more efficiently to dynamic visual cues, and that these improvements in reaction time and eye hand coordination are most likely the results of these neural adaptations. Repeated exposure to strobe disruptions likely made neural efficiency greater in visual and motor systems, allowing for faster, more accurate visual motor coordination. The physiological change was supplemented with psychological enhancement of visual attention and cognitive control, which allowed athletes to make faster decisions and perform better at tasks requiring switching of attention and processing of multiple stimuli at the same time quickly [29]. On the other hand, the control group gained but less, and in less, like simple reaction time. On the other hand, the experimental group showed greater gains in tasks involving more complex cognitive processing, including decision-making and multiple object tracking, indicating that SVT training was specifically directed at areas of visual processing and cognitive control not sufficiently trained by natural training alone.

4. Discussion

The objective of this study is to investigate if the benefits of SVT (Strobe Visual Training) intervention can be transferred to untrained testing tasks and exceptional performance among elite clay target shooting athletes, manifesting measurable changes. Prior research affirmed the efficacy of SVT in improving dynamic visual acuity, attention, short-term memory, time prediction ability, and other general perceptual skills, along with eye-hand coordination, motor skill acquisition, and enhancement in athletic performance. The findings of this study also demonstrate that, following long-term SVT intervention, apart from the three primary visual ability hardware indices of visual clarity, contrast sensitivity, and depth perception, the other 7 categories of visual system software indices combined with the results of Qualifying race exhibited statistically significant differences in the experimental group of clay target shooting athletes.

4.1. Clinical applications of stroboscopic vision training (SVT)

This study's findings show that Stroboscopic Visual Training (SVT) has the potential to be a means for sports injury prevention and rehabilitation, especially in high-speed sports such as clay target shooting. SVT improves visual motor coordination and thus promotes more accurate anticipation and reaction to rapidly changing visual stimuli that reduce the risk of injuries from delayed reaction times, poor decision making reduces risk of injuries from delayed reaction times, poor decision-making, or failure to get out of the way [30]. SVT helps improve dynamic visual acuity and reaction speed, giving athletes a faster response to mitigate risk during competitive performance.

SVT complements traditional injury prevention methods in sports biomechanics by improving visual-motor integration. Athletes who are better able to see and react to visual cues are less likely to misjudge distances and less likely to collide or fall [31]. That's particularly helpful for fast-paced sports, like baseball or soccer, where quick visual responses are needed. In addition to prevention, SVT may help rehabilitate athletes recovering from injuries. It is able to help restore reaction time, motor coordination, and decision-making [32]. Furthermore, SVT enhances neuroplasticity, enhancing recovery and increasing the likelihood of a quicker, safer return to sport, which is particularly important for athletic injury recovery from neurological or physical causes [33].

4.2. Limitations of the study

While this study presents some important information concerning the effect of SVT on visual abilities and performance in sport, it has limited to important limitations which must be considered when interpreting the results. A small sample size of 13 participants per group is a limiting factor to the generalizability of the findings. Type II errors: true effects are not detected because a small sample increases the risk. A clearer understanding of how SVT effects athletes from diverse sports and skill levels would be had with larger and more diverse samples. A further limitation is that the static visual abilities improved such as depth perception and contrast sensitivity were not shown to be significantly improved within the eight weeks of training. In visual processing, perhaps 12–16 weeks of intervention can yield more substantial improvement and neuroplastic change. Finally, the results may have been affected by a host of external factors such as prior experience of athletes with SVT, different levels of motivation, and inconsistent testing conditions. Future studies should control for these variables, in order to find more reliable findings.

4.3. Impact of strobe training on hardware indicators of the visual system

The results of the study indicate that the indices for visual clarity, contrast sensitivity, and depth perception did not exhibit significant differences post-intervention. These three categories of indices are part of the hardware metrics used by the visual system for receiving visual information, with visual clarity primarily representing the athlete's static visual acuity. Adequate static visual ability is a prerequisite for normal visual information acquisition; if static visual acuity is compromised, it will demand more effort from clay target athletes in acquiring visual information, affecting the speed of on-field visual information acquisition and further processing [28]. The anatomical and physiological foundations of static vision render it unamenable to voluntary control; hence, these indices cannot be enhanced through eye muscle training and brain processing of visual signals training, although some necessary corrective measures can be adopted [34]. The assessment of contrast sensitivity evaluates an athlete's visual system's capability to process objects and their spatial background under varying brightness conditions. Contrast sensitivity is also categorized under static vision [35], and its level correlates with visual clarity. Athletes with better contrast sensitivity can see visual targets "clearly" and "accurately," effectively acquiring the necessary visual information and avoiding spending unnecessary energy on distinguishing targets. During competitions, if the background on the field is uncertain, the inability to swiftly clay target the clay target from other interfering backgrounds would affect the clay target athletes' visual information judgment. Besides, since clay target shooting is an outdoor sport, in some scenarios, light conditions change drastically, like during competitions in strong daylight or when shadows are present on the field; athletes' pupils continuously adjust to control light entry while switching different positions. However, the muscles controlling the pupil's light reception, the iris sphincter muscle, and the iris dilator muscle are not under voluntary control, making it difficult to improve this indicator through training, even with sports vision training [34] .The index of depth perception is capable of assessing an individual's binocular judgment of depth and object distance information accuracy, reflecting the athlete's ability to swiftly and accurately judge the distance and spatial relationship of objects in sight [35]. The depth perception assessment of clay target shooting athletes can display their spatial and stereoscopic sense in object identification, particularly when the weather and target field environment change, necessitating athletes to utilize this ability for rapid differentiation and positioning of the clay target targets in flight. However, since the visual perceptual ability of athletes in the experiment was not subjected to systematic, targeted training, studies on strobe interventions have not reported any promotion in-depth perception. This study's results likewise did not manifest a significant enhancement in the athletes' depth perception indices.

4.4. Effects of stroboscopic training on metrics of visual system software

4.4.1. Near/far quickness and target capture

Near/Far Quickness evaluates the athlete's dynamic visual accommodation and convergence capability, specifically the ability to transition the gaze and focal point within the central visual field between far and distant objects. The target capture test mainly reflects the visual sensitivity to the emergence of sudden targets beyond the central visual zone. Both are indicators for Dynamic Visual Acuity (DVA) testing, demonstrating the athlete's ocular muscle coordination and the efficacy of ocular motility. The onset delay of saccadic eye movements in responding to rapidly moving targets is one of the critical factors impacting the outcomes of DVA assessment [36]. During the process of clay shooting, a dynamic reaction is a cucial element; as the flight path of the targets varies in training, athletes must swiftly observe and gather visual information at varying distances, calling for quick adaptability in accommodative convergence. Clay targets are released at speeds that randomly vary within 0–3 s, with an initial speed of up to 25 m/s. The flight of the target might deviate after aiming at the target zone. When the clay target exits the center of the visual field, the athlete must promptly react to the moving target based on dynamic visual sharpness in unpredictable locations and different temporal circumstances [1]. Research indicates that stroboscopic eyewear, serving as a useful instrument to enhance dynamic vision [37], can improve dynamic visual sensitivity and velocity, and facilitate the development of central foveal vision or movements necessitating swift impulses within the central visual region [38]. Furthermore, Stroboscopic Vision Training (SVT) interventions enhance the effective integration of information over time, yielding a perceptual edge once normal vision resume [39]. A wealth of past studies has clay target overed the temporal dependence of visual integration, encompassing the propagation time of light [40], detection and pursuit of moving entities and eye movements during scanning processes [41], all closely linked to the athletic setting and impacted by the intermittent visual conditions generated by SVT. The fluctuation between transparency and opacity by stroboscopic glasses imposes temporal limitations on visual information, compelling athletes to more efficiently process the restricted information. Diminished sensory information input, coupled with heightened task complexity, also prompts an increased focus of external attention on the primary task. Numerous studies have found that in sports performance and learning, external attention surpasses internal attention, particularly for intermediate and elite athletes [42].

4.4.2. Perception span and multiple object tracking

Perceptual span metric tests principally assess an athlete's capability to gauge and recognize the velocity and breadth of objects using binocular vision. This assesses the capacity of clay target shooters to retain the seen targets and their spatial information within a given range during competition and to recreate the corresponding visual data in their minds, essentially the ability to remember and reproduce visual patterns. Multiple object tracking assesses an athlete's capability to concurrently follow multiple moving targets, akin to the perceptual span. This demands significant cognitive memory and visual information processing capacity. The test further scrutinizes the athlete's stamina in cerebral information processing. Classified both metrics under the evaluation modes during the transformation phase of the visual information processing model [43]. In clay target shooting, appropriate positioning and capturing of the clay targets within a specific visual area are necessary. Elite clay shooters demonstrate active target engagement, expansive visual fields, extensive tracking ranges, and logical ocular movement configurations. Additionally, the extended duration of competitions can significantly drain an athlete's energy, necessitating consistent focus on the target under fatigue, and striving for the consistency of sighting precision and quality across 100 shots as if each were one [44]. Based on the findings of this study, perceptual span can be enhanced via stroboscopic training. SVT has bolstered the athlete's capacity for judicious allocation of attention while observing, enabling selective attention to critical visual information to the greatest extent during multitask visual information processing, hence leading to noteworthy alterations in such metrics. Furthermore, when SVT disrupts the standard visual information flow and feedback, the human body compensates for the continuous visual information shortage by preferentially storing external data in visual memory to aid perception and/or motor control [45] research on SVT intervention indicated that the experimental group exhibited an enhanced short-term memory compared to the control group, with this effect persisting for at least 24 h post-training [46]. By learning to utilize peripheral vision to its fullest while maintaining central vision, athletes can attend to diverse scattered targets within an extensive visual range, form transient spatial memories, translate them back into the brain as visual images, and thus considerably boost such indicators. Smith and Mitroff conducted immediate [4], 10-minute, and 10-day follow-up assessments after a brief 5–7 min acute SVT intervention and discovered no enhancement in the experimental group's memory abilities [46]. Similar to the study by Appelbaum, this research utilized a long-term intervention approach for SVT. From this, it can be inferred that the duration of the intervention is also an important factor affecting the effectiveness of SVT [4].

4.4.3. Reaction time, hand-eye coordination, and Go/No go

Reaction time were regarded as classical measures of the efficiency and efficacy of an individual's motor skill performance [47]. The study employs simple reaction time as the visual-motor response time (VMRT), which is the sum of the reaction and action times. Athletes' response times to simple stimulus signals correlate with their central visual field reaction times [1]. Hand-eye coordination indices extend beyond simple reaction times, showing the athlete's capability to process visual information upon receipt and direct controlled, fluid body movements with precision. The assessment of decision-making mechanisms complicates the presentation of visual stimuli, requiring athletes to clay target and select appropriate actions in response to the evolving visual cues during their response process. All three measures are part of the evaluative domain for the effects of visual information processing mechanisms [1]. In the sport of clay target shooting, the flight and firing at the targets are actions completed instantaneously, with the targets moving at high speed. The immediate response to the visual stimulus upon the target's release becomes a key determinant of success. The core skill in clay target shooting is the swift, precise, and consistent coordination of "seeing and catching the target" [48]. Athletes are frequently required to react and move within very brief periods and under sensory limitations, necessitating high levels of eye-hand response and coordination for rapid-fire targeting training. Furthermore, the dynamic complexity of clay target shooting competitions necessitates indispensable decision-making skills, such as controlling one's "subconscious" reactions to interrupt the gun-raising action when fragments from adjacent ranges fly towards them.

From a deeper perspective, the faster visual-motor response after stroboscopic training is related to the arousal of N2 potential by stroboscopic visual stimuli, and a reduction in N2 latency [49]. N2 reflects the perception and processing speed of visual-motor sensitivity in the MT area [3]. Related research using electroencephalogram (EEG) monitoring found that under stroboscopic conditions, the neural activity of the visual-motor system was significantly delayed and weakened, with prolonged N2 latency and reduced amplitude of visual evoked potentials, leading to a significant decrease in visual-motor response time. During the intervention with Stroboscopic Vision Training (SVT), the stroboscopic glasses continuously operate in a flashing state, inducing activation of the primary visual cortex (V1) before the stimulus, which affects the neural activation related to the appearance of the stimulus, interfering with normal visual-motor perception. At the same time, the rapid switching of the brightness of the glasses may induce strong brightness contrast activation, affecting the neural motor response. Previous animal experiments also showed that rapid changes in brightness can delay the visual processing in the visual cortex. However, the adaptive changes in the visual system after stroboscopic training may promote improvements in motor performance. Such studies also support the hypothesis that the improvements in behavior observed after stroboscopic training are mediated by adaptations in the visual areas of the central nervous system. Therefore, after long-term stroboscopic intervention, clay target shooters can physiologically establish improvement mechanisms, leading to the enhancement of performance effect indicators of visual-motor abilities. At the same time, SVT can naturally combine many training methods, and the higher the consistency between the content of training and the content of assessment for athletes, the more they can maximize the transformation of the training content, or transfer it in similar scenarios. The training methods used in this study, such as tennis catching and throwing reaction exercises, are highly related to the assessment tasks of hand-eye coordination and decision-making mechanisms. Through constant changes in the form and difficulty of tennis catching and throwing exercises during training, athletes' stable neural responses and muscle movement sensations are continuously shaped, allowing them to make rapid and accurate responses to novel visual stimuli during testing. Conducted a pilot study on three elite youth soccer players and found that SVT could improve visual reaction time, and the reaction speed of excellent badminton and table tennis players also improved after stroboscopic training [49–56] found similar results in their acute SVT hand-eye coordination study; after training with the wall-mounted Sport Vision Trainer™ with 80 sensor panels, the hand-eye coordination ability of the experimental group was improved immediately ($F = 9.793$, $p = 0.003$), ten minutes later ($F = 12.069$, $p = 0.001$), and ten days later ($F = 10.908$, $p = 0.002$) [56].

Hence, prior research demonstrates that acute interventions maintain a sustained effect on SVT over an extended period, which likewise offers mutual confirmation for the enhancement of hand-eye coordination measures observed in this study following long-term intervention.

4.5. Effects of stroboscopic training on special performance

According to the statistical results, the special performance of athletes in the experimental group has been significantly improved, which also indicates that with the improvement of sports vision ability, the special performance of athletes has achieved synchronous and positive growth, which proves the transfer effect of visual ability improvement to some extent. Many previous studies on stroboscopic training have also proved that the improvement of sports vision ability will be translated into the improvement of sports performance. This study once again reflects the positive effect of systematic stroboscopic training on the special performance of clay target shooters through the statistics of athletes hitting the target in the qualification competition. Although the athletes' special performance may be affected by different factors, through the reasonable control of variables in the experimental group and the control group, the synchronous and positive growth of the sports visual index and exceptional performance in the research results of this paper further explains the importance of visual ability for the clay target shooters. To a large extent, the improvement of sports performance in target interceptive projects depends on the improvement of athletes' visual ability. Meanwhile, according to the results of this study, the hardware indicators of the visual system may not be the most critical factor affecting athletes' sports performance. The key to determining motor performance is the change of the software indicators related to the visual system, which belong to the perceptual and effect mechanisms.

5. Conclusions

Stroboscopic Visual Training (SVT) improves athletes' sports visual ability over time, especially in dynamic visual tasks essential for high-performance athletics. While hardware indicators like visual clarity and depth perception showed minimal improvement, soft metrics of the visual system like near/Far quickness, target capture speed, and multiple object tracking were vastly improved. Better reaction times, hand-eye coordination, and decision-making ability, all of which are critical to success in competition, were also seen as a result of these changes.

The findings indicate that SVT enhances visual-motor coordination to respond more rapidly and accurately to the complex stimuli crucial to sports performance. In particular, the gains seen in controlled training settings will generalize to real-world competition, where athletes must make fast and accurate choices in a hurry. These improvements may also be useful for sports injury prevention and rehabilitation, helping athletes get back in shape and learning motor skills. Future work, however, should investigate how training duration lengths and sample sizes impact these findings across a wider range of athletic populations. Additionally, SVT can even be combined with rehabilitation programs that may assist athletes in returning reaction time and motor coordination after an injury.

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