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Table of Contents

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Abstract

Background: Humans have evolved to sit in a squatting position, whereas in the digitally integrated era epitomized by esports, prolonged sitting on a chair, namely seated position, is a widespread habit linked to body and mind issues. Although standing position promotes health and cognitive performance, the postural influence on cognitive benefits and risks during esports play remains unknown.

Objective: We aimed to test the hypothesis that a standing position enhances esports performance over short periods compared to a seated position, while prolonged standing can lead to cognitive fatigue. Furthermore, we examined whether the forward leaning seated position promotes cognitive dynamics as a possible alternative to the standing position during esports play.

Methods: We recruited 25 collegiate casual esports players. They first performed a crossover session of virtual football gaming for a maximum of 3 hours while standing or seated positions (Experiment 1). During the playing, we measured their subjective sensations, mood, virtual football performance, executive function, heart rate, pupil diameter, and salivary cortisol and testosterone levels. Next, we tested the effect of leaning forward in a seated position during the same virtual football gaming condition through a crossover session with a backward seated position (Experiment 2).

Results: In Experiment 1, standing increased vitality and pleasure, executive function assessed by Flanker interference, and shot performance during the initial 30 minutes. Heart rate, pupil size, and salivary cortisol and testosterone were higher in the standing condition. Beyond 60 minutes, standing slowed interference with increased conceded goals, and 50% of the participants retired during play. In Experiment 2, seated in a leaning forward position enhanced vitality and pleasure, interference, and shot and pass performance than seated in a reclining position during the initial 60 minutes, but led to lower interference and cognitive accuracy after 120 minutes. Reclining seated position slowed interference from the early phase, but accuracy remained unchanged throughout playing.

Conclusions: Our findings provide evidence that standing position for moderate durations (?60 minutes) improves mood, executive function, and esports performance, but standing for prolonged durations (>60 minutes) causes cognitive fatigue, leading to lowered cognitive performances. Furthermore, leaning forward seated position serves as an alternative active sitting mirroring the cognitive dynamics of standing esports play. Reclining seated position supports cognitive endurance with higher accuracy. Ultimately, adopting postures to match cognitive demands could encourage active and healthy lifestyles in today’s co-evolving computer-human society.

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Standing Enhances Esports Performance and Executive Function for Short Durations, but Not for Long: Implications for Positive Sitting

Abstract

Background: Humans have evolved to sit in a squatting, whereas in the digitally integrated era epitomized by esports, prolonged sitting on a chair is a widespread habit linked to body and mind issues. Although standing promotes health and cognitive performance, postural influence on esports play remains unknown.

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Conclusion: Our findings provide evidence that moderate standing (≤60 minutes) improves mood and executive/esports performances, but prolonged standing (>60 minutes) causes cognitive fatigue, leading to lowered performances. Furthermore, leaning forward seating serves as an alternative active sitting mirroring the cognitive dynamics of standing esports play. Reclining supports cognitive endurance with higher accuracy. Adopting posture to match cognitive demands could encourage active and healthy lifestyles in today's co-evolving computer-human society.

Keywords: Cognitive fatigue, esports, mood, posture, virtual football

Introduction

Humans originally evolved to adopt a posture involving constant skeletal muscle activity, often sitting in a 'squatting' position even during intellectual activities and rest [1]. However, people living in industrialized and digitized societies typically sit or recline in a 'chair-style' posture to perform activities such as work, play, or rest, often involving screen time, which greatly reduces muscle activity and the energy costs required to support the body [2,3]. As a result, sedentary lifestyles are known to be associated with a variety of chronic diseases of the body and mind, including cardiovascular disease, diabetes, obesity, cancer, hypertension, osteoporosis, dyslipidemia, depression, and anxiety [4–10]. Furthermore, sedentary behavior impairs not only physical and mental health but also cognitive function and intellectual productivity [11,12]. Exercise may not completely eliminate the health risks associated with sitting, suggesting an inactivity-specific negative effect rather than a lack of exercise benefits [13–15]. Given the pervasiveness of sedentary lifestyles worldwide [16], addressing how chair-sitting habits and postures associated with modern screen time can be modified to mitigate inactivity represents a global challenge that needs resolution ([17,18].

Esports, also known as electronic sports or competitive video gaming, represent a significant form of current sedentary behavior that includes digital cognitive activities [19]. This new category of sports has gained global popularity, especially among young people. Players often engage in extended periods of gameplay for various reasons, such as entertainment, personal achievement, prize money, and honor. While the time spent on esports can vary, a study of 1,835 players revealed an average weekly playtime of 20.03 hours, with 38.85% (approximately 7.75 hours) dedicated to gaming training [20]. Other studies indicate that elite and professional esports athletes may train in gaming between 4.8 and 13.4 hours per day, year-round [21,22]. The physical and mental health implications of prolonged esports play, which involves extended seated screen time, include eye strain, back pain, headache, and insomnia [23,24]. Additionally, a single bout of play can bring cognitive benefits for an hour, but playing for 2 or more hours can lead to cognitive fatigue [25,26]. This fatigue is characterized by a reduction in executive function and pupil constriction, which is an indirect measure of brain activity [25]. Thus, esports, blending intense cognitive engagement with minimal physical activity, present a unique and generalizable context for the cognitive activity and work of modern humans to study the impact of posture on health and cognitive performance.

A growing movement within the esports field advocates the utilization of sports science findings to address these issues, striving to achieve a balance between high performance and health [27,28,29]. A trailblazing study indicated that acute high-intensity intermittent exercise, which is an effective condition for executive function, can enhance esports playing performance in multiplayer online battle arenas [30]. Additionally, a 6-minute walking break during 2 hours of gameplay improves processing speed and executive function, although it does not affect the esports performance in first-person shooters [31]. Given these findings, it is crucial to recognize that incorporating exercise to enhance performance, rather than solely for health benefits, may lead to a reduction in inactivity and poor health. Nevertheless, the primary challenge is that exercise in isolation cannot mitigate the health risks associated with extended sitting periods.

Thus, adjusting the “playing posture,” which underpins basic activity in esports, may be a key strategy for improving performance and resulting in a healthy lifestyle. However, studies examining the effects of posture on esports are lacking. Therefore, could transient postural modifications positively impact cognitive performance? For example, standing, a primary countermeasure to excessive sitting, enhances executive function, as evaluated by the Color-word Stroop task, and cognitive flexibility, as measured by the task-switching test, compared to short periods of sitting (2-10 minutes) [32–35]. Conversely, repetitive tasks in prolonged standing, such as those exceeding 40 minutes, diminish cognitive task performance [36], along with physical symptoms such as pain and discomfort in the back and lower limbs [37]. Therefore, it is tempting to postulate that the standing posture improves esports performance in the short term, while decreasing it over longer durations.

However, most esports activities and related work cannot be completed within 40 minutes. Therefore, adopting a seated posture that mimics the standing position may be a secondarily important strategy. While squatting based on human sitting evolution could be considered for this purpose, it might not be suitable for the movement of modern digital cognitive activities involving screens, such as esports. This raises the following question: Could subtle adjustments in chair posture be employed to modulate cognitive performance? A previous study suggested that subjects in upright sitting postures may demonstrate higher processing speed, while those in stooped sitting postures could exhibit improved processing accuracy, particularly in young adults [38]. Upright sitting postures also enhance calculation and word memory with a positive mood in boys [39]. As a possible mechanism, a leaning forward seated position with an upright back can enhance motivational mood and activate the left frontal area of the brain [40]. This is likely due to the antigravity musculature activity depending on the joint torque required to oppose the gravity toppling torque [41]. Based on these findings, it is possible that a leaning forward seating posture serves as an alternative active posture, mimicking the cognitive dynamics of standing during esports play.

In this study, we hypothesized that a standing position enhances esports performance over short periods compared to a seated position, while prolonged standing can lead to cognitive fatigue. To test this hypothesis, we first engaged collegiate esports players and examined the effects of standing and seated positions on psychophysiological dynamics during prolonged esports play (Experiment 1). The results supported our hypothesis. Next, we explored alternatives to standing by testing the effects of leaning forward or reclining backward in a seated position on psychophysiological dynamics during prolonged esports play (Experiment 2). Our findings suggest that a leaning forward seated position could be an effective alternative to standing for higher cognitive and esports performances.

Methods

Participants

We recruited 25 participants, defined as casual players who typically enjoy playing video games but either do not participate or rarely participate in competitive tournaments. This group consisted of individuals from 2 separate experiments: Experiment 1 included 10 male players, and Experiment 2 included 15 male players. Participants were selected from the University of Tsukuba's student population and attendees of gaming communities in Akihabara, Japan. We conducted a power analysis with $\eta^2 = 0.16$, referring to a previous study on the effects of standing on cognitive tasks [32]. A power analysis using G-power 3.1 software showed that a total of 16 participants (8 participants per condition) would be sufficient to detect a significant difference between 2 dependent means in a 2-sided analysis with 0.05 alpha and 80% power. The inclusion criteria for participation were as follows: age between 18 and 35 years; ability to understand and sign an informed consent form; no color blindness; no current medication for neuropsychiatric, cardiovascular, or metabolic diseases; and the ability to visit the site of the experiment.

Experimental design

This study was approved by the Research Ethics Committee of the Institute of Health and Sport Sciences, University of Tsukuba, and was conducted in accordance with the Declaration of Helsinki. When requesting participation in the experiment, an outline of the experiment was sent to the participants via e-mail. 2 to 7 days before the measurement, the participants played virtual football (eFootball 2021, Konami Digital Entertainment Co., Ltd., Japan) for at least 1 hour at the measurement site to decide on a team to use on the day of measurement and to acclimate to the game environment, postures, and cognitive tasks. Before acclimation, the body weight and height of the participants were measured, and a blood glucose sensor was placed on the participant's nondominant arm. Before the experiment, the participants were prohibited from consuming alcohol from the day before the experiment until its end, from consuming caffeine and engaging in strenuous exercise on the day of the experiment, and from eating 2 hours before the start of the experiment.

On the day of measurement, the room temperature and humidity were maintained at 23 ± 2°C and 50 ± 10%, respectively. The participants visited the laboratory, received an explanation of the experiment again, and signed an informed consent form. A heart rate monitor was placed on the participants' chest and they rested in a sitting position for 10 min. After resting, the participants played a virtual soccer game alone against gaming AI (standard level) for a total of 3 hours while standing or sitting (Experiment 1, Figure 1A) or sitting in leaning forward or reclining backward (Experiment 2, Figure 5A). In Experiment 1, participants could retire if they were unable to continue play due to fatigue, discomfort, etc.

In Experiment 1, for the sitting condition, a functional gaming chair (STRIKER, Okamura, Japan) with an adjustable backrest and seat angle was used (Figure 1B). The chair height was similarly adjusted for a comfortable gameplay. For the standing condition, we used a standing desk (STRIKER DESK Swift, Okamura, Japan) with an adjustable height ranging from 65 to 125 cm. The desk height was adjusted to ensure comfortable gameplay for the participants (Figure 1C), with an average height set at 109.4 ± 4.2 cm. In Experiment 2, for the reclining backward condition, the chair's backrest and seat were reclined by 23 degrees (Figure 5B). For the leaning forward sitting condition, the same gaming chair was utilized, with its backrest and seat angled forward by 10 degrees (Figure 5C). The participants received no posture instructions in either condition.

Playing conditions were as follows: 1) regulation time was 10 minutes per game without extra time, 2) penalty shootout was performed when a game ended in a tie, 3) no injuries in playing avatars, and 4) the weather was sunny. The participants used only 1 team decided before the experiment, and the opponent was the same team by gaming AI (standard level). The participants drank fresh waters total of 400–500 ml separated by 3 times every hour during the experiment. We measured their subjective sensations, mood, and executive function before (Pre) and during the game (15, 30, 60, 120, and 180 min, respectively) and collected saliva to measure cortisol and testosterone levels. During play, the pupil diameters of the participants were measured using an eye tracker. The duration of the experiment, from visiting the laboratory to dismissal, was approximately 300 minutes. After completing the experiment, the participants received an honorarium equivalent to 5,000 yen.

Psychological questionnaires

A two-dimensional mood scale (TDMS) was used to measure mood [42], consisting of eight items that describe mood and represent 4 types of psychological states: activation, which represents energetic arousal; stability, arousal due to tension; pleasure, the degree of overall pleasantness or unpleasantness; and arousal, the degree of overall excitement or calmness. These 4 psychological states can be expressed as composite variables of the scale scores. Responses were scored on a 6-point scale ranging from "not at all" (0 points) to "very much" (5 points).

Participants were asked about 2 subjective sensations, enjoyment and sense of fatigue, using a visual analog scale (VAS). The VAS length was 100 mm, and words indicating the degree of sensation were noted at both ends. According to previous studies [43,44], the enjoyment items ranged from "enjoyed it not at all" to "enjoyed it very much," and the sense of fatigue items ranged from "no fatigue" to "Very severe fatigue." Participants were asked to mark the position in the line segment that best represented the degree of sensation they were currently feeling. The distance from the left end of the line segment to the intersection of the x-mark and line segment was measured and scored as a percentage (%) of the length of the entire line segment.

Executive functions

To measure executive function during esports play, 3 cognitive tasks, the Flanker task, Stroop task, and Simon task, were created using PsychoPy2, according to a previous study [45]. All tasks were presented in random order, with the same number of stimuli for all types presented. All tasks consisted of repeated gazing, presentation, and blank screens. The presentation times were 250 ms, up to 2000 ms, and 1000 ms, respectively. The presentation stimulus was shifted to a blank screen when the participant pressed the key used to answer the questions. The details of each task are shown in our previous study [25]. In all tasks, the reaction time and correct rate were recorded for task performance. This study adopted interference, a specifically defined cognitive process, to elucidate the effect of acute prolonged esports playing on executive function. We detected interference by calculating the incongruent–congruent contrast of the reaction time for all tasks. All cognitive tasks were conducted with participants seated in a chair, positioned at a standard angle, and at an approximate distance of 60 cm from the screen.

Esports performance

We assessed esports performance by measuring in-game statistics as indicators of virtual football performance. The monitored parameters included ball possession, shots, shots on the target, fouls, passes, completed passes, interceptions, tackles, and saves. These parameters were recorded for each match in this study.

Physiological measurements

To evaluate the physiological impacts of prolonged esports play, we measured the heart rate, posture (including hip joint angles and backrest pressure levels), salivary cortisol and testosterone levels, blood glucose levels, and pupil diameter. Heart rate was monitored using a band-type heart rate sensor (Polar H10; Polar, Finland) placed on the chest. Blood glucose levels were measured using a sensor (Freestyle Libre; Abbott, IL) attached to the arm. These measurements were recorded at a frequency of once per second for heart rate and once every 15 minutes for blood glucose levels during gameplay.

To assess posture, we used 2 methods: markerless motion capture and chair pressure sensors. In the markerless motion capture system (Vision Pose, Next System, Japan), we employed a video camera to record the subjects playing esports from the left side. The recordings were segmented at 10, 25, 55, 115, and 175 minutes after gameplay commenced, aligning 5 minutes prior to each measurement time. We then calculated the angle formed between the side of the body and thigh (acromion-abductor-knee angle) to assess the forward-backward inclination of the upper body. For pressure measurement, we used the Life Chair and Life Seat (LIFEFORM AI, Australia) to record the pressure exerted on the chair during the gameplay. Sensors were attached to both the seat and backrest to measure the pressure on the 9 built-in sensors. The pressure readings from these sensors were averaged for different play durations: 0-15 minutes, 15-30 minutes, 30-60 minutes, 60-120 minutes, and 120-180 minutes. These averaged values were then used for the analysis.

Salivary cortisol and testosterone levels were measured as neuroendocrine markers to ascertain the stress response and physical load associated with prolonged esports play. Saliva was spit directly into a sample collection tube using a straw. 2 milliliters of saliva was collected and stored immediately after collection in a freezer at -80°C. To precipitate mucus, sample tubes were centrifuged at 1,500 × g for 20 min each. The supernatant was collected, and aliquots were stored at -80°C until assayed. Cortisol concentration was measured using a commercial OT enzyme-linked immunosorbent assay (ELISA) kit (Salimetrics, LLC.), providing a quantitative assay for cortisol levels in human saliva. Measurements were performed in duplicate according to the kit's instructions. Absorbance was determined, and the concentration of cortisol in the samples was calculated with relevant standard curves using a microplate reader (Varioskan LUX Multimode Microplate Reader, Thermo Fisher Scientific, MA).

An eye tracker (Tobii Pro Nano, Tobii Technology, Sweden) with an infrared camera was used to measure pupil diameter as an indirect indicator of prefrontal activity. The illuminance at the center of the room and the eye position were standardized to 250–300 lux during the playing experiment. The eye tracker was placed at the bottom of the monitor, where the esports game was played, and connected to a dedicated laptop placed next to the monitor for recording. The participants stood or were seated approximately 60 cm away from the monitor in all conditions. The eye tracker was calibrated before the start of the first round of play and was constantly recorded until the end of play. After the experiment, only the recorded data were extracted and included in the analysis. The pupil diameter data were recorded at 60 Hz, according to our previous study [25].

Statistical analysis

GraphPad Prism 10 software was used for all the statistical analyses. The playing proportions to retire were analyzed using a rog-rank test. The playing duration was analyzed using a paired t-test between the standing and seating conditions. Other data measured during the experiment were analyzed using 2-way analysis of variance (ANOVA). When a significant interaction or main effect was observed, Bonferroni’s multiple comparison test was performed. All data are presented as the mean ± standard deviation. The threshold for statistical significance was set at $P < 0.05$.

Results

Experiment 1: Short, but not long, duration of standing enhances mood, executive function, and esports performance

To examine the effect of standing versus seated postures on psychophysiological dynamics during extended esports play, we conducted a crossover session involving virtual football gaming for up to 3 hours (Figure 1A). Ten young adult male casual esports players (age: 24.7 ± 3.1 years, height: 173.8 ± 7.8 cm, weight: 72.3 ± 4.5 kg, playing time per week: 21.4 ± 3.5 hours) participated and alternated between sitting on a chair (Figure 1B) and standing (Figure 1C). During the session, the hip angle in the standing position was significantly greater than that in the seated position (175.6 ± 2.7° vs. 128.9 ± 0.9°, respectively) ($F = 292.2$, $P < 0.05$, $\eta^2 = 0.65$) (Figure 1D). Notably, in the standing condition, half of the participants withdrew due to a sense of fatigue and lower extremity discomfort, whereas all participants in the seated condition completed the full 180 minutes ($\chi^2 = 5.7$, $P < 0.05$) (Figure 1E). The average duration of play while standing was 141.7 ± 45.2 minutes, with the minimum duration being 60 minutes ($t = 2.8$, $P < 0.05$, $d = 1.3$) (Figure 1F). The playing duration for participants who retired from standing condition was 103.4 ± 27.1 minutes. These results suggest that a standing posture limits the duration of esports play.

During the first 60 minutes of esports play, participants in the standing condition showed increased vitality ($F = 3.07$, $P < 0.05$, $\eta^2 = 0.03$) (Figure 2A) and pleasure levels ($F = 1.93$, $P < 0.05$, $\eta^2 = 0.04$) (Figure 2B), along with an increase in subjective fatigue ($F = 7.21$, $P < 0.05$, $\eta^2 = 0.06$) (Figure 2C), compared to those in the seated condition. However, beyond 120 minutes, the differences in these aspects between the standing and seated conditions diminished (Figure 2A-C). Enjoyment levels remained consistent regardless of posture until 120 minutes but decreased at the end of playing in the standing condition compared to the seating condition ($F = 6.72$, $P < 0.05$, $\eta^2 = 0.02$) (Figure 2D). In the standing condition, the interference time for the Flanker task was shorter at 15 minutes into play compared to pre-play, but experienced a greater delay at 60 minutes than in the sitting condition ($F = 3.4$, $P < 0.05$, $\eta^2 = 0.12$) (Figure 2E). In contrast, while seated, the interference time was significantly less than pre-play at 60 minutes but reverted to pre-play levels after 120 minutes (Figure 2E). No significant impact on the correct rate (accuracy) of the Flanker task was found in relation to playing time or posture ($F = 0.43$, $P = 0.75$, $\eta^2 = 0.03$) (Figure 2F). No effect was observed on the performance in the Stroop or Simon tasks throughout the experiment (Supplementary figure 1). These results suggest that short durations of standing (up to 60 minutes) during esports play positively influence mood and executive function more than seated play.

Conversely, standing for more than 60 minutes lead to the opposite effect.

Performance analysis in esports showed that players in a standing position had a significantly higher shot accuracy ($F = 1.47$, $P < 0.05$, $\eta^2 = 0.03$) (Figure 3A), number of shots ($F = 7.4$, $P < 0.05$, $\eta^2 = 0.19$) (Figure 3B), and shots on the target ($F = 7.3$, $P < 0.05$, $\eta^2 = 0.18$) (Figure 3C), particularly during the 15-60 minutes interval, compared to those in a seated position. No significant differences were found in other metrics (Supplementary figure 2), such as the number of passes (Figure 3D) and goals conceded (Figure 3E). However, an increase in goals conceded in the final game was noted among players who withdrew from standing play, in contrast to those who did not withdraw in either the sitting or standing position ($F = 9.32$, $P < 0.05$, $\eta^2 = 0.63$) (Figure 3F). These findings support the hypothesis that standing enhances esports performance over shorter periods than sitting, while prolonged standing leads to cognitive fatigue and decreased esports performance.

Experiment 1: Standing play increases heart rate, cortisol, testosterone, and pupil diameter

Neurophysiological analysis during esports play revealed a consistently elevated heart rate in participants in the standing condition ($F = 7.1$, $P < 0.05$, $\eta^2 = 0.25$) (Figure 4A). Cortisol levels, indicative of stress, were significantly higher in saliva in the standing condition during the first 30 minutes of play, but equalized with those in the seated condition after 60 minutes ($F = 5.8$, $P < 0.05$, $\eta^2 = 0.07$) (Figure 4B). Testosterone levels, associated with self-confidence and cognitive function, were also elevated in the standing condition for the first 30 minutes ($F = 2.5$, $P < 0.05$, $\eta^2 = 0.03$) (Figure 4C). However, after 60 minutes, these levels did not differ significantly from those in the seated condition (Figure 4B, C). No substantial effect of posture on blood glucose levels was observed ($F = 1.9$, $P = 0.14$, $\eta^2 = 0.01$) (Figure 4D). In addition, pupil diameter (Figure 4E) and its change levels (Figure 4F), which serve as indirect markers of brain activity, were consistently larger in the standing condition throughout the play period ($F = 4.2$, $P < 0.05$, $\eta^2 = 0.08$). These findings indicate that the physiological demands of standing play are higher than those of seated play. The increased physiological load associated with standing is likely the mechanism that facilitates body and mind activation, contributing to short-term benefits in cognitive and esports performance. However, these benefits are not maintained over extended periods, leading to cognitive fatigue. This fatigue is potentially due to decreased cognitive efficiency, as evidenced by increased pupil size over time, rather than energy depletion, given stable blood glucose levels.

Experiment 2: Short, but not long, duration of leaning forward seating enhances mood, executive function, and esports performance

To explore alternatives to standing positions, we investigated the effects of leaning forward versus reclining backward in a seated position on psychophysiological dynamics during prolonged esports play. A 3-hour crossover session was conducted, involving virtual football gaming (Figure 5A). Fifteen young adult male casual esports players (ages 24.1 ± 2.9 years, heights 172.4 ± 5.3 cm, weights 71.2 ± 5.5 kg, and weekly playing times of 23.4 ± 6.5 hours) participated, alternating between leaning forward (Figure 5B) and reclining backward (Figure 5C) in their seats. During the session, the hip angle was marginally smaller in the forward-leaning position than in the reclining backward position (120.4 ± 2.8° vs. 131.5 ± 1.3°, respectively) ($F = 9.6$, $P < 0.05$, $\eta^2 = 0.17$) (Figure 5D). The pressure sensors on the chair's backrest (Figure 5E) indicated that the pressure levels were significantly lower at the top ($F = 34.4$, $P < 0.05$, $\eta^2 = 0.18$) (Figure 5F), middle ($F = 39.9$, $P < 0.05$, $\eta^2 = 0.16$) (Figure 5G), and bottom ($F = 12.3$, $P < 0.05$, $\eta^2 = 0.07$) (Figure 5H) of the chair in the forward leaning position. None of the participants withdrew from the session because of fatigue or discomfort. These results suggest the potential of the forward-leaning seating posture to facilitating antigravity muscle mobilization while minimizing fatigue, discomfort, and its impact on the hip angle during prolonged esports play.

During the first 120 minutes of esports play, participants in the leaning forward seating condition showed increased vitality compared to those in the backward reclining condition ($F = 5.6$, $P < 0.05$, $\eta^2 = 0.07$) (Figure 6A), while pleasure levels remained unaffected by sitting posture ($F = 0.53$, $P = 0.75$, $\eta^2 = 0.04$) (Figure 6B). Subjective fatigue increased at the end of play ($F = 17.7$, $P < 0.05$, $\eta^2 = 0.26$), but no significant impact of posture was observed ($F = 2.4$, $P = 0.81$, $\eta^2 = 0.01$) (Figure 6C). Enjoyment increased during play ($F = 9.7$, $P < 0.05$, $\eta^2 = 0.18$); however, sitting postures were not affective ($F = 0.15$, $P = 0.71$, $\eta^2 = 0.001$) (Figure 6D). In terms of executive function, as indicated by the Flanker task, interference time was significantly reduced following 60 minutes of forward leaning compared to backward reclining ($F = 4.4$, $P < 0.05$, $\eta^2 = 0.05$) (Figure 6E). However, this improvement reverted to baseline levels after 120 minutes or more. In contrast, over 60 minutes of backward leaning increased the interference time on the Flanker task ($F = 2.5$, $P < 0.05$, $\eta^2 = 0.08$) (Figure 6E). Accuracy in the Flanker task declined after 180 minutes of forward leaning ($F = 4.4$, $P < 0.05$, $\eta^2 = 0.17$), but remained consistent with backward reclining (Figure 6F). At this juncture, no effect was observed on performance in the Stroop or Simon tasks (Supplementary figure 3). These findings show distinct mental work characteristics associated with virtual football play in both forward and backward leaning sitting positions.

Esports performance analysis revealed that shot accuracy did not change with different posture conditions ($F = 0.001$, $P = 0.97$, $\eta^2 < 0.001$) (Figure 7A). However, players in the forward-leaning seating position had a significantly higher number of shots ($F = 2.3$, $P < 0.05$, $\eta^2 = 0.05$) (Figure 7B), shots on target ($F = 2.1$, $P < 0.05$, $\eta^2 = 0.04$) (Figure 7C), number of passes ($F = 6.4$, $P < 0.05$, $\eta^2 = 0.03$) (Figure 7D), and completed passes ($F = 5.2$, $P < 0.05$, $\eta^2 = 0.04$) (Figure 7E), especially in the initial 15-30 minutes, compared to those in a backward reclining seated position. Conversely, the number of intercepts was greater under the reclining condition than under the forward-leaning condition ($F = 11.8$, $P < 0.05$, $\eta^2 = 0.02$) (Figure 7F). No significant differences were found in other metrics (Supplementary figure 4). These findings suggest that a forward-leaning seated position could be an effective alternative to standing for enhanced cognitive and esports performance, while reclining supports cognitive endurance with higher accuracy.

Long duration of seating while leaning forward, but not reclining, decreases pupil diameter

Neurophysiological measurements taken during esports play revealed that changes in sitting posture did not significantly affect the heart rate ($F = 1.7$, $P = 0.22$, $\eta^2 = 0.02$) (Figure 8A), salivary cortisol ($F = 0.21$, $P = 0.66$, $\eta^2 < 0.001$) (Figure 8B), testosterone ($F = 0.05$, $P = 0.82$, $\eta^2 < 0.001$) (Figure 8C), or blood glucose levels ($F = 0.13$, $P = 0.73$, $\eta^2 = 0.003$) (Figure 8D). However, pupil diameter, an indirect indicator of brain activity, did not change (Figure 8E), but Δpupil size exhibited a significant reduction after 120 minutes compared to after 60 minutes in the forward-leaning sitting condition ($F = 6.0$, $P < 0.05$, $\eta^2 = 0.05$) (Figure 8F). This reduction coincided with the Flanker interference time returning to baseline levels, in notable contrast to the improvement observed at 60 minutes. Conversely, in the backward reclining sitting position, pupil diameter remained unchanged, which mirrored the consistent executive function accuracy observed in this posture ($F = 0.45$, $P = 0.64$, $\eta^2 = 0.009$) (Figure 8F). These results indicate that leaning forward in a chair does not result in a greater physiological load than reclining backward. Consequently, the advantages of forward leaning for up to 60 minutes are likely due to psychological effects via brain activity. In contrast, engaging in esports while leaning forward for over 120 minutes likely leads to cognitive fatigue, which can be attributed to decreased brain activity, as evidenced by a reduction in pupil diameter.

Discussion

Principal Findings

We aimed to test the hypothesis that standing enhances esports performance over short periods compared with sitting, but that prolonged standing may induce cognitive fatigue. To this end, we enlisted casual esports players and investigated the impact of standing versus sitting on psychophysiological dynamics during extended periods of play (Experiment 1). Our findings corroborated the hypothesis, indicating that standing postures restrict the duration of esports gameplay. Subsequently, we examined alternatives to standing, assessing the effects of leaning forward, versus reclining backward, while seated on psychophysiological dynamics in prolonged esports play (Experiment 2). The results indicate that forward leaning seating, as an active sitting posture, emulates the cognitive dynamics of standing in esports. Conversely, reclining appeared to bolster cognitive endurance and enhance accuracy (Figure 9).

Standing play enhances esports performance

In Experiment 1, we observed that up to 60 minutes of standing play in esports, combined with mood and executive function assessments, promoted aggressive gameplay, characterized by increased shooting accuracy and a higher number of shots fired (Figure 3A-C). These positive aspects of standing align with previous research suggesting that standing enhances cognitive function [46,47]. Although the culture of standing play for esports has not yet been established, it may represent an effective new posture strategy that encourages aggressive and speedy play.

It has been noted that standing may require more cognitive resources to maintain balance and posture, potentially enhancing cognitive control, including selective attention [47]. This improvement might be attributed not only to the heart rate elevation we observed (Figure 4A), but also to the activation of the prefrontal cortex, a key area in executive functioning. For instance, studies indicate that challenging postural tasks, such as balancing one leg, stimulate the prefrontal cortex [48]. Moreover, our study observed early increases in cortisol and testosterone levels during standing play (Figure 4B&C). Transient cortisol elevations indicate physiological stress, which is known to enhance amygdala activity and cognitive function [49]. Similarly, temporary testosterone increases, attributed to moderate muscle activity and a "power-posing effect" [50], have been reported to benefit executive function, aggression, and social skills [51]. Consequently, a physiological load with moderate hormonal increases appears to bolster cognitive function, likely influencing aggressive performance in esports.

However, the literature presents a mixed view of the impact of standing on cognitive function. While some studies highlight its positive effects, others report no significant difference in cognitive performance between sitting and standing [52]. Some studies even suggest that sitting is more comfortable and less distracting, although posture does not seem to directly affect cognitive performance [53]. A correlation has also been noted between standing postural balance and cognitive dysfunction, implying a link between balance maintenance and cognitive health [54]. Given that standing postural control often involves multitasking (e.g., reading or talking while standing), it could adversely affect cognitive task performance, especially in individuals with cognitive impairment [55]. Thus, the influence of posture on cognitive performance may depend on specific cognitive tasks, individual differences, and other factors.

Video games are not just cognitive tasks; they also involve a significant play element known to activate the dopamine system as a reward mechanism [56]. Furthermore, although not directly tested in the context of standing posture, recent studies have suggested that muscle activity under central command activates the human dopaminergic system, thereby enhancing cognitive function [57]. Since maintaining a standing posture naturally involves central command, playing esports while standing could additively or synergistically stimulate the dopaminergic system, improving cognitive function and resulting esports performance. This explanation is supported by our findings, in which pupil diameter, an indirect indicator of dopaminergic activity [58,59], was larger during standing play than during sitting (Figure 4E&F).

Prolonged standing during gameplay leads to early cognitive fatigue

While standing play is initially effective, maintaining it for over 60 minutes poses significant challenges. Our study revealed that half of the participants experienced considerable fatigue, leading to withdrawal from the esports play experiment (Figure 1E&F). For the first time, our observations indicate a decline in mood, cognitive function, and esports performance as a consequence of prolonged standing play (Figure 2&3). This cognitive decline hints at the redirection of cognitive resources from primary tasks to maintaining posture, thereby negatively impacting cognitive function and performance. Supporting this, prior research indicates that older adults, often more prone to fatigue, are particularly susceptible to cognitive fatigue owing to the increased attention required for posture processing compared to younger individuals [60]. Such redirection of cognitive effort is likely to result in decreased neural efficiency, culminating in suboptimal performance [61,62]. Notably, in our study, pupil diameter, serving as a marker for dopamine and noradrenaline neuronal activity, was significantly larger during standing play than during seated play, indicating prolonged neuronal overstimulation (Figure 4E&F). The observed increase in pupil diameter occurs simultaneously with heightened cognitive decline, increased feelings of fatigue, and mood aggravation, which is particularly noticeable in the latter half of playing. This period is marked by a decline in cognitive function and esports performance, which is potentially attributable to lowered neural efficiency.

Overall, our results suggest for the first time that standing for short periods of 30-60 minutes is beneficial not only for physical health but also for cognition, particularly in esports performance. Conversely, prolonged standing may have detrimental effects. However, few cognitive activities in the modern world are completed within 30-60 minutes. Therefore, it is crucial to explore “positive sitting” strategies that mitigate the disadvantages while retaining the benefits of standing.

Sitting leaning forward enhances esports performance

Although squatting has evolved into a resting position akin to standing [1], it is unsuitable for contemporary cognitive tasks, particularly when using a keyboard and mouse in front of a screen [63,64]. The optimal posture for such tasks involves sitting with the keyboard and mouse positioned at a comfortable angle to ensure that the wrists are straight for ease of access [65,66]. However, this posture is challenging to maintain during squatting. Therefore, in Experiment 2, we examined the efficacy of a forward-leaning posture in a chair-sitting position and compared it with that of a backward-reclining posture. Our findings indicate that leaning forward significantly reduced the load on the backrest without markedly altering the hip angle (Figure 5D), thereby possibly promoting antigravity muscle activity without excessively burdening the hips and internal organs (Figure 5F-H). Recent studies have shown that postures involving only forward head tilt can impair cognitive function [67,68]. However, a sitting posture in which both the seat and back are tilted forward, inclining the entire body, could be a modern alternative to squatting.

This forward-leaning sitting posture, resembling the standing position, was initially found to enhance positive mood, cognitive agility, and aggressive gameplay, such as shooting and passing, in early stage esports performance (Figure 6&7). While heart rate, hormones, and blood glucose levels remained unchanged (Figure 8A-D), pupil diameter, a proxy for brain activity, and its variability were greater with forward-leaning than reclining conditions (Figure 8E&F). Therefore, anterior tilt in a seated position might modulate brain activity rather than the peripheral bodily state. If increased pupil diameter indicates activation of the dopaminergic system, forward-leaning sitting combined with esports play could enhance mood, cognitive function, and performance through a cumulative increase in dopaminergic activity, as we do with standing play. Earlier research has shown that a forward-leaning seating position with a horizontal seat surface boosts motivational mood and frontal brain activity [40]. Consequently, the forward-tilted sitting posture, including the seat surface, can be considered a contemporary, beneficial alternative to standing or squatting.

However, maintaining a forward-leaning sitting posture for over 120 minutes led to cognitive fatigue, marked by delayed Flanker interference time and diminished accuracy (Figure 6E&F). The reduced pupil diameter during this period suggests that cognitive fatigue stemmed from decreased brain activity (Figure 8F). Conversely, reclining sitting initially delayed Flanker interference time but mitigated the cognitive fatigue (reduced accuracy) caused by prolonged sitting leaning forward (Figure 6E&F). The pupil diameter, which was consistently smaller from the early phase of playing, might have facilitated sustained cognitive endurance while minimizing brain activity. These findings corroborate previous theories on the trade-off between cognitive speed and accuracy [69–71], suggesting that varying leaning forward and reclining backward within the same sitting position can selectively modulate specific cognitive demands for different objectives (Supplementary figure 5).

Evolution of Sitting Posture: From Squatting to Sitting Leaning Forward

Homo sapiens has historically engaged in both physically and mentally healthy activities by adopting a squatting posture while sitting, which links muscular and cerebral functions [1]. This posture is practical for advanced cognition-based human activities, such as hunting and gathering with tools, including language and fire. Such a squatting posture can be viewed as a foundational aspect of the evolution of Homo sapiens as thinking beings. The underlying motivator for this may have been "enjoyment," potentially driven by dopamine release through muscle activity coordinated with central neural commands, thus positioning squatting as a play-based, or "homoludic," posture [72]. However, in our contemporary industrialized and digital world, the widespread habit of sitting in chairs has led to a disconnection from this evolutionarily significant posture and the "cognitive play" it supported. This study, which employed esports as a model of the modern form of cognitive play, provides insights into postures that could further support the co-adaptation of Homo sapiens and Homo ludens in this era of digital-human co-evolution.

Cognitive dynamics exhibited only in the Flanker task

Our study offers significant insights into the impact of posture on cognitive functions in esports play. We observed that moderate play, characterized by relatively short durations, enhances executive performance, as assessed by the Flanker task (Figure 2&6). However, this improvement was not observed in the Stroop and Simon tasks (Supplementary figure 1&3). These data are consistent with those of our previous study [25]. This selective enhancement may be attributed to the strategic transfer of skills to cognitive tests that resemble the tasks encountered in virtual football games. Conversely, prolonged play in leaning forward sitting was found to induce cognitive fatigue, characterized by a decline in both cognitive agility and accuracy (Figure 6E&F), which is also consistent with our previous study [25]. These findings highlight a strong correlation between the specific skills utilized in the esports title and the corresponding improvement or deterioration in cognitive functions, which is called "common demand theory [73]." Therefore, our study contributes to the understanding that the enhancement and fatigue of cognitive abilities in video gaming are distinctly reflected in the skills employed in playing specific esports titles.

Limitations

First, the sample size was estimated *a priori* using G-Power 3.1; however, the sample size was relatively small. Despite this, distinct differences were observed in mood, executive function, heart rate, hormones, pupil size, and virtual football performance, affirming the validity of our results. Second, we proposed possible virtual football-specific cognitive dynamics during play while considering various postures in young adult players (25 male casual players). However, it remains unclear whether this phenomenon can be replicated in other gaming genres or in participants of different genders and ages. Future investigations should involve different titles and diverse participants, as competitive characteristics vary significantly across esports genres, such as first-person shooting, fighting, and racing [74,75]. Third, to assess the influence of each posture in the current study, the participants were instructed to play in a standardized posture for each condition. However, the recent introduction of mixed standing and seated postures has shown potential in reducing postprandial blood glucose levels [76], and improving cognitive function through enhanced cerebral blood flow, increased neurotrophic factors, and reduced inflammation [77]. Consequently, future research into the potential positive effects of periodic postural shifts on esports performance, as well as mental and physical well-being, would present a more effective proposal for the field.

Conclusions

Our findings demonstrate that a standing position improves mood, executive function, and esports performance for short durations (≤60 minutes), whereas prolonged periods (>60 minutes) lead to cognitive fatigue. In addition, the leaning forward seated position mirrors the cognitive dynamics of standing, while a reclining seated position maintains cognitive accuracy, preventing cognitive fatigue during prolonged esports play. Postural modification for required cognitive performance could promote a modern healthy lifestyle.

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T.M. and H.A. conceived and designed the study. T.M., Y.M., and S.T. recruited participants. T.M., Y.M., S.T., and D.F. collected data. T.M., Y.M., S.T., D.F., S.Y., T.Y., and H.M. conducted the data analysis and interpreted the data. T.M. and Y.M. drafted the manuscript. T.M., S.T., S.D., Y.S., H.Y., H.T., M.M., A.S., A.M., and H.A. edited and revised the manuscript. All authors have read and approved the final version of the manuscript.

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Conflicts of Interest

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Abbreviations

TDMS: Two-dimensional mood scale
VAS: visual analog scale

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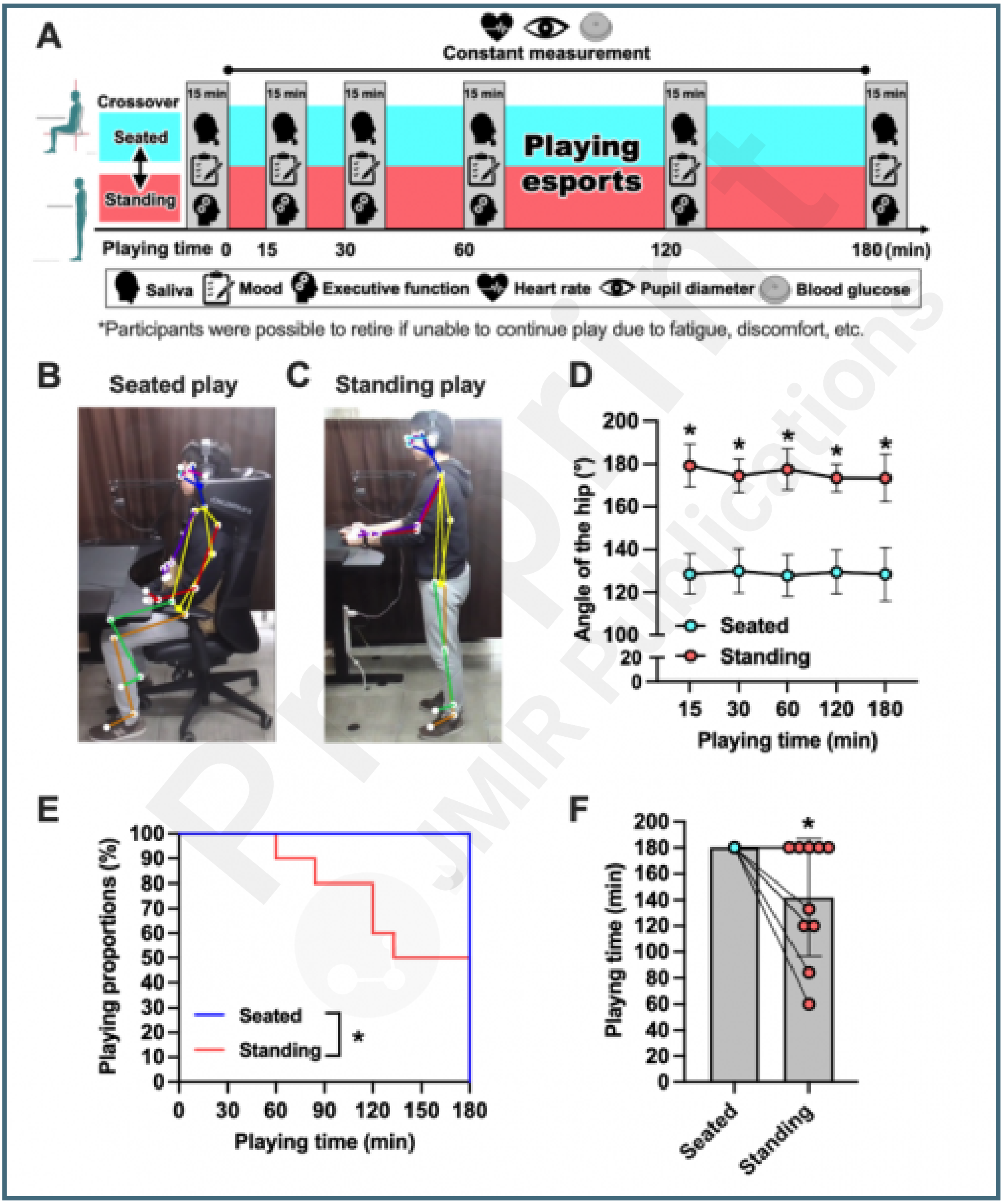
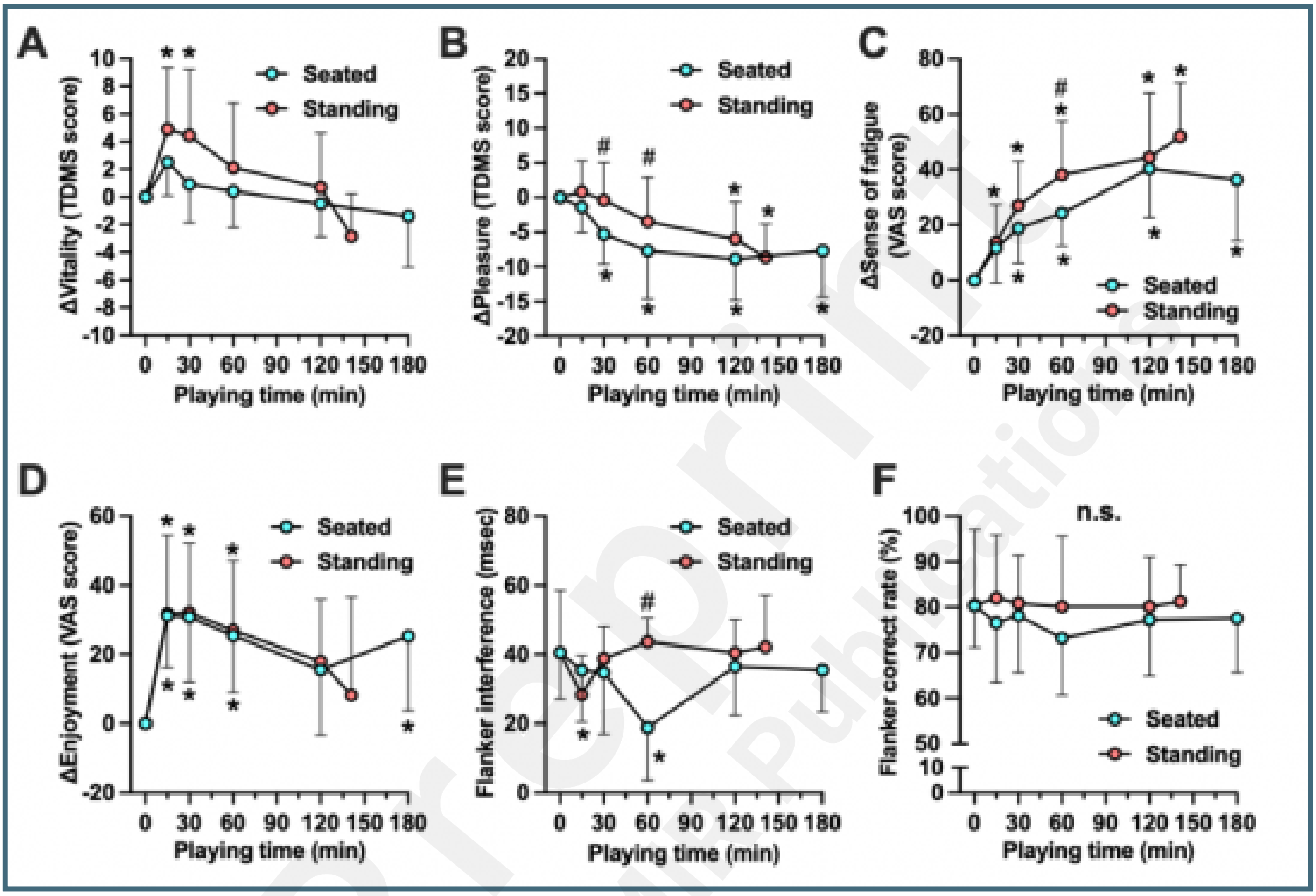
Supplementary Files

Figures

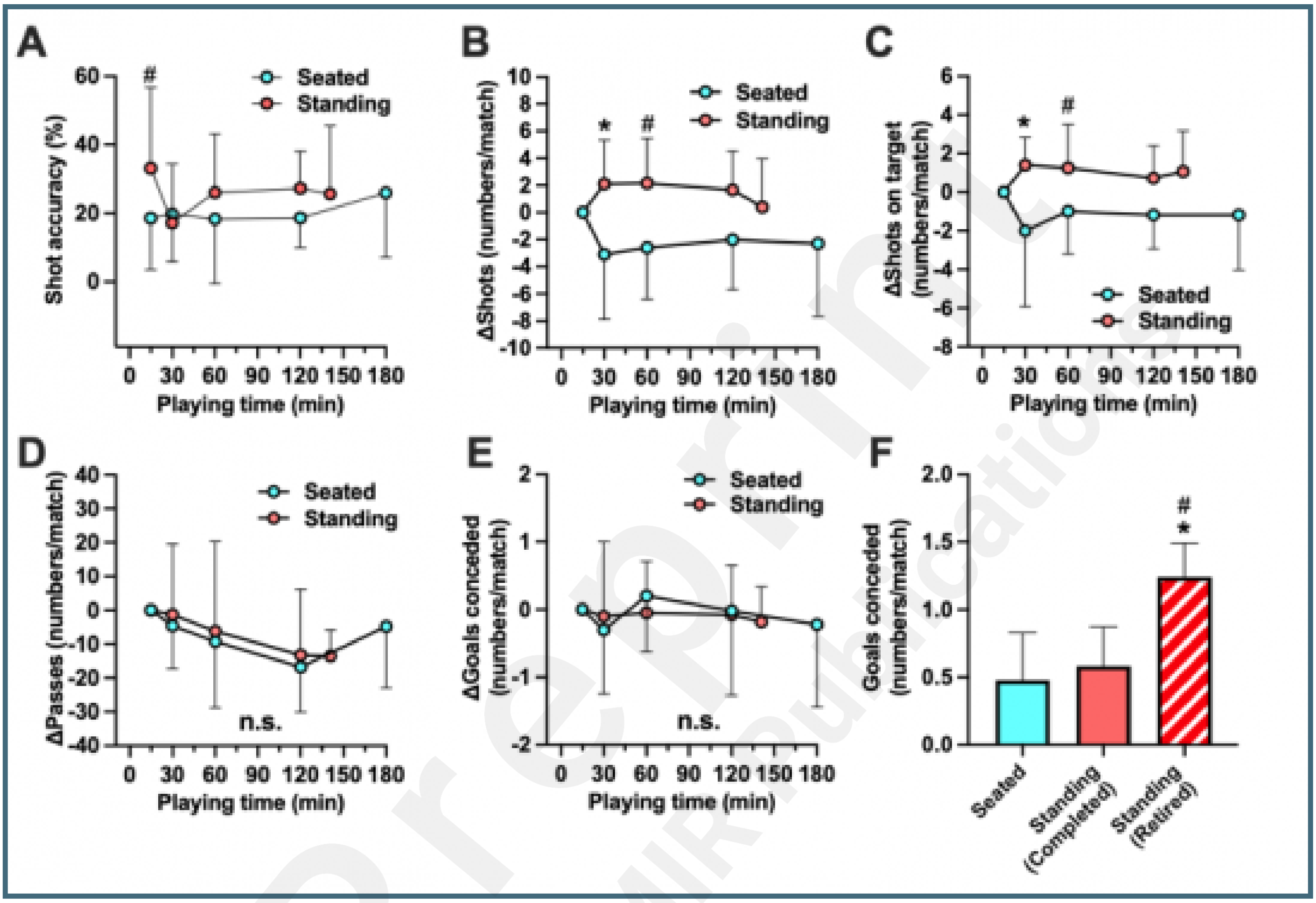
Standing decreases esports playing time to retire. A, the procedure of experiment 1 to examine the effects of standing or seated position on esports play. B, a typical photo of seated play. C, a typical photo of standing play. D, the angle of the hip during playing. E, playing proportions to retire. F, playing time to retire. Data are shown as mean ± standard deviation. *P < 0.05 vs. seated condition.



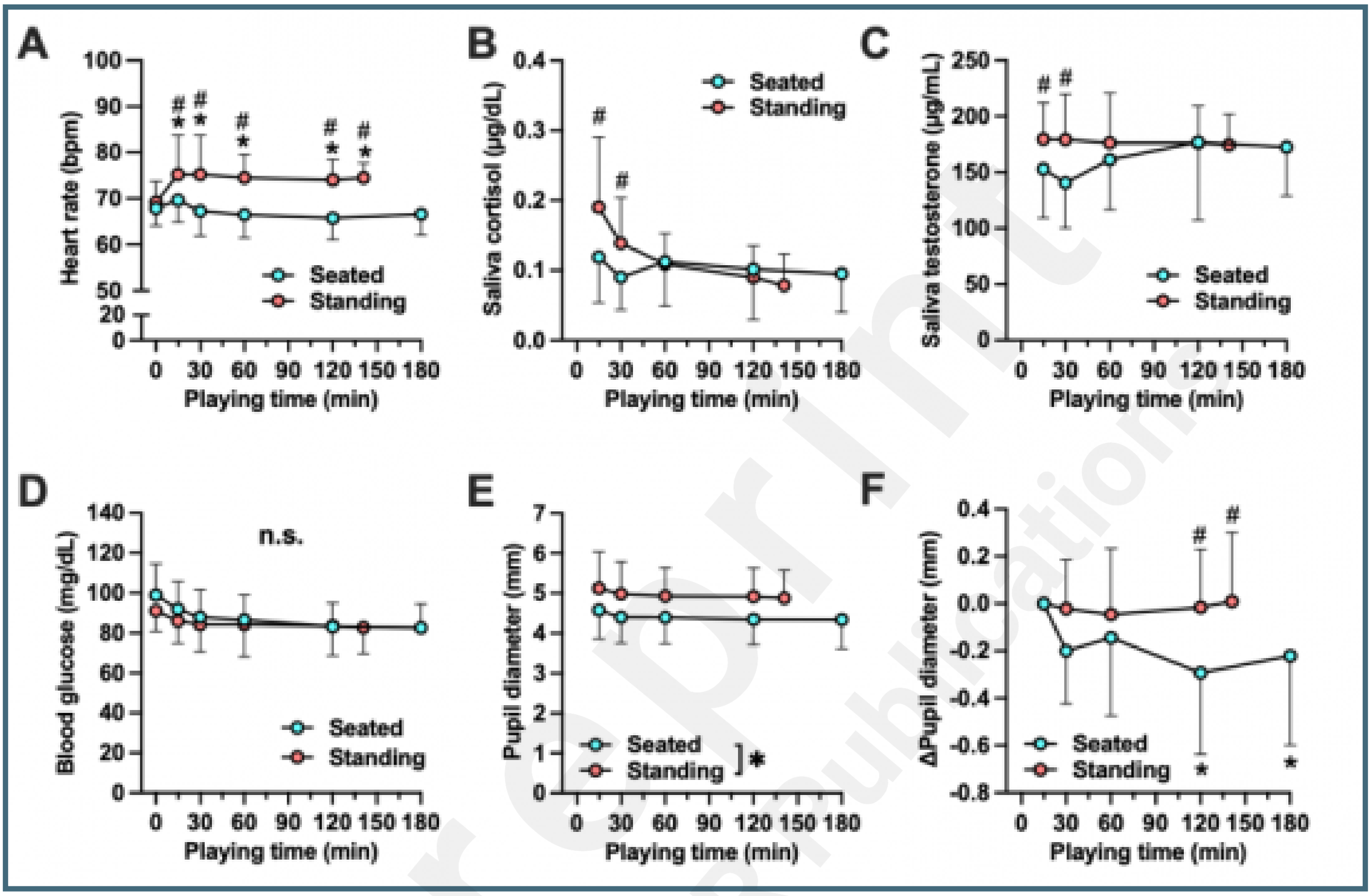
Standing esports play enhances positive mood, and executive function up to 30 min, but leads to cognitive fatigue for longer duration. Data are shown as mean ± standard deviation. A, ?vitality levels of TDMS. B, ?pleasure levels of TDMS. C, ?subjective fatigue of VAS. D, ?enjoyment of VAS. E, interference time in the Flanker task. F, percentage of correct responses in the incongruent Flanker task. *P < 0.05 vs. 0. # P < 0.05 vs. seated condition.



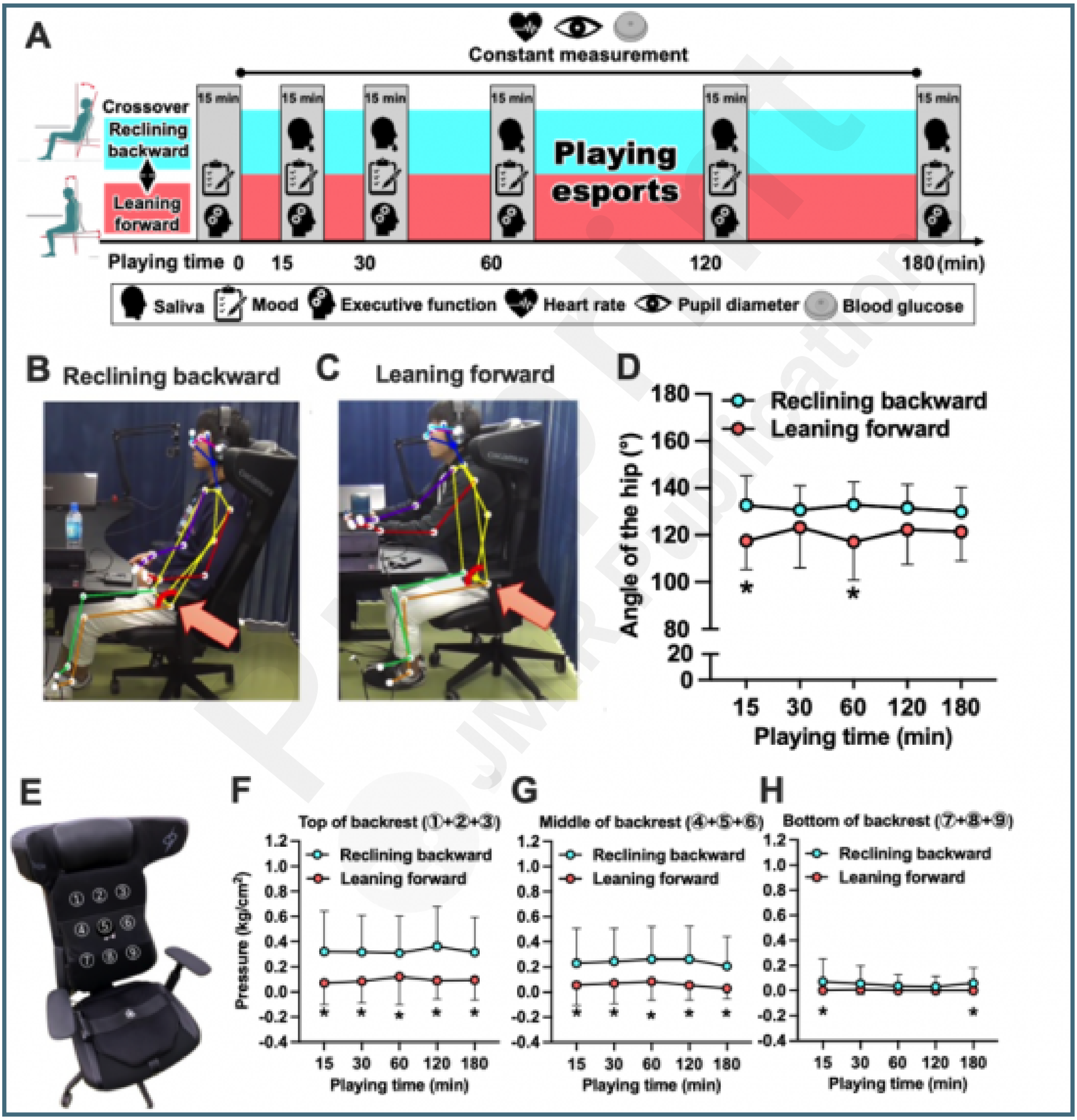
Standing esports play enhances shots performances of virtual football up to 60 min, but increases conceded goals of the last match in retired players during prolonged session. Data are shown as mean ± standard deviation. A, shot accuracy. B, ?shots per match. C, ?shots on target per match. D, ?passes per match. E, ?conceded goals per match. *P < 0.05 vs. 0. # P < 0.05 vs. seated condition. F, conceded goals of the last match. *P < 0.05 vs. seated condition. # P < 0.05 vs. participants completed standing condition for 180 minutes.



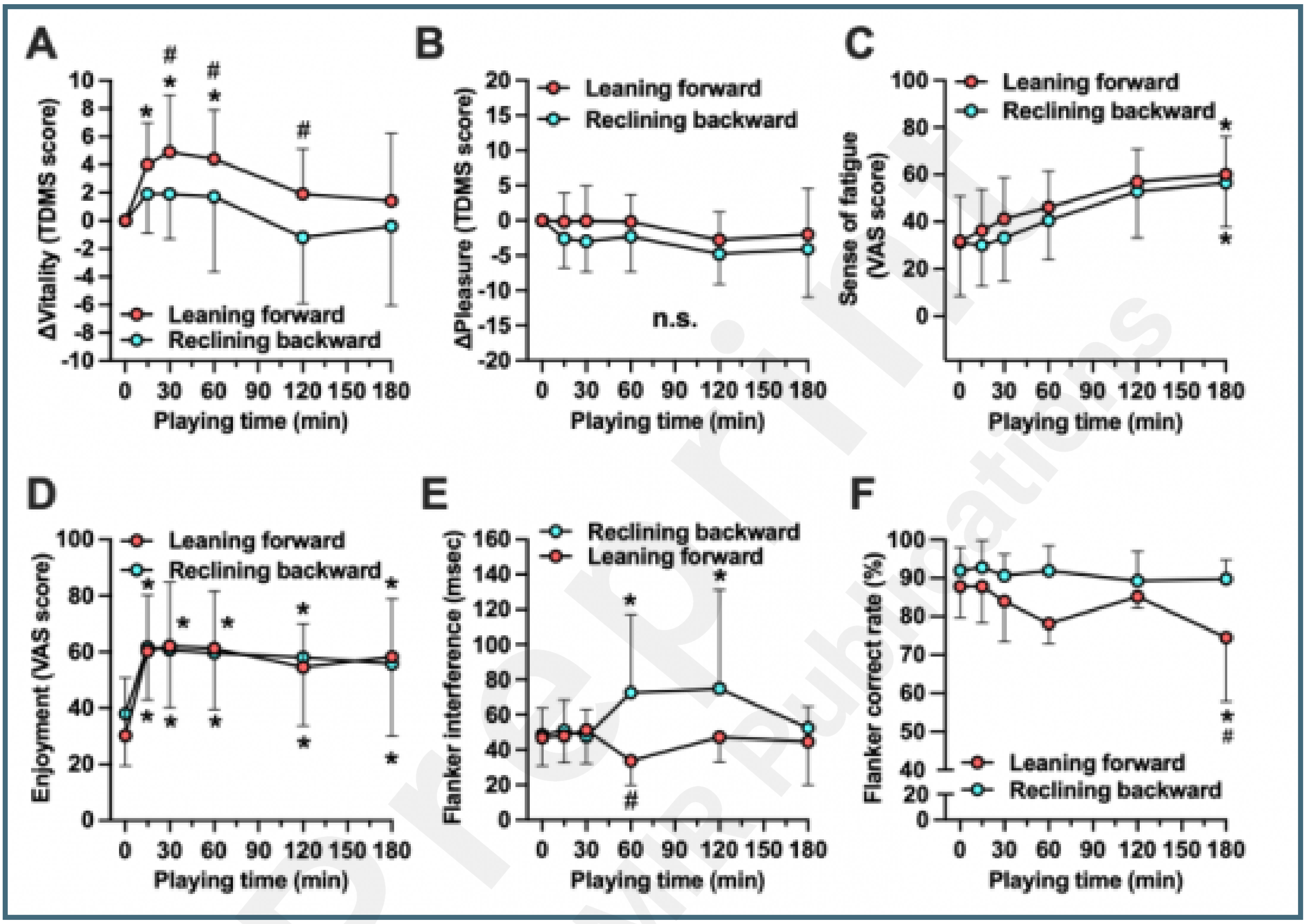
Standing esports play increases heart rate and initial phase of cortisol and testosterone levels in saliva, and pupil size, but does not change blood glucose levels throughout prolonged playing. Data are shown as mean ± standard deviation. A, heart rate. B, saliva cortisol levels. C, saliva testosterone levels. D, blood glucose levels. *P < 0.05 vs. 0. # P < 0.05 vs. seated condition. E, ?pupil diameter. *P < 0.05 vs. 60. # P < 0.05 vs. seated condition.



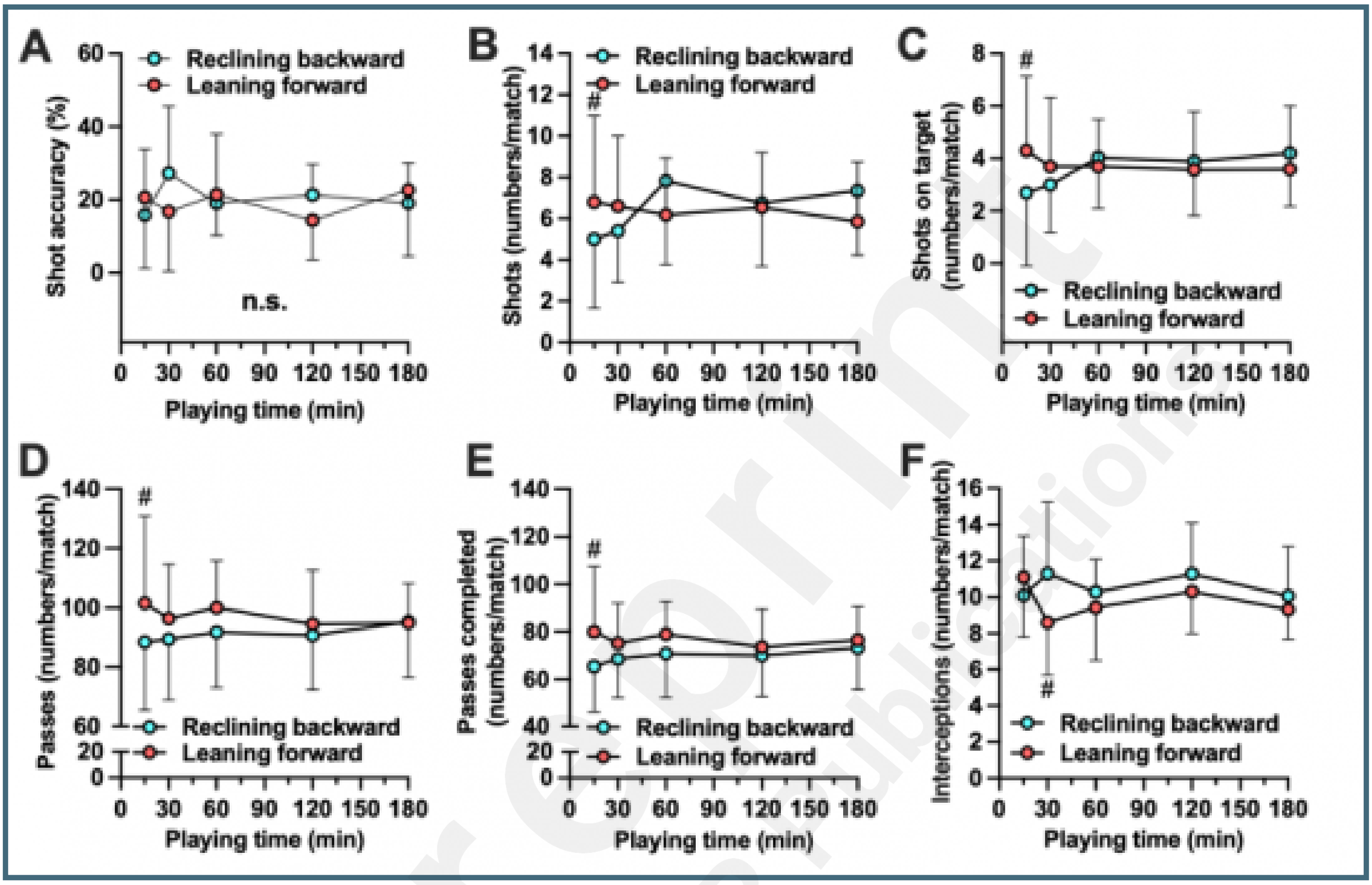
Leaning forward seating slightly decreases hip angle and significantly reduces pressure on the backrest of chair. A, the procedure of experiment 2 to examine the effects of leaning forward or reclining backwards in seated position on esports play. B, a typical photo of play while reclining backward sitting. C, a typical photo of play while leaning forward sitting. D, the angle of the hip during playing. E, an image of a pressure sensor on the chair during esports. F, pressure for top of backrest. G, pressure for middle of backrest. H, pressure for bottom of backrest. Data are shown as mean ± standard deviation. *P < 0.05 vs. reclining condition.



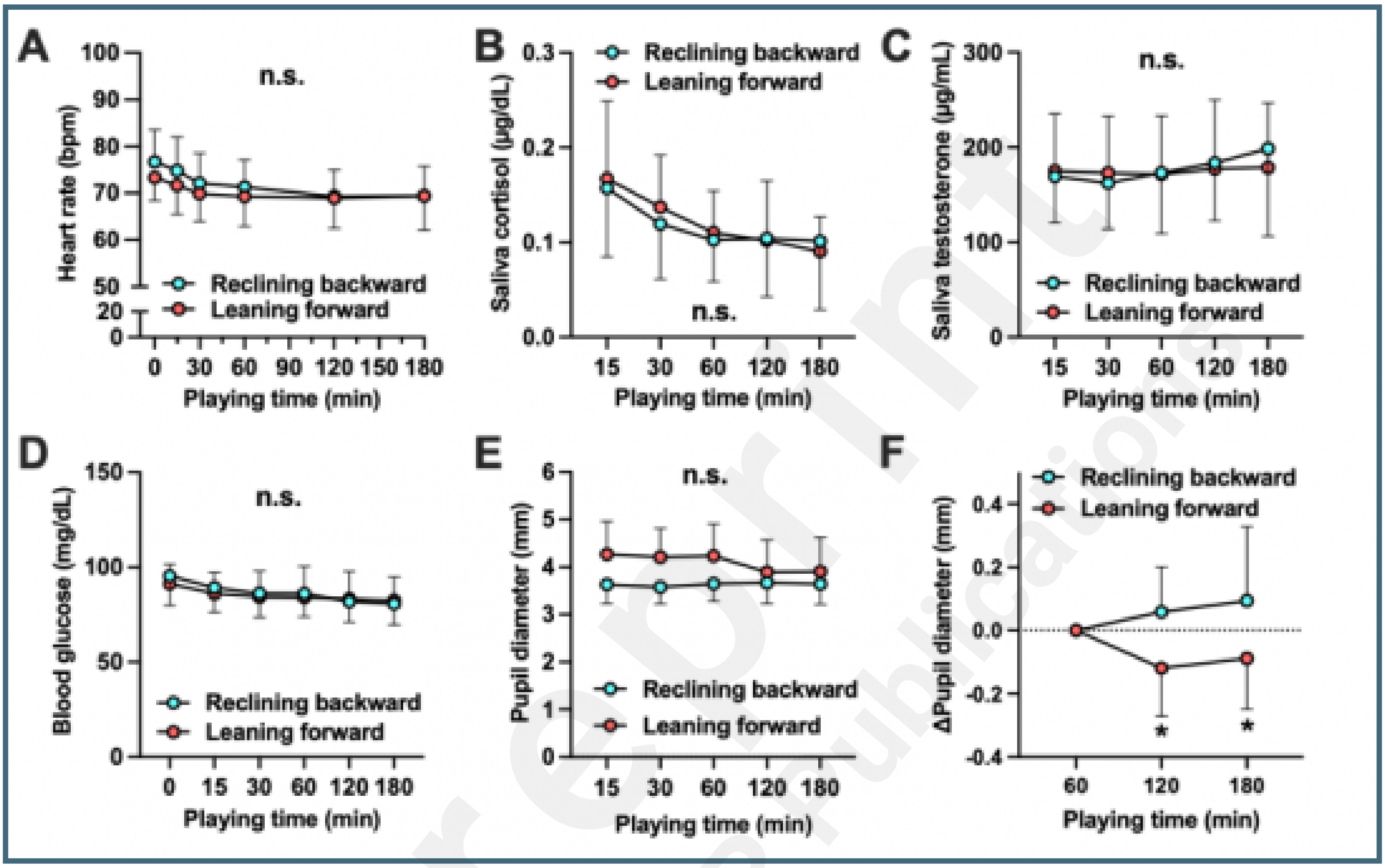
Esports play while leaning forward seating enhances positive mood and executive function up to 60 min, but leads to cognitive fatigue after 120 minutes. Data are shown as mean ± standard deviation. A, ?vitality levels of TDMS. B, ?pleasure levels of TDMS. C, ?subjective fatigue of VAS. D, ?enjoyment of VAS. E, interference time in the Flanker task. F, percentage of correct responses in the incongruent Flanker task. *P < 0.05 vs. 0. # P < 0.05 vs. reclining condition.



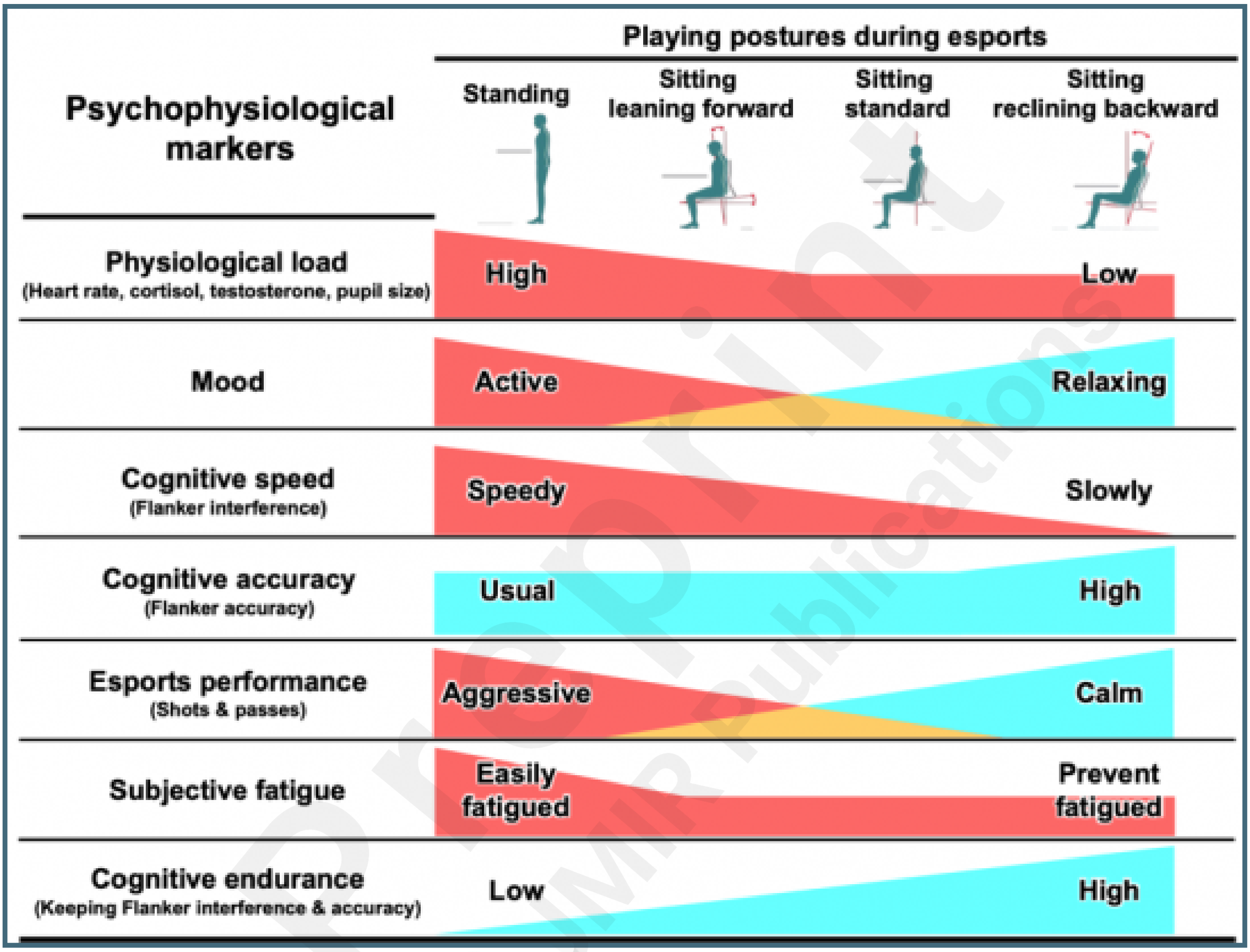
Esports play while leaning forward seating enhances shots performances of virtual football on the initial phase. Data are shown as mean ± standard deviation. A, shot accuracy, B, shots per match. C, shots on target per match. D, passes per match. E, completed passes per match. F, interceptions per match *P < 0.05 vs. reclining condition.



Esports play while leaning forward seating does not affect heart rate, cortisol and testosterone levels in saliva, and blood glucose, but decreases pupil size during prolonged duration, compared to reclining position. Data are shown as mean ± standard deviation. A, heart rate. B, saliva cortisol levels. C, saliva testosterone levels. D, blood glucose levels. E, Pupil diameter. F, ?pupil diameter. *P < 0.05 vs. reclining condition.



Summary of the postural influence on psychophysiological dynamics during esports play. Moderate standing improves mood and executive/esports performances, but prolonged standing (>60 minutes) causes cognitive fatigue leading to lowered performances. Leaning forward seating as an alternative active sitting mirroring the cognitive dynamics of standing during esports play. Reclining supports cognitive endurance with lower output. Modifying posture to match cognitive demands could encourage an active and healthy lifestyle in the digital age.



Multimedia Appendixes

Supplementary figure 1 Standing esports play does not change executive performance of the Stroop and Simon tasks. A. Interference time in the Stroop task. B. Percentage of correct responses in the incongruent Stroop task. C. Interference time in Simon task. D. Percentage of correct responses in the incongruent Simon task.
URL: http://asset.jmir.pub/assets/ab2af9c8dd073d101225264456a5b351.png

Supplementary figure 2 Virtual football performances during prolonged play while standing or seating. A, win probability. B, ball possession. C, goals per match. D, goals conceded per match. E, passes per match. F, passes completed per match. G, pass accuracy. H, interceptions per match. I, tackles per match. J, saves per match. K, shots suffered per match. L, fouls committed per match.
URL: http://asset.jmir.pub/assets/a178ef77e0bbc7219ec4b2895a2a0e2e.png

Supplementary figure 3 Esports play while leaning forward seating does not change executive performance of the Stroop and Simon tasks. A. Interference time in the Stroop task. B. Percentage of correct responses in the incongruent Stroop task. C. Interference time in Simon task. D. Percentage of correct responses in the incongruent Simon task.
URL: http://asset.jmir.pub/assets/701e70405456a3d5bc98b651033a8e3e.png

Supplementary figure 4 Virtual football performances during prolonged play while seating in leaning forward or reclining backward. A, ball possession. B, goals per match. C, goals conceded per match. D, shots per match. E, shots on target per match. F, passes accuracy. G, tackles per match. H, saves per match. I, fouls committed per match.
URL: http://asset.jmir.pub/assets/4ee84db6f0dd279a6b69d0b9b48829b0.png

TOC/Feature image for homepages

Moderate standing improves mood and executive/esports performances, but prolonged standing (>60 minutes) causes cognitive fatigue leading to lowered performances. Leaning forward seating as an alternative active sitting mirroring the cognitive dynamics of standing during esports play. Reclining supports cognitive endurance with lower output. Modifying posture to match cognitive demands could encourage an active and healthy lifestyle in the digital age.