ANALYSIS OF MENTAL FATIGUE IN MOTOR IMAGERY AND EMOTIONAL STIMULATION BASED ON EEG

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Abstract: Fatigue is a set of events produced by labor or prolonged exercise and can affect the performance of any task, since it contributes to the reduction of perceptual, cognitive and motor skills. The main effects of fatigue are: slow cognition, amended surveillance ability, variability of performance, negligence, difficulty of learning and memorizing, decreasing of the degree of motivation, and paradoxical insomnia. There are many parameters for fatigue evaluation. This work analyses fourteen parameters in two studies involving motor imagery and emotional stimulation. The rhythmus "α" and "θ/α" can be used to determine the fatigue. Results showed that motor imagery tasks are more fatiguing than emotional stimulation.

Keywords: Fatigue, Stress, EEG, Emotion, Motor Imagery.

Introduction

Fatigue has been described as a subjective experience of tiredness that affects healthy and sick subjects [1]. Fatigue is a set of events produced by labor or prolonged exercise and can affect the performance of any task, since it contributes to the reduction of perceptual, cognitive and motor skills. Fatigue can negatively influence the alertness of humans, changing the way the subject receives information and stimuli from the environment. It can increase the time needed to respond to an emergency situation or make a correct decision.

The definition of fatigue is still an immature concept and there are few of information in the literature to define it clearly [2]. This definition varies according to the area in which it is studied. For instance, to Psychology fatigue is the state of wear related to reduced motivation [3]; to Physical Education, fatigue is a decline in the ability to generate muscle tension with repeated stimulation [4]; whereas the Engineering defines fatigue as a prevalent mode of failure of structural components caused by periods of stress [5]. Therefore, in general, fatigue can be defined as a subjective feeling of tiredness, weakness or loss of energy [1]. For this study, fatigue is defined according to [6], being regarded as the result of a limitation in adaptability to a stress.

The physiological process of fatigue in healthy subjects appears to be well defined, basically being recognized as an imbalance between accumulation of catabolic products (such as lactate and neurotoxins) and glycogen depletion as a result of overexertion. In health-related studies, fatigue has been described as one of the most frequent symptoms of stress [1].

Due to its high prevalence in different populations and the damage it inflicts on quality of life, fatigue has been object of study in many studies in the health field [2]. There are several factors that can cause fatigue mainly those related to lifestyle and activities in the day-to-day, besides being strongly related to the amount of hours of sleep. The main effects of fatigue are: slow cognition, amended surveillance ability, variability of performance, negligence in non-essential activities, and difficulty of learning new skills, difficulty memorizing, decreasing of the degree of motivation, and paradoxical insomnia [7].

To date, the main form of fatigue assessment is still based on self-report questionnaires. Currently, there are over 20 instruments for fatigue assessment, seven of which are validated in Brazil [1]. Many studies have tried various signals including pulse, facial movement or other physiological signals to develop a fatigue on-line estimating system with high time resolution and high accuracy [8]. A number of studies have showed that in tests that involve mental tasks as when using steady-state visual evoked potential (SSVEP), emotional stimulation, mental calculation and motor imagination among others, most users have uncomfortable and unpleasant feelings, including tiredness, drowsiness, loss of attention and difficulty in concentration, which are symptoms of fatigue [9]. These studies typically involve the collection of signals of electroencephalogram (EEG).

Recent studies [9][8][11][12] have showed that EEG signals can be used for identification and quantification of fatigue. In recent years several features for the EEG to analysis of mental fatigue, especially in studies related to BCIs (Brain Computer Interfaces) have been used. The EEG signal does not capture the activity of a single neuron, but rather reflects the interaction of millions of neurons in the brain, following a chaotic behavior [13]. This rhythmic activity produces a signal that can be divided into several frequency bands as: delta (δ), theta (θ), alpha (α), and beta (β).

There are many parameters to the evaluation of fatigue, for example [9] showed the existence of a relationship between the significant increases in α and (θ +α)/β, as well as the decrease in θ/α associated with the increasing fatigue level. Likewise, [12] used the relations of relative energy between alpha, beta and theta rhythmus as parameters to evaluate fatigue.

This work analyzed fourteen parameters in two studies involving motor imagery and emotional stimulation. The results could help understanding the complex process to quantify fatigue and also improving the performance of a BCI.

Materials and Methods

Data – Based on the aforementioned parameters, this work compares fatigue levels of different stimuli. For this we used EEG data from different studies; the first involving stimulation of emotions [14], and the second one involving motor imagination.

Protocol of emotions stimulation – This study used exposure images for emotional stimulation of the volunteers. A series of images belonging to the IAPS (International Affective Picture System) [15] is presented to participants. Images are displayed for 3.5 seconds, with 10 groups each containing five images. The total time for experiments was 9 minutes.

Protocol of motor imagination – In the study of motor imagination they were asked to imagine four different tasks (contraction of the left arm, right arm contraction, contraction of both arms simultaneously and relaxation). Each task contained 20 repetitions of 10 seconds each with an interval of 10 seconds between them. The total experiment time was 14 minutes.

Acquisition of EEG Signals – In both studies the EEG of the subjects is record using Emotiv Epoc (wireless 14-channel EEG equipment). The EEG electrodes were placed with accordance to the International 10/20 System of Electrode Placement [8]. The position of the 14 electrodes are AF3, AF4, F3, F4, F7, F8, FC5, FC6, P7, P8, T7, T8, O1, O2 and two references (P3-CMS, P4-DRL) are used. The device and electrodes are shown in Figure 1. The sampling frequency of the equipment was 128 Hz.

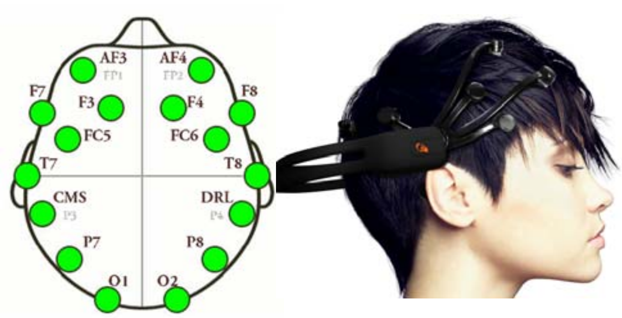

Figure 1: Placement of electrodes on the scalp (left). Emotiv Epoc Headset (right).

Analyses – For fatigue analysis, the F3, F4, O1, O2, P7, P8 channels and first 10 seconds (baseline) of recording and 10 seconds late for each volunteer were used. For this, first the signals were transformed into spectral power by applying a Fast Fourier Transform (FFT) with Hanning window of 10 seconds without overlapping. EEG signals acquired from the 14 channels and DC (direct current) components were use as filter. Five level of EEG signal were decomposed using discrete wavelet packet transform (DWPT). Then, the power of each band was calculate through Equation 1.

$$Power_{band} = \frac{\sum band^2}{\text{length(band)}} \quad (1)$$

This study investigated the three EEG rhythmus: theta, alpha and beta (due to the large quantities of artifacts, delta band is not used) and the engagement indices are calculated using the normalized difference of final and initial values from the three specific brain sites (frontal, occipital and parietal). Table 1 shows all parameters used for comparison between the studies.

Table1: Parameters of fatigue analyses.

Index	Parameter	References
I	α	[11][9][12][16]
II	β	[11][9][12][16]
III	θ	[11][9][12][16]
IV	$\beta / (\theta + \alpha)$	[16]
V	β / α	[16]
VI	$1 / \alpha$	[16]
VII	$(\theta + \alpha) / (\beta + \alpha)$	[11]
VIII	θ / β	[11]
IX	α / β	[11]
X	$(\theta + \alpha) / \beta$	[11][9][12]
XI	θ/α	[9][12]
XII	$\alpha /(\theta+\alpha+\beta)$	[12]
XIII	$\beta /(\theta+\alpha+\beta)$	[12]
XIV	$\theta/(\theta+\alpha+\beta)$	[12]

* α = alpha, β = beta, θ = theta.

Ethical Aspects of Research - This work is in line with the ethical issues inherent in research with humans, established by the *Conselho Nacional de Saúde* having approved the project with Certificate of Appreciation Presentation for Ethics (CAAE: 26225513.6.0000.5060). The experiments were carried out after signing the Informed Consent and volunteers.

Results and Discussion

The analysis of the parameters considered only those that showed significance different between beginning and end of test with *p-value* as shows in Table 2. The occipital and parietal channels showed better results than frontal channel.

Table 2: Analysis for results showing significant *p-value* in ANOVA analysis.

Channel	Parameters of analyses													
	I	**II**	**III**	**IV**	**V**	**VI**	**VII**	**VII**	**IX**	**X**	**XI**	**XII**	**XIII**	**XIV**
F3	-	0.079	-	0.019	0.059	-	0.052	0.089	-	-	-	-	0.035	0.070
F	0.073	0.024	-	0.029	0.092	0.079	0.067	0.089	-	-	-	-	0.045	0.040
F4	0.018	0.001	-	0.018	-	0.014	0.029	0.064	-	-	0.064	-	0.033	0.012
P7	-	0.010	-	0.073	-	-	0.026	0.020	-	0.056	-	-	0.073	0.056
P	0.036	0.004	-	-	-	0.040	0.040	0.043	-	-	0.033	-	-	0.023
P8	0.025	0.004	-	-	-	0.027	-	-	-	-	0.045	-	-	0.073
O1	0.082	0.001	-	0.054	-	0.050	0.054	0.059	-	-	0.014	-	0.092	0.016
O	0.005	0.000	-	0.020	-	0.008	0.017	0.024	-	-	0.002	0.045	0.067	0.004
O2	0.016	0.001	-	0.016	-	0.018	0.010	0.008	-	-	0.001	0.025	0.061	0.001

* F = Frontal, P = Parietal and O= Occipital

Comparison among the significance different of parameters showed results similar to I, IV, VI, VII, XIV (M= 0. 0238 and SD= 0. 0327), VIII, and XIII (M=0. 054 and SD 0. 0264) was the least significant. The better references was the II (M=0. 0137 and SD=0. 0255) and XI (M= 0. 0267 and SD=0. 0254) parameters.

Based on the studies of [9] [12] [17] the better parameters that indicate fatigue are the increase of I, III, X; and decrease of XI, however the parameters X and III did not show significance different and not was used.

The results found to parameters I and XI are similar to those described by [9] [12], which indicate the increase of parameter I and decrease of XI. Henceforth, the analysis of parameters is done based on frontal and occipital channels compared to parameters XI and I.

Due to low significance values the parameters III, V, IX, X, XII of Table 2, they were not used for this analysis. Thereby all other results of parameters are shows in Table 3 the results for the study of motor imagery, and Table 4 the results of emotional stimulation.

Table 3: Variation of parameters between the initial and final values of motor imagery task.

Channel	I	II	IV	VI	VII	VIII	XI	XIII	XIV
F3	−	↑	↑	−	↓	↓	−	↑	↓
F	↑	↑	↑	↓	↓	↓	−	↑	↓
F4	↑	↑	↑	↓	↓	↓	↓	↑	↓
P7	−	↑	↑	−	↓	↓	−	↑	↓
P	↑	↑	−	↓	↓	↓	↓	−	↓
P8	↑	↑	−	↓	−	−	↓	−	↓
O1	↑	↑	↑	↓	↓	↓	↓	↑	↓
O	↑	↑	↑	↓	↓	↓	↓	↑	↓
O2	↑	↑	↑	↓	↓	↓	↓	↑	↓

↑: increase; ↓: decrease; −: unchanged.

Table 4: Variation of parameters between the initial and final test of emotional stimulation.

Channel	I	II	IV	VI	VII	VIII	XI	XIII	XIV
F3	−	↑	↑	−	↓	↓	−	↑	↓
F	↑	↑	↓	↓	↓	↑	−	↓	↓
F4	↑	↑	↓	↓	↓	↓	↓	↓	↓
P7	−	↓	↓	−	↑	↑	−	↓	↑
P	↑	↑	−	↓	↓	↓	↓	−	↑
P8	↑	↑	−	↓	−	−	↓	−	↑
O1	↑	↑	↓	↓	↑	↑	↑	↓	↑
O	↑	↑	↑	↓	↓	↓	↓	↑	↓
O2	↑	↑	↓	↓	↓	↓	↓	↓	↓

↑: increase; ↓: decrease; −: unchanged.

The motor task and emotion stimulation showed similar results, possible to observe an increase in I and decrease the XI parameter. In both studies the parameters II, IV, XIII are alike increasing of I, as well as, the parameters VI, VII, VIII are alike decreasing of XI.

When comparing the behavior for each parameter between the stimulus we found 74.07% of agreement, as evidenced in Table 5. However when performing the comparison between the two different stimuli and based on these parameters, it is noted that the study of emotional stimulations were less fatiguing than motor imagery. This statement is based on the fact that 83.95% of the parameters of motor imagination were significant compared to only 33.33% of emotional stimulus.

Given the results, it should be noted some points that can be highlighted as determinants for the difference in the level of fatigue among different stimulus. Firstly, the duration was highest for motor activity in the imagination. The second point is the fact that motor imagination tasks require concentration and greater activity of the brain while emotional stimulus requires only attention to images.

Table 5: Comparison between different stimulus.

Channel	I	II	IV	VI	VII	VIII	XI	XIII	XIV
F3	+	+	+	+	+	+	+	+	+
F	+	+	-	+	+	-	+	-	+
F4	+	+	-	+	+	+	+	-	+
P7	+	-	-	+	-	-	+	-	-
P	+	+	+	+	+	+	+	+	-
P8	+	+	+	+	+	+	+	+	-
O1	+	+	-	+	-	-	-	-	-
O	+	+	+	+	+	+	+	+	+
O2	+	+	-	+	+	+	+	-	+

+ : same behavior, - : opposite behavior

Conclusions

The analysis of these results showed that the motor imagery is more fatiguing than tests involving emotional stimulation. This result showed that the possibility of analysis of fatigue involving BCIs can be used as a quality control of experiments involving tasks that generate mental fatigue, identifying the time on the volunteer is fatigued. Thus, researcher has a way to track the mental capacity of the volunteer during the experiments. Future work on the analysis of fatigue in paralleling different experiments based on EEG will be implemented and validate.

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