International Journal of Psychophysiology xxx (xxxx) 1–14

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Regular short-duration breaks do not prevent mental fatigue and decline in cognitive efficiency in healthy young men during an office-like simulated mental working day: An EEG study

Marius Brazaitis *, Andrius Satas

Institute of Sport Science and Innovations, Lithuanian Sports University, Sporto 6, LT–44221 Kaunas, Lithuania

ARTICLE INFO

Keywords:
Event-related potential
Oddball task
Mental fatigue

ABSTRACT

Employees in Europe work on average 7.2 h per day. Prolonged periods of uninterrupted cognitive activity during the working day can cause changes in motivation, mental fatigue, and deterioration in cognitive function. In this exploratory study, we aimed to determine the effectiveness of taking 10-min breaks for light exercise every 50 min in preventing these negative effects during a simulated 7-h office-like computer work. Eighteen healthy young adult men (aged 26 ± 3 years) who did not work in an office participated. The effects of 7 h of office-like work with 10-min breaks every 50 min on central nervous system activity, cognitive function, mood, and motivation were investigated and compared with those measured on a control day without work. Our study found that engaging in 7 h of mental work similar to that found in an office environment, with 10-min breaks every 50 min, can negatively impact cognitive efficiency, suppress brain neural network activity, and cause mental fatigue. These effects do not fully recover after a 4.5-h rest. Additionally, taking short breaks during the workday does not prevent mental exhaustion or impairments in cognitive function. These findings should be considered when discussing strategies to prevent mental exhaustion caused by mental work.

1. Introduction

Mental fatigue caused by prolonged periods of cognitive activity can have negative impacts on motivation and lead to a decrease in the enjoyment of work over time (Hockey, 2013). Mental fatigue is characterized by feelings of tiredness, exhaustion, or lack of energy, and can negatively affect health, well-being, and productivity (Sadeghniiat-Haghighi and Yazdi, 2015). As a result of the COVID-19 pandemic, over a billion individuals were forced to stay at home, resulting in an increase in sedentary lifestyle and associated health concerns (Ammar et al., 2020). The pandemic also prompted a shift toward remote work for many individuals and even though restrictions have been lifted, a significant portion of the population continues to work from home.

Workplace sitting is a major contributor to sedentary behavior (Clemes et al., 2014). Data from various countries suggests that adults spend between 6.2 and 9.6 h per day engaging in sedentary behaviors, with a significant portion of this time spent sitting at work (Tudor-Locke et al., 2011). Engaging in continuous cognitively demanding tasks for at least 60 min (Boksem et al., 2005; Fan et al., 2015; Trejo et al., 2015; Wascher et al., 2014) or prolonged sitting for 2–7 h (Baker et al., 2018; Triglav et al., 2019; Wennberg et al., 2016) can lead to subjective mental fatigue (Baker et al., 2018; Fan et al., 2015; Wennberg et al., 2016) and a deterioration in cognitive function, including impacts on visual searching, problem-solving ability, and attention (Baker et al., 2018; Boksem et al., 2005; Fan et al., 2015; Trejo et al., 2015; Triglav et al., 2019; Wascher et al., 2014). The full-time workday in an office setting has also been linked to decreases in arousal level and motivation, as well as negative consequences on cognitive information processing, working memory, and the ability to focus (Boksem et al., 2005; Zhao et al., 2012). Therefore, it is important to explore options for reducing fatigue during sedentary work that requires the use of cognitive resources.

Mental fatigue is a commonly studied phenomenon that can have significant impacts on cognitive performance and attention allocation (Hopstaken et al., 2016). Electroencephalography (EEG) is a widely used tool for assessing brain activity and arousal (Lendner et al., 2020), and changes in oscillatory brain activity, as measured by EEG, have been found to reflect changes in brain arousal and alertness (Craig et al., 2012). Specifically, increases in theta (4–8 Hz) and alpha (8–12 Hz) band spectral power across frontal, central, and posterior cortical sites

* Corresponding author.
E-mail addresses: marius.brazaitis@lsu.lt (M. Brazaitis), Andrius.satas@lsu.lt (A. Satas).

https://doi.org/10.1016/j.ijpsycho.2023.03.007
Received 23 September 2022; Received in revised form 21 February 2023; Accepted 17 March 2023
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have been identified as reliable neural biomarkers of mental fatigue (Tran et al., 2020). In addition, changes in global alpha and theta frequencies have been linked to subjective sleepiness, as measured by resting-state EEG power (Strijkstra et al., 2003). The relative energy ratios between EEG bands, such as (theta + alpha)/beta (Jap et al., 2009) and (theta + alpha)/delta (Kar et al., 2010), have also been considered as indicators of fatigue, with a decrease in alertness level associated with a decrease in these ratios (Brookhuis and de Waard, 1993).

Event-related potentials (ERPs), as measured using the oddball paradigm, are sensitive and reliable indicators of changes in cognitive processes, such as attentional and working memory processes, stimulus discrimination, evaluation, and categorization (Koshkin et al., 2018; Picton, 1992). Changes in the amplitude and latency of EEG ERPs, including N2 and P3 potentials, have been shown to reflect changes in cognitive processes and are usually reflected in changes in reaction time and accuracy during cognitive task performance (Pergher et al., 2019). Shorter N2 and P3 latencies and larger amplitudes have been associated with superior information processing (Polich, 2007).

In addition to EEG, mental fatigue research often includes an examination of autonomic nervous system (ANS) activity (Gergelyfi et al., 2015). The ANS plays a crucial role in regulating physiological changes in response to workload and is responsible for regulating several bodily functions, such as heart rate, breathing, blood pressure, and reflex actions. The ANS consists of two branches: the sympathetic and parasympathetic nervous systems (Massaro and Pecchia, 2019). The parasympathetic nervous system (PNS), which is responsible for relaxing the body, has been found to decrease in activity in response to increases in workload (Hoover et al., 2012). Heart rate variability (HRV) is a commonly used measure to evaluate ANS function (Lipponen and Tarvainen, 2019) and is sensitive to workload increases due to vigilance and situational awareness demands (Jasper et al., 2016). HRV has been used as a marker of ANS activity and its influence on cognitive processing (Jasper et al., 2016). It has been demonstrated that prolonged mental workload can lead to sympathetic hyperactivity, as measured in the low-frequency band (LF) of 0.04–0.15 Hz, and decreased parasympathetic activity, as measured in the high-frequency band (HF) of 0.15–0.40 Hz (Mizuno et al., 2011; Zhao et al., 2012). Changes in the power density spectrum on electrocardiogram may therefore reflect induced mental fatigue and provide additional indicators for assessing the consequences of mental workload.

In the modern world, skilled work is in high demand and it is important to help workers reduce mental fatigue to improve their welfare and productivity both during and after working hours (Albulescu et al., 2022). Mental fatigue can lead to chronic stress and ultimately burnout, which can have negative physical and mental consequences on workers' well-being and health, such as insomnia, depression, hypercholesterolemia, type 2 diabetes, coronary heart disease, hospitalization due to cardiovascular disorders, musculoskeletal pain, changes in pain experiences, prolonged fatigue, headaches, and gastrointestinal issues (Salvagioni et al., 2017). Taking breaks during work, such as lunch breaks, scheduled breaks, or micro-breaks, has the potential to improve individual well-being and performance (Sonnentag et al., 2022). However, research in this area has been limited, and the effects of recovery during these shorter intervals are not yet fully understood (Albulescu et al., 2022; Bennett et al., 2020; Sonnentag et al., 2022). Further research is needed to better understand the effects of recovery during work breaks and to determine the most effective strategies for promoting recovery in the workplace.

The main aim of this exploratory study was to investigate the effects of a 7-h working day that includes short breaks (10 min) every 50 min ("7 x 50/10 minutes" whole working day model) on mental fatigue. It was hypothesized that this model could help to limit or prevent the development of mental fatigue by allowing for short breaks (Baker et al., 2018) and a change in posture during prolonged sitting (Hasegawa et al., 2001), which can have a direct effect on the release of peripheral catecholamines and noradrenaline in the brain (Miyashita and Williams, 2006) and indirectly increase dopamine release (McMorris, 2020). These changes in brain chemistry can be important for enabling motivation to overcome response costs, such as sustained attention to a cognitive task, and for enhancing general motivation (Bromberg-Martin et al., 2010). Even low-intensity physical activity during these breaks, such as walking, may have a direct effect on the central nervous system by increasing heart rate (HR) and improving glucose delivery to active domains in the brain (Kennedy and Scholey, 2000). The Lithuanian hygiene standard "Working with video terminals. Safety and health requirements" (*Dėl Lietuvos higienos normos HN 32:2004 "Darbas su videoterminalais. Saugos ir sveikatos reikalavimai"*, 2004) recommend a 10-min break every hour to reduce fatigue and stress levels, but there is currently insufficient scientific evidence to support this standard. Therefore, the question arises as to whether 10-min breaks of light exercise every 50 min would be effective in preventing mental and cognitive fatigue during a simulated 7-h office-like computer work scenario.

2. Methods

2.1. Participants

Eighteen healthy young adult men participated in this study. Their mean (± standard deviation, SD) demographic/anthropometric parameters were age 26 ± 3 years, height 188.13 ± 9.42 cm, body mass 84.92 ± 17.60 kg, body mass index 23.73 ± 2.39 kg/m^2, and percentage body fat 14.46 % ± 3.34 %. Participants were physically active, as defined by physical activity ≥3 times per week and ≥ 150 min of moderate intensity or ≥ 75 min of vigorous intensity activity per week. Participants were excluded from the study if they reported any significant mental or physical illnesses, including cardiovascular disease, diabetes, or mental health disorders. They were also asked to disclose any medications they were taking and were excluded if they were taking any psychotropic substrates or other drugs that could affect the research results. To reduce the potential for confounding factors, only non-office workers who were familiar with prolonged cognitive work, such as university students, were included in the study. This exclusion criterion was chosen to avoid the possible effects of office work, such as chronic fatigue or stress, on the outcomes of the study. We have excluded female participants from the study in order to control for potential hormonal or physiological differences between men and women, which have been shown to affect fatigue sensitivity (Åkerstedt et al., 2004). To ensure that caffeine intake and withdrawal symptoms did not affect the outcomes of the study, we carefully selected participants who reported consuming less than three cups of coffee per week. During the course of the study, our subjects reported no caffeine withdrawal symptoms. Additionally, subjects had normal or corrected-to-normal visual acuity. Written informed consent was obtained from all participants after explanation of all details of the experimental procedures and the associated discomforts. The experimental procedures were approved by the Lithuanian University of Health Sciences Kaunas Region Biomedical Research Ethics Committee.

2.2. Oddball tasks

An oddball task with 175 visual stimuli was used in this study. Oddball paradigm is widely used in ERP studies due to high reproducibility, simplicity, and applicability across sensory modalities (Patel and Azzam, 2005) and is considered as a classic task used to elicit P3 (Verleger, 2020). Oddball task is believed to trigger selective attention, sensory detection and discrimination of stimuli and working memory (Polich, 2007). Two types of stimuli were used in the task. One required a response (press the left mouse button) to the target stimuli ("X" with 20 % probability) and the other required no response to the standard stimuli ("O" with 80 % probability). The stimulus duration was 0.5 s, and the interstimulus interval was 1.5 s. The stimuli were presented in random order. The reaction times (RTs, in ms) and accuracy of the responses to the target stimulus (%) were measured (Cernych et al., 2018; Polich, 2007).

2.3. Mental workload

To assess performed cognitive work, nine cognitive tasks were chosen from the computerized Automated Neuropsychological Assessment Metrics library (ANAM4, version 4; Vista Life Science, Norman, OK, USA): Code substitution – learning as a measure of complex scanning, visual tracking, and attention; Procedural reaction time as a measure of reaction time and processing efficiency; Code substitution – delayed as a measure of memory; Memory search as a measure of verbal working memory and attention; Running memory continuous performance test as a measure of attention, concentration and working memory; Matching grids as an index of visuospatial processing; Matching to sample as a measure of visual working memory; Spatial processing; and the Stroop test as a measure of processing efficiency, selective attention and executive function. Tasks are described in detail elsewhere (Reeves et al., 2007; Solianik et al., 2018; Terentjeviene et al., 2018) and were chosen according to the functions needed by office employees to perform mental work, such as working memory, attention, concentration, reaction, visual tracking, learning, memory, visuospatial function, selective attention, and executive function. The participants performed the self-controlled tasks (i.e., the participant started each task by pressing the dedicated keyboard button whenever he felt ready to start) in the usual sitting posture in a standard office chair with backrest and regulated height to allow 90° knee flexion. The desk height was adjusted to allow 90° elbow flexion and for the forearms to rest on the desk surface.

Each battery set of nine tasks was presented in random order and performed according the ANAM4 instructions as described in detail (Brazaitis et al., 2016; Brunner et al., 2007; Solianik et al., 2018; Terentjeviene et al., 2018; Xie et al., 2015; Žlibinaitė et al., 2020). Each task from a battery set was performed twice during the 50-min set, and the mean value of the two sets was used in the analysis. Throughput (in correct responses/min) for each trial was calculated using the equation:

$$\text{Throughput} = \text{NumCorr}/\left((\text{NumCorr} + \text{NumInc}) \times \text{MeanRT} + \text{NumLapse} \times \text{Timeout}\right)$$

where Throughput = the number of correct responses per unit of available response time; NumCorr = the number of correct responses; NumInc = the number of incorrect responses; MeanRT = the mean response time of all items (correct and incorrect); NumLapse = the number of trials where no response was made in the allotted time; and Timeout = the allocated time.

The performance of each set took 50 ± 2 min. If a participant completed a set faster than this, he had a longer break and vice versa, so that the duration of each set of task performance and the break totaled 1 h. The researcher remained in the laboratory the entire time to provide motivation and support; for example, after each battery set of nine tasks, the researcher announced the results, and the participant was encouraged to improve his performance.

2.4. Questionnaire

Motivation was assessed using the Dundee Stress State Questionnaire (DSSQ), which contains subscales on success motivation (the participant's motivation to excel in task performance) and intrinsic motivation (the participant's interest in the cognitive task). Each subscale included seven statements that were evaluated using a scale from 0 (not at all) to 4 (extremely), and the seven item scores were summed. All DSSQ Cronbach's alphas exceeded 0.7 (Matthews, 2021). Item 15 provides an overall rating of motivation (Matthews et al., 2002). The 24-item Brunel Mood Scale was used to answer the question "How do you feel right now?" This scale comprises six subscales: anger, confusion, depression, fatigue, tension, and vigor. Each subscale contains four items that are evaluated from 0 (not at all) to 4 (extremely) and are summed to give a score from 0 to 16 (Čekanauskaitė et al., 2020; Terry et al., 2003). Brunel Mood Scale (BRUMS) Cronbach alphas exceeded 0.7 (Anger = 0.86, Confusion = 0.85, Depression = 0.88, Fatigue = 0.89, Tension = 0.83, Vigor = 0.88) (Terry et al., 2022). About 5 min was needed to complete the questionnaires.

2.5. Familiarization session

To attain a stable level of performance, at least 1 week before the experiment, participants were introduced to the experimental procedures and cognitive and oddball testing and were informed of the known risks and associated discomfort of the study. They were familiarized with the procedures over 3 days. On each day, each participant performed a cognitive test battery. During the familiarization visit, they were instructed to sleep for a minimum of 7–8 h on the night before the experiment; to refrain from alcohol, heavy exercise, and caffeine for at least 24 h; and to refrain from consuming any food for at least 12 h before arrival at the laboratory. To standardize the morning state of hydration, the participants were allowed to drink still water whenever they felt thirsty. The study was performed at a room temperature of 22 °C and 50 % relative humidity.

2.6. Experimental protocol

Each participant completed the study trials twice for the experimental (EXP) and control (CON) trials. Both sessions were conducted at the same time of day and at least 7 days apart, and the order of trials was randomized. The experiment (Fig. 1) was designed to investigate the effects of a standard 7-h working day with 10-min breaks every 50 min on central nervous system activity, cognitive function, mood, and motivation. Prolonged (4 h) uninterrupted sitting impairs cerebrovascular blood flow, which can impair cognitive function and increase disease risk, whereas light-intensity physical activity offsets these changes (Carter et al., 2018). Based on this information, we have chosen a protocol that involves interrupting sitting for 10 min every 50 min, plus an additional hour for EEG testing. After having fasted overnight, each participant came to the laboratory at 7:30 am for the morning session (MOR) and was asked to sit at a table in an EEG-dedicated room. The participant sat for 10–15 min to rest as the EEG cap was prepared. The EEG activity was recorded with the participant's eyes closed and during the oddball task. Cardiac autonomic activity was recorded at the same time as EEG. Upon completion of the EEG recording, the participant was asked to complete a questionnaire to estimate his motivation and mood, after which a capillary blood sample was taken.

By the end of the baseline measurements, each participant had a preprepared breakfast. The participant was then asked to start a mental workload comprising seven self-controlled cognitive work sets, 50 min each with 10 min breaks between each set in the EXP trial. In the CON trial, the participants had 7 h of free time during which light-intensity physical activity, such as household chores or walking, was allowed but strenuous physical and cognitive activity were forbidden. For the daily activity observation, a Fitbit Charge HR 2 watch was used, and participants started wearing the watch after MOR measurements and stopped wearing the watch before REC measurements. After the EVE session (both EXP and CON trials), the participant had 4.5 h of recovery (REC), after which REC measurements were obtained. The EVE and REC measurements included all of the same measurements as in the MOR session: EEG with eyes closed and during the oddball task with simultaneous recording of cardiac autonomic activity, completion of the questionnaire, and collection of a capillary blood sample.

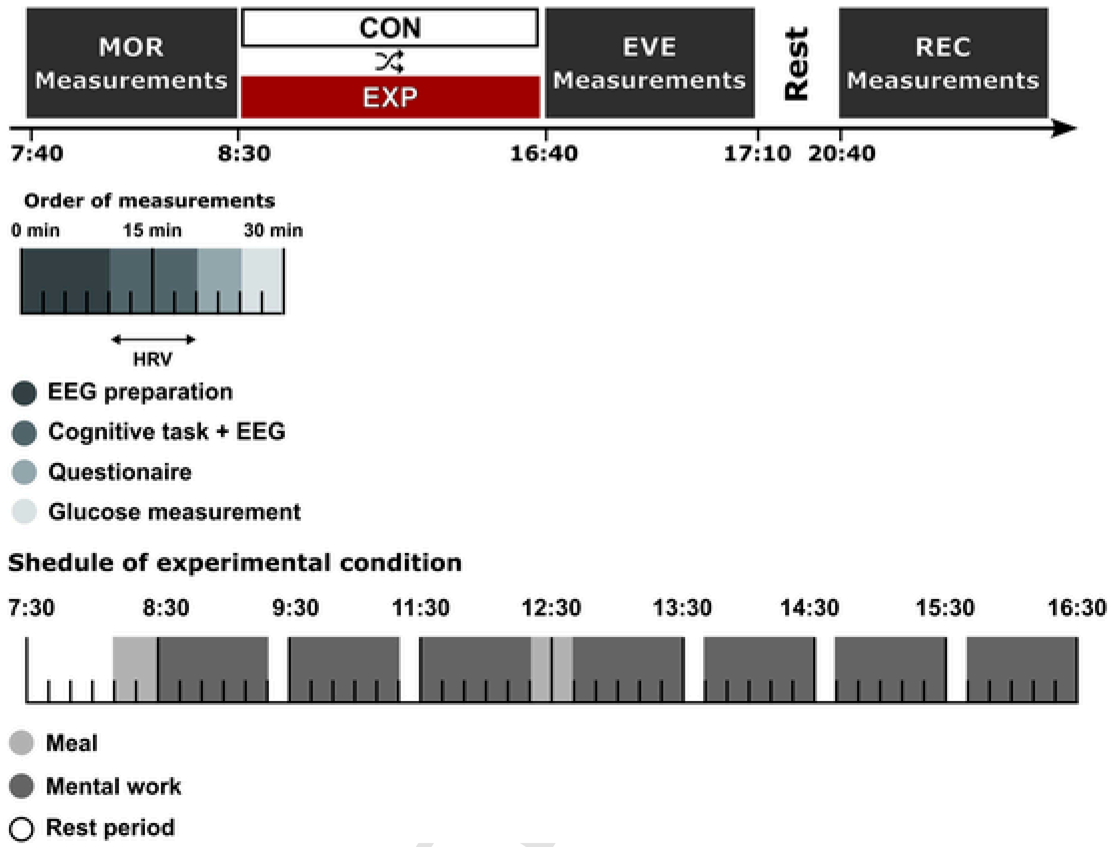

Fig. 1. Schematic representation of the experimental protocol. MOR = measurements in the morning, EVE = measurements in the evening, REC = recovery, EEG = electroencephalography, Cognitive task + EEG = cognitive (oddball) task, HRV = heart rate variation, Glucose = capillary blood collection, CON = control trial, EXP = experimental trial.

2.7. Nutrition and physical activity

A capillary blood sample was obtained, and the participants were given 20 min to eat a preprepared breakfast. Lunch took about 20 min and was scheduled between cycles 3 and 4 of the mental workload (i.e., 4 h before the main EVE measurements). Dinner was served immediately after the EVE measurements. A total nutritional energy value ~2300 kcal was selected according to European Food Safety Authority dietary reference values for nutrients as the adequate intake for sedentary young men aged 18–29 years (Authority (EFSA), 2017). The preprepared meal boxes included ~750 kcal per box and comprised a chicken sandwich (100 g whole meal bread, 50 g chicken, 50 g tomato, 30 g salad, 40 g avocado), 150 g low-fat yogurt, 20 g walnuts, one apple, and one banana, and were the same for all participants in both the EXP and CON trials. Water was the only beverage allowed during the study day.

During the 4.5-h REC, participants were allowed to perform self-controlled activities including conversing, resting in the semi recumbent position with eyes closed or open (no sleeping was allowed), light walking in the laboratory or nearby corridor, light stretching, and use of the bathroom whenever necessary. No strenuous mental workload and/or physical exercise was allowed. These activities were controlled constantly by the lab researcher.

2.8. EEG recording and analysis

EEG was recorded using a 32-channel standard brain cap (EasyCap GmbH, Herrsching, Germany). Fz, Cz, and Pz electrodes were placed according to the International 10–20 System. The ground electrode was placed at AFz, all electrodes were referenced to linked earlobes, the sampling rate was 500 Hz, and the impedance was kept below 5 kΩ. Participants were asked to sit with their eyes closed for 5 min, after which they performed the oddball task (Cernych et al., 2018). About 10 min was needed to complete this task.

Brain Vision Analyzer 2.0 software (Brain Products, Gilching, Germany) was used for off-line EEG data processing. Brain activity data recorded during the resting period with eyes closed were filtered using a low cutoff of 0.53 Hz, high cutoff of 70 Hz, and notch of 50 Hz, and were digitized continuously at 256 Hz with 12-bit resolution (Cernych et al., 2018; Griškova et al., 2007). Epochs containing muscle contraction artifacts were rejected manually. Eye movements and blinks were corrected using independent component analysis. After artifact rejection, data were divided into equal-sized segments (5.12 s), and fast Fourier transformations were conducted. Each participant's data were averaged across the epochs for Fz, Cz, and Pz electrodes, and mean absolute power was computed for delta (δ: 0.5–4 Hz), theta (θ: 4–8 Hz), alpha (α: 8–12 Hz), and beta (β: 12–30 Hz) frequency bands. The EEG band relative power (i.e., slowing ratio) was calculated using equations:

(Jap et al., 2009)

$$\text{Slowing ratio} = (\theta + \alpha)/\beta$$

(Kar et al., 2010)

$$\text{Slowing ratio} = (\theta + \alpha)/\delta$$

Data recorded during the oddball task were filtered using 0.01 Hz low cutoff and 70 Hz high cutoff filters. Epochs containing muscle contraction artifacts were rejected manually. Eye movements and blinks were corrected using independent component analysis. The epoch for each ERP stimulus started 150 ms before and ended 800 ms after the stimulus. Epochs were baseline-corrected to the mean of the prestimulus period (−150 ms – 0 ms). Medial EEG electrodes (Fz, Cz and

Pz) were selected for analysis based on previous studies that demonstrated they yielded the largest responses during P300 analysis in oddball tasks (Picton, 1992). Only correct responses were averaged. The peak amplitudes and latencies of the N2 component were defined as the second negative peak in the time window of 180–270 ms, and the P3 component was defined as the third positive peak in the time window of 240–400 ms. Amplitudes were measured in microvolts (μV) from prestimulus baseline to peak.

2.9. Cardiac autonomic activity

The HR (in beats per minute) and digitized beat-to-beat (RR) intervals were registered using a Polar H2 heart rate sensor with a chest strap (Kempele, Finland) and simultaneously transferred to Polar Pro Trainer 5 software. Kubios HRV 2.2 software (Department of Applied Physics, University of Kuopio, Finland) was used to analyze each RR interval and to calculate the LF (0.04–0.15 Hz) and HF (0.15–0.4 Hz) powers and LF/HF ratio (Čekanauskaitė et al., 2020; Zhao et al., 2012). Before analysis RR intervals were filtered by using automatic beat correction algorithm of Kubios HRV software as described by Lipponen and Tarvainen (2019).

2.10. Capillary blood glucose analysis

Blood glucose concentration was measured in the MOR, EVE, and REC sessions. A capillary blood sample was obtained from a finger-pick test using a CardioChek PA analyzer (Polymer Technology System Inc., Indianapolis, IN, USA).

2.11. Statistical analysis

The number of participants was selected based on the calculated sample effect size after analyzing the data for the first five participants who completed the study. At an α of 0.05 and β (power) of 80 %, our power analysis indicated that, in a within-condition comparison, 14 participants would be required to detect a large effect ($p < .05$; $\eta_p^2 > 0.25$) for the indices of mental workload, changes in electrophysiological activity, cognitive performance during oddball task, cardiac autonomic activity, subjective fatigue. However, to account for possible missing data or dropouts, we planned to include 20 participants (i.e., about one-third more than required). One participant dropped out of the study because of lack of motivation and another because of changes in his daily schedule during the research period.

The data were tested for normality using the Shapiro–Wilk test before parametric statistical analyses were performed. Differences between the two trials (CON vs. EXP) for the baseline (MOR) ERP, oddball performance, EEG power spectrum, EEG slowing ratio, cardiac autonomic activity, and glucose concentration were analyzed using a dependent-sample *t*-test using the Bonferroni correction for multiple comparisons. Two-way repeated-measures analysis of variance (ANOVA) was used to identify the effects of the two conditions (CON vs EXP) as within-subject factors and time (MOR vs EVE vs REC) as within-subject factors on the changes in ERP, oddball performance, EEG power spectrum, EEG slowing ratio, cardiac autonomic activity, and glucose concentration. If significant effects were found, Tukey's post hoc adjustment was used for multiple comparisons within each repeated-measure ANOVA. A dependent-sample *t*-test was used to locate any differences between time points. A nonparametric related samples test was applied to evaluate changes in motivation and mood scales. A dependent-sample *t*-test was used to identify changes in mental workload performance over the 7 h. The partial eta squared (η_p^2) was estimated as a measure of the effect sizes for conditions (CON, EXP) and time points (MOR, EVE, REC). Significance was defined as $p < .05$. Descriptive data are presented as mean ± SD. Statistical analyses were performed using IBM SPSS Statistics (version 22; IBM Corp., Armonk, NY, USA).

3. Results

3.1. Overnight fasting

No differences were observed between the CON and EXP trials in the baseline (MOR) slowing ratio of the EEG power spectrum (Fig. 3), EEG absolute powers frequency bands (Fig. 4), ERP (Fig. 5), capillary glucose level (Fig. 6), oddball performance (Table 1), cardiac autonomic activity (Table 2), and subjective motivation and mood evaluations (Table 3).

3.2. Activity during the simulated working day

Participants were much less active during the 7-h mental workload in the EXP trial than in the 7-h CON trial; the counted steps were

Table 1
Mean response time (in ms) and mean percentage of correct responses (in %) to the target stimuli performing the visual oddball task in the morning (MOR), evening (EVE), and after the 4.5 h of recovery (REC) for the experimental (EXP) and control (CON) trials.

	CON	EXP
Response time, ms		
MOR	369.79 ± 34.05	364.11 ± 29.60
EVE	365.04 ± 36.69	384.57 ± 30.99*,#
REC	355.29 ± 30.74	381.58 ± 29.32*,#
Accuracy, %		
MOR	90.32 ± 7.85	89.84 ± 18.44
EVE	89.68 ± 11.52	72.70 ± 26.45*,#
REC	86.35 ± 13.77	81.27 ± 15.90*

Values are shown as the mean ± SD.
* $p < .05$ compared with MOR.
# $p < .05$ compared with CON.

Table 2
Cardiac autonomic activity response to experimental (EXP) and control (CON) trial conditions measured in the morning (MOR), evening (EVE), and after the 4.5 h of recovery (REC).

	CON			EXP		
	MOR	EVE	REC	MOR	EVE	REC
HR (bpm)	66.57 ± 4.59	70.85 ± 5.03*	65.50 ± 5.04	67.66 ± 3.83	64.42 ± 4.19 *,#	64.07 ± 4.14*
LF (n.u.)	72.37 ± 11.20	67.71 ± 13.25	69.65 ± 16.34	66.75 ± 10.71	54.19 ± 13.56 *,#	57.14 ± 15.20 *,#
HF (n.u.)	27.57 ± 11.15	32.21 ± 13.22	30.23 ± 16.18	33.18 ± 10.69	45.66 ± 13.48 *,#	42.69 ± 15.09 *,#
LF/HF	3.11 ± 1.35	2.71 ± 1.55	3.39 ± 2.41	2.43 ± 1.09	1.60 ± 1.11 *,#	2.00 ± 1.58

Values are shown as the mean ± SD. HR = heart rate, bpm = beats per minute, LF = low-frequency (0.04–0.15 Hz) band, HF = high-frequency (0.15–0.4 Hz) band., NU = normalized units.
* $p < .05$ compared with MOR.
# $p < .05$ compared with CON.

Table 3
Assessments of motivation and mood in the morning (MOR), after 7 h of cognitive work, and in the control condition in the evening (EVE) and after the 4.5 h of recovery (REC) for the experimental (EXP) and control (CON) trials.

	CON			EXP		
	MOR	EVE	REC	MOR	EVE	REC
Fatigue	1.94 ± 1.26	1.17 ± 1.62	3.00 ± 2.06	2.17 ± 2.57	5.00 ± 3.77 $^{*\,\#}$	6.44 ± 3.05 $^{*\,\#}$
Vigor	8.56 ± 3.99	9.72 ± 4.25	8.11 ± 4.79	9.06 ± 1.92	7.06 ± 4.01 $^{*\,\#}$	5.56 ± 3.54 $^{*\,\#}$
Motivation						
Success	19.72 ± 4.78	19.94 ± 6.56	21.00 ± 5.16	20.22 ± 4.21	20.61 ± 4.51	20.78 ± 5.94
Intrinsic	18.78 ± 6.04	18.56 ± 6.35	18.11 ± 6.11	19.44 ± 7.86	17.94 ± 6.73	17.78 ± 6.70
Overall	2.78 ± 1.17	2.89 ± 1.28	3.00 ± 1.19	3.06 ± 1.21	3.17 ± 0.92	3.17 ± 0.99

Values are shown as the mean ± SD; $^{*}p < .05$ compared with MOR, $^{\#}p < .05$ compared with CON.

667 ± 96 and 4812 ± 789, respectively ($t(17) = 15.3$, $p < .001$). According to these results, we were successful in controlling participants' activity levels between the experimental and control conditions.

3.3. Simulated mental workload

One hour after the beginning of the mental workload task in the EXP trial, the throughputs for Code substitution – learning (time effect $F(2.6, 43.5) = 10.46$, $p < .001$, $\eta_p^2 = 0.38$) and throughputs of Code substitution – delayed (time effect $F(3.7, 62.4) = 14.85$, $p < .001$, $\eta_p^2 = 0.46$) (Fig. 2) tasks decreased, and this decrease in cognitive efficiency remained until the end of the simulated working day. The throughput for the Memory search task also decreased 1 h after the start of the mental workload but returned to the baseline level after the lunch break and then decreased again at 6 h and 7 h in the simulated working day (time effect $F(4.4, 74) = 2.58$, $p = .033$, $\eta_p^2 = 0.18$). Performance on the other tasks was not significantly affected (i.e., no change from the first hour) during the following six 50-min work sets.

3.4. Brain electrophysiological activity

There was no significant time × trial interaction effect on the slowing ratio of the EEG power spectrum values calculated using both equations (Fig. 3). Two-way repeated-measures ANOVA revealed a significant time × trial interaction for theta at the Fz ($F(1.8, 31) = 9.3$, $p < .001$, $\eta_p^2 = 0.35$), Cz ($F(2, 34) = 3.5$, $p = .041$, $\eta_p^2 = 0.21$), and Pz ($F(2, 34) = 3.45$, $p = .042$, $\eta_p^2 = 0.20$) sites, alpha at the Fz ($F(2, 34) = 3.6$, $p = .038$, $\eta_p^2 = 0.21$) and Cz ($F(2, 34) = 3.3$, $p = .045$, $\eta_p^2 = 0.18$) sites, and beta at the Fz ($F(2, 34) = 4.3$, $p = .021$, $\eta_p^2 = 0.22$) site (Fig. 4). Analysis of the 7-h mental workload interspaced with regular short breaks (MOR vs EVE) showed increased theta spectrum at all three measured sites: (time effect $F(2, 34) = 14.00$, $p < .001$, $\eta_p^2 = 0.45$, $F(2, 34) = 7.00$, $p = .002$, $\eta_p^2 = 0.29$, $F(2, 34 = 3.4$, $p = .045$, $\eta_p^2 = 0.19$ for Fz, Cz and Pz sites respectively), increased alpha spectrum (time effect $F(2, 34) = 5.4$, $p = .009$, $\eta_p^2 = 0.24$, $F(2, 34) = 4.4$, $p = .019$, $\eta_p^2 = 0.21$ for Fz and Cz sites respectively), and increased beta spectrum at the Fz site ($F(2, 34) = 4.1$, $p = .025$, $\eta_p^2 = 0.21$). These values were significantly higher for the EXP than the CON trial (trial effect, $F(2, 34) = 4.4$, $p = .019$, $\eta_p^2 = 0.23$). All these parameters returned to their respective MOR value after the 4.5-h REC.

3.5. Cognitive performance on the oddball task

In the oddball task, after completion of the 7 h of mental work, the response time to the stimuli increased (time × trial effect $F(2, 34) = 4.1$, $p = .025$, $\eta_p^2 = 0.22$) and the accuracy percentage of correct responses decreased (time × trial effect $F(2, 34) = 9.9$, $p < .001$, $\eta_p^2 = 0.36$) (Table 1). The decreased efficiency (time effect $F(2, 34) = 4.8$, $p < .001$, $\eta_p^2 = 0.26$, $F(2, 34) = 5.8$, $p < .001$, $\eta_p^2 = 0.25$ for accuracy and response time respectively) in the oddball task was not restored to the MOR values following the REC period. In the CON trial, the efficiency in the oddball task was not affected by the time of the day (MOR vs EVE vs REC).

3.6. N2 and P3 ERPs[1]

The grand-averaged ERP waveforms are presented in Fig. 5 and topographical distribution of grand average surface voltages of EXP trial target stimulus are presented in Fig. 6. The latencies of the oddball visual N2 target increased (time effect $F(2, 34) = 3.35$, $p = .045$, $\eta_p^2 = 0.18$, $F(2, 34) = 3.4$, $p = .045$, $\eta_p^2 = 19$ for Cz and Pz sites respectively) and the amplitudes of the visual N2 target decreased (time effect $F(2, 34 = 6.8$, $p = .003$, $\eta_p^2 = 0.28$, $F(2, 34) = 3.9$, $p = .029$, $\eta_p^2 = 0.20$ for Cz and Pz sites respectively) after the 7 h of mental work in the EXP trial (Fig. 5B), but no significant time × trial interaction was found. Both components of the visual N2 target stimuli recovered to the MOR value after the 4.5-h REC period. The time and trial effects, and time × trial interaction effect for latency and amplitude components of the oddball visual N2 standard stimuli were not significant.

Significant time × trial interactions were found for the changes in the latencies of the oddball visual P3 target (time × trial interaction $F(2, 34) = 5.9$, $p = .006$, $\eta_p^2 = 0.26$, $F(2, 34) = 11.0$, $p < .001$, $\eta_p^2 = 0.39$, $F(2, 34) = 5.2$, $p = .010$, $\eta_p^2 = 0.24$ at Fz, Cz and Pz sites respectively). After the 7-h mental workload (MOR vs EVE in the EXP trial), the latencies of the oddball visual P3 target increased on average 37 ms ($q(17)$ 4.0, $p = .032$) at Fz site, 39 ms ($q(17)$ 4.5, $p = .015$) at Cz site and 31 ms ($q(17)$ 4.7, $p = .010$) at Pz site (Fig. 5C). By contrast, in the CON trial, the latencies of the P3 target decreased at the Fz site by 40 ms ($q(17)$ 4.8, $p = .009$) and Cz site by 35 ms ($q(17)$ 4.6, $p = .012$) and were 72 ms ($t(17)$ 4.3, $p < .001$) lower at Fz site, 69 ms ($t(17)$ 4.97, $p < .001$) lower in Cz site and 35 ms ($t(17)$ 2.98, $p = .025$) lower at Pz site than in the EXP trial at the EVE time. The latencies of the P3 target stimuli did not recover to the MOR values only at the Cz site in the EXP trial and were 34 ms higher ($q(17)$ 4.6, $p = .012$). For the EXP trial, the amplitudes of the P3 target stimuli at the Fz (time effect $F(1.6, 28) = 4.4$, $p = .021$, $\eta_p^2 = 0.23$), Cz (time effect $F(1.7, 29) = 5.8$, $p = .007$, $\eta_p^2 = 0.29$), and Pz (time effect $F(1.6, 27) = 4.5$, $p = .020$, $\eta_p^2 = 0.25$) sites were significantly lower at the EVE than at the MOR time points and were significantly lower in the EXP trial than in the CON trial (trial effect $F(1.7, 29) = 7.8$, $p = .002$, $\eta_p^2 = 0.30$).

3.7. Cardiac autonomic activity

For the EXP trial, two-way repeated-measures ANOVA revealed a significant time × trial interaction for HR ($F(1.8, 31) = 45.0$, $p < .001$, $\eta_p^2 = 0.74$), LF ($F(1.6, 27) = 19.0$, $p < .001$, $\eta_p^2 = 0.44$), HF ($F(1.7, 30) = 16.0$, $p < .001$, $\eta_p^2 = 0.38$) and the LF/HF ratio ($F(1.9, 32) = 14.0$, $p < .001$, $\eta_p^2 = 0.36$) (Table 2). Subsequent analysis

[1] P3 and N2 amplitudes were measured as peak-amplitudes and are not directly comparable to mean-measured amplitudes.

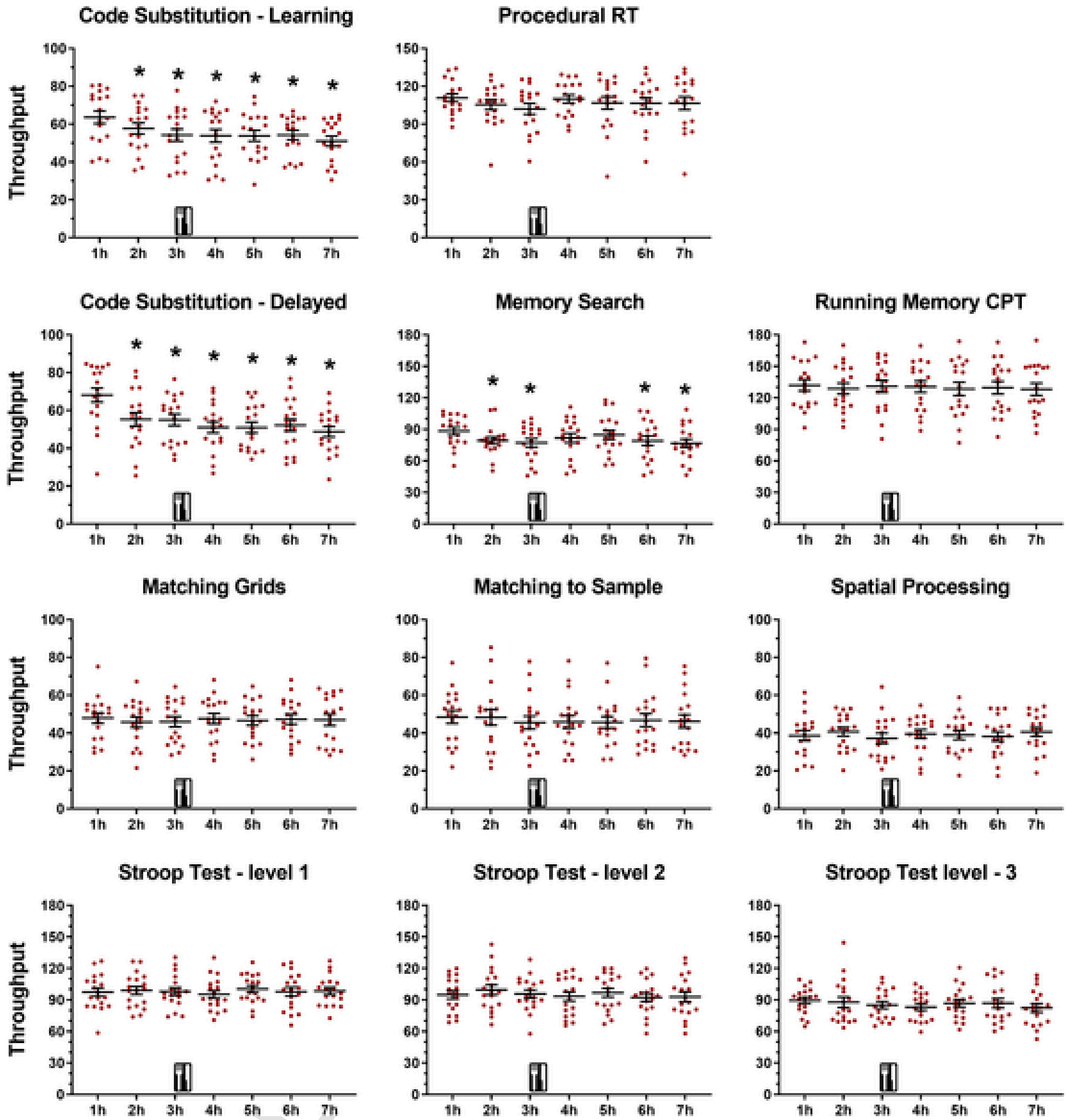

Fig. 2. Throughput for each task during the 7 h of cognitive work. Values are shown as the mean ± SD; *$p < .05$ compared with the first hour (1 h) results. Procedural RT = procedural reaction time; Running memory CTP = running memory continuous performance test.

showed that HR decreased after the 7-h mental workload (EVE) by 3.2 bpm ($q(17)$ 9.0, $p < .001$) and that this decrease did not return to the MOR value after the 4.5-h REC period. The 7-h mental workload increased HF by 12 n.u. ($q(17)$ 5.7, $p = .002$), decreased LF by 13 n.u. ($q(17)$ 5.7, $p = .002$), and decreased the LF/HF ratio by 0.83 ($q(17)$ 4.1, $p = .025$). Only the LF/HF ratio returned to the MOR value after the 4.5-h REC period.

In the CON trial, LF, HF, and the LF/HF ratio did not change significantly at any time (MOR vs EVE vs REC). HR increased after the 7 h of free time (EVE) by 4.3 bpm ($q(17)$ 10.0, $p < .001$) and returned to the MOR value during the 4.5-h REC period.

3.8. Subjective perception of motivation and mood

The participants' subjective perception of success, intrinsic and overall motivation, anger, confusion, depression, and tension analyzed by ANOVA were not significantly affected by either of the conditions (EXP vs. CON) (Table 3). By contrast, in the EXP trial, the 7-h mental workload led to greater fatigue and lower vigor perception compared with the CON trial (time × trial interaction $F(1.8, 30) = 5.2$, $p = .011$, $\eta_p^2 = 0.26$ for fatigue; $F(1.7, 29) = 6.9$, $p = .003$, $\eta_p^2 = 0.32$ for vigor). The values for these perceptional parameters of fatigue and vigor did not return to their respective MOR value after the 4.5-h REC period.

3.9. Capillary blood glucose concentration

The concentration of capillary blood glucose was lower during the 7-h mental workload in the EXP trial than in the CON trial (time × trial interaction $F(2, 34) = 12.0$, $p < .001$, $\eta_p^2 = 0.41$). This concentration did not recover to the baseline MOR level after the 4.5-h REC period (Fig. 7).

4. Discussion

In the present study, we used a duration of 7-h with short (10-min) breaks every 50 min to simulate an office work-rest schedule more closely. This allowed us to determine whether the Lithuanian hygiene standards-recommended breaks of 10 min every 50 min were sufficient to prevent mental and cognitive fatigue during a simulated 7-h office-

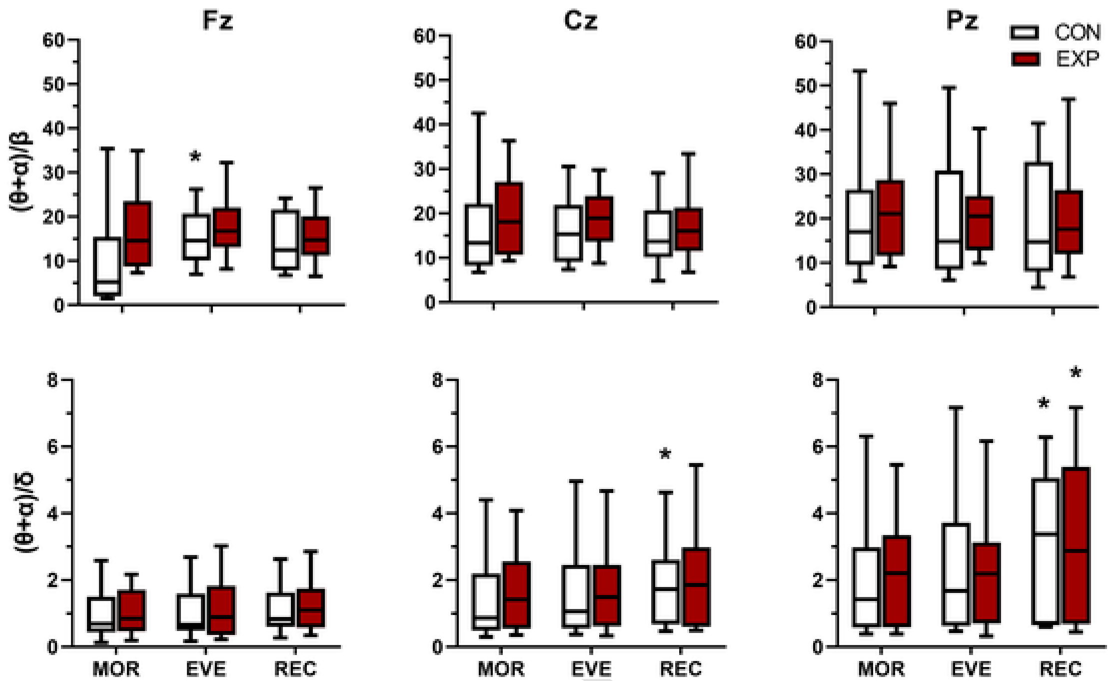

Fig. 3. Box plots of slowing ratio values of the EEG power spectrum in the morning (MOR), evening (EVE), and recovery (REC) for the Fz, Cz, and Pz electrodes, calculated using (theta + alpha)/beta (top) and (theta + alpha)/gamma (bottom) equations for the experimental (EXP) and control (CON) trials, respectively. $^{*}p < .05$ compared with MOR.

like computer work. We found that the cognitive task battery repeated over a 7-h working day induced mental fatigue and impaired cognitive function, and that these functions do not recover fully after a 4.5-h rest. Although it is generally thought that short breaks for low-intensity physical activity (Baker et al., 2018) or changing one's sitting position (Hasegawa et al., 2001) can improve or restore cognitive function through various mechanisms, such as boosting norepinephrine production in the brain's locus coeruleus (Miyashita and Williams, 2006) and increasing HR, blood flow to the brain, and glucose delivery to active parts of the brain (Kennedy and Scholey, 2000), it appears that these types of activities may not be enough to maintain mentally demanding cognitive performance over multiple 50-min working periods.

Fatigue is a common phenomenon that can occur after sustained mental effort, and it has been found to set in after as little as 30 min in some studies (Trejo et al., 2015). In order to more accurately simulate a typical office work schedule and observe the effects of fatigue on mental performance, our study was conducted over a period of 7 h with short breaks every 50 min. This allowed us to replicate the work-rest cycle commonly experienced in an office environment (i.e., formal break for lunch along with morning and afternoon short rest-refreshment breaks) and observe the development and impacts of fatigue over an extended period of time. Our study found that tasks that require high levels of mental effort, such as Code substitution learning, Delayed tasks, and Memory search tasks, deteriorated during the 7-h period of office-like computer work. This may be due to the brain's high energy needs (Raichle and Mintun, 2006) and its reliance on a steady supply of glucose and oxygen to maintain optimal cognitive performance (García et al., 2021).

We also observed that working memory improved after lunch but declined again later in the day, which may be linked to fluctuations in glucose levels. In fact, previous research has shown that increasing glucose levels through supplementation can improve cognitive performance, particularly in tasks with high cognitive demands (Smith et al., 2011). Specifically, when energy production in the brain is impaired, it can lead to attention lapses and a decline in working memory because sustained neuronal firing requires a steady supply of energy, which can be disrupted if energy production is impaired (Killeen et al., 2016). To maintain precise timing of neuronal firing above baseline levels, cells need to quickly restore their energy, either through the production of energy in neurons' mitochondria (Sun et al., 2013) or through the production of lactate in glial astrocyte cells through glycogenolysis (Killeen et al., 2013). The release of norepinephrine through the locus coeruleus-norepinephrine (LC-NE) system leads to increased glucose uptake by astrocytes, which results in the production of more lactate. This lactate is then transported to nearby neurons and axon terminals, where it is converted into ATP (Brown and Ransom, 2007). Therefore, norepinephrine is a key rate-limiting factor for the rapid restoration of energy supply within neurons, which helps meet the energy demands of the brain for biosynthesis, sustained activation, and functionally organized intrinsic neural activity (Tsukahara and Engle, 2021). Dysregulation of the LC may lead to deficits in sustained attention because it is responsible for the production of norepinephrine (Killeen et al., 2016). The blood-brain barrier allows glucose to cross into the brain through the use of glucose transporters (Patching, 2017), and the hypothalamus, a region of the brain involved in the regulation of energy homeostasis, responds to changes in peripheral glucose levels by adjusting neural pathways that control peripheral glucose metabolism (Lam et al., 2005). Research also suggests that peripheral insulin can influence the brain's uptake of glucose, specifically in cortical areas of the brain (Bingham et al., 2002). Additionally, orexins, a neuropeptide, may play a role in activating noradrenergic cells in the LC and may be affected by changes in glucose levels both in the brain and in the body (Sakurai, 2007).

Despite the knowledge that longer (>60-min) cognitive tasks induce fatigue and deterioration in cognitive function (Baker et al., 2018; Boksem et al., 2005; Fan et al., 2015; Trejo et al., 2015; Triglav et al., 2019; Wascher et al., 2014; Wennberg et al., 2016), the long office workday continues, and thus, our research shows that after 7 h of office-like computer work, there is an increase in resting-state EEG alpha and theta power, indicating the development of mental fatigue (Tran et al., 2020). An increase in frontal theta activity, which has been associated with effort and control, may also signify that individuals are exerting more effort to combat mental fatigue during prolonged cognitive tasks (McFerren et al., 2021; Wascher et al., 2014).

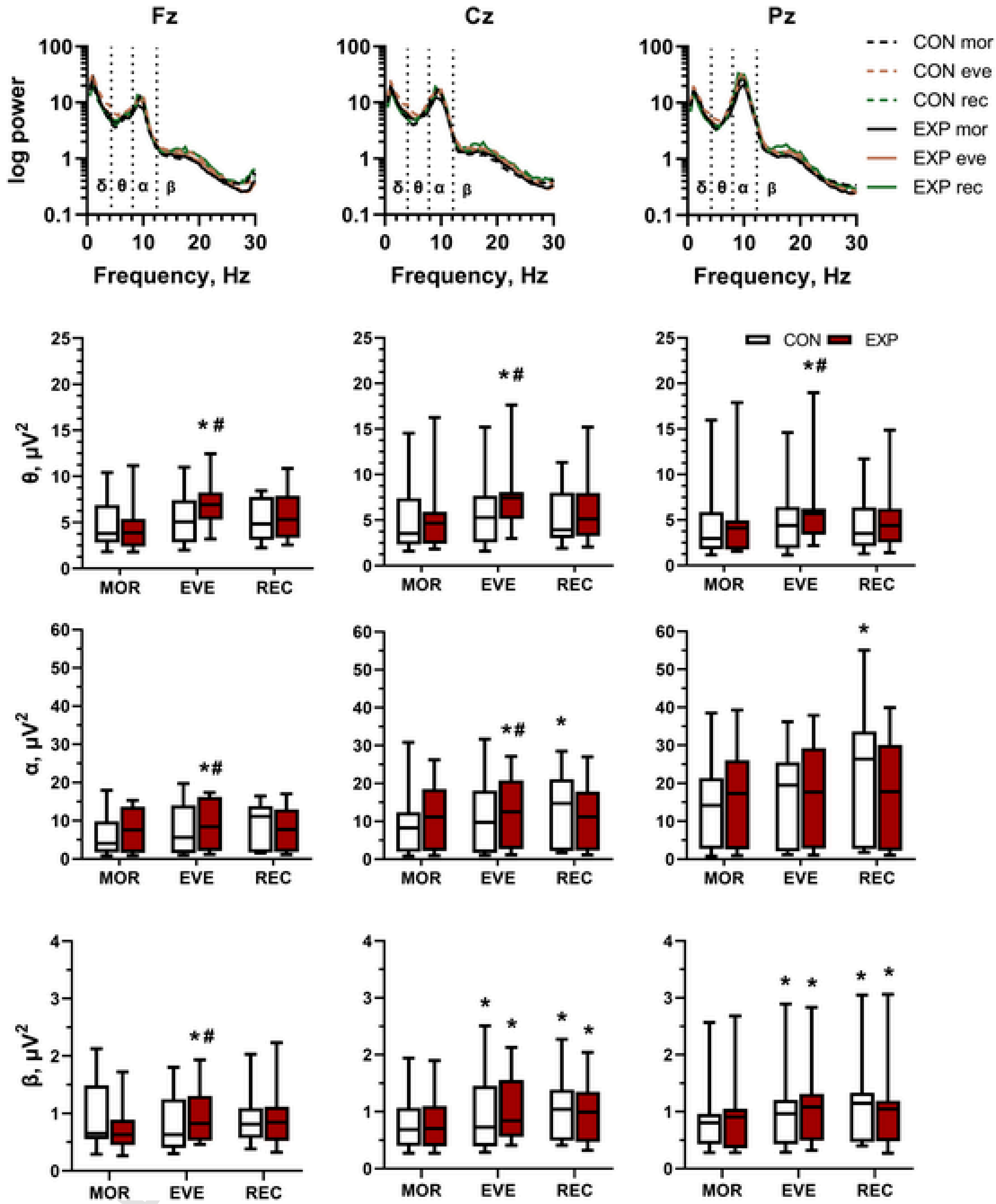

Fig. 4. Box plots of mean absolute powers presented using a base 10 logarithmic scale for the Fz, Cz, and Pz electrodes (top). The mean absolute powers for the theta (θ; 4–8 Hz), alpha (α; 8–12 Hz), and beta (β; 12–30 Hz) frequency bands at three electroencephalography sites Fz, Cz, and Pz in the morning (MOR), evening (EVE), and recovery (REC) for the experimental (EXP) and control (CON) trials. $^{*}p < .05$ compared with MOR, $^{\#}p < .05$ compared with CON.

The findings from the N2 and P3 components of the oddball task suggest that the participants experienced impairments in information processing during the EXP trial (Reuter et al., 2019). The reduced N2 amplitude and increased latency indicate a decreased ability to suppress interference and control of attention allocation (Reuter et al., 2019). The reduced P3 target amplitude suggests that fewer neural resources were allocated for stimulus categorization (Polich, 2007), and the increase in P3 latencies suggests impaired cognitive updating and stimulus classification (Reuter et al., 2019). These changes were reflected in a decline in cognitive performance (accuracy and response time) after the working day on the oddball task, which requires processes such as attention, response selection, and stimulus classification (García-Larrea et al., 1992). This decline was also accompanied by a decrease in glucose levels and an increase in subjective ratings of fatigue. These findings are consistent with previous research indicating that mental fatigue is associated with changes in EEG power, including an increase in alpha and theta power and modulation of low-frequency (LF), high-frequency (HF), and LF/HF ratio of HRV (Vicente et al., 2016).

In our study, we observed that the EEG power slowing ratio remained unchanged, but that there was a relative increase in beta power in parallel with alpha and theta power. This pattern of results may suggest a compensatory response to increasing mental fatigue, as it is known that beta activity is often associated with cognitive effort and the maintenance of alertness (Cunningham et al., 2000). The brain's

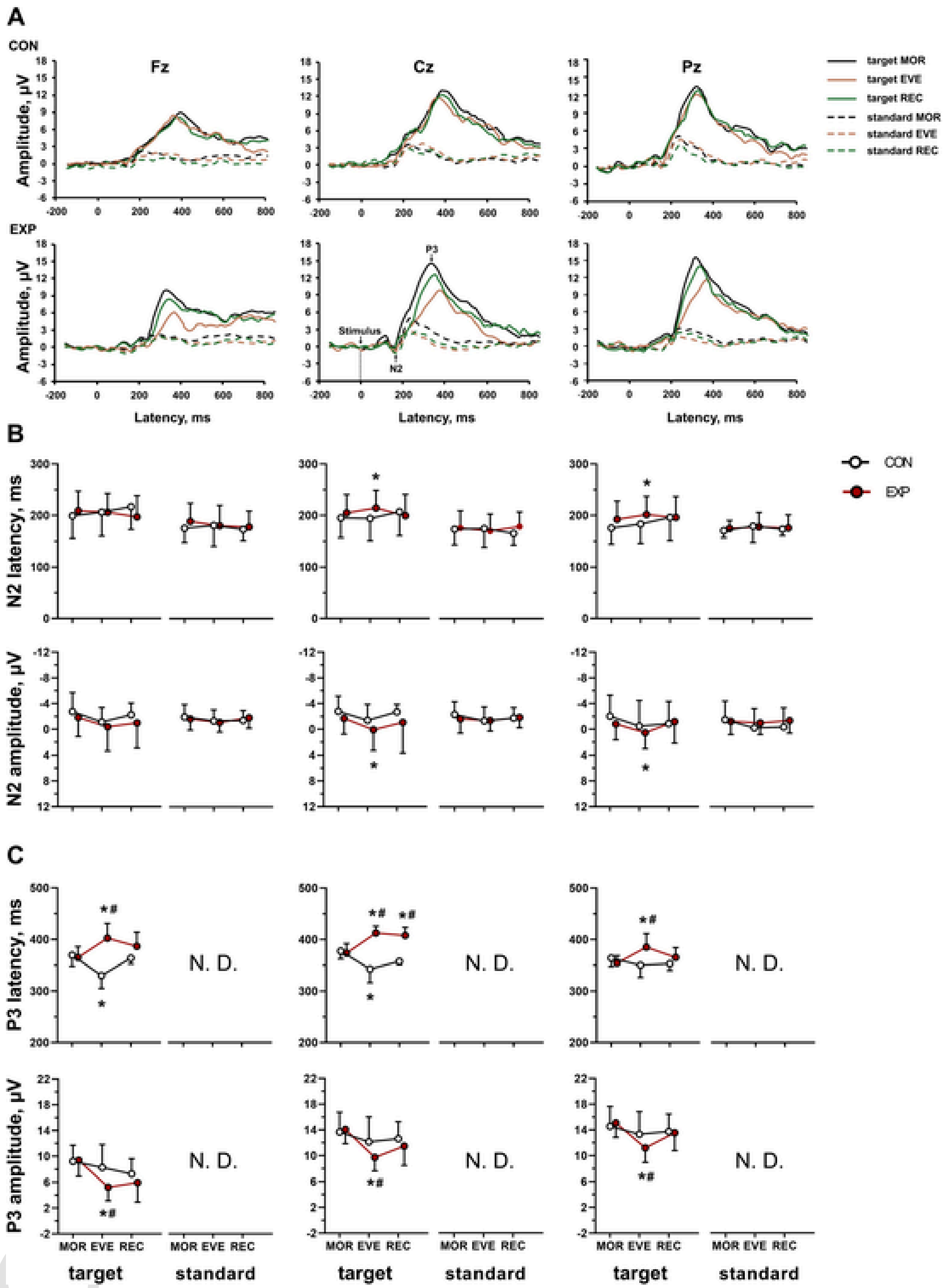

Fig. 5. Grand-averaged event-related potential (ERP) waveforms for the visual oddball task **(A)** at the three electroencephalography (EEG) sites Fz, Cz, and Pz in the morning (MOR), evening (EVE), and recovery (REC) for the experimental (EXP) and control (CON) trials. The mean N2 **(B)** and P3 **(C)** latencies and amplitudes at the three EEG sites Fz, Cz, and Pz in the MOR, EVE, and REC for the EXP and CON trials. Values are shown as the mean ± SD; $^*p < .05$ compared with MOR, $^{\#}p < .05$ compared with CON. ND = not detected; that is, the response of the ERPs for the P3 component in the 80 % nontarget (standard) condition was too small to compute reliable mean responses for amplitude and latency.

ability to increase beta activity in response to mental fatigue may serve to maintain or restore normal cognitive function.

A shorter P3 latency in the evening after the day off (CON) were also observed. A shorter P3 latency is associated with superior information processing (Walhovd and Fjell, 2001). It is possible that superior information processing in an unfatigued person in the evening may compensate for decreases in attention and executive control, which may allow a given task to be performed at a similar level as in the morning.

The declines in P3 target amplitude and oddball task accuracy observed in fatigued participants after the 7 h of office-like work suggest

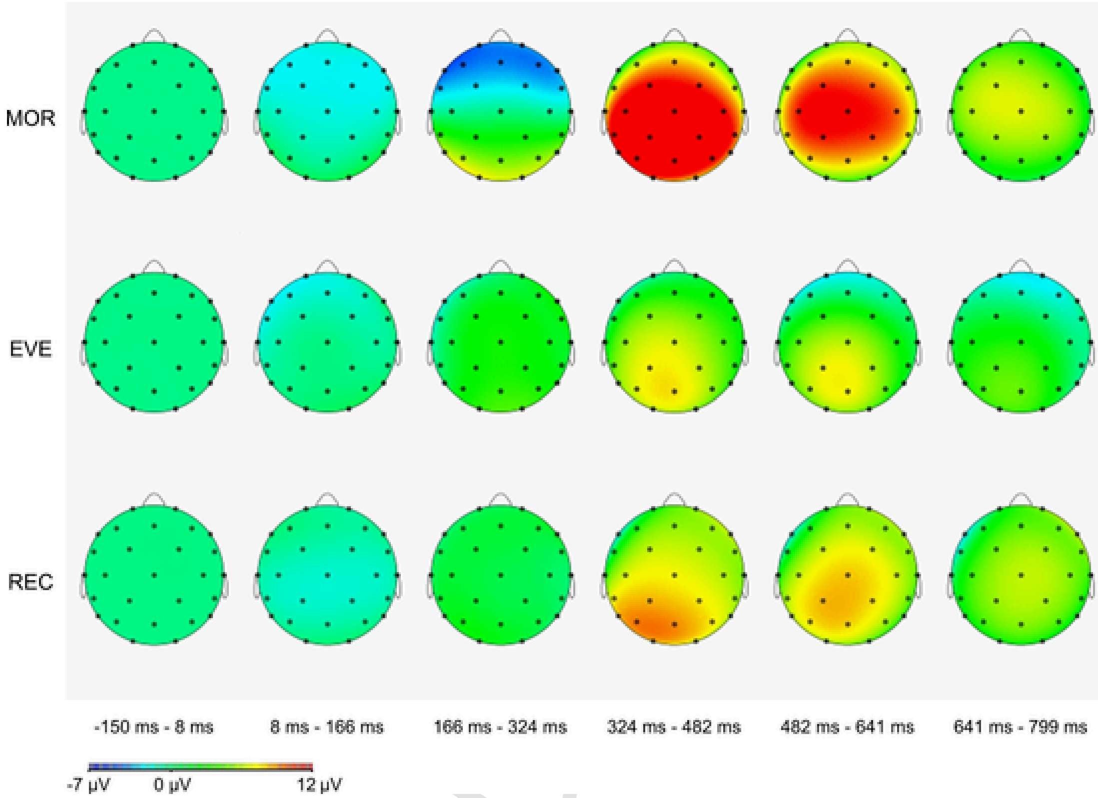

Fig. 6. Topographical distribution of grand-averaged event-related potential (ERP) surface voltages during presentation of target stimulus of oddball task in the morning (MOR), evening (EVE), and recovery (REC) of experimental (EXP) trial.

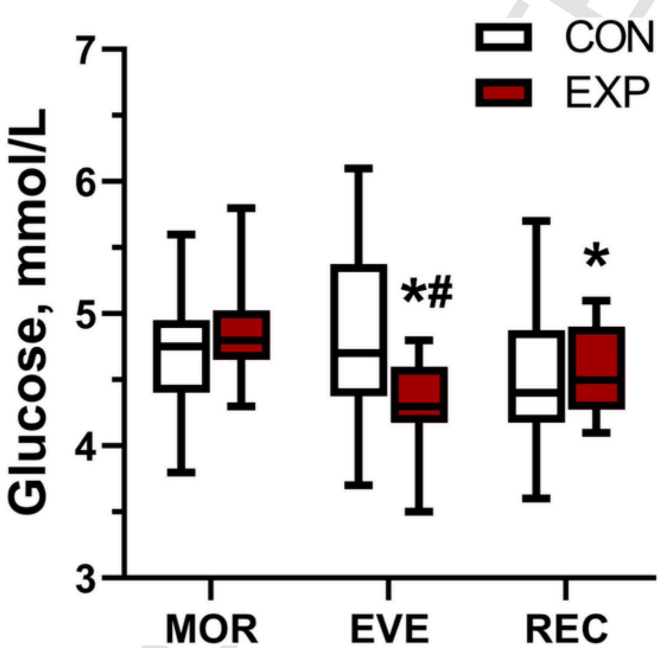

Fig. 7. Box plots of concentration of glucose in capillary blood in the morning (MOR), evening (EVE), and recovery (REC) for the experimental (EXP) and control (CON) trials. **p* < .05 compared with MOR; #*p* < .5 compared with CON.

that 10-min breaks every 50 min are not sufficient to prevent fatigue and maintain working capacity during the full day at work. While the 4.5-h recovery period partially restored mental and cognitive function, the effects of mental fatigue were not fully reversed. The prolonged latency of ERP P3 components and response time after the 4.5-h rest after the workday in EXP trial may originate from a decline in brain function (Okamura, 2007) and suggests that even after the rest after the 7-h working day, participants were not fully recovered from the mental fatigue. The lower capillary glucose concentration, which correlates positively with self-related energy and mood (Owens et al., 1997), may explain the increased self-evaluation of fatigue and decreased vigor levels both immediately after the cognitive work and after the 4.5 h of REC in the EXP trial.

The relationship between cognitive effort and fatigue is a complex and bidirectional one that is affected by various individual factors such as cognitive abilities and stress levels (Müller et al., 2021). One of the most challenging aspects of understanding fatigue scientifically is the interaction between cognition and motivation (Hopstaken et al., 2015). The tasks in the present study were designed to be challenging but still achievable in order to prevent a decline in performance due to fatigue (Dehais et al., 2020). The use of short task duration, randomly appearing tasks, and encouragement from the examiner to perform at a high level likely helped to maintain optimal cognitive performance by minimizing suboptimal neurocognitive states such as mind wandering, effort withdrawal, preservation, inattentional blindness, and inattentional deafness, which are known to lead to degraded performance (Dehais et al., 2020). By minimizing these states, the goal was to support optimal cognitive performance throughout the working day. The lack of changes in self-reported motivation and the increase in beta frequency band (the mental effort to remain vigilant) in the EXP EVE may suggest that the tasks were engaging and novel for the participants. The novelty of participating in the experiment may also have prevented a decrease in motivation due to mental fatigue. Previous research has shown that novel stimuli can activate the substantia nigra and ventral segmental area, releasing dopamine, a neurotransmitter that plays a role in reward-motivated behavior and helps to maintain motivation (Wittmann et al., 2007). Therefore, the novelty of the experimental tasks may have contributed to the subjects' motivation and ability to perform the cognitive tasks.

Overall, our findings indicate that the 10-min break every 50 min of mental work model does not effectively protect against cognitive fatigue and cognitive functions did not fully recover after 4.5 h of rest. However, recent research has demonstrated the potential benefits of shorter but more frequent microbreaks in improving energy levels and reducing fatigue without negatively impacting productivity (Albulescu et al., 2022). Incorporating aerobic physical activity during these breaks can also enhance the restorative effects (Blasche et al., 2018). Additionally, studies have shown that morning mist sauna improves work efficiency during the day (Lee et al., 2015). In light of these findings, future studies should investigate the effects of physical exercise or sauna bathing before and/or after work, as well as the effects of more frequent but shorter duration breaks with high-intensity physical activity as a way to alleviate mental fatigue and improve overall productivity.

The present study has several limitations that should be considered when interpreting the results. Firstly, the study only included young men as participants, which may limit the generalizability of the results to women and to individuals of different ages. Mental fatigue can affect individuals of different ages and sexes differently, and it is important for future research to consider these differences. Secondly, the study's experimental condition involved confining subjects to a room for most of the study, while the control condition allowed subjects to move around and go outside. This difference in environment could have contributed to the observed effects and should be taken into account when interpreting the results. In the future, it would be beneficial to control for environmental factors to ensure a more rigorous test of the effects of prolonged cognitive tasks on mental fatigue. Thirdly, the study only included university students as participants, which may limit the generalizability of the results to office workers. It would be beneficial for future research to consider the experiences and familiarity with such tasks in office workers. Also, health status and physical fitness can greatly impact cognitive fatigue (Kocalevent et al., 2011), and thus, should be taken into account in future research studies. Lastly, the results of our study should be considered exploratory in nature and further research is needed to fully understand the effects of a 7-h working day with 10-min breaks every 50 min on electrophysiological, autonomic, and self-reported markers of fatigue. Despite these limitations, the results of the present study provide useful insights into the effects of prolonged cognitive tasks on mental fatigue.

In conclusion, our findings suggest that Lithuanian hygiene standards involving regular short breaks during the working day do not protect against exhaustion caused by mental work. Even with short breaks, the sensation of fatigue develops and the worker's ability to focus attention and to activate neural resources became compromised during the 7 h of mental tasks. As a result, cognitive functions such as attention, executive control, visual tracking, learning, and visual recognition (which seem to be the most susceptible to fatigue) are affected. These cognitive functions do not seem to recover fully to the baseline level after a 4.5-h rest. These findings should be considered when discussing prevention of exhaustion caused by mental work.

Disclosure statement

No potential conflict of interest was reported by the authors.

CRediT authorship contribution statement

MB conceived and designed research. MB and AS conducted experiments. MB and AS analyzed data. AS prepared tables and figs. MB wrote the manuscript. All authors read and approved the manuscript.

Acknowledgements

The authors acknowledge the subjects who took part in the study.

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