

## A NEUROSCIENCE APPROACH TO A VIRTUAL REALITY (VR) BASED ACCOMMODATION–CONVERGENCE INTERVENTION FOR EVALUATING INTRA-INDIVIDUAL MENTAL FATIGUE DURING NEARWORK: A CROSSOVER EXPERIMENTAL STUDY CONCEPT

Riyadi Hartono<sup>1\*</sup>, Taufiq Fredrik Pasiak<sup>2</sup>, Maria Selvester Thadeus<sup>2</sup>

<sup>1</sup> Master Program in Biomedical Sciences, Faculty of Medicine, Universitas Pembangunan Nasional Veteran Jakarta, Indonesia

<sup>2</sup> Faculty of Medicine, Universitas Pembangunan Nasional Veteran Jakarta, Indonesia

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### Corresponding Author

Name : Riyadi Hartono

Email : riyadihartonohadiwahjono@gmail.com

### Abstract

**Introduction:** Prolonged nearwork is associated with increased mental fatigue, a neurocognitive state marked by slower processing, reduced accuracy, and diminished executive performance. This condition affects up to 60–70% of students and office workers worldwide. **Objective:** Analyzing the effect of a VR-based Accommodation–Convergence Intervention on intra-individual mental fatigue parameters during nearwork from a neuroscience perspective. **Methods:** A crossover experimental study was developed involving 20 healthy male participants (18–25 years) to perform identical 60-minute Pauli test under two conditions: (1) 2D screen-based and (2) 3D VR based (reduce accommodation–convergence by projecting visual object at optical infinity). Mental fatigue was assessed using several biomarkers, including Pauli test performance, P300 amplitude and latency, and EEG Alpha–Theta PSD. Intra-individual differences between conditions were analyzed using a within-subject. The conceptual framework was supported by a synthesis of 100 peer-reviewed studies (2014–2024) establishing mental fatigue indicators biomarker. **Results:** *Hypothetically*, comparisons between 2D screen and 3D VR-based demonstrated improvement in endurance, reflected by a higher Pauli test performance slope, attenuating the increase in P300 latency-amplitude as well as changes in EEG Alpha–Theta indicative of mental fatigue. The results showed a trend of VR exposure across multiple biomarkers, although the confidence intervals were wide in this small-sample pilot study. **Conclusion:** This study illustrated a neuroscience-based framework demonstrating that accommodation–convergence intervention via VR may influence indicators of mental fatigue. By integrating EEG, P300, and the Pauli test, the approach provides an objective model for assessing intra-individual cognitive endurance.

**Keywords:** Mental fatigue, nearwork, accommodation–convergence intervention, EEG, P300 ERP

### Introduction

Prolonged nearwork (short-distance visual activities) is associated with increased mental fatigue, a neurocognitive state marked by slower processing, reduced accuracy, and diminished executive performance. Nearwork is short-distance visual activity performed

at a typical distance of 30–50 cm from the eyes. Examples include screen time (digital-based reading, typing, video watching) , paper-based reading /writing, etc.<sup>1</sup> In the third quarter of 2023, internet users in Indonesia aged 16–64 spent an average of 7 hours and 38 minutes per day on screens (Backlinko.com). This condition affects up to 60–70% of students and office workers worldwide, and becomes more prevalent with the rise of digital learning<sup>2–4</sup>.

Mental fatigue can arise from prolonged visual activity at near distances, such as reading, writing, or working in front of a computer screen. When the eyes focus on near objects for prolonged periods, the extraocular muscles and the optic pathways may become strained, increasing brain load during visual processing. This study employs an intra-individual analysis to compare individual performances and capture parameter fluctuations in behavior and brain function.

Visual mechanisms in nearwork that may cause mental fatigue include continuous high accommodation–convergence. The eyes (the visual system) must maintain sustained ocular accommodation-convergence, to maintain prolonged load on extraocular muscles and increasing visual processing load within the brain <sup>6–9</sup>. Previous studies in visual ergonomics and neurocognitive research have suggested that excessive accommodation–convergence demand contributes not only to ocular discomfort but also to increased cognitive load and accelerated mental fatigue<sup>10</sup>.

VR technology can modulate accommodation–convergence demand during nearwork via optical mechanisms by presenting 3D visual stimuli of objects at virtual fixed and virtual distant depths. This mechanism may reduce fluctuations in accommodative-convergence compared with 2D screen-based viewing. Emerging evidence indicates that VR-based visual rendering can attenuate nearwork-induced alterations in ocular parameters and may influence mental fatigue indication during nearwork<sup>6</sup>.

Currently, research evaluating VR-based accommodation–convergence elimination remains limited. Most existing studies rely on single outcome measures and do not adequately assess cognitive load, which may fail to capture comprehensive biomarker changes associated with mental fatigue. Although objective biomarkers such as electroencephalography (EEG) and P300 event-related potentials (ERP) have been widely used, their combined application with cognitive performance tasks (such as the Pauli test) in VR-based accommodation–convergence interventions has not been systematically explored.

The innovative approach of this study lies in integrating VR technology to eliminate accommodation–convergence during nearwork as a preventive measure against mental fatigue<sup>5</sup>, and in employing multiple objective biomarkers (Pauli test, P300, and EEG) to measure the intervention effects accurately.

A crossover experimental study approach enables a direct comparison of the intervention's effects on mental fatigue within the same individuals, thereby minimizing inter-subject variability<sup>16,17</sup>. Mental fatigue is characterized by a combination of specific subjective, behavioral, and physiological manifestations, caused by prolonged engagement (more than 30 minutes) in cognitive activities (such as reading, writing, and other nearwork tasks), which subsequently affects cognitive performance<sup>11–13</sup>. Mental

fatigue refers to the feelings experienced during or after a period of cognitive activity, including tiredness, exhaustion, reluctance to engage in tasks, and reduced commitment, the conditions that are associated with declines in cognitive and behavioral performance<sup>14,15</sup>. The duration and intensity of a physical task are important factors which influence the extent to which mental fatigue impairs physical performance<sup>5</sup>.

There is evidence that the use of VR technology significantly reduces alterations in ocular parameters (accommodation – convergence) induced by nearwork visual tasks<sup>6–9</sup>. Evidence from visual ergonomics and neurocognitive research indicate that VR can reduce accommodative strain and minimize excessive convergence through its optical rendering mechanisms. This effect occurs when the VR-displayed objects are perceived at a fixed and virtually distant depth, thereby limiting fluctuations in focal demand.<sup>10</sup>

A study found that mental fatigue can be identified by an amplitude exceeding 10.16  $\mu V$  and an increase in P300 latency of up to 29 ms compared to normal conditions<sup>19</sup>. Another study reported that mental fatigue is characterized by an increase in Theta-band (4–8 Hz) Power Spectral Density (PSD) in the frontal region, an increase in Alpha-band (8–13 Hz) PSD in the parietal region, and a decrease in Alpha activity in the occipital region<sup>20</sup>. In relation to the Pauli Test, comparisons between high-fatigue and low-fatigue conditions show that during periods of higher fatigue, the number of correct calculations decreases, while the number of incorrect calculations and correction attempts increases<sup>18</sup>. The factors mentioned above are included as research parameters; the complete details are presented in Table 1.

Two treatments—Treatment A (2D screen-based) and Treatment B (3D VR-based)—will be compared within the same individuals, with the hypothesis that Treatment B will demonstrate better outcomes than Treatment A.

**Table 1.** Research Parameter

Measurement Methode	Measurement Parameter	Unit	Remark	Mental Fatigue Bio Marker
P300 ERP	Amplitude	$\mu V$	Before & after	>10.61 $\mu V$
	Latency	mm	Before & after	>29 ms slower
Pauli test	Simple Mathematic task performance in 60 minute duration	Correct calculation frequency /3 minute	20 x 3 minute	Decrease
EEG measurement	Theta wave (frontal)	$\mu V^2/Hz$	10 x 6 minute	Increase
	Alpha wave (parietal)	$\mu V^2/Hz$	10 x 6 minute	Increase
	Alpha wave (occipital)	$\mu V^2/Hz$	10 x 6 minute	Decrease

Therefore, this study aims to analyze the effect of a non-invasive accommodation–convergence elimination intervention using virtual reality technology on intra-individual mental fatigue parameters during nearwork activities, by assessing changes in objective biomarkers from a neuroscience perspective using a crossover experimental study concept. By integrating objective biomarkers (EEG Alpha–Theta activity and P300 ERP) with behavioral performance measures (Pauli test), this study seeks to provide a comprehensive framework for assessing mental fatigue indication under different visual conditions.

## Materials and Methods

This study employed a crossover experimental design (figure 1) with an intra-individual approach. A total of 20 healthy male participants aged 18–25 years performed identical cognitive tasks (Pauli test) under two conditions: (1) 2D screen-based and (2) 3D VR-based implementing the Accommodation–Convergence Intervention (figure 2). A washout period of 15 minutes was applied between conditions to reduce potential carryover effects. The independent variable is the visual condition, while the dependent variables include EEG Alpha–Theta patterns, P300 and Pauli test performance. This framework is supported by a synthesis of 100 peer-reviewed studies (2014–2024) establishing these biomarkers as indicators of mental fatigue.

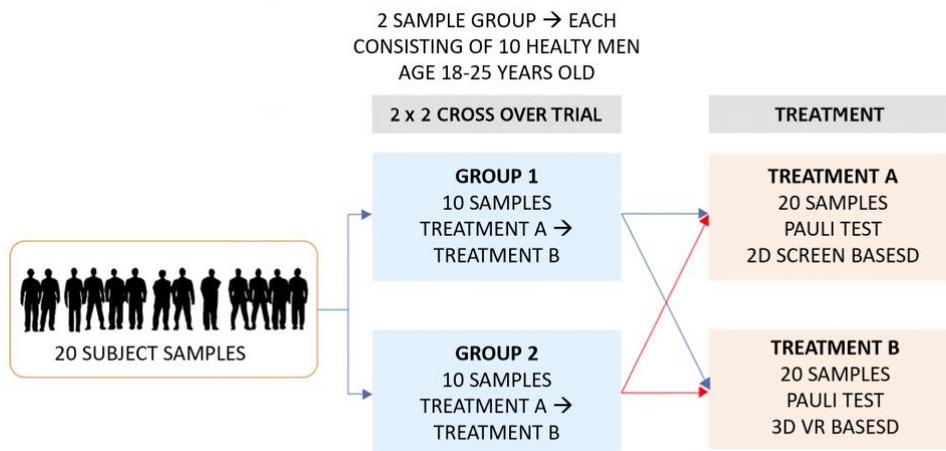
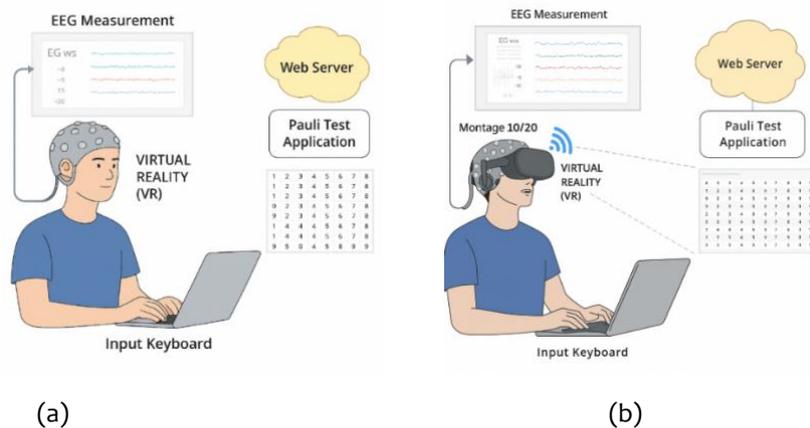


Figure 1. Data Collection Methodology: Formation of Two Groups and Two Treatments Using a Crossover Method.



**Figure 2.** (a) Diagram of 2D Screen-Based EEG Wave Measurement with the Pauli Cognitive Load Test, (B) Diagram Of 3D VR-Based EEG Wave Measurement with the Pauli Cognitive Load Test.

Only male participants were included to minimize physiological variability related to hormonal fluctuations. All participants had normal or corrected-to-normal vision and no history of neurological or ophthalmological disorders. Mental fatigue was assessed using several biomarkers, including the Pauli test, P300 event-related potentials (ERP), and electroencephalography (EEG) Alpha–Theta activity. All outcome measures were collected

under both visual conditions (2D screen and 3D VR) using identical task duration and procedures.

The 3D VR condition is created using a head-mounted display to project images that were optically placed virtually fixed at optical infinity. This configuration aimed to reduce accommodative convergence during nearwork tasks. The Pauli test was evaluated based on right calculation number repeated 3-minute time interval in 60 minutes<sup>18</sup>. Mental fatigue indication was shown as a decline in calculation performance over time, reflected by a reduced performance slope. P300 ERP was recorded using a standard oddball paradigm parameters were P300 amplitude ( $\mu\text{V}$ ) and latency (ms) that was measured before and after load task<sup>19</sup>. Increased P300 latency and amplitude were interpreted as indicators of increased mental fatigue. EEG signals were analyzed using EEG Alpha-Theta power spectral density (PSD) during load task. Mental fatigue was interpreted as an increase in Theta power, particularly in frontal regions, Alpha power in parietal region and reduce in Occipital region. Changes in EEG patterns were evaluated as relative differences between conditions and across time within individuals.

All mental fatigue parameters from outcome measures will be evaluated using a set of objective multi-biomarkers, including Pauli Test performance, P300 ERP latency and amplitude, as well as EEG Alpha and Theta waves using LMEM statistic method. Outcome measures were analyzed using within-subject comparisons appropriate for crossover designs. This method was chosen to provide a more comprehensive and sensitive assessment of cognitive changes induced by visual fatigue during nearwork.

## Results

This research integrates VR optical intervention with cognitive performance metrics. Literature suggests that accommodation–convergence modulation may affect Alpha–Theta patterns, P300 responses, and task accuracy, supporting the potential of VR-based interventions to mitigate mental fatigue during sustained nearwork.

The use of virtual reality (VR), which leverages its ocular optics to intervene in the accommodation–convergence mechanism, thereby reducing accommodative and convergent demands during nearwork, may enhance cognitive performance, as reflected by improvements in P300 measurements, alpha–theta EEG wave activity, and Pauli test outcomes.

## Discussion

This study explored the potential role of a VR-based accommodation–convergence intervention in evaluating intra-individual mental fatigue during nearwork using objective neurocognitive biomarkers. The present findings provide a directional indication that modulating accommodation–convergence demand through VR may influence behavioral and biomarkers associated with mental fatigue.

This project is ongoing; therefore, the present discussion is theoretical based on the reviewed literature. Empirical data are required to determine whether VR-based reduction of accommodation–convergence produces measurable effects on mental fatigue. Future

studies will integrate multiple biomarkers, such as EEG, P300 and pupil diameter, to clarify the mechanisms underlying mental fatigue and to evaluate the potential of VR interventions in supporting everyday activities.

In the future, VR may be utilized to support workers to increase endurance in near-work, and to assist students in sustaining learning and endurance performance during prolonged nearwork activities in their study. Virtual reality (VR) has the potential to transform the way people work and learn. Conventional office tasks such as data entry and other screen-based 2D screen activities may transition to 3D VR environments. Similarly, student activities that are conducted through printed materials or 2D digital screens may be facilitated to be carried out through 3D VR-based platforms.

This study is subject to several limitations as follows: first, sample size. The sample consists of 20 healthy males aged 18–25 years<sup>16</sup>, which does not represent the general population, such as female participants or individuals with specific health conditions. To minimize data variability caused by hormonal fluctuations in females during menstrual cycle, this research only include male subjects. Second, the participants consist of healthy adults (18–59 years old, according to the Ministry of Health of the Republic of Indonesia) who are employed, or individuals aged 18–25 years, as this group is expected to have a good level of comprehension. This age range is considered to have relatively homogeneous cognitive abilities, adequate arithmetic skills, and the capacity to understand the objectives of the study. Third, this approach using Crossover Method may introduce subjective variability in individual responses to Treatment A (2D screen-based Pauli Test) and Treatment B (3D VR based Pauli Test), particularly due to adaptation effects or personal biases<sup>16,17</sup>. Twenty participants will be divided into two groups, with 10 participants in each group. Group 1 will undergo Treatment A followed by Treatment B, whereas Group 2 will undergo Treatment B first, followed by Treatment A. A 15-minute washout interval will be implemented between the two treatments and applied to each study participant.

Other limitations of this study including: first, the measures short-term effects of the observed variables within 1 hour duration based on the standard Pauli Test protocol<sup>18</sup>, without assessing long-term effects. Second, it is limited to nearwork activities based on the Pauli Test, which represents a universal cognitive load but does not encompass other forms of visual tasks. Third, the study does not account for external factors such as lighting conditions, work posture, or prior rest duration, all of which may influence mental fatigue. Fourth, VR technology is evaluated as a single intervention for reducing mental fatigue without comparison to other possible interventions. Finally, the scope of biomarkers is restricted to the Pauli Test, P300 ERP, and EEG waves, without incorporating additional psychological variables.

## Conclusions

By using several bio markers (Pauli Test, P300 and EEG, P300) we were able to provide a model for measuring intra-individual cognitive endurance. This research attempts to illustrate a neuroscience-based framework to prove that accommodation–convergence intervention through VR may have correlation with indicators of mental fatigue.

VR intervention indicate has the potential to improve endurance and slow down the development of mental fatigue during nearwork by optimizing the using of 3D VR device in their daily work in prolonged nearwork.

This crossover study proposes a neuroscience-based approach for assessing intra-individual mental fatigue during nearwork using a VR-based accommodation–convergence intervention. Further research with larger sample sizes, longer observation periods and difference load cognitive task is required to confirm the effectiveness of VR-based interventions in mitigating mental fatigue.

### Competing Interests

There is no conflicts of interest related to this writing material. We work independently with no financial, commercial, or affiliations that may create bias. The virtual-reality equipment thar used for accommodation–convergence intervention device, and cognitive evaluation tools (Pauli Test) utilized in this project were applied exclusively for academic study purposes.

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### References

1. Li, S., Tang, A., Yang, B., Wang, J. & Liu, L. Virtual reality-based vision therapy versus OBVAT in the treatment of convergence insufficiency, accommodative dysfunction: a pilot randomized controlled trial. *BMC Ophthalmol* 22, (2022).
2. Sheppard, A. L. & Wolffsohn, J. S. Digital eye strain: Prevalence, measurement and amelioration. *BMJ Open Ophthalmology* vol. 3
3. Nagarajan, R., Ramachandran, P., Dilipkumar, R. & Kaur, P. Global estimate of burnout among the public health workforce: a systematic review and meta-analysis. *Human Resources for Health* vol. 22
4. Kaur, K. *et al.* Digital Eye Strain- A Comprehensive Review. *Ophthalmology and Therapy* vol. 11 1655–1680
5. Qi, P. *et al.* Neural Mechanisms of Mental Fatigue Revisited: New Insights from the Brain Connectome. *Engineering* vol. 5 276–286
6. Yi, Z., Ningli, W., Kai, C., Yan, H. & Wei, Z. Effects of virtual distant viewing technology on preventing nearwork-induced ocular parameter changes. *Digit Health* 10, (2024).
7. Sokołowska, B. Impact of Virtual Reality Cognitive and Motor Exercises on Brain Health. *International Journal of Environmental Research and Public Health* vol. 20
8. Volkan Dericioglu, B. K. Marmara Medical Journal, Effects of virtual reality usage on kappa angle, accommodation, pupil, depth perception, and examination of the relationship of these parameters with discomfort perception.

9. Mihelčič, M. & Podlesek, A. Cognitive workload affects ocular accommodation and pupillary response. *J Optom* 16, 107–115 (2023).
10. Ueno, T. & Takaki, Y. Super multi-view near-eye display to solve vergence–accommodation conflict. *Opt Express* 26, 30703 (2018).
11. Ishii, A., Tanaka, M. & Watanabe, Y. Neural mechanisms of mental fatigue. *Reviews in the Neurosciences* vol. 25 469–479 Preprint at <https://doi.org/10.1515/revneuro-2014-0028> (2014).
12. Van Cutsem, J. et al. The Effects of Mental Fatigue on Physical Performance: A Systematic Review. *Sports Medicine* vol. 47 1569–1588 Preprint at <https://doi.org/10.1007/s40279-016-0672-0> (2017).
13. Jeroen Van Cutsem. *The Effects of Mental Fatigue on Physical Performance*. ÓSpringer International Publishing Switzerland 2017 (2017).
14. Boksem, M. A. S. & Tops, M. Mental fatigue: Costs and benefits. *Brain Research Reviews* vol. 59 125–139 Preprint at <https://doi.org/10.1016/j.brainresrev.2008.07.001> (2008).
15. Díaz-García, J. et al. Mental load and fatigue assessment instruments: A systematic review. *International Journal of Environmental Research and Public Health* vol. 19 Preprint at <https://doi.org/10.3390/ijerph19010419> (2022).
16. Julious, S. A. Sample size of 12 per group rule of thumb for a pilot study. *Pharm Stat* 4, 287–291 (2005).
17. Jones, Byron. & Kenward, M. G. . *Design and Analysis of Cross-over Trials*. (CRC Press, 2015).
18. Ummu Khuzaimah, M. P. *Tes Inventory: EPPS & PAULI*. (2014).
19. Zelenika Zeba, M., Friganovic, K., Palmovic, M., Išgum, V. & Cifrek, M. Assessment of mental fatigue during examination period with P300 oddball paradigm. in 2019 42nd International Convention on Information and Communication Technology, Electronics and Microelectronics, MIPRO 2019 - Proceedings 1479–1484 (Institute of Electrical and Electronics Engineers Inc., 2019). doi:10.23919/MIPRO.2019.8756850.
20. Trejo, L. J., Kubitz, K., Rosipal, R., Kochavi, R. L. & Montgomery, L. D. EEG-Based Estimation and Classification of Mental Fatigue. *Psychology* 06, 572–589 (2015).