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RESEARCH ARTICLE

Working with cognitive load task: mental fatigue, sleepiness, and performance

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ABSTRACT – Cognitive load experienced over a certain period can cause mental fatigue. Since many studies link mental fatigue with sleepiness, we aimed to investigate whether mental fatigue and sleepiness always co-occur. The aim was to explore the relationship between mental fatigue, sleepiness, and performance. Experiments using mathematics tests were conducted using the method of rm-ANOVA. We use subjective scales such as the Samn-Perelli and KSS to assess the level of fatigue and sleepiness. During the period, reaction times from the PVT and math test scores were also measured, indicating performance. The results showed a statistically significant increase in fatigue and sleepiness scores. Fatigue scores increased sharply while sleepiness scores were still relatively at a safe level. Reaction times increase, especially towards the last stage of the experiment. Over the trial, we find no significant decline in test scores. These findings suggest that although mental fatigue may co-occur with increased sleepiness, it is not always dominant, nor does it necessarily lead to reduced performance. This study increases understanding of the relationship between fatigue, sleepiness, and performance, and cautions against equating indicators of mental fatigue with sleepiness in research.

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1.0 INTRODUCTION

Cognitive load, a basic concept in psychology, relates to the mental effort required to handle information, which includes the total mental resources used in working memory. These include attention, memory, and processing capacity. Although necessary for learning and problem-solving, cognitive overload can impair performance and cause mental fatigue. Intrinsic cognitive load refers to the load inherent to a task. Tasks that are complex or rarely done will provide a higher intrinsic cognitive load. Working with a foreign language or solving mathematics problems with complex formulas will inevitably cause a greater intrinsic cognitive load.

Experiencing cognitive load for a long enough duration may cause mental fatigue (1–4). Mental fatigue is characterized by changes in subjective conditions (e.g. tiredness, feeling, and energy deficiency), behavior (e.g. motivation drop or reaction speed decline), and also physiological decline (e.g. brain signal variation) (3). This situation is caused by tasks that burden the cognitive function (for example, working memory and attention) (3). Cognitive load and fatigue experienced for some time can manifest as difficulty concentrating, making decisions, or solving problems effectively. The effect would be increased errors, decreased alertness, decreased speed, decreased accuracy (2,3), and sometimes can cause death (5). Prolonged exposure to high levels of cognitive load and fatigue may also build up the consequences of stress, burnout, and mental health problems.

Several approaches were frequently used to assess or detect mental fatigue using a subjective or objective approach. Objective approaches include physiological-based, attention-based, and behavior-based (6–9). In some studies that used sleepiness as a response to represent fatigue status (8,10), sleepiness or drowsiness is considered an observable manifestation of mental fatigue or mental load. It reflected the subjective experience of tiredness and decreased alertness resulting from prolonged cognitive activity or sleep deprivation (6,11). Participants have to value their level of sleepiness using subjective sleepiness scales such as the Karolinska Sleepiness Scale (12) , Epworth Sleepiness Scale, or Stanford Sleepiness Scale (13). Higher scores indicate higher levels of sleepiness. This score was often interpreted as an of higher levels of mental fatigue. Some research also used objective approaches such as physiological measurements to assess sleepiness levels. The device such as Electroencephalography (EEG), electrooculography (EOG), and actigraphy (4,14,15) were used as objective indicators of sleepiness. The approach mainly measures the changes in brain activity, eye movements, and physical activity levels that are associated with increased sleepiness and decreased alertness.

Mental fatigue and sleepiness are different concepts, each of which has unique characteristics. Each of these phenomena can influence cognitive performance. Sleepiness is an increased desire to sleep, usually accompanied by physiological responses such as yawning, slowed blinking, and reduced alertness. Sleepiness is often associated with sleep deprivation due to circadian rhythms (16,17). Working monotonously for long periods of time can also cause sleepiness (16,17). Conversely, mental fatigue is mainly caused by high or prolonged cognitive demands in completing tasks (3,6,18). Mental fatigue is usually characterized by fatigue feeling and motivation drop. Sometimes there are also

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decreases in cognitive function. Although both phenomena may affect performance, the knowledge to differentiate between sleepiness and mental fatigue is important to overcome a decline in cognitive performance when doing certain tasks.

This research aims to increase understanding of the interaction between fatigue, sleepiness, and performance in carrying out tasks with cognitive demands. Our research question was whether mental fatigue typically co-occurs with sleepiness. Mental fatigue may not always be accompanied by drowsiness, considering that these two things have different concepts and characteristics, although both may occur together under certain conditions. Therefore, we suspect that mental fatigue may arise because it is triggered by cognitive demands and resource depletion without accompanying sleepiness. In addition, we tried to examine the relationship between fatigue and performance. A related research question is whether mental fatigue always leads to decreased performance. We suspect that fatigue does not necessarily result in decreased performance. Various factors can influence fatigue and performance, creating a diverse and complex relationship between the two. Fatigue may not always be associated with reduced performance, although under certain conditions it can hinder performance.

This research is important because mistakes induced by cognitive fatigue or sleepiness may result in catastrophic consequences, such as accidents, medical errors, or financial losses. It offers insights that may enable practical interventions across multiple domains to improve outcomes for individuals and society as it explores complex interrelations between fatigue, sleepiness, and performance. The urgency of the present study is underscored by the increasing demands on cognitive performance in modern life, together with the necessity for solutions to manage those risks.

2.0 METHODS AND MATERIAL

The cognitive task used was a mathematics test, because mathematics tests have been widely used in research related to mental stress and fatigue (9,19). Experiments were carried out using a repeated measure ANOVA (rm-ANOVA) design (14,20) to examine the effect of working time on fatigue, sleepiness, and performance. Since there were three stages to the experiment, the number of levels was set at three.

2.1. Participants

To ensure that the subjects had sufficient cognitive abilities to work on simple mathematics problems, they were taken from among male or female university students. For the study, 19 male and female students aged 19–23 from the Faculty of Engineering at Atma Jaya Catholic University of Indonesia were used. Previously, the subject had never played with the mathematical application used in this study. Each subject was given a brief explanation until they were completely familiar with the application.

Experiments were carried out in the range of 08.00–19.00. The subject must arrive 30 minutes in advance. During this duration, the subject must rest (not do strenuous physical activity) while being given an explanation regarding the purpose and method of the experiment. Subjects were also asked to fill out an informed consent form and provide their personal data related to their health condition, sleep condition, initial fatigue score, and initial sleepiness score. To get used to the task, the subject warmed up by doing the task on the application used.

2.2. Assessment of sleepiness, fatigue, and performance

Fatigue was assessed using the Samn-Perelli subjective rating scale (5,21,22). It was expected that there would be additional fatigue values over time until reaching fatigue level (fatigue score > 4). The level of sleepiness during the task was also monitored using the KSS scale (23–25). To analyze the decrease in performance along with the increase in fatigue, two indicators were used, namely mathematics test scores and reaction time. Reaction time was measured using the Psychomotor Vigilance Test. PVT is one of the awareness tests that has been validated to have a relationship with physiological fatigue (23,24). Under fatigue conditions, reaction time would increase. During the experiment, it is expected that there will be an increase in reaction time along with an increase in the fatigue score at every stage. The PVT2.0 application was used for the experiment (26,27).

2.3. Procedures

The experiment was carried out in three major stages of doing mathematics tests. Each stage consists of 30 levels. After completing 5 levels, the experiment was stopped for 10 seconds, and subjects filled in the Samn-Perelli fatigue score (5,22,23), KSS sleepiness score (23–25), and the mathematics test score (from the application). PVT measurements were carried out after the subject worked on 15 levels and 30 levels. This procedure was repeated three times (3 stages), and the processing time for each stage was approximately 1 hour. To motivate participants to be serious, prizes were provided for the three participants with the highest final mathematics test score. There were some responses used in the analysis, namely the average fatigue score, the average sleepiness, the average reaction time, and the average mathematics test score.

2.4. Analysis

An analysis of the relationship between time, subjective scale, and performance, was carried out using two approaches. The F test under rm-ANOVA (20,28) was used to analyze whether there was a significant increase in the response at each stage of the experiment. Each stage reflects time-on-task. The responses were the average fatigue score, average sleepiness score, average reaction time, and average math test score. Each response was analyzed separately against time-on-task. The Mauchly test is used when the sphericity assumption is met. If these assumptions are not met, the Greenhouse-Geisser test is used (20,28). If there is a significant difference, a post hoc analysis was carried out using the Bonferroni test to find out which stage was significantly different (29). Pearson's correlation test was used to measure the closeness of the linear relationship between scores of fatigue, sleepiness, reaction time, and mathematics test scores. The correlation test uses a combination of all normalized stages.

3.0 RESULTS AND DISCUSSION

This study aims to analyze whether the value of mental fatigue is always in line with sleepiness. What motivated this research was the large number of articles that estimated mental fatigue values based on sleepiness values. An analysis was also carried out to see whether mental fatigue always goes hand in hand with decreased performance. The interaction between cognitive load, mental fatigue, sleepiness, and performance also makes it possible that cognitive load does not always harm performance. Knowledge of the relationship between fatigue, sleepiness, and performance is important to design performance without causing excessive fatigue and decreased performance.

The rm-ANOVA design was carried out by dividing the experimental time into three consecutive stages of test completion, namely Stage 1, Stage 2, and Stage 3. Using the Samn-Perelli fatigue scale, the trials achieved a fatigue score from very low (value 1) to 6. However, none of the subjects reached a maximum score of 7. For the interpretation of these scores, categorization can be used (5) (Table 1). Because the score of the experimental results has reached 5 or 6, especially at the last moment of the experiment, the subject has shown moderate or severe fatigue. In this condition, there is a possibility of decreased performance due to fatigue.

Table 1. Interpretation of Samn-Perelli score (5)

Score	Interpretation
1-3	No fatigue-related decline in performance is expected
4	There is possibility of performance degradation. However, it is not a main factor
5	Moderate fatigue. Fatigue-related performance decline may occur. Carrying out tasks is permitted but not recommended if it is not urgent
6	Severe fatigue, fatigue-related performance decline is possible. Task execution is not recommended
7	Severe fatigue, impaired performance. Task execution is not recommended.

The value of sleepiness with KSS also increased, with a maximum score of 5 (on a scale of 1-10). The reaction value also tends to increase along with the increase in time on task. This manuscript does not present raw data for each scale, but Table 2 presents the average response value at each stage. For these three responses, the rm-ANOVA calculation was performed with the assumption that there is sphericity because the Mauchly sphericity test is fulfilled (p-value>0.05). Using the F test, the difference in stages was proven to cause significant increases in fatigue, sleepiness, and reaction time. Post hoc analysis using the Bonferroni method concluded that fatigue scores and sleepiness scores increased significantly from the first to the second stage, the second to the third stage, and the first to the third stage. This series of analyses proved that experiments could stimulate an increase in fatigue and sleepiness scores at each stage of the experimental time because of the cognitive load that was felt during the assigned activity.

Table 2. ANOVA result for the responses: Fatigue, sleepiness, reaction time, and mathematics scores

Responses	**Sphericity**	**Anova**		**Mean**			**Bonferroni Test**		
		F	Sig	S1	S2	S3	S1-S2	S2-S3	S1-S3
Fatigue (Samn-Perelli)	Y	863.3	<0.001	1.67	3.41	5.27	Y	Y	Y
Sleepiness (KSS)	Y	17.213	<0.001	1.75	2.19	2.53	Y	Y	Y
Reaction time (PVT)	Y	8.721	0.001	339.42	348.42	380.66	N	Y	Y
Math scores	N	0.172	0.684	134243	135531	135516	N	N	N

Considering performance, reaction time showed a significant increase only in periods 1 to 3 and periods 2 to 3 ($p < 0.05$). The fatigue score from periods 1 to 2 showed an increase but was not significant ($p > 0.05$). From these results, the subjective fatigue score is in line with the objective measurement, namely reaction time. The PVT score, which significantly increased in the third hour, indicated that during this period there had been a slowdown in reactions, which is an indicator of mental fatigue. Contrary to expectations, it turned out that the mathematics test score did not show a decrease at each stage. The average score from stages 1 to 2 showed a slight increase, although not significant. This shows that the working period does not always reduce performance. To further analyze the relationship between fatigue, sleepiness, and performance, a Pearson correlation test was also carried out to see the relationship between the two variables (Table 3). The correlation test was carried out by ignoring the time-on-task factor. The results showed that only fatigue and sleepiness were significantly and positively correlated (p-value < 0.01). This shows that increasing the value of mental fatigue also causes an increase in the value of sleepiness.

Table 3. Bivariate Pearson correlation between fatigue, sleepiness, PVT, and mathematics score

	PVT	Fatigue	Sleepiness
Fatigue	0.25		
	0.061		
Sleepiness	-0.106	0.351**	
	0.435	0.007	
Mathematics score	-0.075	-0.036	-0.127
	0.58	0.793	0.346

Cell Contents
Pearson correlation
P-Value

3.1. Fatigue and sleepiness

The results show that both fatigue and sleepiness result in a significant increase in value at each stage. When participants felt an increase in mental fatigue, they also felt a slight increase in sleepiness. However, the level of increase on these two scales was different. Mental fatigue scores increased sharply (from a score of 1 to a score of 5 or 6 on a maximum scale of 7) throughout the experiment. A scale of 6 means there was severe fatigue, in which decreased performance related to fatigue is possible (Table 1). In the case of fatigue, participants have feelings of exhaustion, reduced motivation, and impaired cognitive function. Conversely, the sleepiness scale only increased slightly, reaching a maximum of 5 out of 10. From the interpretation of the KSS level (25) (Table 4), the sleepiness score resulting from this experiment was in the category of not dangerous or very low (below 6). Therefore, if there was a decrease in performance, it may not be due to sleepiness but to cognitive load.

Table 4. Score interpretation of *Karolinska Sleepiness Scale* (25)

Category	**Score**	**Interpretation**
1	1-6	No drowsiness or low sleepiness
2	7	Level of moderate drowsiness
3	8-10	High level of drowsiness

Different mechanisms between mental fatigue and sleepiness may lead to different strategies to overcome them. Sleepiness is a normal occurrence due to circadian rhythms. Meanwhile, mental fatigue is initiated by the cognitive load in the brain (6,7,30). The load may include working memory, decision-making, and sustained attention (6,30). In this study, mental fatigue and cognitive fatigue were probably related to the fact that taking a simple math test for 3 hours was quite boring. Although completing the task requires cognitive ability, which leads to significant increases in mental fatigue, repeating the test over a long period also causes boredom, which can cause drowsiness as well. However, cognitive activities that cause mental fatigue do not necessarily cause excessive sleepiness, because the sleepiness value is still within the lower limit. Usually, excessive sleepiness occurs when carrying out mental tasks if there is a disruption in the sleep regulation mechanism(24,31). Sleepiness may only increase and still be at a low level if the task demands do not affect sleep-related processes. Moreover, individuals that are able to develop strategies to focus on finishing the task usually tend to have a lower level of sleepiness(17,31). In other words, individuals may experience mental fatigue without feeling high sleepiness if they are able to maintain their alertness through cognitive effort.

Moreover, there are differences among individual. Individuals vary in their susceptibility to mental fatigue and sleepiness. In this research both mental fatigue and sleepiness were assessed through self-report measures that capture subjective feelings (12,13,31). Mental fatigue measures rely on individuals' perceptions of their own cognitive state and may be sensitive to changes in cognitive workload and task demands. Meanwhile, subjective measures of sleepiness measure the individual's perceived sleepiness or alertness. Everyone’s perception and resistance to feelings of fatigue and sleepiness varies, so it can influence the interaction of various factors and the output of these conditions. Some individuals may be better able to maintain cognitive performance without feeling excessive fatigue. Other individuals may perceive feelings of fatigue as sleepiness. Other individuals may fail to create strategies to respond to feelings of tiredness or sleepiness, causing them to lose motivation due to carrying out these cognitive tasks, so that they feel tired and sleepy. This subjectivity may influence their assessment of how they feel and in turn these individual differences will lead to variations in the relationship between mental fatigue and sleepiness observed in studies.

This explanation confirms that although in this experiment there was an increase in the level of mental fatigue and sleepiness, the degree of increase was different. Mental fatigue tended to increase more sharply than sleepiness. Although the rating scale is subjective, both scales have been proven valid in assessing the level of sleepiness and fatigue in previous studies (24,31–33). The complexity and subjectivity of feelings of fatigue and sleepiness, the demands of certain tasks, and individual differences in responding to cognitive load were able to differentiate the level of fatigue and sleepiness felt by the subjects. Besides that, the objective measuring instrument used in this study, which is the PVT, also showed a significant increase in reaction time in the third hour. This is in accordance with the feelings felt by the subjects; if somebody feels mentally tired or sleepy, he will show a slower reaction time for any event.

3.2. Fatigue and performance

Performance is measured using reaction time and math scores. The expectation is increase in reaction time and a decrease in math scores in line with an increase in mental fatigue scores. This experiment showed that the first indicator, which was reaction time, increased significantly, especially when fatigue was high enough (at stage 3). At stage 2 the results of the PVT test were quite varied. Some scores increased, some were the same as stage 1, and some even decreased. However, at stage 3, the average reaction time increased significantly, presumably because fatigue had reached high scores. However, from the Pearson correlation, PVT results did not show significant correlations with fatigue, sleepiness, or performance. This is probably because the increase only occurred at stage 3, so the PVT value at stage 2 did not show the expected pattern. Cognitive demand experienced over a long period can cause a decrease in performance. But apparently, this is not always the case. This research proves that high cognitive load does not always cause a decrease in performance, which can be seen from the math score. Even though reaction time decreases, all math assignments can be completed well. From these results, the relationship between cognitive load and performance does not always go hand in hand. Many factors can influence a person's response to cognitive load and maintaining their performance. When individuals can adapt to their duties, no decline in performance will likely occur; or in some cases, it even may improve. As a second indicator of performance, the math score was not shown to be reduced. The average fatigue score increased slightly at stage 2, presumably because the subject was getting used to the test given. However, fatigue slightly lowers the performance, so the average mathematics test score decreased at stage 3, although the decrease was also not significant. This result followed several studies that stated that an increase in fatigue is not always accompanied by a decrease in performance (6,9,17).

Studies have shown that experienced individuals often have more efficient cognitive processing mechanisms and can sustain higher levels of cognitive load without experiencing a significant decline in performance (6,9,17,34). The mathematics test used in this reseaarch performs a series of simple addition and subtraction mathematical operations that participants may already do often. Because all participants were used to carrying out simple mathematical operations, they tended to develop work strategies to maintain their performance. Individuals can learn to optimize their cognitive resources, prioritize tasks, and manage distractions more effectively, allowing them to maintain performance levels even in the face of ongoing cognitive load (6,34). This adaptation process may involve developing strategies such as grouping information, automating routine tasks, and implementing efficient problem-solving techniques.

Someone who is used to or experienced in doing this tends to be able to carry out cognitive processes more efficiently (6,9,17). He will be able to withstand cognitive loads longer without causing a decrease in work output. In this study, the mathematics test used was a series of simple mathematical operations consisting of addition and subtraction. This task was carried out repeatedly for 3 hours. Because all participants were engineering faculty students, they must have often carried out this simple counting activity. Therefore, it can be said that students were experienced in carrying out this activity. When they are asked to carry out these activities for a long period, they become more familiar with the task and can develop strategies to be able to carry out the task (6,34). The ability to adapt and develop coping strategies in response to prolonged cognitive load can influence performance results in taking mathematics tests. Because all participants were used to carrying out simple mathematical operations, they tended to develop work strategies to maintain their performance. Every individual can develop methods how to use cognitive resources more effectively so that they can develop strategies in prioritizing tasks, overcoming distractions, grouping important information, carrying out effective care to solve problems or carrying out repetitive tasks effectively (6,34). This ability allows them to maintain performance even though they are continuously burdened with cognitive load.

Furthermore, motivation and intelligence factors can influence how individuals act and respond to the cognitive load they feel. A person will be more able to persist in carrying out a difficult task in a situation that is enjoyable, challenging, or meaningful to him. In this study, motivation was triggered by providing monetary incentives to the three participants who had the highest math scores. Other factors such as age, health, and emotional status also influence a person's ability to be able to develop strategies to carry out this task while maintaining their performance.

3.3. Implication

This work theoretically differentiates fatigue and sleepiness, suggesting that they are not entities that accumulate together. Results of this study may enable a refinement of models about cognitive and physical performance and perhaps may help stimulate further research into divergent pathways and mechanisms underlying fatigue and sleepiness. These results also bear on cognitive load theory, suggesting that effects of fatigue might accumulate through the course of sustained mental effort, relatively independently of sleepiness. This might further spur theoretical exploration into how cognitive load affects different aspects of mental and physical condition over time.

Such findings can also be of relevance in work policy, more so in industries that require incessant mental effort: air traffic control, long-distance driving, and health care. This very concept, 'fatigue is not the same as sleepiness,' could be utilized at the level of scheduling practices, breaks, and workload management in producing optimal performance with minimal errors. Tasks and user interfaces could be designed to compensate for the bad effects of fatigue and sleepiness. For example, tasks should be designed to reduce mental fatigue—one that allows regular breaks, variation of level of cognitive demand, or has engaging elements that keep the level of alertness and performance high over time.

3.4. Limitation

Apart from several important findings, this study has several limitations. The first limitation is the use of a subjective scale to assess fatigue. This study used a subjective scale (1-7) in determining the actual state of fatigue. Even though the use of a subjective fatigue scale is very common in various studies related to fatigue, this subjectivity factor still has the potential to cause differences in the assessment of each subject. Because of the subjectivity of each subject, it is sometimes difficult for someone to recognize their physical condition, and many are also influenced by psychological situations, such as emotions, pressure, boredom, and so on. Another limitation of this study is the limited amount of data used which was only taken from the limited population. Caution is needed in generalizing the results of this study. Different populations or experimental conditions also may get different results. In addition, the duration of 3 hours and the given workload were not able to stimulate the subject to reach a fatigue scale of 7. The subject had not reached the maximum fatigue scale, possibly because the trial time was not long enough.

4.0 CONCLUSION AND RECOMMENDATION

This study concluded that on cognitive tasks, fatigue, sleepiness, and time of reaction increase with the activity time increase. The increase in reaction time mainly occurs when the time on task has increased, that is when the fatigue score has been high. The sleepiness score also increased along with the increase in the fatigue score, but the increase was still in the low category. Therefore, if there is a decrease in performance, it is most likely due to mental fatigue, and not due to sleepiness. Mental fatigue and sleepiness are two different concepts and have different characteristics. Mental fatigue is mainly caused by reduced cognitive power when carrying out cognitive tasks in a certain period. Sleepiness occurs naturally due to physiological processes and circadian rhythms. Personal factors and the surrounding environment will affect a person's ability to withstand cognitive load and resist sleepiness.

In this study, performance as not decrease as fatigue increases. This shows that even though fatigue has the potential to reduce performance, there are efforts for everyone to maintain their performance even though they are tired. To strengthen the results of this study, studies with larger data and involving a more diverse population are recommended. In future research, it is suggested to be able to develop indicators of mental fatigue, especially in conditions that do not involve a high level of sleepiness. While prolonged exposure to cognitive load can lead to mental fatigue and a decrease in performance for many individuals, the relationship between cognitive load duration and performance is complex and multifaceted. Someone experienced, skilful, motivated, or not emotional may have a better ability to maintain the work without losing the performance. How individuals respond to prolonged cognitive load also may improve over time since they simultaneously learn about the task.

It was also proven that the incidence of mental fatigue is not always equivalent to sleepiness. Therefore, it is recommended not to equate mental fatigue and sleepiness concepts. The sleepiness or drowsiness level cannot always indicate the mental fatigue level. For further research, it is important to develop objective indicators related to mental fatigue. The research is quite crucial since so far efforts to detect fatigue have mainly used signs of sleepiness to represent mental fatigue. To mitigate cognitive load and prevent mental fatigue, it is essential to employ strategies that optimize cognitive resources and promote efficient information processing. Breaking complex tasks into smaller, managing components, and minimizing distractions, were examples of those strategies. Techniques such as mindfulness meditation, regular physical exercise, and adequate rest can also help replenish cognitive resources and reduce the risk of mental fatigue.

5.0 REFERENCES

1. Di Stasi LL, Mccamy MB, Catena A, Macknik SL, Cañas JJ, Martinez-Conde S. Microsaccade and drift dynamics reflect mental fatigue. Eur J Neurosci. 2013 Aug;38(3):2389–98.
2. Mehta RK. Integrating physical and cognitive ergonomics. IIE Trans Occup Ergon Hum Factors. 2016;4(2–3):83–7.
3. Van Cutsem J, Marcora S, De Pauw K, Bailey S, Meeusen R, Roelands B. The effects of mental fatigue on physical performance: a systematic review. Vol. 47, Sports Medicine. Springer International Publishing; 2017. p. 1569–88.
4. Dasari D, Shou G, Ding L. ICA-Derived EEG correlates to mental fatigue, effort, and workload in a realistically simulated air traffic control task. Front Neurosci. 2017 May 30;11(MAY).
5. Chang Y, Yang H, Hsu W-J. Effects of work shifts on fatigue levels of Air Traffic Controllers. J Air Transp Manag. 2019;76(2019):1–9.
6. Bafna T, Hansen JP. Mental fatigue measurement using eye metrics: A systematic literature review. Psychophysiology. 2021;58(6):1–23.
7. Díaz-García J, González-Ponce I, Ponce-Bordón JC, López-Gajardo MÁ, Ramírez-Bravo I, Rubio-Morales A, et al. Mental load and fatigue assessment instruments: A systematic review. Int J Environ Res Public Health. 2022;19(1).
8. Sahayadhas A, Sundaraj K, Murugappan M. Detecting driver drowsiness based on sensors: A review. Sensors (Switzerland). 2012;12(12):16937–53.
9. Trejo LJ, Kubitz K, Rosipal R, Kochavi RL, Montgomery LD. EEG-based estimation and classification of mental fatigue. Psychology [Internet]. 2015;6(April):572–89. Available from: http://www.scirp.org/journal/psych http://dx.doi.org/10.4236/psych.2015.65055%0AEEG-Based
10. Dawson D, Searle AK, Paterson JL. Look before you sleep: Evaluating the use of fatigue detection technologies within a fatigue risk management system for the road transport industry. Vol. 18, Sleep Medicine Reviews. 2014. p. 141–52.
11. Greenberg S, Aislinn P, Kirsten D. Development and validation of the fatigue state questionnaire: preliminary findings. Open Psychol J. 2016;9(1):50–65.
12. Muslim Y, Widyanti A. Evaluation of Student Mental Workload in Multicampus Lectures of Industrial Engineering Department ' Block System. 2024;2(1):1–8.
13. Duan T, Zhang N, Li K, Hou X, Pei J. Study on the preferred application-oriented index for mental fatigue detection. Int J Environ Res Public Health. 2018;15(11):1–14.
14. Zhang H, Wang J, Geng X, Li C, Wang S. Objective Assessments of Mental Fatigue During a Continuous Long-Term Stress Condition. Front Hum Neurosci. 2021;15(November):1–10.
15. Kunasegaran K, Ismail AMH, Ramasamy S, Gnanou JV, Caszo BA, Chen PL. Understanding mental fatigue and its detection: a comparative analysis of assessments and tools. PeerJ. 2023;11:1–27.
16. Bier L, Wolf P, Hilsenbek H, Abendroth B. How to measure monotony-related fatigue? A systematic review of fatigue measurement methods for use on driving tests. Theor Issues Ergon Sci [Internet]. 2020;21(1):22–55. Available from: https://doi.org/10.1080/1463922X.2018.1529204
17. Hu X, Lodewijks G. Detecting fatigue in car drivers and aircraft pilots by using non-invasive measures: The value of differentiation of sleepiness and mental fatigue. J Safety Res [Internet]. 2020;72(January):173–87. Available from: https://doi.org/10.1016/j.jsr.2019.12.015
18. Young MS, Brookhuis KA, Wickens CD, Hancock PA. State of science: mental workload in ergonomics. Vol. 58, Ergonomics. Taylor and Francis Ltd.; 2015. p. 1–17.
19. Kawamura R, Takemura N, Sato K. Mental fatigue estimation based on facial expressions during speech. In: 2015 IEEE/SICE International Symposium on System Integration, SII 2015. Nagoya; 2016. p. 223–8.
20. Armstrong RA. Recommendations for analysis of repeated-measures designs: testing and correcting for sphericity and use of manova and mixed model analysis. Ophthalmic Physiol Opt. 2017;37(5):585–93.
21. Signal TL, Gander PH. Countermeasures of sleepiness Scheduled napping as a countermeasure to sleepiness in air traffic controllers. 2009;5799:11–9.
22. Samn SW, Ph D, Perelli P. Estimating Aircrew Fatigue : a Technique. 1982;
23. Gander PH, Mulrine HM, van den Berg MJ, Smith AAT, Signal TL, Wu LJ, et al. Effects of sleep/wake history and circadian phase on proposed pilot fatigue safety performance indicators. J Sleep Res. 2015;24(1):110–9.
24. Kaida K, Takahashi M, Åkerstedt T, Nakata A, Otsuka Y, Haratani T, et al. Validation of the Karolinska Sleepiness Scale against performance and EEG variables. Clin Neurophysiol. 2006;117(7):1574–81.
25. Wang X, Xu C. Driver drowsiness detection based on non-intrusive metrics considering individual specifics. Accid Anal Prev [Internet]. 2016;95:350–7. Available from: http://dx.doi.org/10.1016/j.aap.2015.09.002
26. Jongen S, Perrier J, Vuurman EF, Ramaekers JG, Vermeeren A. Sensitivity and validity of psychometric tests for assessing driving impairment: Effects of sleep deprivation. PLoS One. 2015;10(2).
27. Reifman J, Kumar K, Khitrov MY, Liu J, Ramakrishnan S. PC-PVT 2.0: An updated platform for psychomotor vigilance task testing, analysis, prediction, and visualization. J Neurosci Methods [Internet]. 2018;304:39–45. Available from: https://doi.org/10.1016/j.jneumeth.2018.04.007
28. Lane DM. The assumption of sphericity in repeated-measures designs: What it means and what to do when it is

violated. Quant Methods Psychol. 2016;12(2):114–22.
29. Armstrong RA. When to use the Bonferroni correction. Ophthalmic Physiol Opt. 2014;34(5):502–8.
30. Marandi RZ, Madeleine P, Omland Ø, Vuillerme N, Samani A. Eye movement characteristics reflected fatigue development in both young and elderly individuals. Sci Rep. 2018;8(1):1–10.
31. Brandenburger N, Naumann A, Jipp M. Task-induced fatigue when implementing high grades of railway automation. Cogn Technol Work [Internet]. 2021;23:273–283. Available from: https://doi.org/10.1007/s10111-019-00613-z
32. Gawron VJ. Overview of self-reported measures of fatigue. Int J Aviat Psychol. 2016 Oct 1;26(3–4):120–31.
33. Triyanti V, Azis HA, Iridiastadi H, Yassierli. Workload and Fatigue Assessment on Air Traffic Controller. IOP Conf Ser Mater Sci Eng. 2020;847(1).
34. Marchitto M, Benedetto S, Baccino T, Cañas JJ. Air traffic control: Ocular metrics reflect cognitive complexity. Int J Ind Ergon. 2016 Jul 1;54:120–30.