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ORIGINAL RESEARCH

Effects of Exercise Habits and Gender on Sports e-Learning Behavior: Evidence from an Eye-Tracking Study

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Background/Objective: In the post-epidemic era, an increasing number of individuals were accustomed to learning sports and physical activity knowledge online for fitness and health demands. However, most previous studies have examined the influence of e-learning materials and resources on learners and have neglected intrinsic factors such as experience and physiological characteristics. Therefore, we conducted a study to investigate the effect of exercise habits and gender on sports e-learning behavior via eye-tracking technology.

Methods: We recruited a sample of 60 undergraduate students (mean age = 19.6) from a university in Nanjing, China. They were randomly assigned into 4 groups based on 2 genders × 2 exercise habits. Their gaze behavior was collected by an eye-tracking device during the experiment. The cognitive Load Test and Learning Effect Test were conducted at the end of the individual experiment.

Results: (1) Compared to the non-exercise habit group, the exercise habit group had a higher fixation count ($P<0.05$), a shorter average fixation duration ($P<0.05$), a smaller average pupil diameter ($P<0.05$), and a lower subjective cognitive load ($P<0.05$) and better learning outcome ($P<0.05$). (2) Male participants showed a greater tendency to process information from the video area of interest (AOIs), and had lower subjective cognitive load ($P < 0.05$) and better learning outcomes ($P < 0.05$). (3) There was no interaction effect between exercise habits and gender for any of the indicators ($P > 0.05$).

Conclusion: Our results indicate that exercise habits effectively enhance sports e-learning outcomes and reduce cognitive load. The exercise habits group showed significant improvements in fixation counts, average fixation duration, and average pupil diameter. Furthermore, male subjects exhibited superior learning outcomes, experienced lower cognitive load, and demonstrated greater attentiveness to dynamic visual information. These conclusions are expected to improve sports e-learning success and address educational inequality.

Keywords: e-learning, exercise habit, eye-tracking, gaze behavior, gender

Introduction

The outbreak of COVID-19 triggered a remarkable surge in the adoption of e-learning. Statistically, during the pandemic, there was a seven-fold increase in daily e-learners, with a 53% rise in e-learning frequency.[1] E-learning refers to an educational ecosystem that utilizes a variety of Information and Communication Technologies (ICT), including the Internet, computers, and multimedia, to provide learners with a flexible and accessible learning experience.[2–4] Particularly in the context of sport and physical education, utilizing e-learning to address concepts and skills related to human movement presented immense potential for boosting learning motivation and effectiveness.[5] Meanwhile, the health crisis caused by viral infections heightened awareness of the importance of physical activity (PA), fostering a stronger desire and willingness to engage in PA.[6,7] Therefore, e-learning is progressively emerged as a popular approach for individuals to gain knowledge on sports and physical education.

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In recent years, e-learning has become an important hotspot in the field of psychology and behavioral research. Exploring the impact of individual characteristics such as different learning styles,[8] learning habits,[9] willingness,[10,11] and emotions[12] on e-learning can enable the optimization of e-learning paths by providing a deep understanding of learners' requirements, preferences, and decision-making processes. However, the ultimate aim of most of the studies tended to improve the external environment of e-learning, and very few works gave recommendations for the learners themselves.[13] Research on e-learning behaviors was necessary to better facilitate teaching effectiveness and learning quality.[14] The learners' operational behaviors while engaging in e-learning were considered their learning behaviors.[15] Li et al[16] suggested that the diverse individual characteristics of learners may lead to distinct learning behaviors when accessing e-learning materials, which can potentially impact their e-learning performance.

According to constructivist theory, knowledge is constructed through individual experiences and abilities.[17] It was reported that individuals with extensive experience in multiple sports may facilitate the acquisition of new sport-related knowledge and motor skill development through positive transfer, and individuals lacking experience in sports may encounter challenges in acquiring new motor skills.[18,19] Meanwhile, the effectiveness of e-learning is greatly influenced by experience.[20–22] E-learning simply transmitted theoretical knowledge and lacked physical sensation itself,[23] while the features of sports learning was hands-on practice and interpersonal interaction.[24,25] Thus effectiveness of e-learning in sport may depend more on the role of experience. To date and the best of our knowledge, no study investigated the importance of sports experience in e-learning success in sport. Sports experience encompasses a substantial element of tacit knowledge based on senses or intuition, primarily stemming from an individual's direct physical activity.[26] Therefore, we proposed that exercise habits may influence the effectiveness of e-learning in sports. Furthermore, gender differences had been widely taken into account in e-learning environments as a fundamental personal characteristic of learners. Ong et al[27] showed that males typically scored higher than females on computer self-efficacy, perceived usefulness, perceived ease of use, and behavioral intention to use e-learning. Kay et al[28] reported that males held significantly more positive attitudes than females when it came to engagement, evaluation, and perception of e-learning. Some studies concluded that females were not necessarily lagging in e-learning, and in certain aspects they were even surpassing males.[29,30] Given that traditional face-to-face sports learning environments tended to favor males due to physiological dominance,[31] it was important to consider whether gender differences in sports learning still occurred in the relatively equitable e-learning environment. Overall, exploring the effects of learners' exercise habits and gender on sports e-learning behavior had an important role and practical value for their sports e-learning performance.

Previous studies on e-learning behavior primarily utilized subjective evaluations[32] or objective log data,[33] which may not offer an all-encompassing comprehension of internal cognitive and affective conditions. Eye-moving activities could provide rich data for revealing human intentions and behaviors.[34] With the fast progress of eye-tracking hardware, software, and analysis methods, eye-tracking technology has become an essential tool for investigating behavioral mechanisms in a plethora of fields, alongside brain imaging.[35,36] Researchers can objectively and accurately measure and interpret various eye movement indexes with minimal invasiveness while learners view on-screen information,[37] allowing for in-depth study of cognitive processes during e-learning. In addition, several studies showed that physical activity and gender had an effect on eye movement behavior in certain specific contexts. For example, Cheval et al[38] discovered that individuals with higher levels of physical activity had increased odds to fixate on physical activity-related stimuli first (compared to non-physical activity-related stimuli), and for longer, and had larger pupil amplitudes. Sargezeh et al[39] investigated gender differences in the distribution of eye movements when viewing indoor pictures. They found that females had a shorter ratio of fixation durations to saccade duration and exhibited greater saccade amplitudes and longer scan paths compared to males.[40] Unfortunately, no existing studies reported the effects of exercise habits and gender on e-learning behavior in sports from an eye-tracking perspective. Therefore, this study aimed to quantify participants' sports e-learning behavior using eye-tracking technology and to examine the effects of exercise habits and gender on sports e-learning by comparing eye movement indexes and combining them with the Subjective cognitive load scale and the learning test. This study provided a novel perspective on enhancing the effectiveness of online physical education learning by focusing on the learners themselves. It can also be used to inform instructional design reforms to improve the success of sports e-learning and address educational inequalities.

Materials and Methods

Participants

One hundred healthy Chinese adults were recruited from a university in Nanjing. Following inclusion and exclusion criteria, 30 undergraduate students with exercise habit group (HE group) and 30 male undergraduate students without exercise habit group (n-HE group) were screened, with 15 males and 15 females in each group.

We assessed physical activity with the International Physical Activity Questionnaire-Short Form (IPAQ-SF) to determine exercise habits.[41] The IPAQ-SF is a reliable and valid self-report research instrument for measuring physical activity in people between the ages of 18–65 years. Utilizing the IPAQ-SF scoring guidelines, Metabolic Equivalent for Task (MET) scores were computed for walking, moderate-intensity physical activity, and vigorous-intensity physical activity in the preceding 7 days. The IPAQ-SF categorizes individual physical activity standards into low, medium, and high groups according to certain criteria. For this study, a participant was considered physically active if he/she met any 1 of the medium or high criteria listed above. If he/she did not report any activity, or reported some activity but did not yet meet the medium or high criteria, he/she was considered to be physically inactive.

As shown in Table 1, there were no significant differences in demographic variables between the two groups except for physical activity. All subjects were proficient in the use of computers, had some online learning experience, and all subjects had normal visual acuity or corrected vision, normal hearing, no color deficiency or color blindness, and no intellectual or reading disabilities. The study was approved by the Ethics Committee of the Nanjing Sport Institute (Approval No. RT-2022-12), and all subjects signed a written informed consent form before the experiment. Our study adheres to the principles outlined in the Declaration of Helsinki.

Stimuli

The emergence of Massive Open Online Courses (MOOCs) provides learning opportunities to people from all regions and disciplines, which has been embraced by universities around the world.[42] Therefore, according to the number of views of MOOCs from universities in China, we chose the "Development Overview and Trend of Modern Tennis", "Introduction to International Tennis Organizations and Tournaments" of Sun Yat-sen University's "Tennis Technique and Practice Course", and "Basic Forehand Shot Technique", "Basic Forehand Flatback Shot Technique", "Basic Forehand Upswing Technique" and "Basic Forehand Chipper Technique" of East China Normal University's "Tennis Technique and Practice Course" as stimuli. All content was composited via Adobe Premiere Pro 2020 for a total duration of 24 minutes.

Apparatus

The mobile eye-tracking glasses SMI ETG (SMI Eye Tracking Glasses 2W) manufactured by SMI (Senso Motoric Instruments, Germany) were used to record the participants' eye movements. The device has a 60hz/120hz binocular sampling rate, a gaze tracking accuracy of 0.5°, and a gaze tracking range of 80° horizontally and 60° vertically. The eye-tracking glasses, which were used to record and transmit video and were responsible for recording eye movement data, were connected to a Linux-based smart device with a USB-C cable (Figure 1).

Table 1 Basic Information of the Subjects (M±SD)

Characteristic	Exercise Habit				Gender			
	HE (n=30)	n-HE(n=30)	Z	P	M (n=30)	F (n=30)	Z	P
Weekly physical activity/ (MET-min w^{-1})	4627.8±1333.7	440±136.5	−6.667	***	2779.4±2601.3	2288.4±1994.3	−0.600	0.415
Age	19.5±0.8	19.6±0.7	−0.432	0.618	19.4±0.8	19.7±0.8	−1.080	0.243
Pretest	1.3±1.4	1.1±1	−0.486	0.390	1.3±1.2	1.1±1.2	−0.540	0.668

Notes: ***=p<0.001.
Abbreviations: HE, Exercise Habits; n-HE, non-Exercise Habits; M, Male; F, Female.

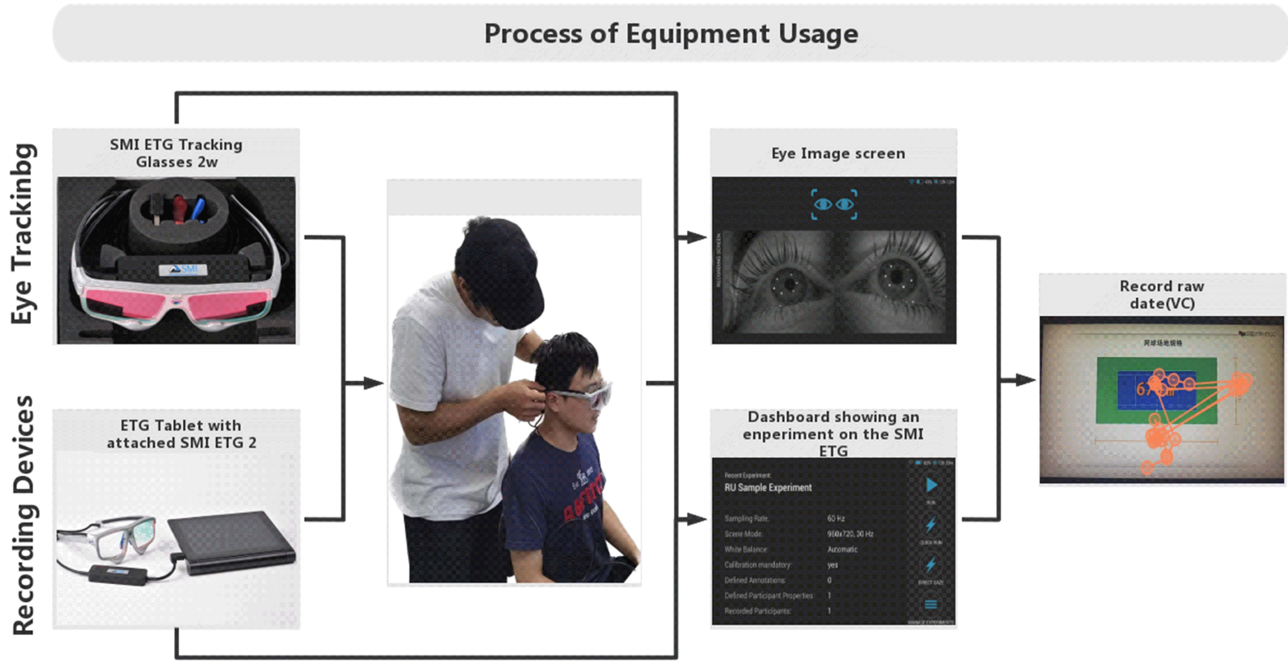

Figure 1 Process of equipment usage.

The monitor was a 24-inch, IPS panel with a resolution of 1920×1080 and a refresh rate of 144 HZ. The same eye-tracking device and the same monitor were used for all subjects. The laboratory was a low-lighting, noise-free environment.

Measure

Pretest

Participants were asked to complete 20 multiple-choice tennis-related questions to test their a priori knowledge level. The results showed that neither exercise habits nor gender showed significant differences, at same time, the level of knowledge could be regarded as the same among the subjects in each group.

Cognitive Load Scale

Cognitive load was measured using a nine-band self-assessment scale (Cronbach's $\alpha = 0.708$) developed by PAAS.[43] The scale consists of mental effort (1 for "least effort", 9 for "very effort"), and mental load (1 for "very easy", 9 for "very hard"). Mental effort is person-centered and is an ability or resource allocated by the learner to be used to adapt to the demands of the task. The mental load is task-centered, a psychological experience resulting from the interaction of subjective individual characteristics and objective task difficulty, usually related to the learner's prior knowledge and the complexity of the learning material or task.[44]

Learning Tests

Similarly, the learning test required participants to answer 20 multiple-choice questions about tennis. To ensure consistency, the content of the pre-tests and learning tests are parallel. For example, the pretest's "What are the standard dimensions of an effective doubles court in a tennis court?" corresponded to "What are the standard dimensions of an effective singles court in a tennis court?" in the learning test. corresponds. A total score of 20 points is used to test the learner's mastery of the content.

Eye Movement Data

First, we loaded the recorded eye tracking data into the SMI BeGaze 3.6 software, which was designed particularly for analyzing the eye movements collected by the SMI iView software. It is noteworthy that the BeGaze 3.6 software consists of a statistics module that supports the analyses and export of more than 100 statistical variables, including but not limited to fixation, blink, and saccade durations. Moreover, the software can display the analysis results as graphs, such as scan path, focus map, and heatmap. Second, to examine participants' cognitive processing of the entire learning material during the experiment, eye-tracking data were processed using SMI BeGazeV.3.6 software and the SMI algorithm. Based on the preprocessed data, we included four common eye movement metrics sensitive to the cognitive processing of the entire material, including fixation counts (FC), average fixation duration (AFD), average pupil diameter (APD), and blink counts (BC).

In sports e-learning, the page layout when explaining skills is usually a combination of text and video information. To investigate learners' visual preference for this part of the content, we divided two areas of interest (AOIs) in this section, the text AOI and the video AOI (Figure 2a). Due to the large sample size, we decided not to use heatmaps to observe participants' visual preferences. Percentage of fixation dwell time (FDT) is the percentage of time a learner focuses on a particular AOI and indicates how much attention a student pays to a particular area of the screen.[45] Therefore, we inferred each participant's visual preference by calculating the ratio of each participant's FDT in the text AOI or video AOI.

Design and Process

The study was a 2 (exercise habitual, non-exercise habitual) x 2 (male, female) between-subjects design. Each participant experimented separately in a virtual simulation lab. Before the start of the formal experiment, we led the subjects into the lab to acclimate them to the environment and helped them put on the eye-tracking device. Although the SMI ETG 2w has full 6 DOF positioning and automatic parallax compensation, we still performed a three-point calibration at the beginning of each eye-tracking session to ensure the quality of the recordings (the SMI mobile eye-tracker offers three calibration options: 0-point, 1-point, and 3-point). The 3-point calibration is expected to provide higher accuracy as it uses a triangular position of gaze points for calibration to track the eye gaze of the participant. Additionally, to avoid wobbling that would reduce data inaccuracies, we fixed the participant's chin on a chinrest 60cm from the screen.[46] Participants began viewing the video material after the experimental guidelines. The participant's eye movements were recorded in real-time at a sampling rate of 30 Hz by the SMI ETG V1.8 software, and the eye tracking data was automatically stored in the ETG Tablet. Participants were asked to complete the learning test and the subjective cognitive load scale after the video finished playing. It took about 45 minutes to complete the experiment.

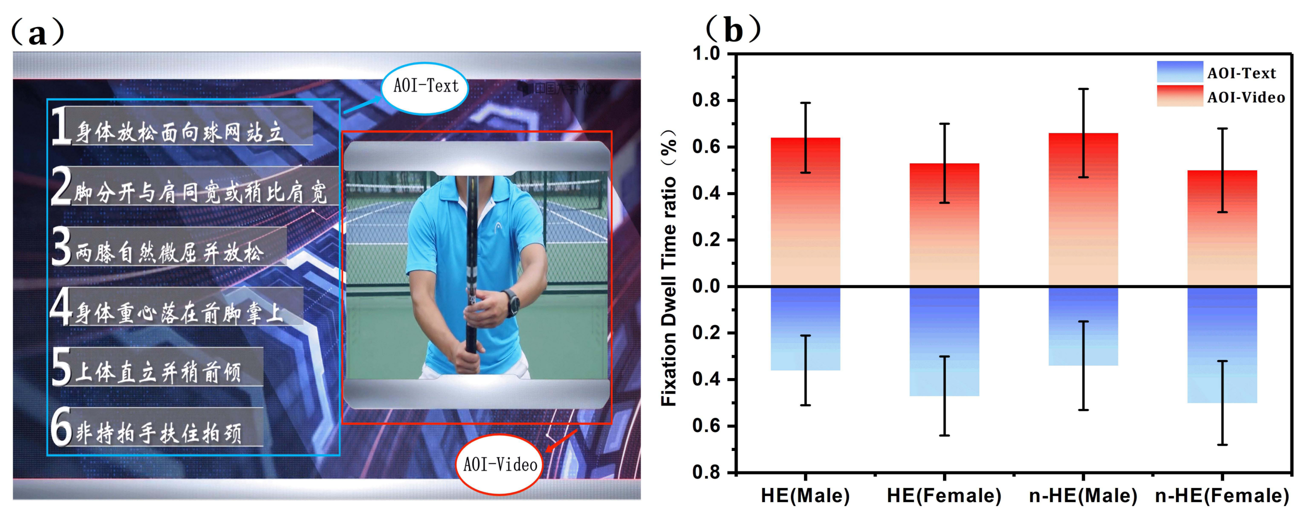

Figure 2 Visual preference. (**a**) AOI delineation rules in the Core Learning Content (Skill Explanation), with interpretive text AOI on the left and dynamic video AOI on the right, (**b**) Fixation dwell time ratio.

Notes: boxes represent mean values; error bars represent the standard deviation.

Abbreviations: AOI, area of interest; HE, exercise habit; n-HE, non-exercise habit.

Statistical Analysis

SPSS 26.0 was used in all statistical analyses. Since the sample size is more than 50, we excluded sensory evaluation attributes, was tested for normal distribution using the Kolmogorov–Smirnov's test and homogeneity of variance with Levene's test. All the variables showed normal distribution and variance analysis was used to determine differences between treatments. To determine the influence of age and gender on the implicit variable, two-way ANOVA was used. The statistical analyses first tested for the presence of an interaction, as we were interested in whether the presence or absence of exercise habits affected performance in sports e-learning by gender. A simple effect analysis was performed if there was an interaction. The main effects of each factor were analyzed individually when there was no interaction. The results of the descriptive statistics are expressed as the mean ± standard deviation (M ± SD). For all analyses, a significance level of 0.05 was used. The effect size of the data in the statistical analysis was calculated using ηp^2, where η_p^2 =0.01, η_p^2 =0.06, and η_p^2 =0.14, representing small, medium, and large effects, respectively.[47]

Results

Visual Preference

According to FDT (Figure 2b), the interaction between exercise habits and gender was not significant ($F=0.31$, $p=0.580$, $\eta_p^2=0.006$). The main effect of exercise habits was not significant ($F=0.01$, $p=0.923>0.05$, $\eta_p^2=0.000$); the main effect of gender was significant ($F=9.13$, $p=0.004$, $\eta_p^2=0.140$), with the male group having significantly higher fixation dwell times in the video area than the female group.

Total Eye Movement Index

According to FC (Figure 3a), the interaction between exercise habit and gender was not significant ($F=0.48$, $p=0.490$, $\eta_p^2=0.009$). The main effect of exercise habit was significant ($F=14.15$, $p=0.000$, $\eta_p^2=0.202$), and the fixation counts were significantly lower in the n-HE group than in the HE groups; the main effect of gender was not significant ($F=1.91$, $p=0.173$, $\eta_p^2=0.033$).

According to AFD (Figure 3b), the interaction between exercise habits and gender was not significant ($F=1.39$, $p=0.243$, $\eta_p^2=0.024$). The main effect of exercise habits was significant ($F=7.28$, $p=0.009$, $\eta_p^2=0.115$), with the n-HE group having a significantly higher average fixation duration than the HE groups; the main effect of gender was not significant ($F=0.67$, $p=0.418$, $\eta_p^2=0.012$).

According to APD (Figure 3c), the interaction between exercise habits and gender was not significant ($F=0.08$, $p=0.774$, $\eta_p^2=0.001$). The main effect of exercise habits was significant ($F=17.54$, $p=0.000$, $\eta_p^2=0.239$), with a significantly higher mean pupil diameter in the n-HE group than in the HE groups; the main effect of gender was not significant ($F=3.48$, $p=0.068$, $\eta_p^2=0.058$).

According to BC (Figure 3d), the interaction between motor habits and gender was not significant ($F=0.13$, $p=0.716$, $\eta_p^2=0.002$). The main effect of motor habits was not significant ($F=0.01$, $p=0.925$, $\eta_p^2=0.000$); the main effect of gender was not significant ($F=0.37$, $p=0.547$, $\eta_p^2=0.007$)

Learning Outcomes and Subjective Ratings

On the learning test, the interaction between exercise habits and gender was not significant ($F=0.01$, $p=0.911$, $\eta_p^2=0.001$). The main effect of exercise habits was significant ($F=6.03$, $p=0.017$, $\eta_p^2=0.097$), with the n-HE group scoring significantly lower than the HE groups, and the main effect of gender was significant ($F=4.46$, $p=0.039$, $\eta_p^2=0.074$), with the male group scoring significantly higher than the female group (Table 2). The results of the study show that subjects in the HE group had significantly better learning outcomes than those in the n-HE group, and that males had significantly better learning outcomes than females.

For mental effort, the interaction between exercise habits and gender was not significant ($F=0.43$, $p=0.516$, $\eta_p^2=0.008$). The main effect of exercise habits was significant ($F=6.02$, $p=0.017$, $\eta_p^2=0.097$) and significantly higher in the n-HE group than in the HE groups; the main effect of gender was significant ($F=5.24$, $p=0.026$, $\eta_p^2=0.086$) and significantly higher in the female than in the male group (Table 2).

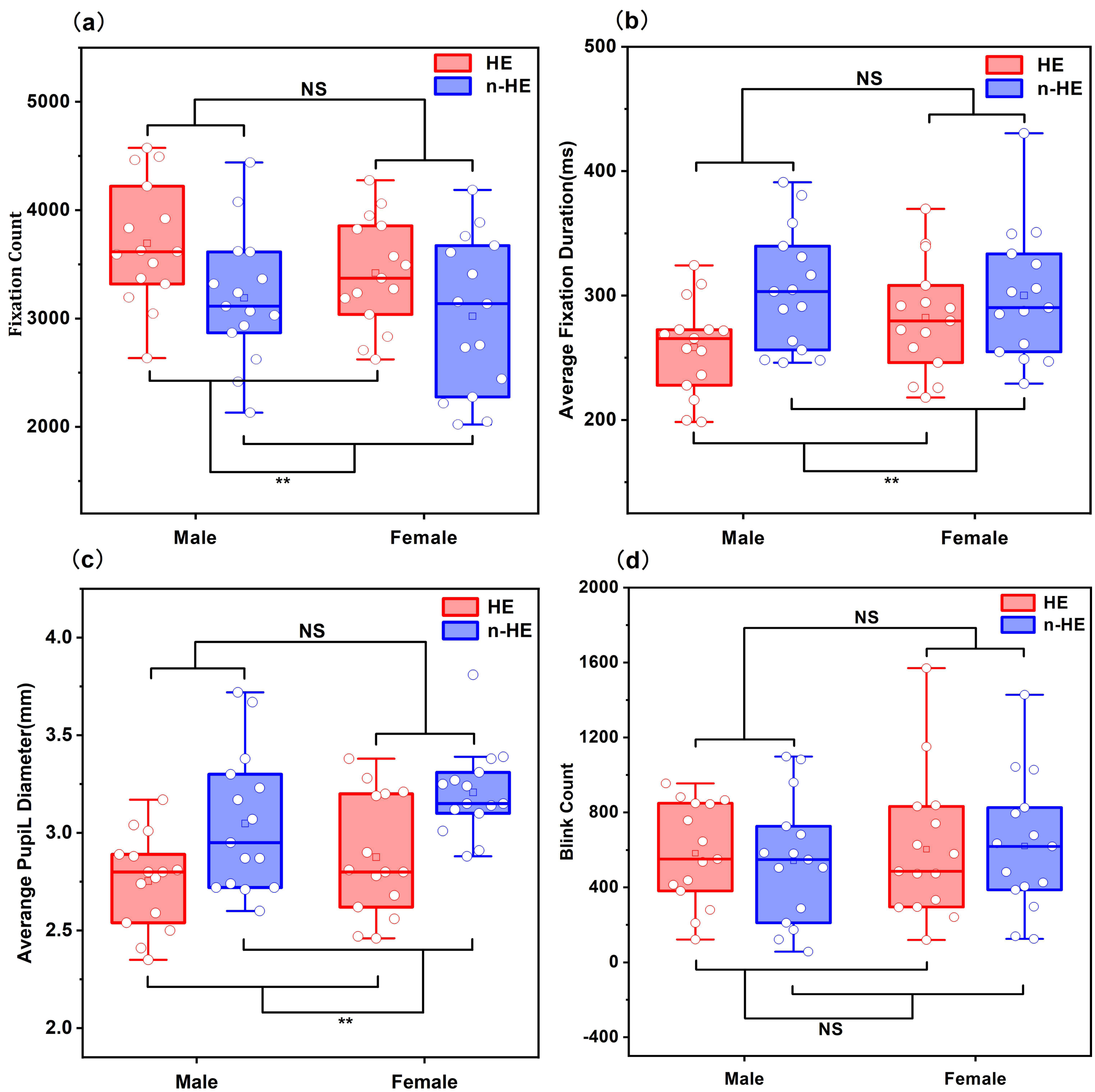

Figure 3 Eye movement results. (**a**) Fixation count, (**b**) Average fixation time, (**c**) Average pupil diameter, and (**d**) Blink count.
Notes: Lines in the boxes represent median values; "□" in the boxes represent mean values; boxes range from the 25th to the 75th percentile; vertical lines range from the minimum to the maximum values, with the symbol "○" represents; NS means this effect is insignificant; *=p <0.05, **=p<0.01.
Abbreviations: NS, non-significant; HE, exercise habit; n-HE, non-exercise habit.

For mental load, the interaction between exercise habits and gender was not significant (F=0.01, p=0.923, η_p^2=0.000). The main effect of exercise habit was significant (F=37.80, p=0.000, η_p^2=0.403) and was significantly higher in the n-HE group than in the HE groups, while the main effect of gender was significant (F=5.04, p=0.029, η_p^2=0.083) and was significantly higher in the female than in the male group (Table 2). The study results indicate that subjects in the HE group had a significantly lower subjective cognitive load compared to those in the n-HE group. Additionally, male subjects had a significantly lower subjective cognitive load than females.

Table 2 Descriptive Statistics for Learning Tests and Subjective Cognitive Load (M±SD)

		HE(n=30)		n-HE(n=30)	
		M (n=15)	**F (n=15)**	**M (n=15)**	**F (n=15)**
Learning outcome	**Learning test**	11.6±1.8	10.3±1.4	10.1±2.7	8.9±2.8
Subjective cognitive load	**Mental effort**	5.9±1.4	6.6±2	6.7±1.7	7.9±1.1
	Mental load	3.9±1.1	4.7±1	6±1.9	6.7±1.2

Abbreviations: HE, Exercise Habits; n-HE, non-Exercise Habits; M, Male; F, Female.

Discussion

We found that although exercise habits did not alter learners' visual preferences, the HE group had lower cognitive load and higher scores on learning tests compared to the n-HE group. This suggests that the HE group is more effective than the n-HE group while dealing with the same task. Sports e-learning is similar to distance learning, while the learner is usually stationary in physical space; therefore, learning effectively needs to rely on the learner's motor imagery skills. Motor imagery is a cognitive process that can be understood as the mental rehearsal of movement or mental representation of movement. It is a way to achieve motor skill learning without relying on muscular activity.[48] While the effects of motor imagery on motor skill learning are inconclusive, some research suggests that the learner's prior knowledge and experience can impact this.[49,50] The subjects in the HE group had a certain knowledge base of motor skills, and the imagery strategy helped to expand their existing mental structures. In contrast, the lack of appropriate schemas may limit the facilitation effect of the n-HE group of subjects who use imagery strategies to construct a systematic mental model. In addition, there is evidence that physical activity, as a spatial activity, is efficacious in improving an individual's ability to perform motor imagery.[51] Specifically, it's possible that physical activity alters the left parietal lobe,[52] which is critical for visuospatial processes related to motor imagery performance.[53] Moreover, long-term physical activity has been shown to enhance feedback from the left inferior parietal lobe in both motor execution and prediction tasks.[54] Therefore, we hypothesized that practice habits would develop learners' motor imagery skills. The HE group was able to transform learning content into a more appropriate mental model, reducing redundant memory and comprehension behaviors during learning. This allowed for the release of working memory load, decreased overall cognitive load and increased learning.

We found that FC was significantly higher in the HE group than the n-HE group. FC is proportional to cognitive demand[55] and reflects the content's attractiveness to the learner.[56] In general, those in the HE group demonstrated greater acceptance of different sports. Through regular physical exercise, individuals accumulate cognitive schemas related to the domain of sports that unconsciously interact with learning materials, reducing unfamiliarity and increasing interest and concentration in new content. As a result, the HE group exhibits higher FC. Furthermore, it has been proposed that a higher number of FC indicates a relatively ineffective visual search process.[57] The phenomenon in question may be linked to using an expert/novice research paradigm. The information reduction hypothesis posits that experts optimize their information processing abilities by directing attentional resources towards relevant stimuli while disregarding irrelevant ones.[58] Notably, this hypothesis assumes that the learning task must be within the expert's domain of expertise.[59] In this study, all subjects in the research were given a novel task to learn. Under this premise, higher FC indicates greater processing efficacy whereby HE group subjects processed more information within a given timeframe. Therefore, the correlation between subjects and materials must be taken into account when utilizing FC to quantify visual search efficacy.

We discovered that the AFD in the HE group was shorter than in the n-HE group. The AFD serves as a typical measure to assess learners' cognitive processing efficiency.[60] A lengthier AFD indicates a higher cognitive allocation to specific stimuli. A cross-disciplinary meta-analysis demonstrated that novices have higher AFD than experts in visual scanning tasks.[61] As previously stated, engaging in exercise may lead to acquiring diverse sports-related cognitive schemas. These schemas may include both conscious rules of motion or unconscious laws of motion and are stored in long-term memory. When relevant learning occurs, these schemas are activated, reducing the strain on working memory.

This implies that the HE group is adept at quickly comprehending and integrating novel information to tailor their internal mental representation within the original cognitive frameworks.

In terms of AFD, we found a significant difference between the HE group and the n-HE group. The size of the pupil is known to increase with cognitive load and is widely used to measure the intensity of mental activity and changes in mental state.[62] Research suggests that learners with higher prior knowledge experience less intrinsic cognitive load than those with lower prior knowledge when presented with the same material.[63] Learning involves the construction of cognitive schemas, where each cognitive schema can be processed as a single piece of information in working memory, and the learner's level of prior knowledge affects the composition of the single piece of information.[64] For subjects in the n-HE group, highly interactive learning materials can result in a working memory threshold below that required by the learning task due to an inability to retrieve relevant schemas from long-term memory to match. Consequently, they must invest more mental effort in balancing cognitive load and learning goals, which is often accompanied by pupil dilation.

Widely accepted as a valid predictor of mental fatigue is the BC.[65] Mental fatigue is a psychobiological state caused by prolonged mental exertion that leads to fatigue and reduced energy, which can result in decreased cognitive performance or the necessity of more effort to maintain initial performance.[66] Indications illustrate that physical activity is a crucial remedy for mental fatigue, and this effect is intensified with increased exercise capacity.[67] However, there was no significant difference in BC between the HE and n-HE groups. Two possible explanations for this result are surmised. First, researchers have suggested that cognitive tasks must last over 30 minutes to induce mental fatigue.[68] In the present study, the task duration was only 24 minutes, which may have obscured any resistance to mental fatigue advantages in the HE groups. Second, we explicitly informed each subject that they needed to do their best to accomplish the tasks in the experiment before the experiment. No monetary remuneration will be provided if the standard is not met during the learning test. The monetary incentive may have equalized the variance in mental fatigue between the HE and n-HE groups.

We noticed considerable differences in visual preferences between males and females. The most notable difference is that males focus more on the content in the video AOI. This aligns with the findings of a prior study conducted by Huang et al, which found that males tend to spend a greater amount of time reviewing visual-based diagrams when solving scientific problems, while females display more frequent transitions between graphical and textual information.[69] Motor skills involve three-dimensional (3D) movement, but most current sports e-learning videos present only a limited or fixed visual angle. Without the aid of Augmented Reality, learners may not be able to fully observe the demonstrator's actions from various perspectives.[70] The translation of a two-dimensional (2D) view into a motor skill trajectory in 3D space would then rely on the spatial ability of the learner. Research in Science, Technology, Engineering, and Mathematics (STEM) fields has indicated that the underrepresentation of females could be attributed to their spatial ability deficit.[71] Multiple studies have consistently shown that males perform better in processing spatial tasks, particularly in mental rotation, whereas females excel in verbal skills.[72,73] Although the underlying mechanisms for this expression of gender dimorphism are not clearly understood, there is considerable evidence that physiological factors play major roles. For instance, males possess a greater proportion of parietal cortex[74] and endogenous testosterone levels[75] are associated with visuospatial cognitive function. The parietal gray matter volume is higher among females, potentially impairing their performance on the mental rotation task.[76] Moreover, as with other cognitive skills, instruction, and training can substantially reduce sex differences in spatial task performance. An assessment of female high school students revealed that three training sessions boosted their mental rotation abilities by a standard deviation.[77] However, there is a lack of training scenarios explicitly designed to enhance female spatial abilities. Instead, some daily activities that are typically associated with males, such as playing video games or building with construction toys, inadvertently stimulate spatial learning experiences.[78,79] This may further amplify sex differences in spatial abilities. Therefore, we hypothesized that for female participants with a weaker learning prerequisite (spatial ability), textual information in the text AOI was required to mentally stereoscopically represent the 2D view in the video AOI. Nevertheless, attention allocation and focus are in conflict. Due to the inability to pause and backtrack throughout the experiment, almost all information acquisition was mostly fleeting. As female subjects diverted more attention from focusing on the whole to auxiliary details, it was easy to break the overall coherence of cognitive thinking and even lead to the collapse of cognitive activities. In contrast, male subjects with higher spatial ability could maintain their attention in the video AOI. Evidence suggests that dynamic visualization learning may be well-suited to learning motor skills due to the "mirror neuron system", resulting in less cognitive load and more positive attitudes among learners exposed to dynamic visualization.[80] It is evident that the specific inclination towards video AOI diminishes males' perception of information or task complexity exactly, thereby allowing them to conserve more cognitive resources during the actual learning process. This provides the necessary conditions for deeper processing of content, construction of more precise mental representations, and ultimately superior learning outcomes.

Interestingly, a discrepancy emerged between subjective and objective measures of cognitive load among females. They self-reported higher cognitive load than males, yet eye-tracking data demonstrated no difference between males and females. The cognitive differences between genders are not solely caused by physiological differences but are also exacerbated by gender stereotypes at the societal level, as evidenced by the learning outcomes. Gender stereotypes arise from a communal agreement regarding gender roles and represent usual behavioral patterns for men and women that are socially and culturally predictable.[81] Regrettably, gender stereotypes are still prevalent in the field of sport and physical activity, despite the growing push for gender equality. After the age of 6, females prefer to adopt a more sedentary lifestyle, while males tend to be more physically active.[82] A study conducted in 62 Global South countries demonstrates that adolescent females exhibit significantly lower physical activity levels than males, particularly in countries with higher incomes and human development indexes.[83] Furthermore, once formed, stereotypes may even influence preschoolers' future interest in academic fields and careers that are inconsistent with their gender self-concept.[84] The current underrepresentation of females in Physical Activity and Sport Science degrees,[85] sport-related professions,[86] and research in sport science[87] is a concerning trend. Gender role mediation theory proposes that gender role identity can either promote or hinder cognitive abilities in sex-typical areas of cognition.[88] This means that positive gender stereotypes improve the cognitive performance of those in the stereotyped group while negative gender stereotypes decrease it. Moreover, females' cognitive performance appears more susceptible to negative stereotypes than males'.[89] For instance, in a soccer task, females showed significantly lower levels of athletic performance, learning ability, and self-efficacy in a stereotype threat scenario.[90] Consequently, we hypothesized that gender self-concepts among females conflicted with the established gender stereotypes of sports e-learning. Women who are bound by the solidified ideas of the gender model tend to value a pretty face and a slim body more, and they fear that participating in traditionally male sports will make them lose their femininity.[91] It is possible that these negative gender stereotypes lower females' self-efficacy, motivation, and emotions during sports e-learning, thereby intensifying their subjective cognitive load, subsequently impacts learning outcomes.

Limitations and Future Directions

This study also has some limitations. Firstly, this study examined the effects of different exercise habits and gender on sports e-learning outcomes, cognitive load, and eye movement metrics, but the cross-sectional study did not reveal causality. Secondly, this study utilized the IPAQ scale to evaluate participants' exercise habits. However, the scale was unable to distinguish the effects of different types of exercise on sports e-learning, despite its ability to calculate the metabolic equivalents of the participants. Thirdly, with the emergence of various platforms and self-publishing media, there is a great deal of variation in the current design, style and category of sports e-learning, which may affect the applicability of the findings. Finally, the study participants were primarily undergraduate students receiving higher education in China, with some geographical and age limitations. Considering that e-learning in sports is inevitably used by a diverse range of individuals in the digital age, this sample may not be representative of all learners. Future studies can further enrich the relevant theories by designing randomized controlled trials with longitudinal interventions and conducting more empirical studies across a wider range of regions, populations, and platforms on more granular sport programs, types, and intensities.

Conclusion

The Internet has made e-learning a crucial channel for people to acquire knowledge about sports and physical activity due to its flexibility and convenience. Exploring and revealing the behaviors and habits of individuals in sports e-learning has significant theoretical and practical value. This study investigated the mechanisms by which exercise habits and gender affect e-learning in sports using eye-tracking technology. The study results indicate that exercise habits effectively enhance sports e-learning outcomes and reduce cognitive load, with significant improvements in fixation counts, average fixation duration, and average pupil diameter in the exercise habits group. Consequently, in order to increase the effectiveness of online learning in sport, learners should be encouraged to develop exercise habits and have sufficient sports experience before learning to facilitate the acquisition and construction of relevant schemas. In addition, the study found that gender plays a role in sports e-learning, with male participants experiencing better learning outcomes and lower subjective cognitive load than female participants. No significant differences were found in eye movement indexes between genders, except for visual preference. Specifically, male participants paid more attention to dynamic visual information than female participants. In general, biological and social factors appear to interact in complex ways that may place females at a disadvantage in sports e-learning. It is crucial for females to challenge traditional perceptions, actively participate in a variety of sport activities, gain a deeper understanding of diverse sport cultures, and break through the potential limitations of internal and external environments on individual behavior.

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Disclosure

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