Journal of Neurology & Neurophysiology 2020, Vol.11, Issue 4, 001-006 Review Article

Systematic Review on the Use of Electroencephalogram in Detecting Work Fatigue

Gregory Xavier[1]*, Anselm Su Ting[2], Norsiah Fauzan[3]

[1]*Department of Public Health, University Malaysia Sarawak, Malaysia*

[2]*Occupational Health University, Malaysia Sarawak, Malaysia*

[3]*Cognitive Psychology/cognition in learning & intervention, University Malaysia Sarawak, Malaysia*

Corresponding Author*

Dr. Gregory Xavier
Faculty of Medical and Health Sciences,
Department of Community and Public Health Medicine,
University Malaysia Sarawak (UNIMAS)
94300 Kota Samarahan, Sarawak
Malaysia
Tel: +60169595583
Email: gregshc@yahoo.co.uk

Received 25 May 2020; **Accepted** 03 July 2020; **Published** 10 July 2020

Abstract

Fatigue is one of the causes of occupational accidents and injuries especially among motor-vehicle users and those working in high risk jobs. For over many years there were attempts to quantify and objectify fatigue using an electroencephalogram (EEG). This systematic review is to the study protocols used and explore the results obtained to potentiate EEG's ability as a fatigue prevention-screening tool. We used the PRISMA statement method to identify, collate and classify the articles for review from PubMed database. Three investigators, independently, using predefined criteria, assessed selection of the articles. They assessed its quality following a standard set of information too. Of the 962 articles, scanned only 24 articles met the criteria and showed acceptable quality. Almost no papers attended to the sampling method. However, their variable measurements and analysis are appropriate according to respective objectives. EEG recording is an objective assessment and readily duplicated but we could not perform meta-analysis due to inadequacy in standardized methods of data collection and analysis. Nevertheless, the EEG changes showed consistency in findings whereby theta and alpha wave bands are the best indicators in fatigue detection. Hence: making EEG a potential screening tool for fatigue.

Keywords: Electroencephalogram • Fatigue • Workers

Introduction

Fatigue is a condition affecting both the mental and physical state of a person carrying out prolonged work, which can be either active or mundane. Fatigue experienced by normal people is a condition that can disappear with adequate rest. In the working population, fatigue is a common complaint with approximately 20% reporting rate [1]. The Maastricht Cohort Study carried out in 1998 Netherlands claimed prolonged fatigue was common among workers at around 21.9% transecting over 12 sectors and work trades [2].

There is a multitude of effects of fatigue in relation to work. Those effects and subsequent consequences of fatigue such as risky behaviours, risky work practices, and various addictions but more importantly accidents and injuries, are not only detrimental to the workers and their life but to their employers too. Employers would have to then deal with absenteeism, prolonged medical leave, and disciplinary problems. Such issues are also economically counterproductive for the employer's business [3]. A fatigue commercial passenger vehicle driver or pilot can make potentially fatal errors, which could cost lives. Patients treated by fatigue doctors could have been mismanaged or even potentially mistreated causing death [4]. These hazards are fatigue related, as fatigue constitutes reduced cognitive ability (decision-making and response time). During fatigue, there is decrease in physiological arousal, slowed sensorimotor functions, and impaired information processing, and impaired workers' ability to respond effectively in emergencies or unusual situations [5].

Many studies have been conducted using the electroencephalogram (EEG), which is an instrument used to detect bioelectrical brain waves (extracellular current flow). Electroencephalogram signals are indicated to be very predictive and reliable tool to detect alertness levels [6] and could be used in preventing fatigue related errors or as a trigger in counter-measure instruments [7]. These changes can be explained by analyzing the four types of brain waves detected by EEG. They are delta (0 to 4 Hz), theta (4 to 8 Hz), alpha (8 to 13 Hz), and beta (13 to 20 Hz) [8]. Delta waves are more frequent during sleep. An early stage of drowsiness indicated by an increase in theta waves. Alpha waves reflect a relaxed wakefulness state and decrease with concentration, stimulation or visual fixation, a state where the worker is fatigued enough to fall asleep [8,9].

The objective of this systematic review is to explore the use of various experimental designs and research methods in the collection of EEG data for detecting and evaluating work fatigue. From this exploration, further inspection of the results in the reviewed articles, are explored. The inspection of the result collates the common findings found in work fatigue evaluation. The results of this review could then provide a deduction of usefulness of using EEG as a tool for detecting and evaluating work fatigue.

Methods

Search Strategy

We searched the PubMed online database using the terms "electroencephalogram" and "fatigue", without setting the limit on publication dates of the articles due to its limited numbers. PubMed is a source of clinical and health linked research study articles only. Many studies of EEG and fatigue are found in other search engines too but are not clinically/health linked or attuned. This study wishes to select articles of studies within the clinical field under the framework of occupational health. All articles obtained from the search were screened and filtered using the PRISMA reporting method as shown in Figure 1 [10, 11].

The search result was screened for duplicates and removed. The cleaned titles were screened by three independent reviewers according to relevancy and shortlisted. The second level of screening was by reviewing the articles abstract for relevance. Any discrepancy was solved by majority consensus between the three reviewers. Full texts were retrieved from the final list of articles. Applying a set of inclusion and exclusion criteria, the three reviewers further screened and selected the eligible articles for full review.

Inclusion and exclusion criteria

The articles selected for systematic review included those of human studies only and must be in English. Title of the studies must be of clinical or health concern under the frameworks and concepts of occupational health. We also chose to include studies that use the following algorithms of EEG spectral analysis: absolute power and relative power of all brain waves, and the formulas: $(\alpha + \theta)/\beta$ and α/β [12]. The studies should have objectives to study fatigue among workers at different working conditions with contributing attempts for developing countermeasure protocols, prevention of accidents and relevant to occupational health [13,14]. Studies of fatigue carried out on non-specified occupation were also considered.

We excluded articles related to diseases caused by fatigue and chronic fatigue syndrome. Studies about fatigue but did not use EEG were excluded. The objectives that do not share this review's objective to identify the suitability of EEG in the detection of fatigue were excluded. We also excluded in addition, articles that did not come with an abstract or full text. We also removed articles using other than the specified algorithms and those attempting to create newer algorithms. Studies that induced fatigue using non-occupational or work-related methods such as alcohol were also excluded. Lastly, studies that are engineering based and not clinically related were also excluded.

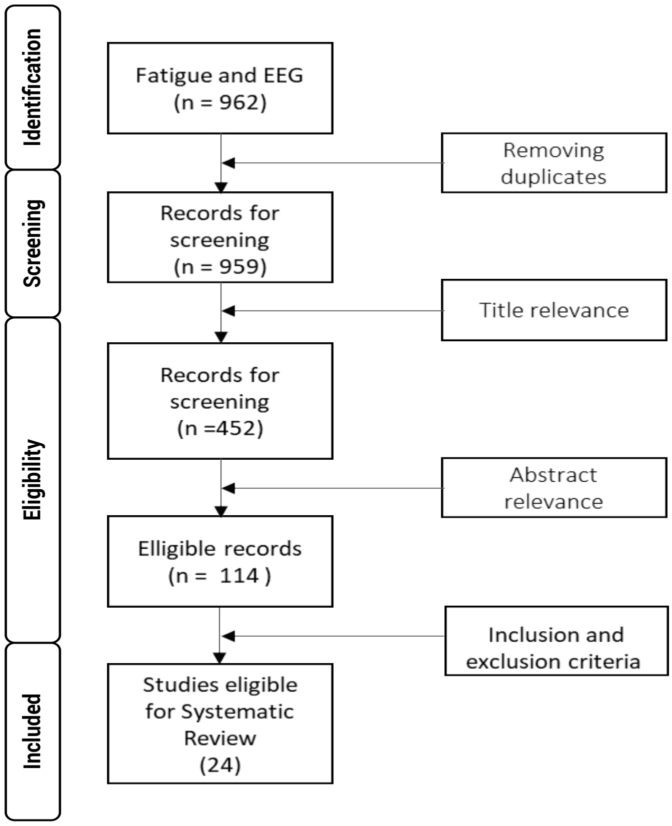

Figure 1. The flow diagram of systematic review process.

Quality Assessment

We assessed the quality of the included articles using the quality assessment tools, adopted and adapted from, Appraisal Tool for Cross-sectional Studies Axis and Guyatt et al into a modified scoring system [11, 15]. The criteria for assessment were divided into five major headings: Introduction, Method, Results, Discussion and Others. The Introduction heading ensures if the article has a clearly defined objective (one question). Under the Method heading, the sampling method subheading carries six questions on how the sampling was done and on whom. The Research design subheading questions the how and what measurements are used on the variables. In addition, it also reviews the analytical plan and the study's reproducibility. The Results heading has two questions on its clarity. The Discussion heading reviews the articles justification of the results and limitations. The two last questions under Others headings inspects any conflict of interest and ethical issues.

The original Axis Tool carries few questions that could not assess EEG studies, were removed. These questions were only relevant to population studies. Data collection methods and the study designs of EEG studies use instruments and are experimental. Hence, the results representation over a population is unlike what is expected from conventional population studies. Question 4 of the current quality assessment tool was added from one of the items in the quality assessment tool proposed by Guyatt et al. This question is adopted in the current quality assessment tool because of the small number of samples in most of the included articles.

Electroencephalogram recordings are objective assessments of subjects' brain waves. Hence, all living subjects produce results. However, due to technicalities the recording could become corrupted. Example: Instrument failure, software corruption etc. Resulted corrupted recordings have the possibility of being removed. To rectify this issue the subjects were either replaced or the recordings repeated. Each question in the modified Axis Tool was assessed as yes, no or undetermined answers. They are scored 1 for yes, 0 for no and undetermined. Articles scored 10 and above are considered as acceptable, 5 to 9 as satisfactory and 0 to 4 as poor.

Results

PRISMA reporting method

Figure 1 describes the search in PubMed using terms "electroencephalogram" and "fatigue" returned 962 articles. After the removal of duplicates, 959 articles went through the process of screening and exclusion ending up with 24 articles for systematic review. Eight articles were from European countries, 4 from China, 4 from other Asian countries, 4 from Australia and 3 from the United States were included in this review. The publication years of the articles were from 1987 to 2018. Twenty-one of them were published after the year 2000 and three before.

Quality Assessment

Sixteen of the reviewed articles were of acceptable quality, eight were satisfactory and none was poor. All papers scored less in the sampling method section but faired very well in their study design. Only eight studies had basic data described in their result section, but short to only the description of age and gender. Most of the respondents were young adults and majority were males. No other demographic or anthropometric descriptions were present. However, the authors following their objectives did describe the results with relevance. As part of the discussion, only four studies revealed their limitations. None showed ethical issues and had conflict of interest except one undetermined for both [11]. Scoring of all included articles is shown in Table 1.

Sampling methods

Many of the subjects recruited were volunteers from a particular community. Four studies did not disclose their sampling frame but merely noted them as volunteers. The numbers of samples were generally small. The least were eight and the most were 105 with the average of 27 respondents. None of the studies showed sample size calculations nor justified their numbers. However, the authors did subject the respondents to a set of selection criteria and screening. The criteria and screening were mainly to exclude those respondents who had diseases or illness related to the mind and brain such as psychiatric cases and those suffering from seizures. Only healthy individuals were recruited. The studies that were carried out on one group of subjects – without a comparison group – were subjected to different tasks or protocols instead. The studies that included different groups of respondents did not describe the selection or randomisation process. Most studies recruited student volunteers as respondents, and they were subjected to fatigue by either driving or conducting a series of cognitive test via various protocols. The other studies focused on professionals such as aviators and drivers.

Study designs and research methods

Table 2 describes the study methods and tools used in the included studies. All included studies were cross-sectional studies. Questionnaires used were either to complement the EEG findings, part of the tasks or part of

Table 1 : Quality assessment of review papers.

	I	Methods										Result		Discussion		Others		Total	Verdict
		Sampling							Design										
Author/Question																			
Jagannath, [30] (India)	1	0	0	0	1	0	1	1	1	1	1	0	1	0	0	1	1	10	A
Lal, [6] (Aus)	1	1	0	0	0	0	0	1	1	1	1	0	1	1	0	1	1	10	A
Lal & Craig, [27] (Aus)	1	1	0	0	0	0	0	1	1	1	1	0	1	1	0	1	1	10	A
Perrier et al., [31] (France)	1	0	0	0	0	0	0	1	1	1	1	0	1	0	0	1	1	8	S
Eoh et al. [23], (Korea)	1	1	0	0	0	0	0	1	1	1	1	1	1	0	0	1	0	9	S
Laskova, [18] (Russia)	1	1	1	1	1	1	0	1	1	0	0	1	1	0	0	0	0	10	A
Yamamoto, [16] (Japan)	1	0	0	0	0	1	0	1	1	1	1	0	1	1	0	1	1	10	A
Lees et al., [13] (Australia)	1	1	1	1	1	1	0	1	1	1	1	0	1	1	1	1	1	15	A
shyh-Yueh Cheng, [24] (Taiwan)	1	1	0	0	0	0	0	1	1	1	1	0	1	0	0	1	1	9	S
Macchi et al., [14] (USA)	1	1	0	1	0	1	0	1	1	1	1	1	1	1	0	0	1	12	A
Wascher et al., [32] (Germany)	1	1	0	0	0	0	0	1	1	1	1	0	1	1	0	1	0	9	S
Shou et al, [17] (USA)	1	1	0	0	0	0	0	1	1	1	1	0	1	1	0	1	1	10	A
Sauvet et al., [32] (France)	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0	1	1	14	A
Lorist et al., [34] (Dutch)	1	1	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	8	S
Zhao et al., [28] (China)	1	1	0	0	1	0	0	1	1	1	1	1	1	0	0	1	1	11	A
Fan et al., [25] (China)	1	0	0	0	0	0	0	0	1	1	1	0	1	0	1	1	1	8	S
Xie et al., [26] (China)	1	0	0	0	0	0	0	0	1	1	1	0	1	0	0	1	1	7	S
Papadelis et al., [29] (Greece)	1	0	0	0	1	1	0	1	1	1	1	0	1	0	0	1	1	10	A
Ma et al., [22] (China)	1	1	0	0	1	1	0	1	1	1	1	1	1	1	0	1	1	13	A
Jap et al., [21] (Australia)	1	0	1	1	1	1	0	1	1	1	1	0	1	0	0	1	1	12	A
Torsvall et al., [20] (Sweden)	1	1	0	0	1	1	1	1	1	1	1	0	1	1	0	1	1	13	A
Craig, et al., [35] (Australia)	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	16	A
Akerstedt et al., [8] (Sweden)	1	1	0	0	0	0	0	1	1	1	1	0	1	1	0	0	1	9	S

I: Introduction, A: Acceptable, S: Satisfactory, P: Poor. 1 = yes, 0 = absent/undetermined.

Table 2: Summary of studies on their experimental methodology.

Author	Subjects	Groups	Experimental design	Other test	Questionnaire	Comment
Jagannath,[30] (India)	20 male public volunteers	one	Simple driving simulation	EMG, seat interface pressure, blood pressure, heart rate and oxygen saturation level	nil	-
Lal, [6] (Aus)	36 (26m, 9f) student volunteers	one	Driving simulation, subjected to road stimuli and speeds.	EOG, Blood pressure, heart rate, facial fatigue feature recognition	Spielberger State–Trait Anxiety Inventory, The Profile of Mood States & Locus of control of behavior	Subjects were sleep deprived
Lal & Craig, [27] (Aus)	35 student and 20 professional drivers	two	Driving simulation, subjected to road stimuli and speeds.	EOG, facial fatigue feature recognition	nil	Driving till fatigue
Perrier et al., [31] (France)	24 (12m, 12f) student volunteers	One	Simple driving simulation	nil	Groningen Sleep Quality	2 sessions; before and after sleep
Laskova, [18] (Russia)	nuclear power plant workers. 45 shift, 60 rested (males)	two	Just EEG recording	Blood pressure, visual analog scales, Scheme for identifying signs of autonomic impairments	nil	Relationship between neurological changes, wellbeing and shift work
Yamamoto, [16] (Japan)	21 office workers	three	Series of task using visual display terminal (VDT)	nil	nil	relationship between EEG activity and VDT performance
Lim & Chia, [25] (Singapore)	31 (17m, 15f) student volunteers	one	auditory oddball task	nil	nil	Before and after 'break' sessions.
Lees et al., [13] (Australia)	63 (54m, 9f) train drivers	One	train driving simulator program	Blood pressure	Pittsburgh Sleep Quality Index, Epworth Sleepiness Scale, Karolinska Sleepiness Scale	Driving till fatigue
shyh-Yueh Cheng, [24] (Taiwan)	23 male volunteers students	one	visual display terminal	nil	Erikson Flanker Test, NASA-Task Load Index and Scale	Prolonged testing to subject mental fatigue
Macchi et al., [14] (USA)	8 drivers (7m, 1f)	one	Simple Driving simulation	nil	visual analog scales, Walter Reed performance assessment battery, Sleep Quality Questionnaire	Before and after sleep

Eoh et al. [23], (Korea)	8 male drivers	one	Simple driving simulation	nil	nil	Different road conditions
Wascher et al., [32] (Germany)	14 (7m, 7 f) volunteers	One	Series of task	nil	nil	Prolonged task, inducing fatigue
Shou et al, [17] (USA)	11 male student volunteers	one	Air traffic control simulation with task.	nil	nil	-
Sauvet et al., [32] (France)	14 male pilots	one	Real time flight piloting	nil	Karolinska Sleepiness Scale	On the job recording, long haul, overnight piloting
Lorist et al., [34] (Dutch)	26 volunteers (12m, 14 f)	one	Series of task	nil	AD–ACL scoring	Prolonged task, inducing fatigue
Zhao et al., [28] (China)	13 male student volunteers	one	Simple driving simulation	Oddball task	nil	-
Fan et al., [25] (China)	10 male student volunteers	one	Visual search task	nil	Subjective fatigue evaluation scoring	-
Xie et al., [26] (China)	9 student volunteers (6m, 3f)	one	Steady-State Evoked Potential Based Brain Computer Interface Tasks	nil	nil	Periodic flickering and motion-reversal stimulation paradigms task
Papadelis et al., [29] (Greece)	21 student volunteers	one	Real time driving sessions	nil	Karolinska Sleepiness Scale, Epworth Sleepiness test	ambulatory EEG monitoring system. Subjects were sleep deprived
Ma et al., [22] (China)	21 male taxi drivers	one	Simple driving simulation	nil	Swedish Occupational Fatigue Inventory, Karolinska Sleepiness Scale	-
Jap et al., [21] (Australia)	52 drivers (36m, 16 f)	one	Two driving simulation sessions with and without stimuli.	nil	nil	-
Torsvall et al., [20] (Sweden)	11 male train drivers	one	Real time overnight train driving	EEG and EOG	nil	-
Craig, et al., [35] (Australia)	48 (23f, 25m) volunteers	one	Simple driving simulation	EOG and facial fatigue signs recordings	Chalder Fatigue Scale	-
Akerstedt et al., [8] (Sweden)	8 male volunteers	one	Time induced fatigue without sleep. Activities present	EOG	visual analog scale, Karolinska Sleepiness Scale	EEG recordings with eyes opens and closed
Huang et al., [7] (Taiwan)	12 (7m, 5f) volunteers	one	virtual reality based highway driving	nil	nil	Two different road conditions – prolonged driving induced fatigue

m: male, f: female.

the selection process prior to the study proper. The questionnaires assessed the subjects' moods and sleep patterns as well as directly assessing fatigue.

Two studies were conducted in real working environment. The rest of the studies were conducted in a controlled environment using simulators. Real working environment studies had EEG recording done while the subject was driving or piloting. Safety was ensured with the presence of co-drivers, tested safe driving routes and comfort wear of the equipment. These studies used professionals and not volunteers with ethical approvals. Nine other studies used specific set of tasks to induce fatigue. They were either sleeping deprived, conducted long series of visual display tasks or exercising. In two studies, the subjects had to conduct some test or task while undergoing the simulation. The inducement of fatigue in all the studies was done in a controlled environment.

Study analysis and results

This review included studies, which used the absolute and relative power of the brain wave's formulas and the two algorithms. In addition to these formulas, some studies included other methods of brain wave analysis and interpretation such as P300 waveform, sample entropy area and wave spindle analysis.

Table 3 summarises the prominent and discussed results of the articles reviewed. Most studies investigated the bioelectrical brain waves of the frontal, parietal and occipital regions. However, the location points of EEG recording that corresponds to a brain region differed from study to study and many did not specify the recording points included in the studied region. Much differences exist with the division of regions itself in their presentation of results. As a result, much of the interpretation concerning brain regions could not be conclusive. However, the presentations of results according to brain waves were clear and comprehensible. The graphic presentation of the brain wave results differed in all studies. Some used line graphs, tables, bar charts and topographic display diagrams.

Theta wave was consistently and persistently increased in subjects who were considered to be fatigued in all included studies. In most of the included studies, theta wave changes occurred mainly in the frontal region. The alpha wave was also increased during fatigue in most of the studies, but the findings were not consistent in relation to the brain regions. Beta waves changes were not consistent in all the studies. Few studies described the changes of delta waves and only one described about gamma wave changes.

Discussion

From this review, we found the experts that conducted these studies were from the engineering, physiologist and cognitive science backgrounds with very few from the medical fraternity. In general, their objective is to investigate how to detect fatigue at real time. The aim of most of these studies is to develop counter-measure devices to detect fatigue in real time and prevent potential accidents. Therefore, many of these studies were carried out mostly on drivers. Unfortunately, to date none materialised due to technical conveniences for practical use [7]. The studies used mainly volunteers from students with few using professionals such as clerks, controllers, drivers [13,14,16-23]. Otherwise, none of the studies reviewed used subjects from other professions such as doctors, oilrig workers and other high-risk jobs.

The recording of EEG is an objective assessment of brain waves. Unlike cross-sectional studies using questionnaires, the inspection for internal consistency had no purpose, hence, the low scoring in the quality assessment. It seemed that the authors also did not mind ignoring further data collection on the demographics of the respondents besides age and gender. This could

Table 3: Summary of studies results.

Author	Results indicating fatigue/region		
	alpha	beta	theta
Jagannath, [30] (India)	↑ F, T , O	↓ F, T, O	↑ T, O
Lal, [6] (Aus)	↑ F, O	↑ P, O	↑ F, P
Lal & Craig, [27] (Aus)	No change	↑ No region specified	↑
Perrier et al., [31] (France)	↑	↑ on task only Regions not specified	↑
Laskova, [18] (Russia)	↑ P,	- -	↑ postT, P
Yamamoto, [16] (Japan)	- -	- -	↑ Frontal midline
Lees et al., [13] (Australia)	↑	- Regions not specified	↑
shyh-Yueh Cheng, [24] (Taiwan)	↑	↑ Regions not specified	↑
Macchi et al., [14] (USA)	↑	- Regions not specified	↑
Eoh et al. [23], (Korea)	↑	↓ Regions not specified	=
Wascher et al., [32] (Germany)	↑ F,O	- -	↑ F
Shou et al, [17] (USA)	- -	- -	↑ F
Sauvet et al., [32] (France)		Fatigue algorithms used Regions not specified	
Lorist et al., [34] (Dutch)	-	- Regions not specified	↑
Zhao et al., [28] (China)	↑ C, P, O, T	↓ F, C, O, T	↑ F, C, O
Fan et al., [25] (China)	↑ F, C, postT, P, O	↓ preF, infF, postT, O	↑ F
Xie et al., [26] (China)	↑	- Regions not specified	=
Papadelis et al., [29] (Greece)	↑ C,P	↓ F,C	↑ F,C,P,O
Ma et al., [22] (China)	-	↑ (higher speed) Regions not specified	-
Jap et al., [21] (Australia)	↑ O	↓ F,T	↑ G,F,C,P,O
Torsvall et al., [20] (Sweden)	↑	- Regions not specified	↑
Craig, et al., [35] (Australia)	↑ F, C, P, O	↑ F, C, P, O	↑ F
Akerstedt et al., [8] (Sweden)	↑	- Regions not specified	↑
Huang et al., [7] (Taiwan)	↑	- Regions not specified	↑

↑:increase, ↓:decrease, =: equivalent, F:frontal, P:parietal,T:temporal,O:occipital,G:global,post:posterior,inf:inferior

be due to the assumption that the physiological mechanism of brain wave production is independent of any external factors. Furthermore, among the variables measured (brain waves) it did not include any confounders. The cofounders were instead, controlled prior to the study proper. For instance, respondents were refrained from drinking coffee and consuming alcohol.

The interpretation and presentation of results in most studies were technical. They skipped the description of basic data despite having clear differences especially about gender. There were more males than females in almost all the studies with some biased just to one gender. This difference was also not regressed statistically on the results obtained and could be due to the common small sample sizes. There are studies that did not follow the IMRAD method of scientific writing and the presentation too.

There is lack of analysis of brain wave changes in relation to the corresponding functional brain regions. The changes seen in the waves does not uniformly relate to a certain brain region in all the studies. The reason for this occurrence was also not explored in these articles. The possible explanation could be connected to the type of task and simulation conducted and activated, corresponding functional brain region. Furthermore, the demarcation of brain regions was not the same between studies. The EEG electrode placement sites and subsequent analysis were also not the same across the reviewed articles as there was also no standard to reference from.

The study, which used visual display task, shows increase of theta waves at the occipital region [16,17,24-26]. This is absent in studies conducted on driving simulation and another fatiguing task. Theta wave is however, increased persistently and consistently in all studies regarding fatigue as compared to alpha and beta waves. Beta waves are increased in the frontal region in studies that conducted mind stimulation task [19,27]. In contrast, it decreases in monotonous driving simulations [21, 23,28,29]. Alpha waves increase when fatigue, but it depends at which brain region the fatiguing task is related to.

The studies did not have the objectives to detect a fatigue worker before they start to work. There are occupations where the workers continue to work the next day but due to inadequate rest and stress go in fatigue. However, the results obtained are promising that such an attempt is possible to be carried out. The changes in waves and its occurrences in particular regions should be related to the type of job or task given. Hence, a more accurate and realistic interpretation is possible. Furthermore, a universal device for fatigue mitigation can be developed to be used for all kinds of occupations [30-35].

The review has identified gaps for further exploration and study. Conducting an EEG study to detect fatigue should have a proper sampling method, with enough respondents to reduce the play of chance. It should furthermore be representative of a targeted population. For practical purpose and use, future studies could be conducted at real time and not in simulated environment. Factors that can influence fatigue or confounders can be identified earlier via use of questionnaires and statistically regressed. This includes further demographic profiling. The corresponding brain regions should also be considered besides changes in brain waves. Physiologically, there is a correlation between brain wave changes and region, and this is influenced by the type of fatiguing task or environment endured by the respondent in the study.

Conclusion

Most of the included articles in this review were of good quality in respect to the authors' area of expertise and the results answered the study objectives. The review shows theta and alpha waves are possibly the most reliable indicator for fatigue and probably can be utilised to develop a counter-measure device or preventive tool for fatigue detection. However, the result of the reviewed articles should be interpreted with caution considering the possible presence of confounding factors, lack of subjects' variability, small sample sizes and lack of confirmation of fatigue status among the subjects.

References

1. Bultmann, U., et al. "Fatigue and psychological distress in the working population." *J Psychosom Res* 52 (2002): 445-452.
2. Kant, I. "An epidemiological approach to study fatigue in the working population: the Maastricht Cohort Study." *Occup Environ Med* 1:60 (2003):32-39.
3. Irene, L.D. "Time to wake up to the consequences of fatigue." *The International Maritime Human Element Bulletin*. 13 (2007): 1-2.
4. Gander, P.H., et al. "Work Patterns and Fatigue-Related Risk Among Junior Doctors. Occup Environ Med [Internet]. 2007 Mar 26 [cited 2018 Sep 27]; Available from: https://oem.bmj.com/content/early/2007/03/26/oem.2006.030916
5. Mascord, D.J., & Heath, R.A. " Behavioral and physiological indices of fatigue in a visual tracking task." *J Safety Res* 23(1992): 19-25.
6. Lal, S.K.L., et al. "Development of an algorithm for an EEG-based driver fatigue countermeasure." *J Safety Res* 34 (2003): 321-328.
7. Huang, K.C., et al. "An EEG-Based Fatigue Detection and Mitigation System." *Int J Neural Syst* 26 (2016): 1650018.
8. Akerstedt, T., & Gillberg, M. "Subjective and objective sleepiness in the active individual." *Int J Neurosci* 52 (1990): 29-37.
9. Stern, J.M., et al. "Atlas of EEG patterns [Internet]. Philadelphia." *Lippincott Williams & Wilkins* 2005 [cited 2019 Aug 16]. Available from: https://trove.nla.gov.au/version/13069668.
10. Moher, D., et al. "Preferred Reporting Items for Systematic Reviews and Meta-Analyses: The PRISMA Statement. [Internet]." *The PRISMA Group* 2009: Available from: DOI: 10.1371/journal.pmed1000097.
11. Guyatt, G.H., et al. "Users' guides to the medical literature. II. How to use an article about therapy or prevention. B. What were the results and will they help me in caring for my patients? Evidence-Based Medicine Working Group." *JAMA* 271 (1994): 59-63.
12. Ferreira, C., et al. "Electroencephalographic changes after one nigth of sleep deprivation." *Arq Neuropsiquiatr* 64 (2006): 388-393.
13. Lees, T., et al. "Electroencephalography as a predictor of self-report fatigue/sleepiness during monotonous driving in train drivers." *Physiol Meas* 39 (2018): 105012.
14. Macchi, M.M., et al. "Effects of an afternoon nap on nighttime alertness and performance in long-haul drivers." *Accid Anal Prev* 34 (2002): 825-34.
15. Downes, M.J., et al. "Development of a critical appraisal tool to assess the quality of cross-sectional studies (AXIS)." *BMJ Open* 6 (2016): e011458.
16. Yamamoto, S., & Matsuoka, S. "Topographic EEG study of visual display terminal (VDT) performance with special reference to frontal midline theta waves." *Brain Topogr* 2 (1990): 257-67.
17. Shou, G., & Ding, L. "Frontal theta EEG dynamics in a real-world air traffic control task." *Conf Proc Annu Int Conf IEEE Eng Med Biol Soc IEEE Eng Med Biol Soc Annu Conf* 2013: 5594-5597.
18. Laskova, I.V., & Tret'yakova, E.E. "Characteristics of neurological status and the electroencephalogram in nuclear power station control operators." *Neurosci Behav Physiol* 40 (2010): 457-60.
19. Lal, S.K.L., & Craig, A. "Driver fatigue: Electroencephalography and psychological assessment." *Psychophysiology* 39 (2002): 313-21.
20. Torsvall, L., & Akerstedt, T. "Sleepiness on the job: continuously measured EEG changes in train drivers." *Electroencephalogr Clin Neurophysiol* 66 (1987): 502-11.
21. Jap, B.T., et al. "Using EEG spectral components to assess algorithms for detecting fatigue." *Expert Syst Appl* 36 (2009): 2352-2359.
22. Ma, J., et al. "The Relationship Between Drivers' Cognitive Fatigue and Speed Variability During Monotonous Daytime Driving." *Front Psychol* 9 (2018): 459.
23. Eoh, H.J., et al. "Electroencephalographic study of drowsiness in simulated driving with sleep deprivation." *Int J Ind Ergon* 35 (2005): 307-20.
24. shyh-Yueh, Cheng. "Electroencephalographic study of mental fatigue in visual display terminal task." *J Med Biol* 27 (2007): 124-31.
25. Fan, X., et al. "Electroencephalogram assessment of mental fatigue in visual search." *Biomed Mater Eng* 26 Suppl 1 (2015): S1455-1463.
26. Xie, J., et al. "Effects of Mental Load and Fatigue on Steady-State Evoked Potential Based Brain Computer Interface Tasks: A Comparison of Periodic Flickering and Motion-Reversal Based Visual Attention." *PloS One* 11(2016): e0163426.
27. Lal, S.K.L., & Craig, A. "Reproducibility of the spectral components of the electroencephalogram during driver fatigue." *Int J Psychophysiol* 55 (2005): 137-43.
28. Zhao, C., et al. "Electroencephalogram and electrocardiograph assessment of mental fatigue in a driving simulator." *Accid Anal Prev* 45 (2012): 83-90.
29. Papadelis, C., et al. "Indicators of sleepiness in an ambulatory EEG study of night driving." *Conf Proc Annu Int Conf IEEE Eng Med Biol Soc IEEE Eng Med Biol Soc Annu Conf* 1 (2006): 6201-4.
30. Jagannath, M., & Balasubramanian, V. "Assessment of early onset of driver fatigue using multimodal fatigue measures in a static simulator." *Appl Ergon* 45 (2014): 1140-7.
31. Perrier, J., et al. "Driving performance and EEG fluctuations during on-the-road driving following sleep deprivation." *Biol Psychol* 121 (2016, Pt A): 1-11.
32. Wascher, E., et al. "Frontal theta activity reflects distinct aspects of mental fatigue." *Biol Psychol* 96 (2014): 57-65.
33. Sauvet, F., et al. "In-flight automatic detection of vigilance states using a single EEG channel." *IEEE Trans Biomed Eng* 61 (2014): 2840-7.
34. Lorist, M.M., et al. "The influence of mental fatigue and motivation on neural network dynamics; an EEG coherence study." *Brain Res* 13 (2009): 95-106.
35. Craig, A., et al. "Regional brain wave activity changes associated with fatigue." *Psychophysiology* 49 (2012): 574-82.

Cite this article: Gregory Xavier, Anselm Su Ting, Norsiah Fauzan. Systematic Review on the Use of Electroencephalogram in Detecting Work Fatigue. J Neurol Neurophysiol, 2020, 11(4), 001-006.