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# Evaluation of Diurnal Changes of Mental Fatigue Using a New Portable Device for Visual Cognitive Evoked Potentials

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ABSTRACT

In the age homogenous group of 13 healthy volunteers, we examined visual evoked potentials (VEP) visually evoked cognitive potentials (event-related potentials – ERP) and choice reaction time (CRT) five times during the day (from 10.00 a.m. up to midnight) to verify whether there are significant changes of the measured parameters of the cortical evoked potentials and CRT which might reflect the level of the mental fatigue. The electrophysiological testing was done with the use of a new portable VEP device named "VEPpeak" enabling to perform the examination outside standard labs in almost any conditions. It was found that the latency of ERP (P300 peak time) and CRT displayed significant prolongation toward midnight while VEP latency and all amplitudes did not change significantly. This pilot study supports our idea that the portable VEP device possibly might be used for the objective examination of mental fatigue that is needed in many situations. This should be confirmed in a larger study also including a comparison with non-electrophysiological fatigue testing.

KEYWORDS

visual evoked potentials (VEP); event related potentials (ERP); P300; mental fatigue; VEPpeak device

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## INTRODUCTION

Fatigue of the central nervous system (CNS) is quite frequently tested as the exercise-induced central fatigue in various sport activities (1). Attempts for objective electrophysiological evaluation of mental fatigue are not so common (2) so far and the results are not too satisfactory (3–5). However, diurnal changes of event-related potentials (ERPs) were proved (e.g. 6) and confirmed the presumption that they might reflect the level of mental fatigue.

We came to the idea of evoked potentials application for fatigue testing when the development of the portable VEP device "VEPpeak" (7; https://www.veppeak.com /en/home-page/) was finished in our Electrophysiological Lab. This device allows visual evoked potential (VEP) and visual cognitive/event-related potential (ERP) examination outside the lab in almost any environment and it can be used also for simple self-monitoring. Thus, we decided to verify in this pilot study the possibility of this device to detect possible mental fatigue related to prolonged standard diurnal study activity in home conditions. The survey was performed by international students of our Faculty of Medicine who have been working for three years in the Electrophysiological lab in the form of students' research activity.

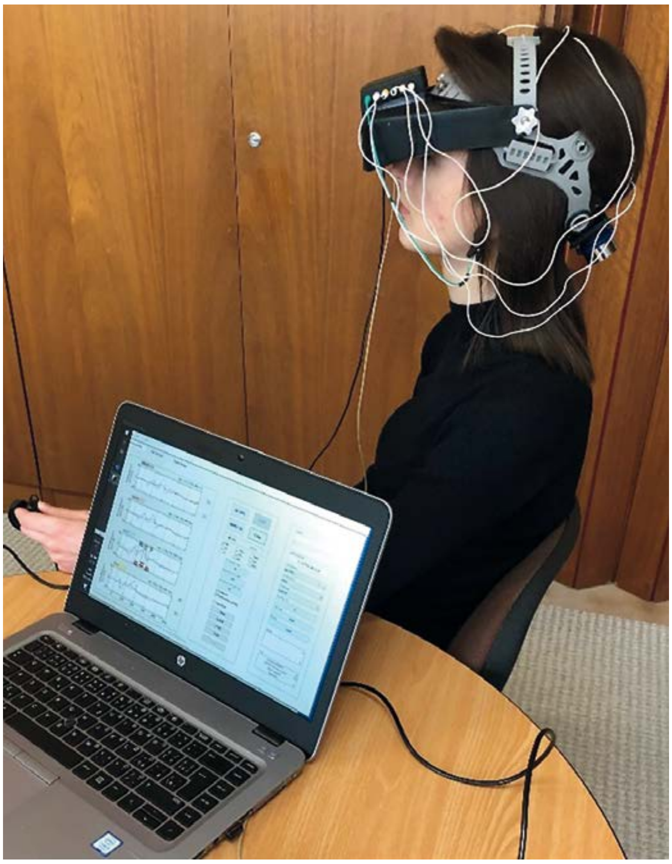

**Fig. 1** Experimental subject during the examination of VEP, ERP, and CRT.

## MATERIAL AND METHODS

### SUBJECTS

Age homogenous group of 13 healthy volunteers, students of the Faculty of Medicine (6 men and 7 women – mean age of 23 years) served as experimental subjects after signing a written consent – agreed by the Ethical Committee of the University Hospital in Hradec Králové) that has approved the experimental person examinations accomplished in the study.

All procedures performed in our study were in accordance with the 2000 Helsinki Declaration and comparable ethical standards.

### CHARACTERISTICS OF THE PORTABLE DEVICE FOR VEP AND ERP EXAMINATION "VEPPEAK"

The prototype of the device constructed with the help of RCD Radiokomunikace Ltd. (Czech Republic) consists of a built-in LED visual stimulator, 4-channel low-noise EEG amplifiers, and a control unit. It includes a 3D accelerometer for the rejection of EEG epochs with head movement artifacts and a surrounding luminance detector for the possibility of adaptive regulation of visual stimuli luminance. Thus, the examination can be performed in various luminance environments. Digital inputs allow to detect the subject's reactions (via pressing a button) in cognitive evoked potential examination and triggering of external visual stimulators. All parts are built into a headset (see Fig. 1), which can be fixed on the head of the examined subject with an adjustable fastener band. The device with a total weight of 390 g is connected by a galvanically isolated USB interface with a control and evaluation unit, such as a laptop computer. Special software was prepared for visual stimuli generation, recording, and evaluation of VEPs and ERPs.

Four unipolar channels were used for the recording of VEPs and ERPs. Two of them use dry electrodes incorporated in the fixing belt of the device. They are located in about Fp1 and Fp2 positions (non-hairy part of the head) and thus they do not require any special mounting they are ready immediately after fixing the device on the head. For the remaining two channels standard Ag/AgCl electrodes were used at locations Oz and Pz (relevant for the below specified visual and cognitive stimuli as it was learned based on the preliminary tests). EEG low-noise amplifiers (0.8–100 Hz) with attenuation of the high pass filter of 40 dB/decade, and that of the low pass filter of 60 dB/decade) and an integrated 16-bit A/D converter with a sampling frequency of 1 kHz provided a signal resolution of about 0.1 μV. The reference electrode and the electrode for noise suppression of the recorded signal (Czech Technical University in Prague – patent CZ 302454) were placed on the opposite sides of an earlobe clip. Signal smoothing with a Savitzky-Golay filter was applied (for more details about VEPpeak see Kuba et al. (7)).

### USED VISUAL STIMULI FOR VEP END ERP ACQUISITION

The built-in visual stimulator consists of a matrix of 32 color LEDs (diameter of 5 mm) placed in two horizontal rows (2 × 16) in the front part (peak) of the device at about

7.5 cm from the subject's eyes. Thus, the angular size of each LED is about 4°, and the total stimulus field subtends about 65° × 10°. It is possible to produce flashes, pattern reversals, the pattern on/off, apparent motion, color, or cognitive stimulations. Additional external stimulators can be eventually used for neuroophthalmological diagnostics where better parameters of visual stimulation are needed. On the basis of our previous testing of the available visual stimuli we selected the following two that provide enough robust reactions with low inter-individual variability, and they can be used with the built-in LED stimulator (more simple examination of VEPs and ERPs):

*Isoluminant (40 cd/m²) red/green LED stimuli* alternating in the full field with the frequency of 1 Hz. This kind of visual stimulation provided in the preliminary testing the largest VEPs with wide distribution over the head. Although this kind of VEPs does not belong to the standard set of VEPs used in neuro-ophthalmological diagnostics, because of its robustness and topography it seemed to be suitable for the detection of the fatiguability of CNS.

*Visual stimuli for cognitive potential (ERP – P300) examination* consisted of recognition of randomly presented isoluminant violet and green colors in the odd-ball paradigm (1:4 proportion of the rare/target and frequent/non-target stimuli) with the signaling of the target color by pressing a button, which also allowed the choice reaction time (CRT) measurement. Of the three opposite color pairs, red-green was chosen, but after adjusting for physiological color isoluminance, the resulting color was more violet than red.

We applied the cognitive task in the visual stimulation since ERP (P300) latency seems to better reflect changes in more complex (cognitive) information processing in CNS and it is reported that ERPs reflect better also CNS aging, psychic disorders, possibly also the level of fatigue (3, 8, 9).

## VEP, ERP AND CRT RECORDING

20 single VEPs (red/green alteration) and 15 ERPs were averaged for obtaining the average responses from all 4 recorded channels. Only the channel with the dominant response (largest interpeak amplitude) was evaluated. In the case of VEPs, it was almost exclusively the Oz lead which includes a reaction from the primary visual cortex, and in the case of cognitive potentials (ERPs), it was the reaction from Pz, although in a lot of subjects also prefrontal leads provided usable reactions with shorter latencies (see Fig. 2), which gives a good chance for ERP self-monitoring with built-in dry electrodes (when it is not necessary to make a montage of standard Ag-AgCl electrodes).

Electrophysiological examinations of the possible fatigue effect with the recording of the CRT started in all subjects at 10.00 a.m. and continued at 3.00 p.m., 8.00 p.m., 10.00 p.m., and 12.00 p.m. Subjects were prohibited from consuming caffeine, alcohol, and pharmacs potentially influencing their sleepiness, and from performing intense exercise one day before and during the day of the examination. During the whole time of the electrophysiological testing, subjects kept their standard diurnal weekend regime including predominantly learning activity (reading of textbooks). At each time all data recordings were repeated three times (altogether 15 VEPs, ERPs, and CRTs were evaluated in each subject) and averaged values of latencies and amplitudes of the dominant peaks (after the elimination of a few recordings containing artifacts) and average CRTs were used for statistical evaluation.

## STATISTICAL EVALUATION

All data were first tested for the normality of their distribution (Anderson-Darling test) which was not confirmed in the majority of cases. Thus besides the means and standard deviations also medians and percentiles are used in the descriptive statistics of P300 latency in Tab. 1.

Since the averaged values of the tested parameters from all particular times of the performed examinations did not differ significantly (graphs of the personal changes show that the trends of potential fatigue markers are interindividually different – see Fig. 3), time changes of relative individual values (related to their mean) were evaluated (for all parameters from all time intervals). The trends (slopes) were determined by linear regression and either the t-test or Wilcoxon test was performed in the group of trends, according to the data distribution. The alpha, significance level, was set at 5% for all comparisons.

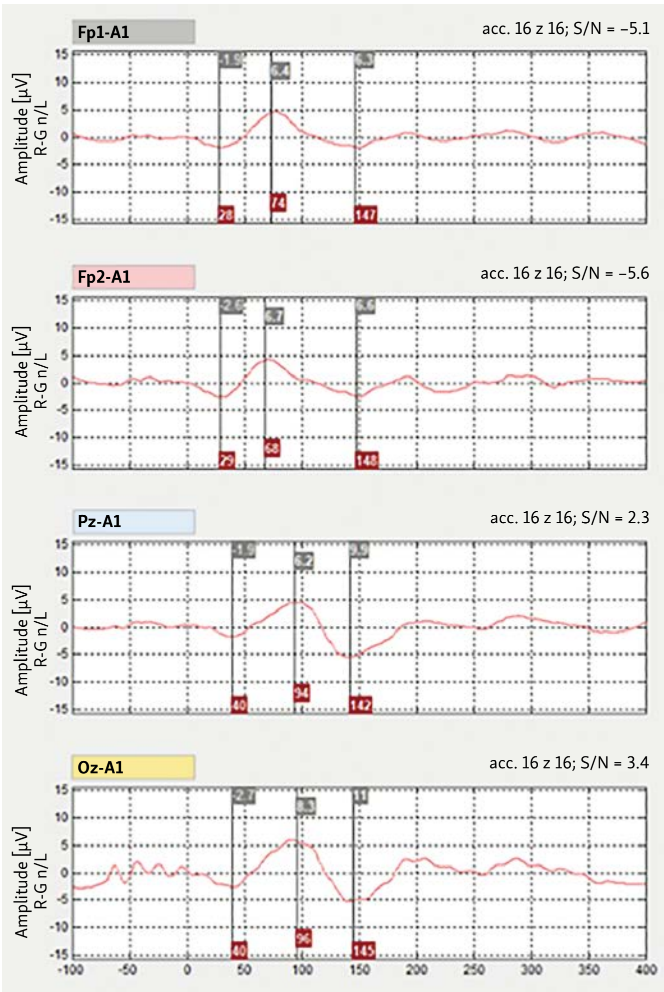


**Fig. 2** Example of an individual VEP with red-green stimulation.

**Tab. 1** P300 average latencies at all examination times [ms].

| Time | N | 25q | Median | 75q | Mean | SD | Min | Max |
|---|---|---|---|---|---|---|---|---|
| h10 | 13 | 339 | 358 | 374 | 359 | 27 | 322 | 414 |
| h15 | 13 | 343 | 368 | 394 | 372 | 48 | 301 | 493 |
| h20 | 13 | 345 | 355 | 366 | 358 | 22 | 322 | 403 |
| h22 | 13 | 330 | 343 | 370 | 349 | 21 | 320 | 387 |
| h24 | 13 | 344 | 355 | 376 | 361 | 29 | 313 | 431 |
| all | 65 | 339 | 355 | 374 | 360 | 31 | 301 | 493 |

## RESULTS

In the used VEPs with red-green stimulation, a positive peak with a latency of 105 ± 12 ms (Median 104; 25q 97; 75q 113) and amplitude of 6.2 ± 3.4 µV (Median 4.9; q25 4.0; q75 7.4) dominated in Oz lead (primary visual cortical area) in the majority of subjects (Fig. 2) but both parameters of this VEP did not display any significant changes during the whole-time span of examinations.

The dominant positive peak is present in the occipital-parietal cortical area but "usable" earlier reactions (signalizing "something happened") are detectable in this individual also in pre-frontal leads.

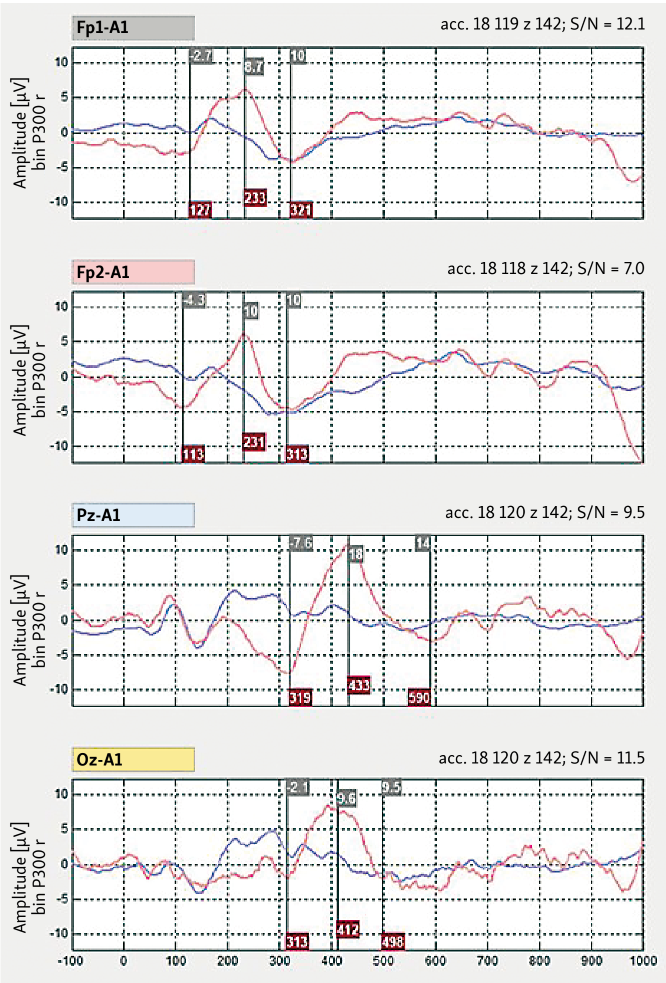


**Fig. 3** An example of individual ERP recordings from all four leads.

In all four channels, the number of accepted single trials (not including artifacts) and signal-to-noise ratio is indicated by the right upper corner.

ERP examination provided well recognizable P300 wave dominating in the Pz lead with an average latency of 360 ± 31 ms and the average amplitude of 13.7 ± 5.4 µV (see Tab. 1 and Fig. 3).

P300 peak latencies and inter-peak amplitudes are indicated in the responses to the target stimuli (in red). Blue traces represent responses to non-target stimuli, which are comparable only within 100–200 ms in the primary visual area (Pz). Dominant P300 in the Pz location has longer latency (over 400 ms) in this particular record due to fatigue. Earlier positive waves, also suitable for the detection of latency changes are present also in prefrontal leads.

The individual latencies displayed highly significant ($p = 0.006$) time-related changes (prolongation) signalizing a possible CNS fatigue development toward midnight. This is evident in Fig. 4 showing the individual time-dependent trends of the latencies. Eight subjects have latency prolongation but, in three cases, either no changes or even the opposite reaction – latency shortening in two subjects are recognizable, which might be interpreted as evidence of different (changed) diurnal regimes in these subjects – students of medicine.

Experimental subjects S1–S13. It is evident that the time dependence of the P300 latency (representing potentially the level of fatigue during the observed time) is not uniform but individually different. Subjects with latency prolongation (8) or shortening (2) are signed by symbols ↑ or ↓, individuals with inconsistent latency changes are signed as ↑↓ (3).

Although there was also a predominant trend of amplitude decrease with increasing fatigue toward midnight in most subjects, this effect was not significant. Probably due to the higher intraindividual variability of amplitudes compared to latencies (see the Discussion).

The CRT values were on average 329 ± 48 ms, which means CRT was shorter than P300 latencies (see the Discussion for explanation) but with higher variability, mainly for some (probably not fully cooperating) subjects. The average CRT variation coefficient (from all examination times) was 29% compared to 9% for P300 latency and the highest was at 3:00 p.m. (both for CRT and P300 latency). Despite it, on average CRT also exhibited significant ($p = 0.007$) prolongation which can be related to fatigue. However, there was no significant correlation between the P300 latencies and CRT.

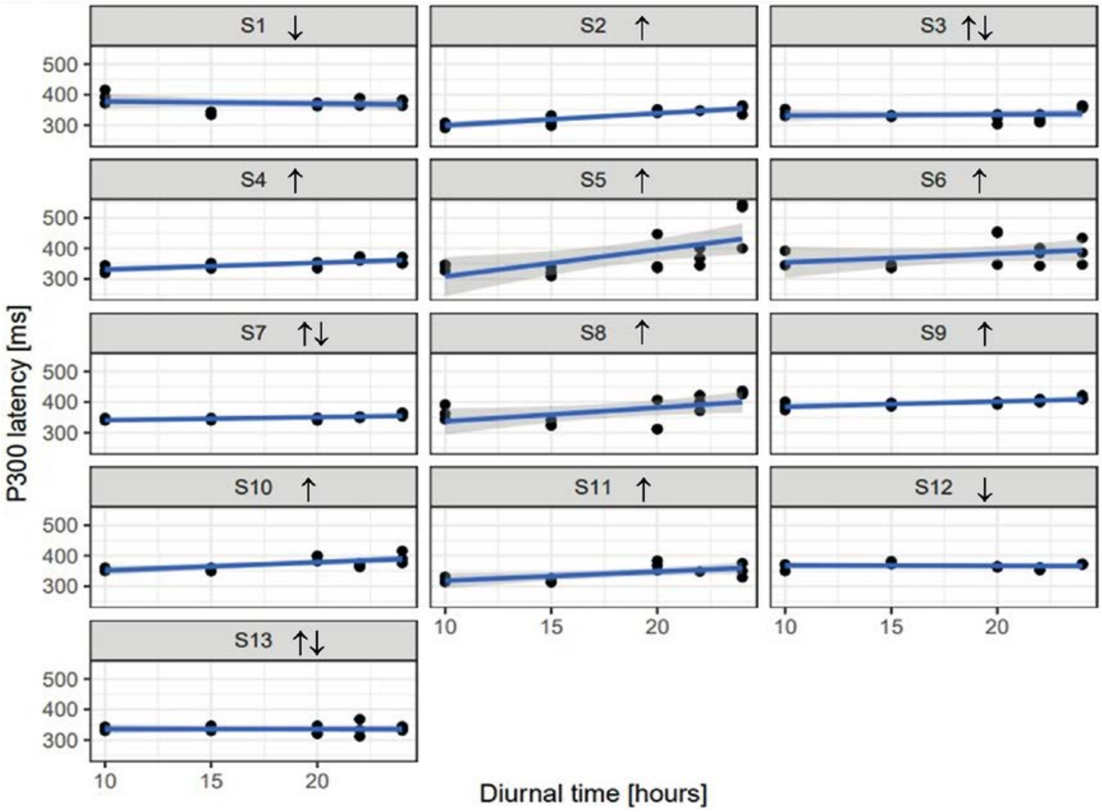


**Fig. 4** Individual changes of P300 latency in 13 subjects between 10.00 a.m. and 24.00 p.m.

## DISCUSSION

We believe that the demonstrated prolongation of P300 latencies and CRT during the day by midnight can be considered a sensitive tool for the evaluation of a potential increase in CNS fatigue as it was already reported (6, 10, 11).

It was mentioned in the Results that there was no significant correlation between the found prolongation of P300 latencies and prolonged CRT. Although it might be expected that both these parameters will react similarly during the development of CNS fatigue, their independence is a common observation (12) since the P300 represents a much more complex reaction (corresponding to activation of the larger part of the brain), compared to the CRT that on the other hand also includes the executive (motoric) reaction. It is probably also the reason, why surprisingly CRT is typically shorter than the P300 peak latency in most subjects. This is more consistent with parallel rather than serial models of information processing. Simultaneous measurement of the P300 latency and CRT may probably differentiate whether a delay is related to neuronal networks concerned with stimulus evaluation or to those concerned with response execution (13).

Possible considering whether CRT (that is simpler for an examination compared to electrophysiological testing) cannot be preferable for fatigue detection in comparison with ERP (P300) latency, should take into account that CRT is more inter- and intraindividually variable (more dependent on good cooperation and attention) and thus it is not so objective parameter as P300 latency. Moreover, as above explained, CRT does not represent so complex CNS activity as it is considered for the P300 wave, so it need not be so sensitive to CNS fatigue but could be influenced by some pathology of the motor pathway (13). On the other hand, if an efficient brain network is associated with reduced CRT variability (14), this parameter should also be considered as a potential marker of fatigue, as well as some other reported changes in ERPs (e.g. 15).

The fact that amplitudes of VEPs and ERPs were not significantly changed due to fatigue (despite some trend to their reduction) is not surprising, since in all evoked potentials, amplitudes have larger inter- and also intra-individual variability compared to latencies (9) depending on a lot of personal characteristics and fluctuation of attention paid to stimulation. Thus, diagnostic applications of cortical potentials amplitude changes are rather limited.

It is important to mark that our examination performed with the use of the mobile device VEPpeak seems to be well applicable in almost any conditions, comfortable for subjects, and fully comparable with a standard way of VEP, ERP, and CRT examination in electrophysiological labs. When the examination can be done almost anywhere, it significantly helps with its practical use for the tested purpose. It could be very useful in many human activities to check/monitor the level of CNS fatigue to prevent failures of personnel or to signalize critical levels of brain functions. Since the device can be used for self-examination (without any assistance), mainly when only the built-in recording electrodes fixed to the forehead provide sufficient information, it gives a chance for a fully automated evaluation with software providing signalization of critical limits of the tested parameters.

We found interindividual differences in the circadian trends of P300 latency (eight subjects lengthened them, two shortened them, and three subjects had inconsistent changes) and as it is partially recognizable from Fig. 4, the subjects with prolonged latencies display also larger intraindividual variability. Our subjective evaluation is that it fits well with the recognized "morning-type, evening-type, and intermediate-type" individuals in the population according to their mental performance and sleepiness at different times (6). If it would be confirmed in the planned larger study, it could represent an objective confirmation of this subjective characteristic of people.

We are aware of the limited validity of the results of this pilot study which must be enlarged not only by a higher number of experimental subjects but also by repeated examinations over several days in combination with some standard subjective questionnaires and psychophysical tests for individual detection and quantification of fatigue. For more reliable testing of the electrophysiological approach to quantitative fatigue detection, it would also be useful to use only experienced experimental subjects.

## CONCLUSION

This pilot study supports our idea that the new portable device VEPpeak (enabling examination of visual evoked potentials (VEP) and event-related cortical potentials (ERP) outside electrophysiological labs) can be used for the evaluation of CNS fatigue in almost any environment. Prolongation of ERP latencies, tested this way, seems to be a simple and sensitive tool for its objective detection.

## ACKNOWLEDGEMENTS

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## REFERENCES

1. Tornero-Aguilera JF, Jimenez-Morcillo J, Rubio-Zarapuz A, Clemente-Suárez VJ. Central and Peripheral Fatigue in Physical Exercise Explained: A Narrative Review. Int J Environ Res Public Health 2022; 19: 3909.
2. Lamti HA, Khelifa MMB, Hugel V. Mental fatigue level detection based on event related and visual evoked potentials features fusion in virtual indoor environment. Cogn Neurodyn 2019; 13: 271–85.
3. Polich J, Herbst KL. P300 as a clinical assay: rationale, evaluation, and findings. Int. J. Psychophysiol 2000; 38: 3–19.
4. Lee MH, Williamson J, LeeYE, Lee SW. Mental fatigue in central-field and peripheral-field steady-state visually evoked potential and its effects on event-related potential responses. Neuroreport 2018; 29: 1301–8.
5. Sabeti M, Boostani R, Rastgar K. How mental fatigue affects the neural sources of P300 component? J Integrat Neurosci 2018; 17: 93–111.
6. Huang H, Katsuura T, Shimomura Y, Iwanaga K. Diurnal Changes of ERP Response to Sound Stimuli of Varying Frequency in Morning-type and Evening-type Subjects. J Physiol Anthropol 2006; 25: 49–54.
7. Kuba M, Kremláček J, Vít F et al. VEP examination with new portable device. Doc Ophthalmol 2023; 146: 79–91.
8. Pavarini SCI, Brigola AG, Luchesi BM et al. On the use of the P300 as a tool for cognitive processing assessment in healthy aging – a review. Dement Neuropsychol 2018; 12: 1–11.
9. Kuba M, Kremlacek J, Langrova J, Kubova Z, Szanyi J, Vit F. Aging effect in pattern, motion and cognitive visual evoked potentials. Vision Res 2012; 62: 9–16.
10. Kaseda Y, Jiang C, Kurokawa K, Mimori Y, Nakamura S. Objective evaluation of fatigue by event-related potentials. J Neurol Sci 1998; 158: 96–100.
11. Higuchi S, Liu Y, Yuasa T, Maeda A, Motohashi Y. Diurnal variation in the P300 component of human cognitive event-related potential. Chronobiology Internat 2000; 17: 669–78.
12. Duncan-Johnson CC, Donchin E. The Relation of P300 Latency to Reaction Time as a Function of Expectancy. Progress in Brain Res 1980; 54: 717–22.
13. Kraiuhin C, Yiannikis C, Coyle S et al. The relationship between reaction time and latency of the P300 event-related potential in normal subjects and Alzheimer's disease. Clin Exp Neurol 1989; 26: 81–8.
14. Machida K, Murias M, Johnson KA. Electrophysiological Correlates of Response Time Variability During a Sustained Attention Task. Front Hum Neurosci – Sec. Brain Health and Clin Neurosci 2019; 13: 363.
15. Zhou Y, Wang W, Yan L, Yang B. Research on the Relationship between Fatigue and P300 Potential in Multi-Stage RSVP Small Target Detection. Proceedings of the 10th International Conference on Computing and Pattern Recognition 2021: 92–98.