Differences in hand-eye coordination: a comparative analysis between eSports and non-eSports populations

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Research Article

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Differences in hand-eye coordination: a comparative analysis between eSports and non-eSports populations

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Abstract: E-sports necessitate maintaining high-speed reactions as well as precise and frequent hand-eye coordination during competitions. This study employs literature review, experimental methods, and statistical analysis to compare the hand-eye coordination abilities of e-sports participants with non-e-sports participants. Additionally, it investigates the correlation between hand-eye coordination and the duration of gaming. The study encompasses a total of 90 subjects, categorized into three groups based on their weekly gaming hours. The first group comprises e-sports participants who engage in gaming for 14 hours or more per week, while the second group consists of those who game for less than 14 hours per week. The third group includes non-e-sports participants. The findings of the study are as follows:1.E-sports participants exhibit significantly superior visual reaction times and hand-eye coordination abilities compared to non-e-sports participants.2.Among e-sports participants, those who game for more than 14 hours per week demonstrate better visual reaction times, hand-eye coordination, and short-term decision-making capabilities.3.Within the e-sports cohort, FPS (First-Person Shooter) players outperform MOBA (Multiplayer Online Battle Arena) players in visual reaction times and hand-eye coordination. Conversely, MOBA players excel in short-term decision-making compared to FPS players.

Keywords: eSports; visual reflexes, hand-eye coordination;

The global popularity of e-sports is increasing rapidly (Sainz et al., 2020). According to a report by Newzoo, the number of gamers worldwide was close to 3.2 billion in 2022, and it is projected to reach 3.5 billion by 2025, with the market size expanding to $225.7 billion. The e-sports user base stands at 2.47 billion, accounting for 48.3% of the global internet population. A joint report by the Consumer Technology Association (CTA) and market research firm Interpret predicts that by 2024, the global e-sports audience will grow to 519 million. The benefits of e-sports extend beyond the gaming experience itself. The rise of e-sports is spurring a series of experimental studies aimed at identifying specific abilities and mechanisms that are altered through gaming. Research indicates that individuals with extensive experience in action video games exhibit superior sensory, perceptual, and attentional abilities compared to those without such experience. For instance, compa

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red to non-gamers, action video game players (AVGPs) typically exhibit faster reaction times (Castel et al., 2005; Dye et al., 2009; Orosy-Fildes & Allan, 1989; Yuji, 1996; West et al., 2013; Li et al., 2022), more focused and efficient attention (Schenk et al., 2020), and greater capacity for simultaneous tracking and comprehension of multiple objects (Green & Bavelier, 2006a, 2006b; Trick et al., 2005).Different types of games enhance attention in various ways. For example, FPS games are particularly effective at improving selective attention (Green & Bavelier, 2003; Kaufman et al., 2012). Additionally, AVGPs demonstrate superior spatial (Boot et al., 2008; Feng et al., 2007; Green & Bavelier, 2003, 2006, 2007) and temporal abilities (Donohue et al., 2010; Green & Bavelier, 2003; Li et al., 2009; West et al., 2008), as well as exceptional information processing skills (Yuji, 1996; Dye et al., 2009; Kowal et al., 2018), task-switching abilities (Boot et al., 2008; Cain et al., 2012; Colzato et al., 2010; Green et al., 2012; Toth et al., 2020; Miyake et al., 2000; Monsell, 2003), working memory (Boot et al., 2008; Colzato et al., 2012; Blacker, 2013), and strategic skills (Chisholm et al., 2010; Clark et al., 2011).The enhancement of spatial skills through video games (Spence, 2009) and motor skills has been proven to be applicable in endoscopic surgery performance (Lynch, 2010; Schlickum, 2009). However, different game genres improve different brain regions and skills. For instance, action shooting games (ASG) like first-person shooters (FPS) are characterized by distributed intensity but require high levels of attention and executive functions (Bavelier & Davidson, 2013). Sports racing games (SRG), which typically have shorter playtimes, necessitate sustained high-intensity attention (Anguera et al., 2013), visual capabilities, top-down attention (Wu & Spence, 2013), and multitasking abilities. flexi Real-time strategy games (RTS) require flexible task-switching abilities, strategic skills, and strong eye-tracking capabilities.

Hand-eye coordination refers to an individual's ability to effectively synchronize visual input with hand movements during task execution, commonly known as "eye-hand coordination." This capability reflects the high level of synchrony between the brain's processing of visual information and the command of hand movements. Hand-eye coordination is crucial in many daily activities such as writing, typing, drawing, driving, and various sports like basketball and table tennis. The enhancement of hand-eye coordination not only represents an improvement in individual skills but also signifies a comprehensive enhancement of the visual, motor, and central nervous systems' information processing abilities. E-sports, as a cognitively demanding yet physically light activity, place higher demands on athletes' hand-eye coordination compared to traditional sports. In a three-dimensional virtual environment, e-sports players need to perform highly precise operations based on varying depths within the scene. During competitive play, players must react swiftly to dynamic changes within the virtual environment through electronic interfaces. Victory or defeat often hinges on milliseconds, requiring players to possess exceptionally high levels of hand-eye coordination.

In e-sports scenarios, when players face instantaneous targets, they typically go through six steps (Figure 1): First, their peripheral vision detects the target that appears momentarily in the scene; second, they focus their attention on the target; third, they move to the target location as quickly as possible; fourth, they make the necessary fine adjustments;

fifth, they confirm that the cursor overlaps with the target; finally, they execute the action. Professional e-sports athletes can even perform firing actions during movement. This is especially true for first-person shooter (FPS) players, who use a technique known as "firing while moving." This technique requires an extraordinary level of hand-eye coordination, as the firing action is executed before the movement is completed. The processing of visual information begins with the eyes, where it is converted into electrical signals by the retina. These signals are then transmitted via the optic nerve to the visual cortex in the brain, primarily located in the occipital lobe. Here, the primary visual information is decoded and further processed. Subsequently, this information is relayed to other areas of the brain, particularly the prefrontal cortex, which is responsible for higher cognitive functions such as decision-making, planning, and attention control. Once a decision is made, the brain sends instructions to the motor cortex, which plans and executes specific physical actions. These signals are then transmitted through the spinal cord to the relevant muscle groups, ultimately reaching the hand muscles. E-sports, as an activity within a virtual space, involves complex tactical, skill, and decision-making processes. Scholars refer to this as a "cognitive game in virtual reality" (Jia Peng & Yao Jiaxin, 2005; Qi Changzhu et al., 2004). In this process, the mouse, keyboard, or other controllers become the players' avatars in the virtual space. Through the concept of "nymph" (Lan Jiang, 2021), the "self" in the virtual world possesses the consciousness of the material world. Players interact with the virtual environment through these controllers, and the results are fed back to the players via the screen, forming a closed-loop feedback system (Figure 2).

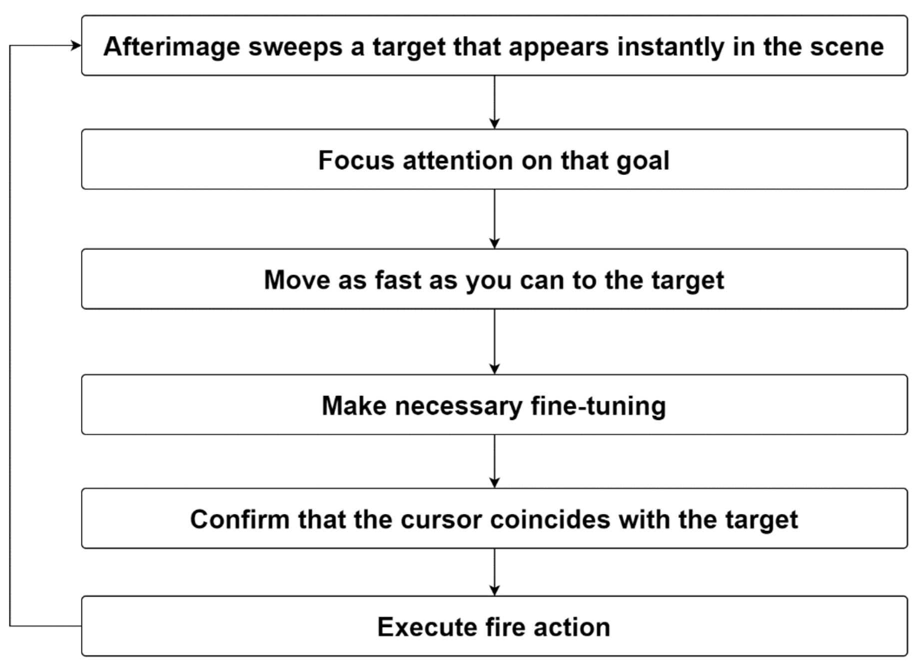

Figure. 1 FPS player executes the complete action process

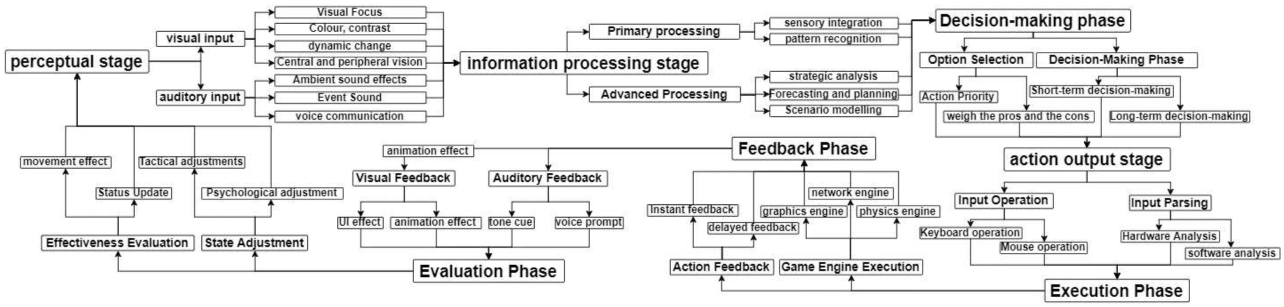

Figure. 2 Closed-loop feedback process for eSports

Despite the significant advantages of e-sports in enhancing hand-eye coordination, current research in China largely remains theoretical, lacking substantial empirical studies. This study aims to empirically validate whether e-sports can improve hand-eye coordination by comparing e-sports players with non-e-sports players. We hypothesize that long-term engagement in e-sports can enhance hand-eye coordination and visual reaction abilities, and that these abilities are correlated with the amount of gaming time. Through a series of tests designed to evaluate these differences, we hope to provide scientific evidence for the selection and training of e-sports athletes. In the future, e-sports could potentially be integrated into the training regimens of traditional sports athletes.

1.Research Objectives and Methods

1.1 research target

This study included a total of 90 participants from Inner Mongolia Normal University, Shandong Sport University, Chengdu Sport University, Capital University of Physical Education and Sports, Beijing Sport University, Hong Kong Polytechnic University, Korea University, and the University of Cambodia. All participants were male, as males tend to perform a few milliseconds faster in simple visual reaction time tests compared to females, which may be due to differences in the nervous system (Hülsdünker & Mierau, 2021; Lipps, 2011). Females, on the other hand, tend to excel in complex and multitasking activities, particularly sequential multitasking, likely due to advantages in working memory and processing speed (Hirsch, 2019). To avoid gender-related biases, all participants in this study were male. Informed written consent was obtained from all participants after explaining the nature of the study. The participants were divided into two major groups: those who had engaged in e-sports in the past 12 months and those who had not. The e-sports group was further divided into (1) individuals who played games for more than 14 hours per week (Group 1) and (2) individuals who played games for less than 14 hours per week (Group 2),The non-e-sports group consisted of individuals who had never engaged in e-sports activities (Group 3), But they are all PC users. Participant selection criteria were as follows: 1.rticipants aged between 22 and 28 years to avoid physiological factors causing research bias. 2.dividuals who had played games for 14 hours or more per week, less than 14 hours per week, or never engaged in e-sports in the past six months (proficient in us ing PC devices). 3. visual, auditory, or neurological impairments. 4. history of upper limb potential diseases or surgeries. 5. recent use of stimulant medications.6.clusion of partici pants who were involved in puzzle-solving or role-playing games. 7.clusion of mobile de vice users. Participants' sociodemographic characteristics, such as height and weight, wer e recorded. Personal information such as smoking habits, alcohol consumption, use of ant idepressants or stimulants, history of upper limb surgeries, potential brain diseases, and vi sual or auditory issues was collected. All participants were tested using standardized equi pment and conducted under the supervision of professionals to avoid research errors due t o equipment differences. Before the experiment, participants were not informed of the stu dy's theme to avoid bias in the results. According to a Simon task experiment (Ziv), partic ipants who completed an e-sports questionnaire before performing the task had faster reac tion times (RTs) than those who completed the questionnaire after the experiment. Answe ring an e-sports-related questionnaire before the experiment may lead to a response expec tancy effect, which is positive for gamers but negative for non-gamers. Therefore, to prev ent bias in the study results, participants were not aware of the experiment's theme before hand.

1.2 Research methodology

1.2.1 Experimental equipment

The equipment used for testing in this experiment, including data collection and out put, was an MSI GP75 laptop with an Nvidia 1660TI graphics card and a screen refresh r ate of 144Hz. However, during the Escape Test, the speed of the blue blocks at 144Hz wa s too fast, resulting in no significant differences between the data of different groups. The refore, for the Escape Test, we reduced the screen refresh rate to 60Hz. During the experi ment, the CPU temperature for each set of test data was maintained between 55-65°C. Th e external mouse device is a Razer Poison Viper 8KHZ, with each tester adjusting the mo use speed to their own appropriate speed.

1.2.2 Reaction Time Test

In this study, reaction time was measured using the Visual Reaction Time test fro m Human Benchmark (https://humanbenchmark.com/). The testing procedure is as follo ws: (1) Once the participant is ready, they press 'Get Started' to begin the test. (2) Wait wh en the screen display colour is red.. (3) When the screen colour changes from red to green they quickly click the screen. The test is repeated five times, and reaction times are recor ded in milliseconds (ms). The average visual reaction time from the five trials is calculate d and used as the data for this experiment.

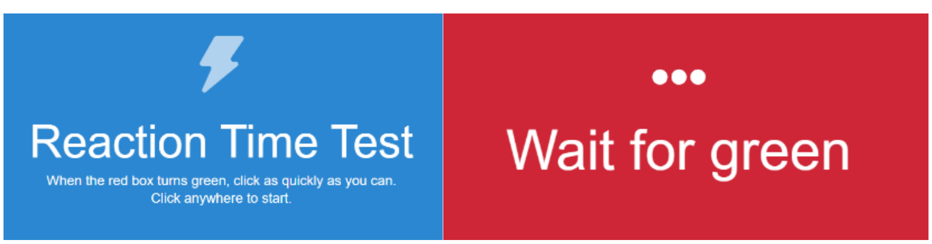

Figure 3 Reaction Time Test

1.2.3 Hand Eye Coordination Test

（1）Hand Eye Coordination Test

Hand-eye coordination was tested using Hand Eye Coordination from A Real Me (https://www.arealme.com/) , designed to assess participants' hand-eye coordination abilities. The A Real Me test comprises two levels: a basic test and an advanced test. The basic test involves a green marker moving back and forth on the screen, while the advanced test requires a single swipe to the end of a straight line. The testing procedure is as follows:1. Once the participant is ready, the test begins. 2.Participants are instructed to click on the screen to fix the position of the green marker within a white circle as accurately as possible. 3.Upon completion of the test, the output score provided by the platform serves as the reference standard. The test is repeated five times in total, and the final score provided by the platform is used to calculate the average score of the five trials. This average score is used as the data for this experiment.

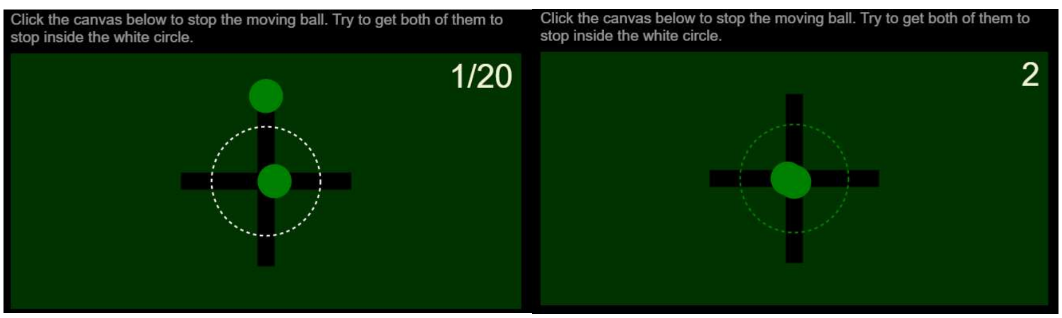

Figure 4 Hand Eye Coordination Test

（2）Aim Trainer test

To evaluate the participants, this study employs both static and dynamic tests. The static test is based on the Aim Trainer test from Human Benchmark (https://humanbenchmark.com/), while the dynamic test is based on the Aim Test from A Real Me (https://www.arealme.com/). The results from both types of tests are combined to comprehensively assess the participants' hand-eye coordination abilities. Each test is conducted five times, and the final displayed times and scores from the platforms are used to calculate the average time and scores of the five trials. This average time and scores serves as the data for this experiment. Static Test Procedure**:** (1) Once the participant is ready, the test begins. (2) The participant is required to click on the targets that appear on the screen as quickly as possible. (3) A total of 30 targets are presented, and the average time to hit each target is calculated. Dynamic Test Procedure: (1) Once the participant is ready, the test begins. (2) The participant is required to click on the bullseye of targets appearing on the screen as quickly as possible within 1 minute. Hitting the bullseye scores 10 points, the middle area scores 3 points, and the outer red area scores 1 point. (3) At the end of the 1-minute period, the score is calculated based on the different areas hit within the allotted time.

Figure 5 Static Aim Trainer test

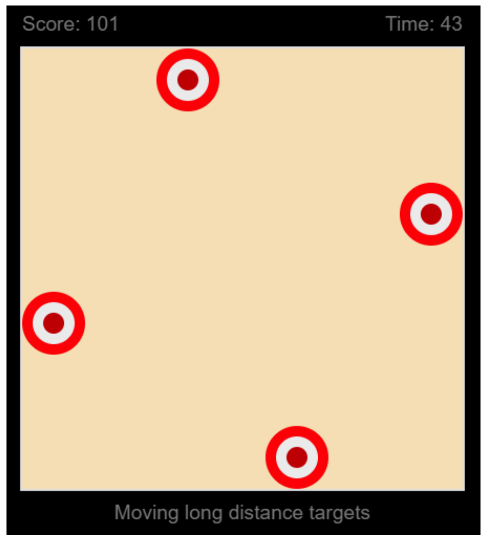

Figure 6 Dynamic Aim Trainer

（3）Escape Test

The Escape Test is a comprehensive assessment of reaction speed, hand-eye coordin ation, and logical decision-making. The testing procedure is as follows: (1) Once the parti cipant is ready, the test begins. (2) The participant clicks on the red block to start the expe riment, with the objective being to prevent the red block from being touched by the movi ng blue blocks. The experiment is conducted five times to minimize the influence of inter nal and external factors that could skew the results. The test is repeated five times, and th e final score provided by the platform is used to calculate the average score of the five tri als. This average score is used as the data for this experiment.

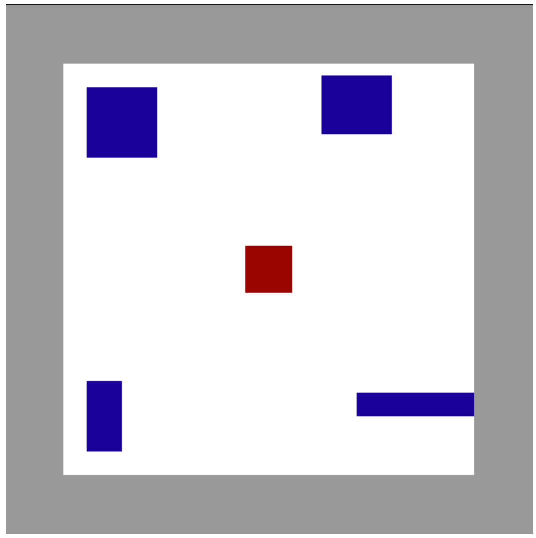

Figure 7 Escape Test

1.2.6 实验数据分析

Statistical analysis was performed with Prism v8.0 (GraphPad).Date are represented as mean ± SD，Differences between mean values of normally distributed data were assessed with two-tailed Student’s t-test.P values < 0.05 were considered signifcant (*P < 0.05, **P < 0.01, ***P < 0.001).

2.Findings and analysis

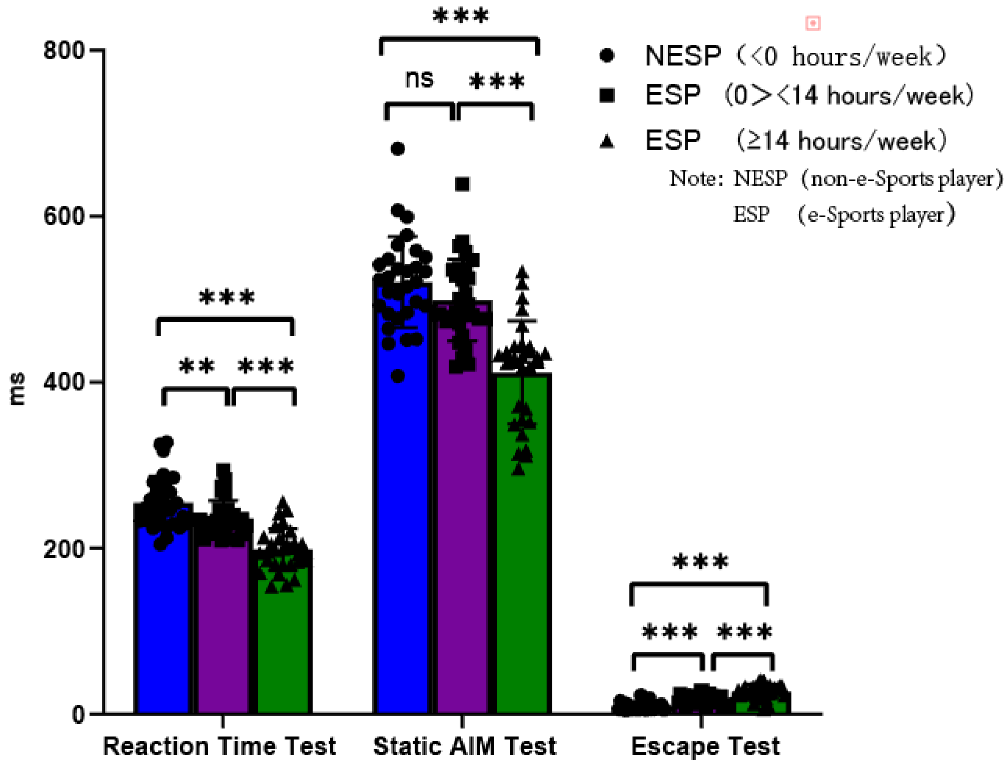

Figure. 8 Time for visual reflexes, static target test, and escape test by group

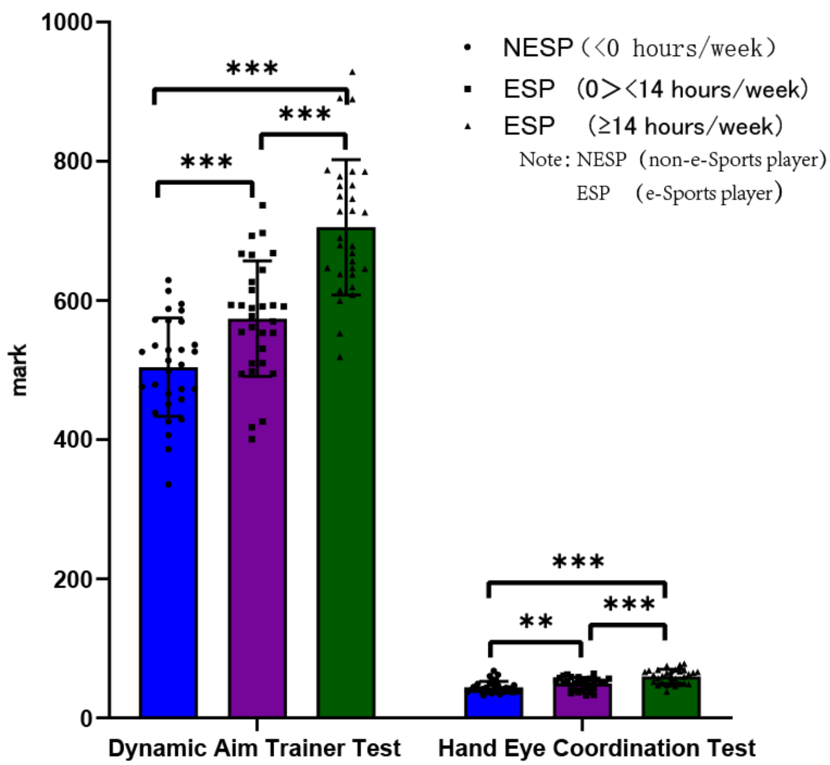

Figure 9 Dynamic target test, hand-eye coordination scores by group

Ninety participants were divided into three groups: the first group comprised individuals who engaged in e-sports activities for 14 hours or more per week (n=30); the second group included those who engaged in such activities for less than 14 hours per week (n=30); and the third group consisted of individuals who did not participate in e-sports activities (n=30). All participants' data were included in the analysis. The average age of the participants was 24.07 years, and aside from smoking, all groups met the screening criteria. Figures 8 and 9 display the average performance of the three groups in visual reaction time and hand-eye coordination tests, conducted over five trials. The data indicate that e-sports participants demonstrated superior visual reaction times, especially those who engaged in e-sports for 14 hours or more per week, significantly outperforming those who participated for less than 14 hours per week. Non-e-sports participants exhibited the slowest reaction times. T-test analysis among the groups revealed that the differences between the first group and the other two groups were highly significant ($P<0.001$), while the differences between the second and third groups were also significant ($P<0.01$). These test results corroborate and extend the findings of Ersin's research. In the series of hand-eye coordination tests, the first group showed highly significant differences compared to non-e-sports participants across all tests ($P<0.001$). The second group exhibited significant differences in the reaction time test and hand-eye coordination test ($P<0.01$) compared to non-e-sports participants, and highly significant differences in the escape test and dynamic aim trainer test ($P<0.001$). Notably, in the static aim test, there was no significant difference between the second group of e-sports participants and non-e-sports participants, though the former still showed a certain advantage. From the above analysis, it can be concluded that long-term engagement in e-sports activities can enhance visual reaction abilities and hand-eye coordination. The duration of engagement in e-sports activities within a certain range influences these abilities. Intra-group comparisons among e-sports participants reveal that the differences between the first and second groups were highly significant across all tests ($P<0.001$). Specifically, in the static aim test, there was no significant difference between the second group and non-e-sports participants, which may be attributed to the shorter duration of e-sports engagement.

3. Discussion

In this study, we first tested the visual reaction abilities of the participants. The speed of visual information processing is a foundational capability for e-sports athletes to manage complex gaming environments. It represents the initial stage of the visual information processing pathway, involving rapid capture of information from the environment and swift reaction. Our test results showed that individuals who frequently participate in video gaming activities (playing more than 14 hours per week) exhibit significantly better visual reaction abilities than those who play less and non-e-sports players (NESP). This advantage likely stems from prolonged training and activation of the visual system, leading to neural adaptations. Improved visual reaction abilities help to shorten the time required for visual information processing (Dye et al., 2009; Green & Bavelier, 2012; Green, Pouget, & Bavelier, 2010), which directly impacts the precision and speed of operations in e-sports. This finding not only supplements Ersin's related research but also aligns with studies by other scholars such as Boot and Kristjansson, who found that action video games significantly enhance visual sensitivity. Enhanced visual sensitivity allows e-sports players (E

SPs) to detect smaller changes in grayscale levels within a grating pattern (Boot et al., 2011), as well as improve brightness sensitivity, color perception sensitivity, and spatial frequency sensitivity. Color perception sensitivity refers to the ability to detect changes in different colors and hues. Consequently, in visual reaction tests, ESPs can more quickly perceive the threshold point of red and green screen transitions, thereby shortening the time for visual information processing. Additionally, enhanced visual sensitivity enables e-sports players (ESPs) to recognize fast-moving targets and subtle visual differences in low-contrast environments more rapidly (Dawson, 2017), as well as the ability to discern differences between two shapes (Li et al., 2009). Therefore, in dynamic AIM Trainer tests, ESPs can swiftly distinguish the position of the bullseye target. It is noteworthy that the benefits of visual capabilities extend beyond the visual modality to influence multisensory processing abilities (Donohue et al., 2009, 2010).Research indicates that prolonged visual training not only improves the speed of visual information processing (Bavelier & Green, 2019) but also reduces the cognitive load of tasks, enabling the brain to recognize and analyze complex virtual scenes and respond to visual stimuli more quickly, while flexibly switching between different subtasks. Switching from one task to another requires reconfiguring the cognitive task set, a process often found to delay response times after the first switch—referred to as the task-switching cost (Waszak, 2003). Studies show that ESPs possess superior cognitive control skills, allowing them to disengage from the previous task and quickly transition to the next one with higher task-switching flexibility and lower task-switching costs (Colzato et al., 2010; Dobrowolski et al., 2015; Green et al., 2012; Karle et al., 2010; Strobach et al., 2012).Importantly, the enhancement of visual sensitivity in ESPs is particularly evident in their rapid recognition of dynamic and static visual stimuli (Li et al., 2009), such as quickly locating and identifying suddenly appearing targets in AIM trainer tests. This ability is closely related to prolonged game training rather than gender or other simple variables (Appelbaum et al., 2013). Due to prolonged exposure to intense visual stimuli, ESPs exhibit superior visual attention compared to NESPs. Attention includes selective attention, dispersed attention, and sustained attention (Bavelier et al., 2012). Studies indicate that excluding innate genetic factors, ESPs show significant advantages in attention allocation, effectively processing environmental distractions and allocating more attention resources to adjacent areas (Bavelier et al., 2012; Ersin et al., 2022). As the game task load increases, the frontal and parietal lobes of NESPs recruit a large number of neurons, but ESPs show the opposite, thereby reducing cognitive load (Figure 10). This ability allows ESPs to perform better in multi-target tracking tasks (Trick et al., 2005), tracking more dynamically moving objects (Dye et al., 2009; Green & Bavelier, 2003, 2006b; Trick et al., 2005). In RTS games, players often need to simultaneously track multiple target stimuli, several or even dozens of combat units, requiring intense attention and strong eye-tracking abilities. The increase in tracking quantity enables ESPs to track more targets in dynamic AIM tests, allowing them to complete tasks more quickly. Notably, NEPPs can also increase the number of tracked objects after exposure to e-sports stimuli (Green & Bavelier, 2006a). In the e-sports environment, ESPs not only need to manage multiple visual input sources but also execute precise hand-eye coordination actions. They often use more economical eye movement paths to quickly and accurately track targets (Lee et al., 2005), closely coordinating with hand movements to respond rapidly to changes in the game. This exceptional visual tracking and hand-eye coordination ability is particularly evident in AIM Trainer tests, requiring participants to identify, track, and "hit" multiple d ynamic targets within a very short time, followed by quickly entering the next round of human-computer interaction loops. ESPs outstanding performance in AIM tests is also attributed to their superior visual search abilities (Castel et al., 2005). In the virtual competitive environment, subtle changes require continuous feedback and adjustment in the cognitive process (Sun Peng, 2007). High-level e-sports athletes can quickly adjust visual attention and refocus on new targets, allowing them to maintain high-performance attention switching in multi-task environments (West, 2008) and increase the frequency of closed-loop feedback systems. This depends not only on rapid visual information processing but also reflects excellent dynamic visual attention processing abilities and hand-eye coordination skills, enabling quick recovery of attention and accurate command execution in the face of multiple distracting stimuli (Sun Peng, 2007). During the video input stage, ESPs focus intensely on changes in the game scene on the screen, paying less attention to the relative position of their hands and input devices and the accuracy of operations. This intense concentration and optimization of visual information processing effectively shorten information processing time and improve the precision of visual feedback information (Ersin et al., 2022). In discussions with top e-sports athletes, we found that they habitually project the targets that need to be locked onto in the virtual environment to the center area of the image. The higher the precision of visual feedback information when the target is projected in this area. During this process, e-sports players consciously move the target to the center area of the screen rather than merely searching for the target. Enhanced peripheral vision allows electric players to significantly improve their performance in the effective visual field (Green & Bavelier, 2003, 2006). The effective visual field refers to the visual area from which information can be extracted in a brief glance without eye or head movement (Ball, 2002), enhancing information extraction efficiency. This high concentration of attention and optimisation of visual information processing effectively reduces the information processing time and improves the accuracy of visual feedback information (Sun Peng, 2007).

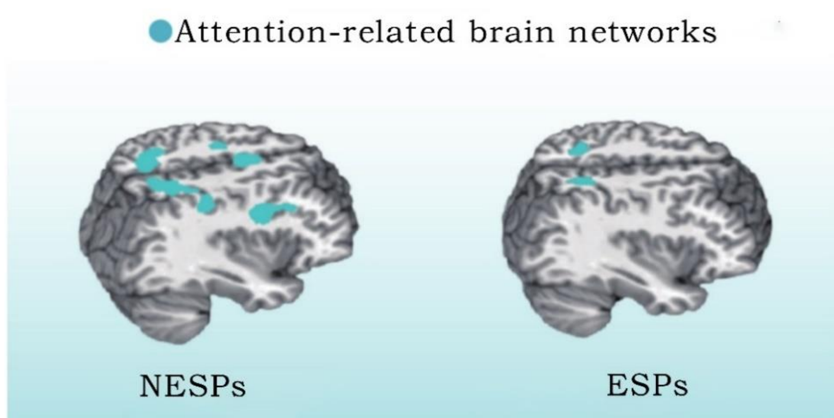

Figure 10 The comparison of attention functions between habitual player and non—habitual player（Bavelier et al.,2012）

In hand-eye coordination tests, we found that ESPs exhibited significant advantages compared to NESPs, displaying notable activation in motor regions. We believe this diffe rence may stem from the prolonged engagement of EVPs in video game activities that require high-frequency, precise hand movements, continuously activating key areas responsible for motor control in the brain, particularly the primary motor cortex and cerebellum. These regions are crucial for the regulation of fine motor skills. In the e-sports environment, players need to rapidly convert visual information into precise physical actions, often adjusting the fineness of hand movements based on changes in the scene, which is related to the depth (of a battlefield or terrain) in the virtual competitive environment. Functional magnetic resonance imaging (fMRI) studies have shown that during relevant task execution, the motor cortex activity of video game players is significantly enhanced. This increased regional activity not only improves motor precision and coordination but also enables players to perform fast and accurate keyboard and mouse operations. Neuroplasticity—the brain's ability to adjust its structure and function based on experience—plays a crucial role in this process (Boot, 2011). The brain, as the highest center governing all human life activities, is a key subject in understanding human cognition (Liu et al., 2018). Long-term e-sports training can observe changes in the brain's white and gray matter structures, confirmed through MRI technology. Changes in gray matter volume (Basak et al., 2011) primarily occur in the medial prefrontal cortex, cerebellum, somatosensory area, and dorsolateral prefrontal cortex, enhancing motor planning and decision-making functions. Gray matter is also related to improved visual analysis and recognition abilities, which are fundamental for seamless visual experiences in daily life. Regarding the impact on white matter, even short-term e-sports activities can cause microstructural changes, closely related to changes in the fornix (Hofstetter et al., 2013). Different types of e-sports affect different regions of white matter; for instance, action games mainly affect the white matter FA of the right striatum and the terminal of the fornix, while strategy games are related to the white matter FA of the hippocampus and left cingulate gyrus (Amado et al., 2016). White matter plays a critical role in visual function, with myelinated axons capable of rapidly transmitting visual signals, connecting the retina to the brain's visual cortex and other processing areas, accelerating visual information processing, and promoting the integration, memory, and recognition of visual information. This also facilitates the coordination with other sensory information, effectively supporting our perception and response to the environment. In contrast, NESPs exhibit lower activity in these brain regions, likely due to a lack of stimulation and training in these areas during their daily activities. This difference indicates that a lack of high-demand fine motor activities, such as those in e-sports, may not sufficiently stimulate the same level of neuroplasticity and brain region activity. Additionally, through the close collaboration between the visual cortex and prefrontal cortex, ESPs ability to react and perform complex operations in a very short time is enhanced. We believe that appropriate stimulation and repetitive action training can significantly improve motor precision and reaction speed, closely related to increased activity in the cerebellum and motor cortex (Granek et al., 2010). Long-term, high-intensity physical training optimizes the speed and efficiency of neural signal transmission from the prefrontal cortex (decision-making) to the motor cortex (action execution), thereby enhancing neuromuscular coordination (Green & Bavelier, 2003; Green & Bavelier, 2006b; Dye et al., 2009), making the conversion process from visual stimulus to hand response faster and more automatic. Synaptic plasticity is a key mechanism by which the nervous system adjusts its response to the same stimuli, including long-term potentiation (LTP) and long-term depression (LTD). These processes can change the strength of connections between neurons, speeding u p the transmission of neural signals. Furthermore, neurotransmitter levels, such as dopami ne and acetylcholine, also significantly impact the efficiency of synaptic. For example, in creased dopamine not only enhances the sensitivity of neural networks to rewards but als o strengthens learning and memory processes, especially in rapidly changing visual envir onments, which is crucial for handling the fast-paced tasks common in e-sports. Acetylch oline enhances visual attention and improves synaptic transmission efficiency, facilitating these processes. Long-term e-sports training may lead to the release of more neurotransm itters such as glutamate, which is crucial in learning and memory (Blakely et al., 2011). G lutamate enhances its effects by regulating NMDA and AMPA receptor activity. These n eurochemical changes support the higher neural adaptability of ESPs when performing ta sks. Additionally, structural changes in the brains of ESPs may lead to increased gray mat ter density, indicating more neurons involved and stronger network connections during ta sk execution. This structural optimization helps improve the efficiency and accuracy of ta sk execution. The superior hand-eye coordination abilities of ESPs compared to NESPs may largely result from enhanced synaptic plasticity, adjusted neurotransmitter levels, an d adaptive changes in brain structure. These neurobiological mechanisms collectively im prove their reaction speed and accuracy in complex visual environments. This means the visual information processing time and the entire closed-loop operation time are shortene d. It is also noteworthy that long-term engagement in e-sports activities induces beneficia l and reversible adaptive changes in brain structure (Gong et al., 2019; Martin-Niedecken & Schättin, 2020).

In the Escape Test, participants control a red block to avoid collisions with moving b lue blocks. This test not only assesses hand-eye coordination but also evaluates operation al thinking abilities. ESPs exhibit significantly superior decision-making skills in dynami c environments compared to NESPs, a performance that correlates positively with gamin g time under certain conditions (Sun Peng, 2007). Action games enhance their ability to manage rapidly moving objects and make swift decisions in complex environments. Thu s, in the Escape Test, ESPs view the moving blue blocks as enemies and demonstrate exc eptional decision-making capabilities, selecting optimal escape routes to achieve longer s urvival times. By reviewing relevant literature, we believe that this difference stems from two key aspects of neural adaptability: enhanced abilities in processing visual informatio n and coordinating motor responses, and cognitive improvements in complex decision-m aking and strategic planning. The superior performance of ESPs in this test can be attribut ed to their advanced cognitive functions in decision-making and strategy execution. The c ore of this ability lies in the dorsolateral prefrontal cortex (DLPFC), a critical brain regio n for executive functions, including high-level decision-making, problem-solving, and co ordinating behavior based on internal goals (Miller & Cohen, 2001; Ramnani & Owen, 2 004). ESPs DLPFC is particularly trained and developed through prolonged exposure to f ast-changing gaming environments that require rapid responses (Basak et al., 2011). Long -term training may have adapted the DLPFC of ESPs to high-pressure, rapidly changing e nvironments, enabling faster reaction times and greater strategic flexibility in the Escape Test (Kühn, 2014). The DLPFC is the core correlate of executive control and strategic pla nning, which are essential cognitive domains for successful video gaming (Kühn, 2014). I n terms of decision-making in this test, the advantages displayed by ESPs are primarily re flected in two aspects: First, tactical planning ability. Players need to evaluate multiple m ovement paths and strategies in a very short time to choose the optimal escape route. This ability is particularly important in the Escape Test due to the random movement of the blue blocks, which requires players to continuously adjust and optimize their decisions. Second, problem-solving ability. Faced with constantly changing paths of the blue blocks, ESPs can quickly identify and adjust their strategies to adapt to environmental changes. This flexible strategy adjustment ability is learned from e-sports competitions, where opponents' actions are also constantly changing and unpredictable. However, experienced players learn to recognize patterns and predict enemy movements, benefiting from their ability to anticipate future events, thus showing high adaptability in responding to dynamic environments. In the virtual competitive environment, being able to predict opponents' behavior and preemptively respond is key to winning. This predictive ability is part of the brain's predictive coding mechanism, which allows the brain to anticipate future events based on past experiences and current information, preparing corresponding neural responses and making optimal decisions quickly. Thus, in predicting the movement paths of the blue blocks, ESPs may perform better than NESPs. Additionally, the improvement in visual reaction speed may also be related to the brain's ability to anticipate upcoming stimuli (Clark, 2013).

It is worth noting that although Multiplayer Online Battle Arena (MOBA) games and First-Person Shooter (FPS) games both belong to the category of action video games, they exhibit significant differences in visuomotor synchronization (hand-eye coordination) and reaction time (Kühn, 2014). FPS games typically utilize a first-person perspective, which enhances player immersion and bodily resonance, thus placing higher demands on their visuomotor coordination abilities. FPS players must swiftly and accurately locate and aim at appearing enemies, with professional e-sports athletes often able to target specific body parts of their opponents. This continuous high-load training significantly enhances their visuomotor synchronization abilities. In contrast, MOBA games have lower requirements for visual complexity, with combat interactions mainly occurring within a predetermined visual range, and emphasize tactical anticipation rather than immediate precise operations. Therefore, in tests of visual reaction and visuomotor coordination, FPS players outperform MOBA players (Deleuze et al., 2017; Santos et al., 2018; Sousa et al., 2020). However, in the Escape Test, MOBA players demonstrate better performance. MOBA games, conducted in a 2D visual environment, require players to monitor multiple targets and predict their movement patterns, focusing on tactical planning and strategic application. In comparison, FPS games emphasize immediate reactions and motor precision.

4. Shortcomings in the study

First, ESPs naturally have advantages over NESPs. during the operation process, This may be attributed to the testing platform's alignment with e-sports scenarios. The test required participants to complete a series of tasks using a keyboard and mouse. Although NESPs are also long-term users of electronic devices, this factor may have had some influence on the process. However, the differences observed in the test data do not appear to be the primary cause of the experimental results. Secondly, our collected data did not exclude the distribution of ESPs activity times. Some ESPs participants may have concentrated their gaming activities on a single day rather than distributing their time evenly. Concent rated practice and distributed practice may have different impacts, suggesting that this could be a crucial moderating variable warranting further investigation in studies of other video games. Additionally, the ESPs tested mainly came from MOBA and FPS games, without encompassing all e-sports categories. Future research could focus on exploring the differences in hand-eye coordination abilities among various e-sports disciplines.

5. Future development

Video games are often perceived as a form of entertainment media. However, when the term "video games" is mentioned, most people tend to associate it with negative connotations, believing it to be a threat to proper social behavior. Contrary to this belief, video games now strive to improve cognitive abilities, much like any other medium, and can be used for education, cultural promotion, and even rehabilitation purposes. The application of e-sports training methods in rehabilitation medicine, particularly for patients with impaired hand-eye coordination (such as stroke patients and those with traumatic brain injuries), is already showing promising results. There is evidence suggesting that e-sports can improve conditions for patients with spinal cord injuries (SCI) and limb paralysis (Tabacof et al., 2021). Furthermore, it is becoming feasible to help the elderly adapt and restructure their cognitive systems to meet the demands of constantly changing scenarios. By developing personalized training programs, we can aid patients in recovering and enhancing their hand-eye coordination, thereby improving their quality of life. This application not only holds significant clinical value but also expands the social impact of e-sports training. Additionally, e-sports training methods could be beneficial for professional fields requiring high-speed and precise reactions, such as pilots, surgeons, and emergency responders. Moreover, it has potential as a tool for mental health improvement (Kowal et al., 2021). Future research can further refine the specific mechanisms through which e-sports training enhances hand-eye coordination. For instance, through big data analysis and machine learning algorithms, we can identify the specific game operations and response patterns that most effectively improve hand-eye coordination. This will not only help to optimise eSports training programmes to design efficient hand-eye coordination enhancement methods for ESPs it will also enable the development of effective methods to improve hand-eye coordination in youth sport activities. Additionally, exploring changes in hand-eye coordination over different time spans will allow us to analyze whether training effects accumulate or decline over time. This is crucial for developing scientifically sound e-sports training plans.

6. Ethical declaration

All participants consented to a protocol approved by the Ethics Committee of Inner Mongolia Normal University. This study adheres to the ethical standards set forth by the Declaration of Helsinki. The research was approved by the Research Ethics Committee of Inner Mongolia Normal University and conducted in accordance with the ethical guidelines of the World Medical Association (Declaration of Helsinki). Informed consent and written consent were obtained from all participants.

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