MENTAL FATIGUE ANALYSIS BASED ON ELECTROENCEPHALOGRAPHY SPECTRUM, MENTAL FATIGUE SCALE, AND REACTION TIME

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To my beloved parents, thank you.

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ABSTRACT

Fatigue is a condition that affects a wide range of individuals. In this pandemic era, students spend a lot of their time in front of the computer, tablet, or laptop as a medium in their online learning. The objectives of the project are to analyses the subject's mental state by analysing waveforms using electroencephalography (EEG). Next, to evaluate the mental state of subjects from the Mental Fatigue Scale (MFS) and lastly, to analyses how mental fatigue can impact someone reaction time (RT). The methodology for this project is divided by two parts. Part one is about the mental fatigue from the EEG waveform, and the second part is about the mental fatigue analysis from Mental Fatigue Scale (MFS) and the reaction time. All of the analysis were done in IBM SPSS software to show the correlation between each condition. The result of the paired T-test between condition_1 and condition_2 shows that were significant difference between those condition ($P<0.05$). The power spectrum for the subject that induced mental fatigue during the arithmetic test was higher for each channel. The ANOVA analysis (one way) showed that the score of MFS results were not statistically significant between the age of the subjects and the score also between the sex of the subject and the score of the MFS ($P>0.05$). Participants that did not suffer mental fatigue were highly from the male compared to female participants. In the reaction time test, the final reaction time was longer compared to the early reaction for each of the subjects and the paired T-test shows that the final reaction time were statistically significant from the early reaction time ($P<0.05$). In conclusion, the most prominent finding to emerge from this study is that the increase of reaction time can prove that someone has induced MF while doing the arithmetic test and the rise in the power spectrum of EEG signal.

ABSTRAK

Fatigue adalah keadaan yang memberi kesan kepada pelbagai individu. Dalam era pandemik ini, pelajar menghabiskan banyak masa mereka di hadapan gajet elektronik sebagai medium dalam pembelajaran atas talian mereka. Objektif projek ini adalah untuk menganalisis keadaan mental subjek dengan menganalisis bentuk gelombang menggunakan *electroencephalography* (EEG). Seterusnya, untuk menilai keadaan mental subjek daripada *Mental Fatigue Scale* (MFS) dan akhir sekali, untuk menganalisis bagaimana *Mental Fatigue* (MF) boleh memberi kesan kepada masa tindak balas (RT) seseorang. Metodologi untuk projek ini dibahagikan kepada dua bahagian. Bahagian satu ialah mengenai MF daripada bentuk gelombang EEG, dan bahagian kedua ialah mengenai analisis MF daripada *Mental Fatigue Scale* (MFS) dan masa tindak balas. Kesemua analisis telah dilakukan dalam perisian IBM SPSS untuk menunjukkan perkaitan antara setiap keadaan. Keputusan *paired T-test* antara kedua-dua keadaan menunjukkan terdapat perbezaan yang signifikan antara keadaan tersebut ($P<0.05$). Spektrum kuasa untuk subjek yang menyebabkan MF semasa ujian aritmetik adalah lebih tinggi untuk setiap saluran. Analisis *ANOVA* (sehala) menunjukkan bahawa skor keputusan MFS adalah tidak signifikan secara statistik antara umur subjek dan skor juga antara jantina subjek dan skor MFS ($P>0.05$). Peserta yang tidak mengalami MF adalah tinggi daripada peserta lelaki berbanding peserta perempuan. Dalam ujian masa tindak balas, masa tindak balas akhir adalah lebih lama berbanding dengan tindak balas awal bagi setiap subjek dan *paired T-test* menunjukkan bahawa masa tindak balas akhir adalah signifikan secara statistik dari masa tindak balas awal ($P<0.05$). Kesimpulannya, dapatan yang paling menonjol daripada kajian ini ialah peningkatan masa tindak balas boleh membuktikan bahawa seseorang telah mendorong MF semasa melakukan ujian aritmetik dan peningkatan dalam spektrum kuasa isyarat EEG.

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LIST OF SYMBOLS AND ABBREVIATIONS

ANOVA	-	Analysis of Variance
COVID	-	Coronavirus Disease
ECG	-	Electrocardiogram
EDF	-	European Data Format
EEG	-	Electroencephalogram
EF	-	Emotional Fatigue
MCO	-	Movement Control Order
MF	-	Mental Fatigue
MFS	-	Mental Fatigue Scale
MOHE	-	Ministry of Higher Education
RPE	-	Rating of Perceived Exertion
RT	-	Reaction Time
SARS	-	Severe Acute Respiratory Syndrome
SD	-	Standard Deviation
UTHM	-	Universiti Tun Hussein Onn Malaysia
V	-	Voltage
WBRT	-	Whole Body Reaction Tester

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CHAPTER 1

INTRODUCTION

1.1 Background Study

Fatigue is a condition that affects a wide range of individuals. Even though medical or psychiatric conditions frequently cause exhaustion, many people experience fatigue due to behavioural or situational variables, including lack of sleep or stress [1]. Fatigue is a medical condition that reduces mental or physical capability caused by a lack of sleep, a disruption in the circadian period, or a serious effort. Potential health consequences of significant computer-related research have been a source of considerable concern over the past few years, with weariness and musculoskeletal issues, as well as idea worries, being key examples [2].

Because of its high temporal resolution, non-invasiveness, and low financial cost, electroencephalography (EEG) is often utilized in studies including neural engineering, neurology, and biomedical engineering like in brain computer interfaces (BCI) during sleep analysis and seizure identification. EEG analyses the combined brain impulses of a group of nerves with an amplitude of a few microvolts. EEG is now widely employed in numerous domains, including neuroscience, psychology, cognitive science, and psychophysiology research [3][4]. Sleeping problems, stress, epileptic activity, dementia, Alzheimer's disease, and schizophrenic are all diagnosed and identified using EEG in clinical research. As a result, developing tools for interpreting underlying data in EEG signals is critical. As a result, power spectrum analysis is favoured for EEG quantification. Absolute power, which quantifies information about the condition of the brain, is the amount of power really present in each band of EEG.

While some argue for a one-dimensional definition of fatigue, it is generally divided into two categories: physical fatigue and mental fatigue (MF). Mental exhaustion occurs as a result of extended periods of cognitive activity and results in a decrease in cognitive and behavioural output. Physical fatigue is characterised as a reduction in capacity to perform physical work because of activities that require physical effort. Physical output has been shown to suffer as a result of mental exhaustion [5].

One of the most thoroughly researched procedures in behavioural neuroscience is the choice reaction time task. More often than response time variability, which is normally computed as the standard deviation of the reaction times, the median or mean reaction time (RT) is analysed [6]. As the range of observed values rises with variability, RT and reaction time variability are linked positively. A statistical reason for the positive association is that a large difference of response times on the same task will typically lead to a larger mean or median. While some studies believe that investigating response time variability adds little value, others maintain that RT and reaction time variance are two main basic chronometric variables.

A new infectious disease known as COVID-19 was discovered in November 2019, causing a pandemic caused by SARS-CoV-2. Coronavirus disease (COVID-19) is a contagious infection caused by a recently identified coronavirus [7]. The COVID19 outbreak has triggered a global public health crisis. While several cases requiring hospitalisation and intensive medical care focus on cardiorespiratory treatment, a number of cases exhibit neurological symptoms [8]. Ministry of Higher Education (MOHE) said that all students must go through online learning without physically attending the university or college [9]. Aside from abrupt changes in typical face-to-face learning styles, students were subjected to higher academic stress, which may result in adverse health consequences such as fatigue [10]. In Malaysia, a survey on MCO enforcement was conducted among the general public; however, no related survey on health science undergraduates has been conducted thus far [11].

1.2 Problem Statement

In this pandemic era, students spend a lot of their time in front of the computer, tablet, or laptop as a medium in their online learning [12]. Students also did not use the laptop only for studies, but they also used it to find study material, access information, watch movies and others. During the Covid-19 pandemic, a quick shift from the old and wise learning process to online learning may have resulted in poorer learned theory quality and higher lateness. Both of which are frequently connected with sedentary ways of living, which may have led to more fatigue among students.

This conclusion is supported by a recent Hong Kong research finding that roughly 70% of nursing students suffered educational stress [13]. Thus, this research helps the management identify the classifications of MF to the students. Also, the ministry of education can take proper action on online learning to reduce MF among the students. With this research, all people will pay more attention to mental health or fatigue during online classes while facing pandemics.

1.3 Objectives

This study aimed to assess MF using electroencephalographic measures before and during mental arithmetic tasks. The Mental Fatigue Scale (MFS) and reaction time test will also be used to analyses the MF.

The objectives of the project are:

1. To analyses the subject's mental state by analyzing waveforms using electroencephalography (EEG).
2. To analyses the mental state of subjects from the Mental Fatigue Scale (MFS) and how mental fatigue can impact someone reaction time (RT).

1.4 Scope of Project

The project will research students aged 19 – 30 years old in Universiti Tun Hussein Onn Malaysia (UTHM). The EEG waveform database was collected from the internet that consists of 30 subjects to analyse the subjects' EEG spectrum [14]. The waveform recordings were included before and during the mental arithmetic task. Then, the waveform data will be analysed by using IBM SPSS 26 software.

Most of them are currently going through online learning because of this COVID-19 pandemic. The questionnaire will do on an online platform by using Google form. The participants will be asked about their basic information such as gender and age in the form. They will also be asked about their mental state using the Mental Fatigue Scale (MFS) that will contribute to the analysis of MF. The target participants to answer the form is 30 students.

The participants will do an RT test based on the arithmetic task. All of the data will be analysed either using one way ANOVA analysis or paired T-test analysis. The difference between groups is evaluated to the variability within the groups in one-way ANOVA [15]. One one-way ANOVA explores the effect of varying amounts of only one factor on the parameter. For even more than two groups, one-way ANOVA is usually employed because two groups can be compared using the T-test. Paired sample T-test is employed when every observation for one category is paired with a close observation from the other category. The samples are often made up of matched pairs of comparable units or examples of repeated measurements [16].

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter covers the literature review about fatigue, mainly on MF. There are also on what type will use the output of EEG sensor to detect MF. This paper will use MFS to analyse MF with the different research papers about MFS. RT also will be discussed in this chapter if the RT is related to MF. Furthermore, this section will review the previously published article on MF in this chapter.

2.2 Fatigue

Fatigue is a subjective, physiological condition that people undergo due to physical or mental exertion [5] [17]. Physical fatigue affects an individual's ability to maintain physical behaviour, while MF affects an individual's cognitive processes. Both forms are cumulative; for example, the fatigue caused by a task increases as the task is completed more frequently. After a time of rest, all forms of fatigue subside. Traditionally, fatigue tracking has focused on subjective data gathered through questionnaires [18]. As a result, these approaches rely on manual data collection and are impractical for continuous fatigue tracking.

MF is a neurophysiological state characterized by subjective feelings of "tiredness" and "lack of capacity" induced by prolonged periods of stressful cognitive activity [19]. The impact of mental exhaustion on cognitive capacity and professional performance of drivers and air pilots has received much attention. The body of research reveals the neuronal changes induced by extended periods of demanding mental activity in both health and disease. Fatigue expresses itself as a growing aversion to continuing with a task; as long as it can overcome this resistance, success continues, but with subjectively more tremendous effort. Fatigue is either central (related to the nervous system) or peripheral [20]. Fatigue impacts psychomotor performance because of its physiological effects and because it influences decision-making ability.

Attention is a critical aspect of dynamic human behaviour since it enables individuals to filter the intake of new data so that people can focus on the information that is essential to attaining the present objectives while intentionally ignoring extraneous information that may conceivably contradict with those priorities [21]. Mental weariness has been shown to indicate an increased chance of mistake; it has become one of the main prevalent symptoms encountered by those suffering from neurological illnesses [22]. Mental exhaustion can present itself in a variety of ways, including emotionally, behaviourally, and physically. Subjectively, people have reported feeling more fatigued, having less energy, and having less drive and attention. Mental weariness is behaviourally defined as a decrease in effectiveness (reaction time) on a mental processing [23]. Finally, it has been demonstrated that changes in brain activity are a physical expression of mental tiredness [24].

One notion examined by D. Li and W. Sullivan is that attentional tiredness is a consequence of stress, and hence the visual attention restoration effect is dependent on physiological and emotional alterations [25]. On the other side, stress can be produced by a person's impression of insufficient resources. When a challenging endeavour depletes one's attentional resources, a person's assessment of insufficiency can lead to physiological stress. There are a lot of factors that contribute to the MF, such as lack of sleep duration or insufficient time amount of sleep. Li et al. [26] stated that it is possible to ascribe MF to alcohol, task stress, and inadequate rest/sleep. Insufficient sleep is a crucial source of mental weariness, and it is frequently noticed in organizations with inconsistent shift schedules.

2.3 Electroencephalography (EEG) and Brainwaves

An electroencephalogram (EEG) is a test that measures electrical activity in the brain. Electrical impulses enable brain cells to interact with one another [27]. An EEG may be used to aid in the detection of possible issues associated with this task. An EEG is a device that monitors and records brain wave patterns. Small flat metal discs known as electrodes are wired to the scalp. The electrodes detect electrical impulses in the brain and transmit signals to a device, recording the effects. The most accurate way to test neurons is with an EEG, which is one instrument that can precisely measure neuronal activity.

Our brain comprises millions of brain cells, also known as neurons. Neurons in our brain interact with one another through electric impulse waves. Neurons in the nervous system are interconnected by creating neural nets linked by a passage called a 'synapse', which enables activities [28]. Brain waves are oscillating electrical voltages in the brain with magnitudes of a few millionths of a volt. Different parts of the brain do not emit the same frequency of brain waves simultaneously. An EEG signal between electrodes on the scalp is composed of many other waves.

The brain is broken into two brain structures: left and right. The frontal, temporal, occipital, and parietal lobes and the central sulcus are all part of the cerebral cortex. The frontal lobes are located ahead of (in front of) the parietal lobes. The temporal lobes lie below and below the frontal lobes. The occipital lobes are the smallest of the four actual lobes in the human brain, positioned in the back of the skull and behind the parietal lobes.

The central sulcus connects the parietal and frontal lobes [29]. G. Rojas et al. [30] stated that every electrode's identification consists of a letter and a number. The letter denotes the area of the brain in which the electrode is placed, such as F: frontal, C: central, T: temporal, P: parietal, and O: occipital, while the numbering denotes the cerebral hemisphere, with even digits in the right hemisphere and odd digits in the left. Figure 2.1 demonstrates the electrode placement location on the scalp that uses the 10-20 placement protocol. M. Azarnoosh et al. [31] claimed that in concentrated activities, the frontal and central areas of the brain play an important role. This area of the brain might be due to their brain abilities. Based on the extracted feature from the identified channels, comparing the start of the long-term attentive work and the emergence of mental tiredness revealed substantial disparities.

Other studies were also done to analysing mental fatigue by using EEG such as EEG coherence analysis has been employed in recent studies to study physiological progress in various settings. EEG coherence with repetitive driving has been studied in a few research. The inter-hemispheric coherent value throughout the alpha band indicated a significant difference between the early and final driving phases, with coherence level in other frequency bands increased slightly across operating periods [32]. Deep learning methods also increasingly been used to the decoding and classification of EEG signals, that are often linked to poor signal to noise ratios (SNRs) and complexity of the data, as a result of the increasing availability of massive EEG datasets [4]. Event-related potential (ERP) elements accurately represent the difference interpretation of attentive and unattended information, according to studies on the subject. Direct evidence on the amount of processing accomplished by these stimuli may be acquired by collecting ERPs to attentive and unattended stimuli [21].

In 2015 L. Trejo et al. [33] pointed to some of the ways to examine EEG alterations that were similar to all individuals, we investigated the prediction that perhaps the power spectral density (PSD) of theta, alpha, as well as other EEG groups would co-vary with the degree of mental tiredness that patients experienced on a regular basis. While numerous research has looked at EEG connections underlying generic weariness, weariness, and sleepy, our work focused on producing mental exhaustion by doing a cognitive activity for up to an hour while limiting other effects. A study of EEG categorization of mental weariness utilising support vector machines with people doing an auditory vigilance task, for example, found prediction accuracy ranging from 87.2 % to 91.2 %. The patients had suffered 25 hours of insufficient sleep before undertaking the vigilance test, therefore the results might have confounded tiredness with mental exhaustion. Previous research has found that the system design in classification algorithms is quite varied, with just a few techniques, such as Bayesian neural networks (BNN), k-nearest neighbour (kNN), and support vector machines, being used in more than one publication (SVM) [34].

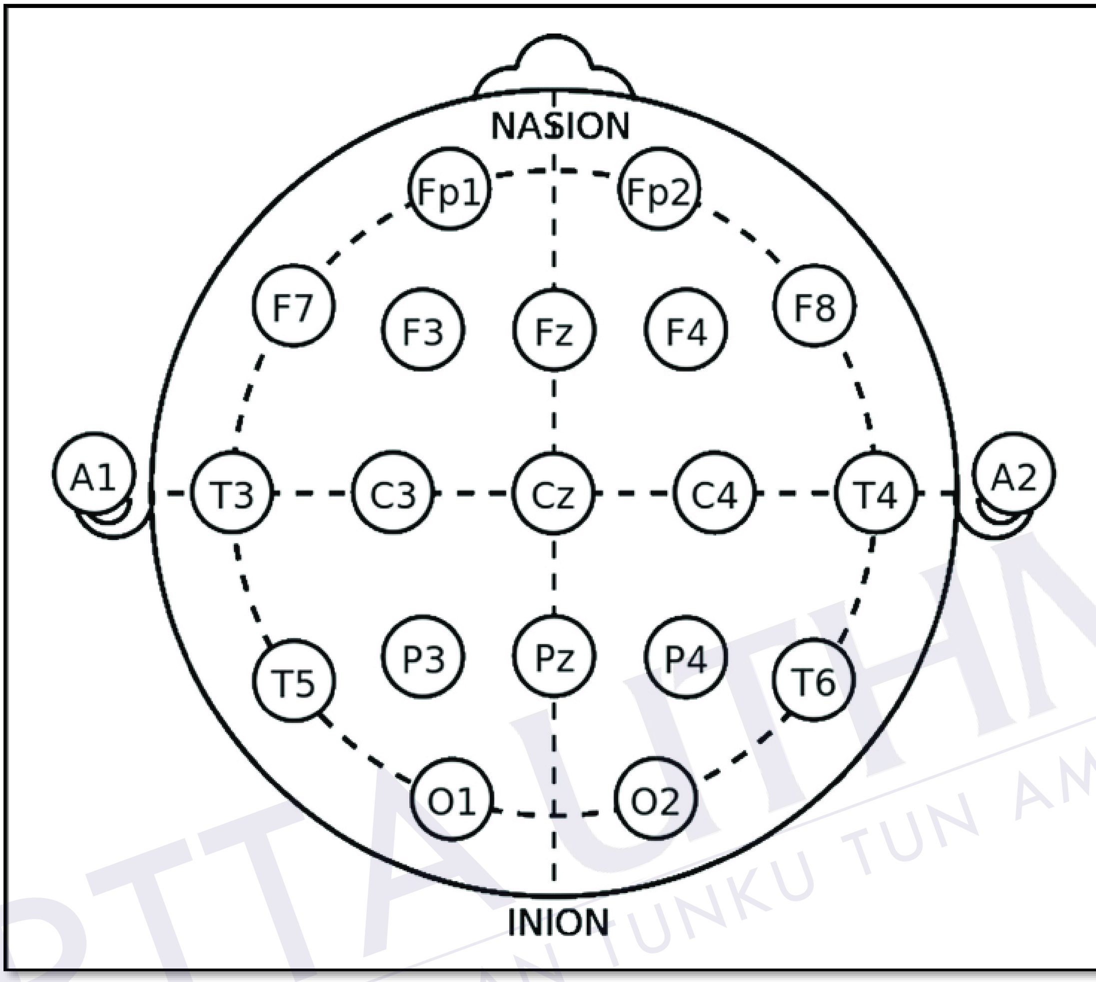

Figure 2.1: Electrode placement on the scalp [30].

2.4 Mental Fatigue Scale (MFS)

Fatigability is important in therapeutic practise, but so is tiredness perception. Several synonyms are often used to convey exhaustion, and depending on how they are phrased, they can imply various things to different individuals. For instance, 'exhaustion' was much less common than 'general weariness,' while 'feeling weary all the time' is more prevalent than 'feeling weak' [35]. Fatigue can be depicted as a single phenomenon or as a discrete variable, although it is probably more suitable to think of it as a continuous dimension that is felt as a personal emotional feeling.

The Mental Tiredness Measure (MFS) is a self-rating scale used to evaluate mental fatigue and associated symptoms in adults following neurological illness or injury. The MFS encompasses a greater variety of symptoms when compared to other self-reported fatigue measures, all of which are strongly related to mental tiredness and its influence on daily living [36]. The MFS was focused on everyday tasks and related to the estimate of different options. Other researchers employed this MFS, which is comprised of questions based on symptoms recorded in long-term case series suffering TBI, tumours, infection, vascular illnesses, and other brain disorders [37], [38].

The mental fatigue scale (MFS) is a multivariate questionnaire with 14 questions. There is currently no agreement on definitions, variables leading to mental weariness, or underlying processes. The MFS has been validated in individuals suffering from stroke and traumatic brain damage. This sample shows excellent internal consistency, with a Cronbach's alpha of 0.964 for all 14 items, consistent with previous findings [39]. These findings make accurate assessments of mental tiredness and the development of treatment options challenging. As a result, credible estimates of mental exhaustion must be developed, and better estimations of patients' ability for work and rehabilitation, because the activities offered, must be on a sustainable level.

B. Johansson et al. [40] stated that fatigue is typically measured as a subjective condition using self-report questionnaires, making an objective evaluation as a technique of evaluating it challenging to connect. It considers emotional, cognitive, and sensory symptoms and sleep duration and symptom severity change during the day [41]. The authors also show MFS for every difference's type of disease in Figure 2.2. The questions are about general exhaustion, amount of initiative, MF, mental recoveries, focus issues, problems with memory, quickness of thought, reactivity to stress, greater inclination to become agitated, anger, sensitivity to light and noise, and finally, diminished or increased sleep-in individuals.

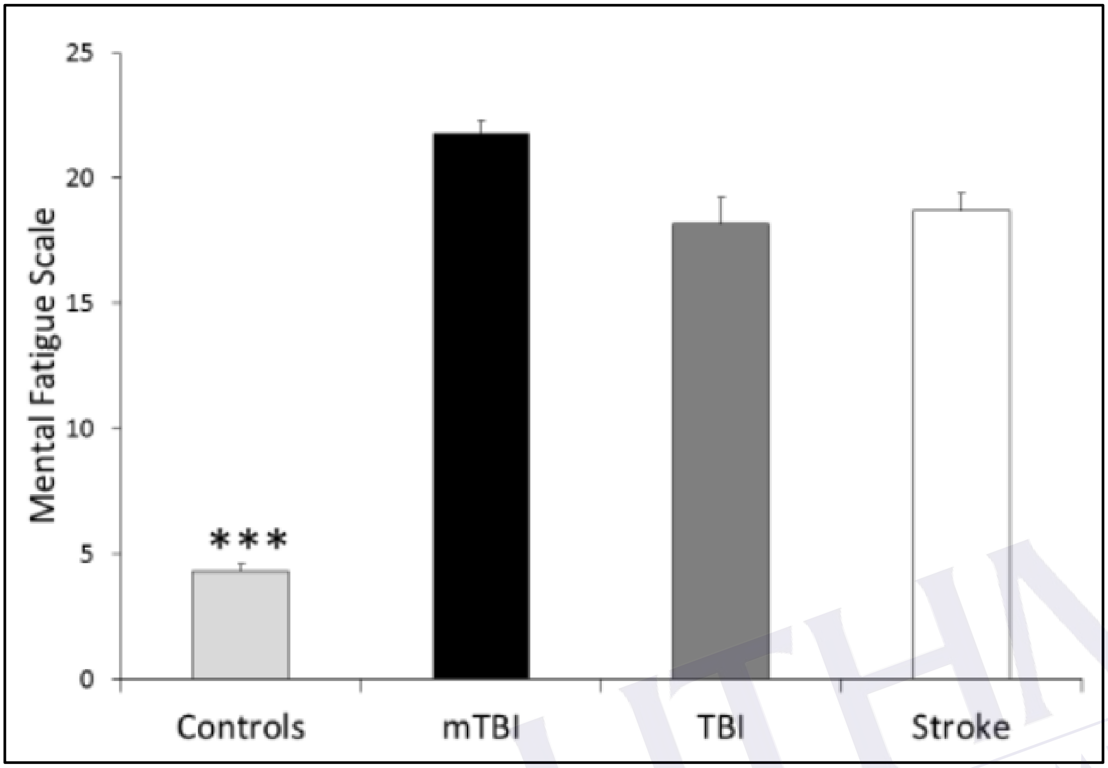

Figure 2.2: Result of mental fatigue scale [41].

2.5 Reaction Time (RT)

Butlewski and Hankiewicz [20] mentioned that evaluating fatigue enables the early detection of bad situations caused by various factors. The understanding about readings of the performance of specific tasks, such as the endurance of activities in states of best potential and lack there, RT for a response, traditional ergonomic factors such as sustaining back straight without having problems, the value of precise angle of range of view for the designed task, is the initial step in developing a fatigue framework [20]. Psychomotor performance is defined as the connection of mental activities and physical reactions, and it is often tested in terms of RT and motor abilities.

The most often utilised method for inducing mental weariness in individuals is the response time task. Slower RT is connected with mental weariness, which impacts energy, arousal levels, and mood. Research in mental exhaustion affects simple response time in non-athletes worse than athletes, indicating that mental fatigue has a lower influence on productivity in athletes than non-athletes during protracted simple reaction time activities [42]. Guo et al. [43] predicted that MF would worsen response inhibition, resulting in increases in RT. The authors also find that after manipulating MF, RT and miss rate rose considerably, indicating that MF had an unfavourable effect on response inhibition, as shown in Figure 2.3.

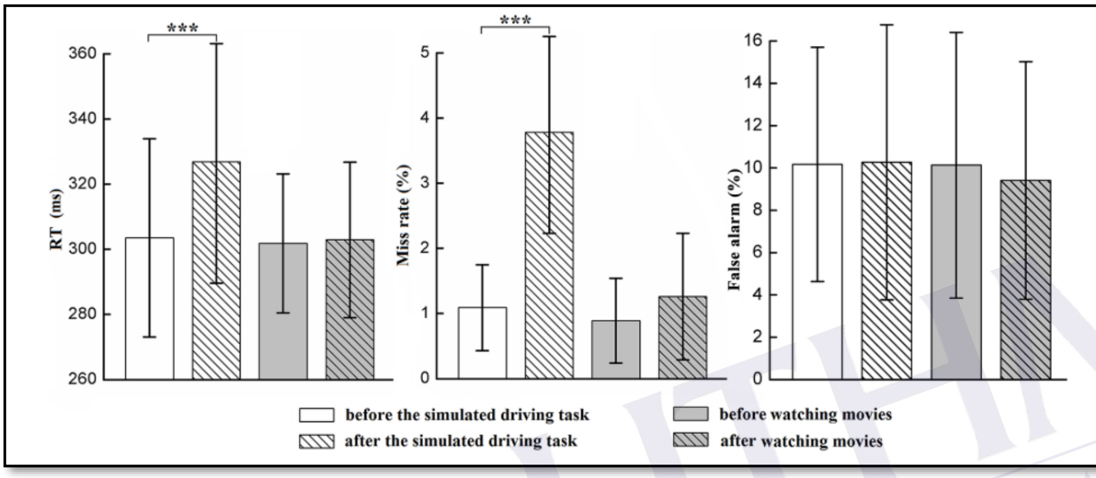

Figure 2.3: Result of reaction time, miss rate and false alarm [43].

It is customary to predict performance deterioration when one is mentally exhausted, such as reduced response time [44]. As a result, performance evaluations are commonly used to determine MF. For example, a study by Li et al. [45] on the relationship between reaction ability and mental state of driving fatigue; mentioned that the driver got tired as the amount of time spent driving grew, expressed as increasing concentration levels and increased RT.

R. Pavelka et al. [46] found increased reaction times in Greco-Roman fighters throughout the second and third rounds of a three-round bout, but non-significant outcomes in Judo or Jiu-Jitsu, and non-significant findings in MT and total responding performance in Taekwondo. Future research should utilise several trials of exhausting tasks–or settings that are generally comparable to the real tournament better define trends in reaction times measuring changes owing to cumulative tiredness, they stated.

The reaction timer test is concerned with the speed with which data is analysed as well as the appropriate choices. When people are sleep deprived, they get drowsy and lose their attentiveness [47]. It may also result in cognitive function issues such as a loss of capacity to focus, a loss of ability to learn, an increase in response time and the inability to recall new knowledge, as well as defective motor abilities. In 2015, X, Fan et al. [48] published a paper in which they described to quantify weariness caused by a lengthy visual search task, an EEG power spectrum throughout the wavelet domain was used in conjunction with subjective assessment and response time evaluation.

2.6 Previous Studies

Table 2.1 provides the article summary from the latest year of research from 2017 until 2020. This summary discusses the previous researchers' objectives, methods, disadvantages, and future recommendations. There was only one paper research about students' mental awareness at the higher education level from the previous study. This gap made that this project was done to study the MF level among students in higher education.

This study used other parameters such as the Mental Fatigue Scale (MFS) to see the students score of MF in the online study era. Also, their RT to see if their focus can be changed for a more extended period of attention in their online class. Because of the lack of equipment in UTHM, online EEG signal related to MF were collected and analysed to see if the power spectrum of the EEG signal were different during relaxation time and when the subjects had induced MF. Because of the COVID-19 pandemic, many people struggle with their mental health and must keep track of their studies in this pandemic.

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