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Examining the effects of changing physiological and psychological conditions and Schumann frequency on time perception and anticipation timing in male referees with EEG

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Abstract

Background: Physical exertion and external stimuli can impact cognitive performance. This study explored how match-like environments and Schumann's binaural beat stimulation affect time perception and anticipation timing, critical for football referees' decision-making. **Methods**: Using a quasi-experimental time series design, 24 active male referees participated voluntarily. Time perception and anticipation timing were assessed under four conditions: baseline (B), aerobic exercise (E), aerobic exercise with 85 dB crowd noise (ECN) and 7.83 Hz Schumann binaural beat stimulation (SBS). Heart rate and electroencephalogram (EEG) data were continuously monitored. Data on time perception (ms), anticipation timing (ms), heart rate (bpm), and EEG (microvolts) were analyzed using repeated measures analysis of variance (ANOVA) in SPSS 26.0. **Results**: The results showed significant differences in time perception between E, SBS, ECN and SBS conditions ($p < 0.05$), but no significant differences in anticipation timing across conditions. EEG data revealed increased alpha and theta band power during the SBS condition compared to others ($p < 0.05$). Additionally, theta band power was significantly higher in the ECN condition than in the B condition ($p < 0.05$). The findings highlighted improved time perception under the ECN condition, with a positive correlation between elevated theta band power and enhanced time perception. However, despite a similar increase in theta power during the SBS condition, referees did not show significant improvements in time perception. **Conclusions**: These results suggest that theta oscillations may play a role in time perception, but other neurophysiological and environmental factors likely influence this relationship. Further research is needed to understand the complex interplay between these variables and their impact on cognitive performance in referees.

Keywords

Time perception; Anticipation timing; EEG; Referees; Schumann frequency; Binaural stimulation

1. Introduction

Soccer, a globally esteemed sport, engages millions of spectators across diverse platforms. Refereeing is pivotal in soccer's spectators, players and referees triumvirate. Referees assess game dynamics, regulate player behavior, resolve disputes and maintain communication throughout matches [1]. During this process, they may be influenced by numerous factors such as audience, experience, knowledge, motivation, enjoyment and environmental and psychological conditions [2]. Notwithstanding these various factors, the capacity to swiftly and precisely make decisions relies on the swiftness of perceiving and comprehending events transpiring on the field. Perception involves a mental process where individuals analyze data about their surroundings using different senses and can be impacted by both physical and social cues [3]. The concept of time is paramount in identifying the perceptual limitations that can lead to referee errors and bias [1]. Time is intricately linked to perceptions and experiences, often regarded as a palpable force during all significant occurrences [4].

The perception of time is also connected to the understanding that time has elapsed and is elucidated by environmental, psychological and physiological mechanisms [5]. Research indicates that various factors such as age, gender, body temperature, health condition, level of mental concentration, intensity of physical activity, focus and sensation of numbness can affect how time is perceived [6]. Given the demanding physical and psychological conditions referees are exposed to during matches, such as fatigue and stress, they may experience cognitive impairments such as distraction, slower reaction times and altered time perception [7].

In high-speed team sports, where the ball is constantly on the move, the ability to predict events makes anticipation timing a crucial element in cases of perceptual distortion [8]. Anticipation timing is the accurate prediction of the endpoint or reachable location of a moving object, ball or object [9]. This skill, crucial for expertise in sports, pertains to the capacity to foresee an event before it occurs. Research in the field encompasses a range of psychological and neurological investigations exploring alterations in anticipation timing in response to rises in heart rate associated with effort [10]. Numerous studies have also emphasized the influence of physiological and psychological factors on human cognitive performance [11–17]. It can be argued in this scenario that the precision of immediate judgments, such as offside calls, throw-ins, penalties, and so on, is contingent upon the referee's sense of anticipation timing and time perception.

Variations in perceptual states during the decision-making phase, which fluctuate with transient circumstances, might correlate with alterations in cerebral electrical activity alongside variables such as distractions or diminished concentration [18]. These changes are caused by the interaction of brain waves generated by rhythmic vibrations and brain neurons and are measured by electroencephalography (EEG) [19]. The recorded electrical signals exhibit variability based on physiological and mental conditions. They are classified into distinct frequencies like Delta, Theta, Alpha, Beta and Gamma according to their occurrence within specific time frames [20]. These waves are associated with different levels of consciousness and awareness and can be seen in varying intensities in various brain regions [21]. For instance, mental calmness and low-stress states have been associated with Alpha and Theta brainwaves [22]. These brain waves can be regulated using external stimuli [23]. One external stimulus that can be utilized is the incorporation of binaural beats.

Binaural stimulation involves the brain perceiving a third beat when presented with two sound tones with a specific frequency difference. This phenomenon occurs when the two tones are separately played into each ear. This resultant beat can potentially influence the brain waves and achieve the desired mental state [23, 24]. In terms of these features, this study uses the Schumann Frequency at the lower limit of Alpha and the upper limit of Theta as auditory binaural stimulation. The renowned Schumann frequency, positioned at approximately 7.83 Hz, is thought to engage with brainwave activity, potentially affecting brain areas linked to relaxation and stress alleviation [25]. Elevated stress levels may detrimentally affect the decision-making capacities of referees [26]. According to Ingendoh *et al.* [27], most studies have examined frequencies within 1 to 57.3 Hz and their effects on cognitive performance. Although binaural beats have been demonstrated to influence brainwave activity, the specific impact of 7.83 Hz remains relatively unexplored [27]. Hence, this study suggests that employing Schumann's binaural stimulation could reduce referees' stress levels. Although research on the impact of exertion or stress on cognitive abilities has garnered considerable interest, investigations into the effects of auditory binaural beats are still relatively scarce [28]. Most studies in this area have primarily concentrated on improving athletic performance, with less attention given to soccer referees who face the distinct challenge of maintaining concentration and making precise judgments amidst prolonged physical and mental pressure. This research aims to fill this gap by investigating the factors that impact referees' time perception and decision-making accuracy in the face of external influences. Specifically, the study seeks to uncover the circumstances in which referees exhibit minimal disruptions in their time perception and ability to anticipate timing when external interventions are introduced. By aiming to identify perceptual deviations in refereeing, observing changes in alpha and theta waves in the frontal lobe offers alternative explanations from physiological psychology and neuroscience perspectives within sports science.

2. Materials and methods

2.1 Participants

Twenty-four male football referees from Mugla province, actively involved in the Turkish Football Federation's provincial refereeing classification and having officiated at least 20 matches within the past two years, voluntarily participated in this research between 01 August 2024 and 15 November 2024. The average age of the referees was determined to be 24.29 ± 2.89 years, with an average height of 181.45 ± 5.29 cm, an average body weight of 77.50 ± 7.52 kg and an average heart rate during exertion measuring 125.95 ± 7.67 bpm, with an average of 4.08 ± 2.76 years of experience. An "a priori" statistical power analysis (software package, G*Power 3.1.9.7 Heinrich Heine University, Düsseldorf, NRW, Germany) was conducted based on the time perception of related studies [29] to achieve ${\eta_p}^2 = 0.167$, an alpha of 0.05, an effect size of 0.4 and a statistical power of 0.95 using the F-test family. The analysis indicated that 15 participants per condition was sufficient to achieve adequate statistical power. The participants were selected through purposive sampling, a non-probability method [30].

2.2 Study design and procedures

In the experimental part of this study, a time series design, one of the quasi-experimental designs, was used. This design is also known as a single-factor repeated measures design. In a time series design, the effect of a treatment applied to a single group is tested by taking multiple measurements of the same variable using the same instrument before and after the treatment on the same individuals [31]. Following the approval of the ethical review board at Mugla Sitki Kocman University Social Sciences and Humanities Research Ethics Committee (Protocol No: 240097, Decision No: 96), the data collection took place in a serene laboratory setting at the Faculty of Sports Sciences between 16:00 and 17:00, with temperature controlled at 22–23 °C. Before the measurements, participants were directed to avoid consuming food, beverages or caffeine for a minimum of two hours and to adhere to their regular sleep routines. Furthermore, participants were requested to refrain from using traditional or digital timekeeping devices throughout the experiment.

After participants signed the informed consent form, they were provided with wearable gadgets such as the Emotiv Insight 2 (5-channel EEG system) and Polar HR10 heart rate monitor (Polar, Kempele, Finland). The electrodes were placed on the scalp based on the 10–20 International System, and the conductive gel was used to guarantee the best signal accuracy [32]. Bluetooth connectivity was established between the EEG device (Emotiv Insight-2, EMOTIV Inc., San Francisco, CA, USA) and the EmotivPro Android software (version of 4.2.7.544, EMOTIV Inc., San Francisco, CA, USA). Participants were provided a brief training session to familiarize themselves with experimental procedures and ensure accurate device usage.

The participants were presented with tasks in a randomized sequence to reduce the impact of learning, and no feedback was provided on their performance. After ensuring the stability of brain wave patterns by examining the EEG signal through the application, the participants were encouraged to concentrate and commence the test. The study was designed to investigate time perception and estimation tasks under four different conditions (see Fig. 1 for an overview).

2.2.1 Phase 1: baseline measurements

At the outset of the research, the participants were tasked with completing time perception and anticipation timing exercises without external cues. Meanwhile, EEG data was collected. These initial assessments lasted 8–10 minutes to establish the participants' baseline values for time perception and anticipation timing, denoted as "baseline" (B) values.

2.2.2 Phase 2: effort condition

Following the baseline measurements, participants were seated on a stationary bicycle ergometer, and their heart rate was adjusted to 60%~70% of their maximum heart rate using the Karvonen method. The heart rate range known as "Zone 2" in academic literature [33] is linked to aerobic exercise intensity. While maintaining this exercise intensity, participants repeated the time perception and anticipation timing tasks, and EEG data was continuously recorded. These data were labeled as "effort" (E) measurements.

2.2.3 Phase 3: effort with crowd noise condition

After conducting the E measurements, the participants were subjected to 85 decibels of crowd noise at the same exercise intensity to re-perform the time perception and anticipation timing task. EEG data was collected during this period and identified as measurements of "effort with crowd noise" (ECN). This phase aimed to investigate the effects of exercise and external noise on time perception and estimation.

2.2.4 Phase 4: post-Schumann binaural stimulation measurements

After the ECN measurements, participants were exposed to 15 minutes of 7.83 Hz binaural beats. This auditory stimulation was intended to synchronize brain waves and induce relaxation. After receiving the binaural stimulation, the participants proceeded to redo the time perception and anticipation timing tasks while EEG data was being collected. These subsequent assessments were explicitly termed the "Schumann Binaural Stimulation" (SBS) measurements, aimed at assessing the impact of binaural stimulation on time perception and anticipation timing.

2.3 Data collection

Time perception data (in milliseconds), anticipation timing data (in milliseconds), heart rate data (in beats per minute), and EEG data (in microvolts) were collected from participants.

2.3.1 Time perception

Time perception measurements were performed with electronic timing system (Newtest 1000, Oulu, Finland) with a sensitivity of 0.001 seconds. During the entire data collection process, the screen of the Newtest 1000 device was covered so that the participant could not see it. After the participant had completed the first-time interval production trial measurements, the Newtest 1000 screen was opened, and the researchers observed whether the participant understood the test by giving neutral feedback. In football matches, referees must swiftly make decisions responding to dynamic on-field developments, often within split seconds. To accommodate the standard 45-minute match halves and ensure minimal disruption to the referees' workflow, shorter time intervals of 1, 3 and 5 seconds were employed for time production tasks. Such shorter intervals are typically preferred in scenarios characterized by rapidly changing variables, such as fatigue levels and limited data collection time. This approach facilitated the completion of all tests within a 45–50 minutes timeframe, with each time interval repeated five times per condition. This decision mirrors prior studies that utilized time intervals from 0.5 to 10 seconds in time production tasks [34–38].

The referees' time perception values were divided into B, E, ECN and SBS assessments, with five measurements taken for each category at every time interval. The absolute error score was determined using the formula (Target Duration − Measured Duration)/(Target Duration) for period production scores (TPPS), and the mean score for each duration was documented in the data collection chart.

2.3.2 Anticipation timing

The researchers assessed anticipation timing using the Bassin Anticipation Timer while the participants moved at six mph. The target lamp, the 11th lamp in the 3rd section, was identified for the task. Moreover, to ensure that the participants' vision was not hindered, a marker of contrasting color was positioned beside the target lamp [39]. The participant was given the right to try 3 times before measurements. The participants' anticipation timing scores were categorized as B, E, ECN and SBS measurements. Measurements were performed 5 times in each category, and the absolute error average was recorded in the data collection chart in milliseconds. Our research considered the suggestions by Lyons *et al.* [40] and Morrison and Reilly that measuring anticipation timing should occur during exercise rather than post-exercise [41]. This is because physiological changes can quickly return to normal levels after cessation of exercises [42].

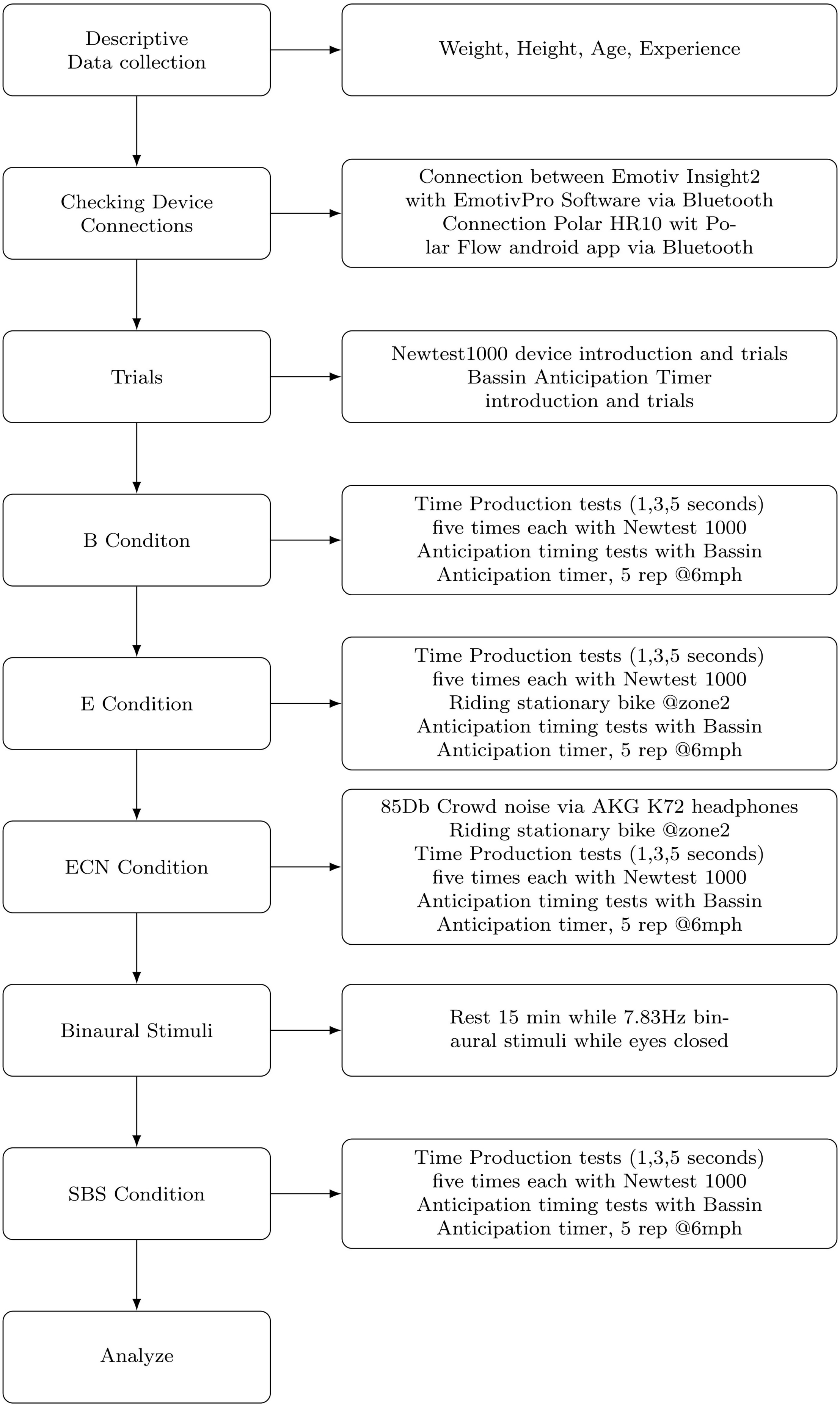

FIGURE 1. The study design. B: baseline; E: aerobic exercise; ECN: effort with crowd noise; SBS: Schumann binaural beat stimulation.

2.3.3 Heart rate measurement

Heart rate data was obtained with the Polar H10 chest strap and instantly monitored and recorded with the Polar Flow mobile application. Considering the Karvonen method, the zone 2 training interval was calculated according to the participant's age and resting heart rate. The E and ECN measurements were made on the road bike installed on the Tacx Blue motion trainer, keeping the trainer difficulty level constant, cadence and gear adjustment according to the participant's preference and driving was carried out. Once the participant achieved the target heart rate within zone 2, time perception and anticipation timing assessment commenced. Subsequently, as the participant transitioned into the zone 3 training intensity, they were instructed to pedal at a slower cadence, resulting in the heart rate dropping back to the zone 2 range. It was noted that the participant ceased pedaling during the evaluation. The data collection chart documented the average heart rate readings for both E and ECN measurements, accounting for the timestamps indicating the initiation and conclusion of the exercise [29, 43].

2.3.4 EEG and binaural stimulation

The AF3, AF4, T7, T8 and Pz electrodes of an Emotiv Insight 2 (5-channel) EEG system were prepared with conductive gel and positioned on the participant's scalp according to the 10–20 International System, as described by [44]. A calibration procedure was conducted using EmotivPro Android software to optimize electrode placement, ensure stable Bluetooth connectivity, and verify the quality of the EEG signal.

Following the international 10–20 system, the portable EEG device Emotiv Insight 2 was employed to record neural activity from the frontal (AF3, AF4) and temporal (T7, T8) regions, as well as the parietal (Pz) region [44]. To selectively examine neural oscillations underlying higher-order cognition, as indexed by activity in the AF3 and AF4 regions, data from these electrodes were subjected to high-pass filtering (3 dB at 0.5 Hz) to attenuate artifacts and noise and subsequently analyzed using Fast Fourier Transform (FFT) to quantify the power spectrum (Theta 4–8 Hz, Alpha 8–12 Hz) with EmotivPro software thereby providing insights into the frequency characteristics of neural activity associated with cognitive functions such as attention and reasoning [45]. Precise recordings were made for each task condition's start and end times (B, E, ECN and SBS). Subsequent EEG data segmentation and categorisation were done based on their respective Unix timestamps to synchronize with the specific task conditions. Binaural beats, a phenomenon related to auditory perception, emerge when two tones with slightly different frequencies are delivered separately to each ear. This auditory illusion leads to the experience of a third tone, pulsating at the frequency difference between the two original tones. This perceived frequency difference, typically 1–30 Hz, corresponds to the prominent EEG frequency bands linked to human brain activity [27]. In this study, a 15-minute binaural stimulation protocol was administered using the Mistikist mobile application. The stimulation consisted of a 400 Hz tone to the left ear and a 407.83 Hz tone to the right ear [46].

2.3.5 Statistical analysis

All statistical calculations were conducted using SPSS Statistics version 26 (IBM Corp., Released 2019. IBM SPSS Statistics for Windows, Armonk, NY, USA). The Shapiro-Wilk test was employed to assess the normality of the data. Results indicated that anticipation timing, time perception, and EEG data were normally distributed. The Repeated Measures ANOVA was utilized for statistical analysis. Table 1 presents the skewness and kurtosis values for anticipation timing, time perception and EEG data. A normal distribution is typically assumed within a range of −2 to +2 for skewness and kurtosis. Based on this criterion, the EEG, anticipation timing and time perception data were deemed normally distributed [47].

3. Results

3.1 Comparison of time perception by conditions

Participants completed time perception tasks under four distinct conditions. A repeated measures ANOVA, with Greenhouse-Geisser correction ($\varepsilon = 0.619$) due to a violation of the sphericity assumption (χ^2 (5) = 21.328, $p = 0.001$), revealed significant differences in time perception values across the four conditions (F (1.857, 42.717) = 5.339, $p = 0.01$, $\eta^2 = 0.188$). *Post hoc* Bonferroni comparisons indicated that performance during the E condition (M (Mean) = 0.128) differed significantly from both the B and SBS conditions ($p < 0.05$). Furthermore, performance in the ECN condition (M = 0.113) differed significantly from both the B and SBS conditions ($p < 0.05$).

3.2 Comparison of anticipation timing by conditions

Participants performed anticipation timing tasks under four different conditions. A repeated-measures ANOVA examined the differences in anticipation timing values across these conditions. Mauchly's sphericity test was insignificant (χ^2 (5) = 6.452, $p = 0.265$), indicating that the assumption of sphericity was met. The analysis revealed no significant differences in performance across the four conditions (F (3, 69) = 1.589, $p = 0.200$, $\eta^2 = 0.065$). *Post-hoc* Bonferroni comparisons did not reveal any significant pairwise differences.

3.3 Comparison of theta brain waves by conditions

A repeated-measures ANOVA was conducted to examine differences in AF3 theta band power across B, E, ECN and SBS conditions. Mauchly's sphericity test was insignificant (χ^2 (5) = 7.780, $p = 0.169$), indicating that the assumption of sphericity was met. The analysis revealed significant differences at AF3 theta band power across the B, E, ECN and SBS conditions (F (3, 69) = 17.285, $p < 0.001$, $\eta^2 = 0.429$). *Post hoc* analyses with Bonferroni correction revealed a notable increase in theta power at the AF3 electrode during the SBS condition (M = 12.223) compared to the rest of the experimental conditions ($p < 0.05$). A significant variance in theta power was noted between the ECN (M = 11.458) and B (M = 10.341) conditions,

TABLE 1. Anticipation timing, time perception and EEG data normality table.

Conditions-Variables	N	$\bar{x} \pm sd$	Skewness	Kurtosis
Baseline-Time Peception	24	0.152 ± 0.048	0.483	0.019
Baseline-Anticipation Timing	24	0.039 ± 0.011	−0.806	0.038
Effort-Time Peception	24	0.128 ± 0.007	0.085	−0.787
Effort-Anticipation Timing	24	0.038 ± 0.015	1.029	1.366
Effort and Crowd Noise-Time Peception	24	0.113 ± 0.031	−0.141	−1.138
Effort and Crowd Noise-Anticipation Timing	24	0.038 ± 0.015	0.490	−0.542
Schumann Binaural S.-Time Peception	24	0.148 ± 0.059	0.466	−0.484
Schumann Binaural S.-Anticipation Timing	24	0.035 ± 0.012	0.107	−0.521
Baseline-Theta-AF3	24	10.341 ± 1.074	−0.513	−0.624
Baseline-Theta-AF4	24	10.231 ± 1.229	−0.322	−0.896
Effort-Theta-AF3	24	10.880 ± 1.393	0.040	−1.204
Effort-Theta-AF4	24	11.458 ± 1.586	−0.093	−1.087
Effort and Crowd Noise-Theta-AF3	24	11.285 ± 1.449	−0.223	−0.297
Effort and Crowd Noise-Theta-AF4	24	12.223 ± 1.545	−0.373	−0.680
Schumann Binaural S.-Theta-AF3	24	12.237 ± 0.824	0.468	0.527
Schumann Binaural S.-Theta-AF4	24	7.296 ± 1.182	0.033	0.850
Baseline-Alpha-AF3	24	7.070 ± 1.591	−0.297	−0.900
Baseline-Alpha-AF4	24	7.757 ± 1.746	−0.567	−0.270
Effort-Alpha-AF3	24	7.521 ± 1.539	−0.246	−0.921
Effort-Alpha-AF4	24	8.133 ± 1.614	0.063	−1.193
Effort and Crow Noise-Alpha-AF3	24	7.955 ± 1.324	−0.152	0.000
Effort and Crow Noise-Alpha-AF4	24	8.957 ± 1.542	−0.149	−0.391
Schumann Binaural S.-Alpha-AF3	24	9.059 ± 0.994	0.745	−0.137
Schumann Binaural S.-Alpha-AF4	24	11.458 ± 1.152	0.653	0.221

The normality assumption was met, as evidenced by the results of the Shapiro-Wilk test ($p > 0.05$).
Time perception (TP) and Anticipation timing (ANT) values as miliseconds, Electroencephalogram (EEG) values as μV. sd, standard deviation.

showing a higher theta power level in the ECN condition.

A repeated measures ANOVA test was conducted to examine differences in AF4 theta band power across R, E, ECN and SBS conditions. Mauchly's sphericity test was insignificant (χ^2 (5) = 7.703, p = 0.174), indicating that the assumption of sphericity was met. The analysis revealed significant differences at AF4 theta band power in B, E, ECN and SBS conditions (F (3, 69) = 17.292, $p < 0.001$, η^2 = 0.375). Bonferroni-corrected *post hoc* analyses indicated that theta power at the AF4 electrode was significantly greater during the SBS condition (M = 12.236) relative to all other experimental conditions ($p < 0.05$). Furthermore, a significant difference was observed in theta power between the ECN (M = 11.285) and B (10.231) conditions, with higher theta power observed in the ECN condition ($p < 0.05$).

3.4 Comparison of alpha brain waves by conditions

A repeated measures ANOVA, with Greenhouse-Geisser correction (ε = 0.783) due to a violation of the sphericity assumption (χ^2 (5) = 11.426, p = 0.044), revealed significant differences in time perception values across the B, E, ECN, SBS conditions (F (2.348, 54.009) = 10.117, $p < 0.001$, η^2 = 0.305). Bonferroni-corrected *post hoc* analyses indicated that alpha band power at the AF3 electrode was significantly greater during the SBS condition (M = 8.9575) relative to all other experimental conditions ($p < 0.05$).

A repeated measures ANOVA test was conducted to examine differences in AF4 alpha band power across B, E, ECN and SBS conditions. Mauchly's sphericity test was insignificant (χ^2 (5) = 10.486, p = 0.063), indicating that the assumption of sphericity was met. The analysis revealed no significant differences in performance across the four conditions (F (3, 69) = 17.434, $p < 0.001$, η^2 = 0.315). Bonferroni-corrected *post hoc* analyses indicated that alpha power at the AF4 electrode was significantly greater during the SBS condition (M = 9.059) relative to all other experimental conditions ($p < 0.05$).

4. Discussion

This study aimed to examine the impact of different physiological and psychological stressors, such as aerobic exercise, crowd noise and Schumann binaural auditory stimulation, on referees' anticipation timing and time perception abilities through electroencephalography (EEG). The results were categorized and discussed under three main headings.

4.1 Effects of effort

Research results indicate that the exertion made in the aerobic zone has a positive impact on time perception ($p < 0.05$). In our study, a group of 24 referees who participated in 4–5 training sessions weekly exhibited enhanced accuracy in time perception when their heart rate reached 125 bpm, as opposed to measurements taken with B and SBS devices. This aligns with the hypothesis by Edwards and McCormick that well-trained referees have a more precise sense of time while exercising, mirroring the outcomes observed in our research [48]. Unlike our study, Moore and Olson investigated the effects of exercise on time perception in untrained subjects in their study. They emphasized that the subjects produced ~8.4% more time than the target intervals when they were tired, which caused a slower time perception [34]. Variations in results among different studies may be due to disparities in participants' level of training or to variations in the exercise intensity at which measurements were conducted. Our research indicates that well-trained individuals with extensive experience with aerobic exercise may be able to sustain their concentration on tasks without succumbing to fatigue. Research indicating that physical exhaustion can alter cognitive time processing highlights time dilation during aerobic activities, impacting cognitive performance and decision-making [37, 49, 50]. On the other hand, studies also draw attention to the fact that physiological changes during aerobic exercise cause the brain to focus on the exercise and become less sensitive to environmental stimuli, causing the perception that "time passed faster" [51–53].

Significant changes in the cognitive and emotional context are thought to affect individuals' time perception in conditions of intense physical activity [48]. In their study on the impact of physical activity on time perception, Brewer *et al.* [54] demonstrate that variables like perceived exertion and task familiarity contribute to individuals' perception of time. In our study, the fact that the study group was well trained and exercised at an aerobic level for a long time in competitions may have affected the focus of attention shifting to the given task instead of feeling tired. According to existing research, there is evidence suggesting that the intensity of exercises has no impact on anticipation timing, a finding that aligns with the results of our study [37, 55]. In addition, studies have found that exercises performed at different intensities affect anticipation timing [9, 56, 57]. The variations in findings can be attributed to the timing of anticipation measurements, with some conducted during high-intensity workouts and others during moderate or low-intensity physical activities. Research indicates moderate-intensity exercise can enhance cognitive function [39], while high-intensity exercises can negatively affect cognitive performance [12, 47].

Moreover, the timing of anticipation measurements during or after exercise is believed to impact the results. It is essential to acknowledge that the findings indicating a restricted influence of aerobic activity on cognitive functions should not be overlooked [58]. In their study on referees, Ahmed *et al.* [59] stated that exercise of optimal duration and intensity can acutely increase cognitive performance and that this result can be used in the warm-up practices of referees before matches.

When the EEG data are examined, although theta activity increased compared to reference values while exerting effort in the aerobic zone, the difference is not statistically significant. Bailey *et al.* [60] examined the brain activity associated with increasingly intense exercise on a bicycle in their study with 20 male participants with an average age of 24.0 ± 1.5. During the research, it was observed that the power of theta brain waves in the frontal cortex rose as the intensity of exercise increased. After peaking at an average heart rate of 133 bpm, the theta band power declined as the exercise intensity escalated [60]. Ghorbani *et al.* [61] studied 14 female cyclists aged 25.9 ± 3.8 years and found an increase in theta band power from resting state until a heart rate of 118 ± 8.67 bpm was reached. Likewise, Hottenrott *et al.* [62] in their study with 16 male cyclists aged 25.9 ± 3.8 years, found an increase in theta band power until a heart rate of 118.50 ± 8.61 bpm was reached. Adam *et al.* [63] in a study involving 10 participants aged 19–22, found a decrease in theta band power during aerobic exercise performed at an average heart rate of 91.3–103.65 bpm.

Similarly, Devilbiss and colleagues observed reduced theta band power following moderate-intensity exercise in a cohort comprising eight male and eight female participants [64]. Our research findings did not show any noticeable variance in theta band power due to exertion, which goes against what has been previously reported in the literature. Similarly, no statistically meaningful distinction was noted in alpha brain activity during exertion in the aerobic zone compared to the baseline readings taken at rest. Past studies have reported an uptick in alpha brain activity as the exercise intensity surpassed the aerobic zone [61, 64–66]. So, in our study, the fact that there was no difference in alpha band strength due to keeping the exercise intensity constant in the aerobic zone is in line with the previous studies.

4.2 Effort + the effect of loud crowd noise from the stands

In addition to the effort exhibited in the aerobic zone in time perception measurements, 85 dB loud crowd noise was used as a different condition in the study. An improvement was observed in time perception ($p < 0.05$). It can be said that the participants did not perceive the crowd noise as stress; on the contrary, the noise they were familiar with positively affected their awareness and caused them to act more carefully. It is believed in this context that offering referees familiar environmental conditions may benefit their cognitive functions. Existing studies have suggested that the convergence of psychological and physiological factors can enhance cognitive functions among individuals, mainly when higher levels of arousal and satisfaction are present [12, 67, 68]. These studies align with our research findings that the combined effect of exercise and different conditions can optimize individuals' cognitive performance. McMorris and Hale's meta-analysis suggests that physical activity can lead to short-term improvements in cognitive control. Intense physical activity, specifically, can boost cognitive function by triggering central neurochemical alterations through heightened stress perceptions.

Additionally, it has been shown that engaging in moderate physical activity can enhance cognitive processing speed [69]. Research has highlighted the impact of both physical and mental arousal on time perception, which is influenced by the level of arousal and the intensity of physical activity in exercise. Additionally, these studies explore the intricate connection between the mind and body and emotional responses [5, 10, 70]. In contrast, Davis *et al.*'s [71] combined load of sport-specific cognitive tests and time trial cycling exercise did not affect cognitive performance accuracy. Zhang *et al.* [72] emphasize the importance of understanding the psychological states of referees in competitive sports and improving the quality of the management's decisions.

In the EEG data analysis, no significant statistical variance was observed in the theta band power when compared to the baseline measurements. Studies conducted separately from exercise intensity have observed an elevation in theta brain activity in response to the escalating cognitive task demands [73, 74]. Adam *et al.* [63] found in their study that the accuracy rate in memory and problem-solving tasks decreased with the decrease in theta band power. According to forecasts, the augmentation of theta band activity, linked to emotional responses, could potentially enhance concentration and judgment during pivotal sports moments [75]. There is a belief that distractions may influence performance, particularly in tasks requiring high mental focus and relaxation methods could mitigate such impacts [76].

In his study, Zokaei detected an increase in alpha band power in the EEG data of 72 participants with an average age of 26.27 years who were exposed to 85 dB noise [77]. An increase in the alpha activity of the brain was detected in different studies where participants were exposed to 85 dB noise [78]. In this study, when effort and 85 dB crowd noise were combined, no significant difference was observed in alpha and theta band power. Therefore, it is difficult to explain the difference in time perception compared to other conditions solely by alpha or theta activity changes.

4.3 Effects of Schumann binaural stimulation

Our study observed a statistically significant difference in alpha and theta band power under SBS conditions compared to other conditions. No significant differences were found in anticipation timing and time perception measurements. The referees exhibited delays in tasks associated with time perception and anticipation timing, falling short of the expected pace. It is reasonable to speculate that the observed delays in our research may have been caused by an overabundance of relaxation brought about by heightened alpha and theta brainwave activity levels [79]. This speculation is supported by the proven link between elevated alpha and theta activity and decreased stress levels, leading to relaxation [80–82]. Goodin *et al.* [83] performed 4 minutes of binaural stimulation at 7 Hz frequency and concluded no statistically significant difference in theta frequency in the pre-test and post-test results.

Similarly, Omeroglu and Li concluded in their study that they performed binaural stimulation at 7 Hz frequency for 12 minutes with 10 participants. There was no significant difference in theta band power in the pre-test and post-test findings [84]. On the other hand, Ala *et al.* [85] conducted a study that administered binaural stimulation at a 7 Hz frequency and noted a rise in the brain's alpha activity. Given the inconsistent findings in studies examining the effects of binaural stimulation, Ingendoh *et al.* [27], have highlighted the need for standardized research protocols to investigate brainwave entrainment reliably. Our study further supports this notion, emphasizing the importance of selecting task-appropriate binaural stimuli and developing distinct procedures to investigate potential effects on time perception and anticipation timing.

4.4 Limitations

The study's sample of 24 male referees, while statistically substantiated through a priori power analysis, is relatively modest in size and limited to a single gender, which may restrict the applicability of its findings to female referees or a more diverse cohort of sports officials. The controlled laboratory setting, although effective in ensuring methodological consistency, does not entirely reflect the dynamic, high-pressure context of an actual football match, potentially limiting the ecological validity of the observed outcomes. Additionally, the use of the Emotiv Insight 2 EEG system, with its five-channel configuration, represents a practical choice but may not fully capture the nuanced complexity of brain activity, as might be achieved with systems offering greater channel density and sensitivity. The study's focus on aerobic exercise conditions, while valuable, excludes the anaerobic efforts frequently experienced in refereeing, which could uniquely influence cognitive functions. For future research, expanding the sample size and diversity to include female referees could enhance representativeness, while adopting a fully experimental design with a control group might strengthen causal inferences. Simulating match-like conditions with increased realism, employing advanced EEG systems with higher spatial resolution, and exploring a wider range of physiological intensities, including anaerobic zones, would further refine the study's robustness and relevance, offering a more comprehensive understanding of referees' cognitive performance under varied demands.

5. Conclusions

Our study observed a significant improvement in time perception when participants engaged in aerobic exercise and were exposed to crowd noise. However, despite the increase in alpha and theta band power after Schumann binaural stimulation, there was no difference in time perception and anticipation timing. Including larger sample sizes and incorporating various auditory and physiological stimuli in research on the impact of brain waves on time perception and anticipation timing can significantly enhance our understanding of the cognitive mechanisms involved in refereeing. Based on the findings, it can be hypothesized that the background noise and physical exertion commonly experienced by referees could enhance their time perception and anticipation by creating a stimulating environment. This enhancement may be influenced by factors such as the individual's aerobic capacity, sensitivity to stimuli and psychological traits like motivation. Therefore, personalized pre-game training programs tailored to the cognitive needs of referees are recommended in light of these discoveries. While our study focused exclusively on measuring effort in the aerobic zone, it is essential to note that referees also exhibit performance in the anaerobic zone during competitions. Therefore, future studies should incorporate anaerobic effort loading in their experimental designs.

AVAILABILITY OF DATA AND MATERIALS

The data are contained within this article.

AUTHOR CONTRIBUTIONS

AGG and LYC—designed the study. LYC, US, AA and KS—completed and supervised the data collection. AGG, LYC, US and AA—analyzed the data and interpreted the data. LYC, US, GBI and KS—prepared the manuscript for publication. LYC, AGG and GBI—reviewed the draft of the manuscript. All authors read and approved the final manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The Mugla Sitki Kocman University Social and Humanities Research Ethics Committee has granted approval for this research study (Protocol No: 240097, Decision No: 96). All referees who expressed their willingness to participate in the study were licensed and healthy individuals. Participants provided written informed consent, and no participant was classified as a patient.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

REFERENCES

[1] Vater C, Schnyder U, Müller D. That was a foul! How viewing angles, viewing distances, and visualization methods influence football referees' decision-making. German Journal of Exercise and Sport Research. 2024; 54: 476–485.

[2] Put K, Wagemans J, Spitz J, Williams AM, Helsen WF. Using web-based training to enhance perceptual-cognitive skills in complex dynamic offside events. Journal of Sports Sciences. 2016; 34: 181–189.

[3] Burge T. Perception: first form of mind. 1st edn. Oxford University Press: Oxford. 2022.

[4] Wearden J. The psychology of time perception. 1st edn. Palgrave Macmillan: London. 2016.

[5] Kondo HM, Gheorghiu E, Pinheiro AP. Malleability and fluidity of time perception. Scientific Reports. 2024; 14: 12244.

[6] Gardner HR, Konrad A, Alizadeh S, Graham A, Behm DG. Temporal perception is distorted by submaximal and maximal isometric contractions of the knee extensors in young healthy males and females. Frontiers in Sports and Active Living. 2023; 5: 1185480.

[7] Pizzera A, Laborde S, Lahey J, Wahl P. Influence of physical and psychological stress on decision-making performance of soccer referees. Journal of Sports Science and Medicine. 2022; 40: 2037–2046.

[8] Piras A, Lobietti R, Squatrito S. Response time, visual search strategy, and anticipatory skills in volleyball players. Journal of Ophthalmology. 2014; 2014: 189268.

[9] Williams AM, Jackson RC. Anticipation in sport: fifty years on, what have we learned and what research still needs to be undertaken? Psychology of Sport and Exercise. 2019; 42: 16–24.

[10] Wittmann M. The inner sense of time: how the brain creates a representation of duration. Nature Reviews Neuroscience. 2013; 14: 217–223.

[11] Sudo M, Costello JT, McMorris T, Ando S. The effects of acute high-intensity aerobic exercise on cognitive performance: a structured narrative review. Frontiers in Behavioral Neuroscience. 2022; 16: 957677.

[12] Schneeberger M, Pszeida M, Lenger M, Heiler L, Simi H, Wallner D, *et al*. Impact of acute physical exercise on cognitive performance. Cognitive Computing and Internet of Things. 2023; 73: 93–103.

[13] Ovchinnikova NA, Medvedeva EV, Yezhova GS, Krivoshchekov SG, Kapilevich LV. Influence of physical loads on cognitive functions and bioelectric activity of the brain in athletes of various specializations. Human Physiology. 2023; 49: 502–512.

[14] Dufner TJ, Moon JM, Wells AJ. Cycle-based high-intensity sprint exercise elicits acute cognitive dysfunction in psychomotor and memory task performance. Frontiers in Cognition. 2024; 3: 1419734.

[15] Molinaro L, Taborri J, Pauletto D, Guerra V, Molinaro D, Sicari G, *et al*. Measuring the immediate effects of high-intensity functional training on motor, cognitive and physiological parameters in well-trained adults. Sensors. 2023; 23: 3937.

[16] Festa F, Medori S, Macrì M. Move your body, boost your brain: the positive impact of physical activity on cognition across all age groups. Biomedicines. 2023; 11: 1765.

[17] Ceylan HI, Saygin O. Acute effect of various exercise ıntensities on cognitive performance. European Journal of Physical Education and Sport Science. 2018; 4: 157–172.

[18] Katahira K, Yamazaki Y, Yamaoka C, Ozaki H, Nakagawa S, Nagata N. EEG correlates of the flow state: a combination of increased frontal theta and moderate frontocentral alpha rhythm in the mental arithmetic task. Frontiers in Psychology. 2018; 9: 300.

[19] Ettefagh A, Ghassemi F, Tabanfar Z. Time-frequency analysis of electroencephalogram signals in a perceptual decision-making task of random dot kinematograms. Frontiers in Biomedical Technologies. 2022; 9: 170–175.

[20] Pathak D, Kashyap R, Rahamatkar S. A study of deep learning approach for the classification of electroencephalogram (EEG) brain signals. In Pandey R, Khatri SK, Singh NK, Verma P (eds.) Artificial intelligence and machine learning for EDGE computing (pp. 133–144). 1st edn. Academic Press: Cambridge. 2022.

[21] Clements GM, Bowie DC, Gyurkovics M, Low KA, Fabiani M, Gratton G. Spontaneous alpha and theta oscillations are related to complementary aspects of cognitive control in younger and older adults. Frontiers in Human Neuroscience. 2021; 15: 621620.

[22] Amil AF, Albesa-González A, Verschure PFMJ. Theta oscillations optimize information rate in the hippocampus. PLOS Computational Biology. 2024; 20: e1012628.

[23] Dos Anjos T, Di Rienzo F, Benoit CE, Daligault S, Guillot A. Brain wave modulation and EEG power changes during auditory beats stimulation. Neuroscience. 2024; 554: 156–166.

[24] Kerna NA, Chawla S, Carsrud NDV, Pruitt KD, Nwokorie U, Flores JV, *et al*. Binaural beats: novel approach to managing certain physiological

and psychological conditions. EC Psychology and Psychiatry. 2022; 11: 58–69.

[25] Nalluri VRS, Sonti VK, Sundari G. Analysis of frequency dependent Vedic chanting and its influence on neural activity of humans. International Journal of Reconfigurable and Embedded Systems. 2023; 12: 230–239.

[26] Piffaretti M, Carr B. "We react less. We react differently. We react better": a case study of a mindfulness-based intervention for Olympic referee performance. Case Studies in Sport and Exercise Psychology. 2022; 6: 78–93.

[27] Ingendoh RM, Posny ES, Heine A. Binaural beats to entrain the brain? A systematic review of the effects of binaural beat stimulation on brain oscillatory activity, and the implications for psychological research and intervention. PLOS ONE. 2023; 18: e0286023.

[28] Ke J, Du J, Luo X. The effect of noise content and level on cognitive performance measured by electroencephalography (EEG). Automation in Construction. 2021; 130: 103836.

[29] Goudini R, Zahiri A, Alizadeh S, Drury B, Anvar SH, Daneshjoo A, *et al*. The effects of physical and mental fatigue on time perception. Sports. 2024; 12: 59.

[30] MacKenzie CA, Christensen J, Turner S. Advocating beyond the academy: dilemmas of communicating relevant research results. Qualitative Research. 2013; 15: 105–121.

[31] Yeaton WH. Experimental and quasi-experimental designs–verities and balderdash 1: designating designs to discern the difference. 2nd edn. Routledge: London, England. 2024.

[32] Macorig G, Crespel A, Nilo A, Tang NPL, Valente M, Gigli GL, *et al*. Benign EEG variants in the sleep–wake cycle: a prospective observational study using the 10–20 system and additional electrodes. Neurophysiologie Clinique-Clinical Neurophysiology. 2021; 51: 233–242.

[33] Ullah I, Khan SSB, Gul R, Ullah A. Effects of aerobic training on targeted heart rate zone. Hec Recognized Journal. 2022; 7: 16–25.

[34] Moore AR, Olson M. Sense of time is slower following exhaustive cycling exercise. Psychological Research. 2024; 88: 826–836.

[35] Wohldmann EL, Healy AF, Bourne LE III. Task integration in time production. Attention Perception and Psychophysics. 2010; 72: 1130–1143.

[36] Wild-Wall N, Willemssen R, Falkenstein M. Feedback-related processes during a time-production task in young and older adults. Clinical Neurophysiology. 2009; 120: 407–413.

[37] Tonelli A, Lunghi C, Gori M. Moderate physical activity alters the estimation of time, but not space. Frontiers in Psychology. 2022; 13: 1004504.

[38] Rioux PA, Lebrun C, Demers A, Grondin S. Investigation of the psychological length of a 1-s interval with a time production task. Canadian Journal of Experimental Psychology. 2023; 77: 177–184.

[39] Saygin O, Goral K, Ceylan HI. An examination of the coincidence anticipation performance of soccer players according to their playing positions and different stimulus speeds. The Sport Journal. 2016; 24: 1–11.

[40] Lyons M, Al-Nakeeb Y, Nevill A. Post-exercise coincidence anticipation in expert and novice Gaelic games players: the effects of exercise intensity. European Journal of Sport Science. 2008; 8: 205–216.

[41] Morrison JD, Reilly J. An assessment of decision-making as a possible factor in the age-related loss of contrast sensitivity. Perception. 1986; 15: 541–552.

[42] Davranche K, Audiffren M. Facilitating effects of exercise on information processing. Journal of Sports Science and Medicine. 2004; 22: 419–428.

[43] Radun J, Maula H, Rajala V, Scheinin M, Hongisto V. Acute stress effects of impulsive noise during mental work. Journal of Environmental Psychology. 2022; 81: 101819.

[44] Macorig G, Crespel A, Nilo A, Tang NPL, Valente M, Gigli GL, *et al*. Benign EEG variants in the sleep-wake cycle: a prospective observational study using the 10–20 system and additional electrodes. Clinical Neurophysiology. 2021; 51: 233–242.

[45] Le Bouc R, Garcin B, Urbanski M, Volle E, Dubois B, Levy R. Anatomy and disorders of frontal lobe functions: fundamental functions. In Sala SD (ed.) Encyclopaedia of behavioural neuroscience (pp. 266–279). 2nd edn. Elsevier Science: Edinburgh, UK. 2022.

[46] Borges LR, Arantes APBB, Naves ELM. Influence of binaural beats stimulation of gamma frequency over memory performance and EEG spectral density. Healthcare. 2023; 11: 801.

[47] Siraj-Ud-Doulah M. An alternative measures of moments skewness kurtosis and JB test of normality. Journal of Statistical Theory and Applications. 2021; 20: 219–227.

[48] Edwards AM, McCormick A. Time perception, pacing and exercise intensity: maximal exercise distorts the perception of time. Physiology and Behavior. 2017; 180: 98–102.

[49] Skala F, Zemkova E. Effects of acute fatigue on cognitive performance in team sport players: does it change the way they perform? A scoping review. Applied Sciences. 2022; 12: 1736.

[50] Nurcahya Y, Rusdiana A, Hidayat Y, Sidik DZ, Kusumah W, Yamin M, *et al*. The effect of physical fatigue on football referee's decision making. Physical Activity Journal. 2023; 5: 91–98.

[51] Bullock T, Giesbrecht B. Acute exercise and aerobic fitness influence selective attention during visual search. Frontiers in Psychology. 2014; 5: 1290.

[52] Kubitz KA, Pothakos K. Does aerobic exercise decrease brain activation? Journal of Sport and Exercise Psychology. 1997; 19: 291–301.

[53] Steptoe A, Moses J, Mathews A, Edwards S. Aerobic fitness, physical activity, and psychophysiological reactions to mental tasks. Psychophysiology. 1990; 27: 264–274.

[54] Brewer BW, Schwartz LO III, Cornelius AE, Van Raalte JL, Urbina EL, Stubbs JS III. It's about time: effects of physical exertion on duration estimates. Journal of Functional Morphology and Kinesiology. 2019; 4: 6.

[55] Bard C, Fleury M. Influence of imposed metabolic fatigue on visual capacity components. Perceptual and Motor Skills. 1978; 47: 1283–1287.

[56] Duncan M, Smith M, Lyons M. The effect of exercise intensity on coincidence anticipation performance at different stimulus speeds. European Journal of Sport Science. 2013; 13: 559–566.

[57] Duncan MJ, Smith M, Bryant E, Eyre E, Cook K, Hankey J, *et al*. Effects of increasing and decreasing physiological arousal on anticipation timing performance during competition and practice. European Journal of Sport Science. 2016; 16: 27–35.

[58] Tomporowski PD. Cognitive and behavioral responses to acute exercise in youths: a review. Pediatric Exercise Science. 2003; 15: 348–359.

[59] Ahmed HS, Marcora SM, Dixon D, Davison G. The effect of a competitive futsal match on psychomotor vigilance in referees. International Journal of Sports Physiology and Performance. 2020; 15: 1297–1302.

[60] Bailey SP, Hall EE, Folger SE, Miller PC. Changes in EEG during graded exercise on a recumbent cycle ergometer. Journal of Sports Science and Medicine. 2008; 7: 505–511.

[61] Ghorbani M, Ghazalian F, Ebrahim K, Abednatanzi H. Altered neural response induced by central-fatigue in the cortical area during high-intensity interval pedaling. Basic and Clinical Neuroscience. 2019; 10: 631–639.

[62] Hottenrott K, Taubert M, Gronwald T. Cortical brain activity is influenced by cadence in cyclists. The Open Sports Sciences Journal. 2013; 6: 9–14.

[63] Adam M, Childs A, Quraishi A, Redkar A, Yeske B. Brief aerobic exercise increases mathematical ability in undergraduate students. Journal of Advanced Student Sciences. 2016: 1–19.

[64] Devilbiss DM, Etnoyer-Slaski JL, Dunn E, Dussourd CR, Kothare MV, Martino SJ, *et al*. Effects of exercise on EEG activity and standard tools used to assess concussion. Journal of Healthcare Engineering. 2019; 2019: 4794637.

[65] Kao SC, Wang CH, Kamijo K, Khan N, Hillman C. Acute effects of highly intense interval and moderate continuous exercise on the modulation of neural oscillation during working memory. International Journal of Psychophysiology. 2021; 160: 10–17.

[66] Ciria LF, Luque-Casado A, Sanabria D, Holgado D, Ivanov PC, Perakakis P. Oscillatory brain activity during acute exercise: tonic and transient neural response to an oddball task. Psychophysiology. 2019; 56: e13326.

[67] Hötting K, Röder B. Beneficial effects of physical exercise on neuroplasticity and cognition. Neuroscience and Biobehavioral Reviews. 2013; 37: 2243–2257.

[68] Ploughman M. Exercise is brain food: the effects of physical activity on cognitive function. Developmental Neurorehabilitation. 2008; 11: 236–240.

[69] McMorris T, Hale BJ. Is there an acute exercise-induced physiological/biochemical threshold which triggers increased speed of cognitive functioning? A meta-analytic investigation. Journal of Sport and Health Science. 2015; 4: 4–13.

[70] Edwards AM, Menting SGP, Elferink-Gemser MT, Hettinga FJ. The perception of time is slowed in response to exercise, an effect not further compounded by competitors: behavioral implications for exercise and health. Brain and Behavior. 2024; 14: e3471.

[71] Davis PA, Sörman D, Carlberg A, Rognsvåg E, Stenling A. The psychophysiological influence of exertion and affect on sport-specific cognitive and physical performance. Journal of Science and Medicine in Sport. 2022; 25: 764–769.

[72] Zhang L, Shi H, Zhang H, Ding J, Wang Z. How do anxiety and stress affect soccer referees? An ERPs study. Frontiers in Psychology. 2024; 15: 1294864.

[73] Ishihara T, Yoshi N. Multivariate analytic study of EEG and mental activity in juvenile delinquents. Electroencephalography and Clinical Neurophysiology. 1972; 33: 71–80.

[74] Yamamoto S, Matsuoka S. Topographic EEG study of visual display terminal (VDT) performance with special reference to frontal midline theta waves. Brain Topography. 1990; 2: 257–267.

[75] Jiang F, Chen Z, Zhao L, Zou S. Study on emotional event-related potential by EEG data. 2010 International Conference on Multimedia Technology. 29–31 October 2010. Ningbo, China. IEEE: Zhejiang. 2010.

[76] Jafari MJ, Khosrowabadi R, Khodakarim S, Mohammadian F. The effect of noise exposure on cognitive performance and brain activity patterns. Open Access Macedonian Journal of Medical Sciences. 2019; 7: 2924–2931.

[77] Zokaei M, Mohammadian F, Takallou BA. Changes of alpha and beta brain waves in exposure to different levels of noise. Occupational Medicine. 2023; 15: 35–44.

[78] Kumar A. The effect of noise exposure on cognitive performance and brain activity patterns. The Scientific Temper. 2021; 12: 137–142.

[79] Pscherer C, Wendiggensen P, Mückschel M, Bluschke A, Beste C. Alpha and theta band activity share information relevant to proactive and reactive control during conflict-modulated response inhibition. Human Brain Mapping. 2023; 44: 5936–5952.

[80] Yao KS, Wu SH, Wang Y. Preliminary assessment of the changes of ındividual electroencephalogram and salivary alpha-amylase activity after inhalation of agarwood. Special Issue of Hsiuping Journal. 2019; 1: 53–62.

[81] Paszkiel S, Dobrakowski P, Łysiak A. The impact of different sounds on stress level in the context of EEG, cardiac measures and subjective stress level: a pilot study. Brain Sciences. 2020; 10: 728.

[82] Jirakittayakorn N, Wongsawat Y. Brain responses to a 6-Hz binaural beat: effects on general theta rhythm and frontal midline theta activity. Frontiers in Neuroscience. 2017; 11: 365.

[83] Goodin P, Ciorciari J, Baker K, Carey AM, Harper M, Kaufman J. A high-density EEG investigation into steady state binaural beat stimulation. PLOS ONE. 2012; 7: e34789.

[84] Omeroglu F, Li Y. Effects of binaural beats on mood and cognition. Proceedings of the Human Factors and Ergonomics Society Annual Meeting. Los Angeles, USA. 2022; 66: 1386–1390.

[85] Ala TS, Ahmadi-Pajouh MA, Nasrabadi AM. Cumulative effects of theta binaural beats on brain power and functional connectivity. Biomedical Signal Processing and Control. 2018; 42: 242–252.

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