An Experimental Study of Typography Using EEG Signal Parameters

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Abstract. Brain-Computer Interaction (BCI) technology can be used in several areas having recently gained increased interest with diverse applications in the area of Human Computer Interaction (HCI). In this area one of the central aspects relates to the ease of perceiving information. Typography is one of the central elements that, when properly used, can provide better readability and understanding of the information to be communicated. In this sense, this multidisciplinary work (typography and cognitive neuroscience) examines how the brain processes typographic information using EEG technology. In this context, the main goal of this work is to obtain information about the users when reading several words written in different typefaces and deduce theirs mental states (fatigue, stress, immersion) through user's electroencephalogram signals (EEG). Additionally, several EEG features were extracted, namely the energy of Theta, Alpha and Beta waves, as well as, the variability of these bands' energy. It is considered that this is a preliminary study in this area and may be extended to another type of design features.

Keywords: EEG · Mindwave · Fatigue · Immersion · Stress

1 Introduction

The construct of mental workload can be understood as the level of cognitive engagement which has a direct impact on the effectiveness and quality of a learning process. Mental states can be detected through several noninvasive sensing and imaging technologies, such as, fMRI and EEG [10]. However, not all of these available interfaces are suitable for mental state detection in real life situations. Of the several associated problems, the portability and difficulty of acquisition stand out. In recent years, vast researches have concentrated towards the development of EEG based human computer interface in arrangement to enhancing the quality of life for medical as well as non-medical applications [8]. It can be used in smart city applications such as brain-computer interface in industrial

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applications or intelligent wireless wearable EEG solutions for daily life applications [1], [7]. Industry and community of research has been attracted by wireless EEG devices and they are easily available in the market. Such technology can be incorporated to psychology, medical applications, and real-time monitoring of patients. Neurosky Mindwave headset [11] is a portable device and is generally used to detect and measure electrical activity of the user's forehead and transmit the collected data wirelessly, to a computer for further processing [9], [13]. After processing the data base, the signals are categorized into various frequency bands for feature extraction, namely attention, concentration and blinking. In the literature some works describe a variety of EEG features extracted by various algorithms to detect of mental states, such as adaptive auto-regressive parameters, time frequency features and inverse model-based features. Comparing the time frequency features, some works suggested frontal midline theta as a better candidate than frontal alpha activity for use in a BCI-based paradigm designed to detect and modulate emotional reactions. Frontal midline theta was considered to be associated with positive emotional experience and with the relaxation state from anxiety [14]. Theta band waves exist during tasks that require the correlation of increased mental effort and sustained concentration [12]. In the other hand, alpha band waves exist when a person is in relaxation mode, and they may reflect the progress of perceptual processing, memory tasks, and the processing of emotions. Other time frequency features, such as, attention, fatigue, immersion and stress based on power energy of theta, alpha and beta band can be useful to detect mental stage in routine activities. Attention levels can be indicated by several physiological markers, namely eye tracking; eye pupil dilation, which is proportional to attention; the blinking rate, which decreases as attention level increases and the modulation of the EEG activity [15]. Fatigue is a complex state manifested by a lack of alertness, weakness, dizziness, or queasiness, which leads to inefficiency and performance reduction [4]. Immersion is another parameter used. In [6] immersion and concentration are compared and it was found that concentration and immersion states increased alpha waves and theta waves decreased during concentration or increased during immersion. In [2] the immersion is discussed and can be detected in different situations providing the state of immersion as one of the game parameters or to generate a control signal that may be used to provide a warning message or abort the game when the situation of the excessive indulgence in the game reaches. The stress parameter is widely discussed in numerous works with different focuses [3], [5]. The purpose of this study was to analyze mental workload while comparing three types of letters and also their influence in seven words related to emotions. This study aimed to assess mental fatigue, stress and immersion by using electroencephalographic measures during visual screen words. This paper is divided into four sections. Section 2 describes the material and methods followed in experimentation: the participants, the experimental design, the data acquisition and the data processing and analysis. In Sect. 3 the results and how they were used to characterize the stress, fatigue and immersion parameters are also described, and, finally, Sect. 4 contains the conclusions and finally some topics for further work.

2 Materials and Methods

In this section the participants characterization, experimental design as well as the data acquisition and data analysis are described.

2.1 Participants

Thirty participants (9 males and 21 females), aged 18–21 years (mean: 19 ± 0.8 years), were recruited to perform a monotonous reading task. All participants provided informed consent prior to participating in the study. At the beginning of the experiment, a questionnaire was made to each participant in order to obtain a more detailed characterization of the population in question: age, sex, level of education and the existence of visual problems.

2.2 Experimental Design

The experiment was undertaken in a usability laboratory. The experiment was considered correct if there were no interruptions. It consisted of a sequential visualization of seven white "emotional words" (Joy (J), Sadness (S), Love (L), Hate (H), Sympathy (Sy), Unrest (U) and Calmness (C)) written in a black screen, considering three typography fonts and each typefaces respectively:

– Sans Serif – Open Sans;
– Serif – Old London;
– Handwriting – Dancing Script;

Figure 1 presents a sequential example with three screens. The words occurred on the screen in a sequence of 21 possible combinations, Table 1. During this task, each word was presented for 3 s at the center of the screen, followed by a pause with a white screen for 1 s totalizing 83 s, as shown in Fig. 2. Participants only have to see the word and read the word presented in the screen. In total, each participant will be exposed for 83 s to 21 frames with words written in white on

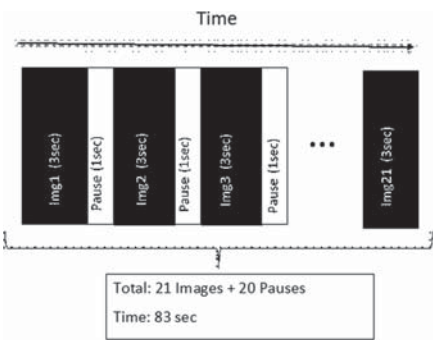


Fig. 1. The timing diagram of the experiment.

Table 1. Coding combinations of typefaces with the selected emotional words.

	Open Sans	Old London	Dancing Script
Joy	J_{OS}	J_{OL}	J_{DS}
Sadness	S_{OS}	S_{OL}	S_{DS}
Love	L_{OS}	L_{OL}	L_{DS}
Hate	H_{OS}	H_{OL}	H_{DS}
Sympathy	Sy_{OS}	Sy_{OL}	Sy_{DS}
Unrest	U_{OS}	U_{OL}	U_{DS}
Calmness	C_{OS}	C_{OL}	C_{DS}

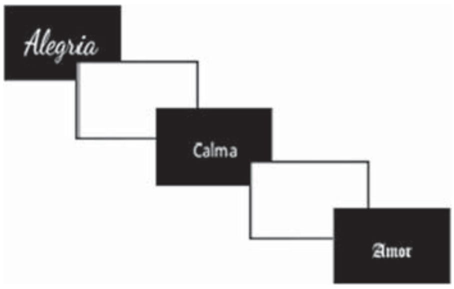


Fig. 2. Experimental time sequence (an example)

a black screen and 20 transition frames in a white screen. It should be noted that the location on the screen, as well as, the size of the words did not change. The participants were also asked not to blink and not to move their eyes and body during the visualization of the screens. The purpose of this procedure is to eliminate ocular and muscular artifacts, thus avoiding signal loss. At the end of the experiment, users were asked to choose on paper which typographic font they preferred and which they found more frequently.

2.3 Data Acquisition

Neurosky's Mindwave is a device that measures brain activity using a sensor on the forehead ($Fp1$) and a clip located on the left ear that acts as a ground and reference. It can provide a raw signal at a sampling rate of 512 Hz and 12 bits of resolution as well as processed information like power bands. However, bands and indicators are sent at a rate of 1 Hz. The software checks the POORSIGNAL indicator sent by Neurosky's Mindwave every second. A value of 0 in this indicator guarantees good contact between electrodes and the skin and, therefore, a good quality signal. In the case of poor signal quality, the attention value is rejected and not recorded by the software. The main frequency range of the EEG signal is [0.5–30] Hz, which contains information about mental states and can be divided into 5 main bands, delta waves [0.5–4] Hz, theta waves [4–8] Hz, alpha waves [8–13] Hz, beta waves [13–30] Hz and gamma waves [30–40] Hz. For different brain activities, the power changes of the three bands (theta, alpha and beta) comply with different patterns, which implies that the power of the 3 bands are key indicators of mental states, such as, stress, immersion and fatigue indicators.

2.4 Data Processing Ad Analysis

The EEG signal as well as the signal associated to the power bands, for each participant, were divided into 21 segments of 3 s related to each task (visualization and reading each screen). The average of the segments by group of words and by group of typography was analyzed for each participant and for all participants. This analysis was performed for each of the frequency parameters namely Theta activity - θ, Alpha activity - α and Beta activity - β. Using the frequency information bands three different metrics were computed to characterize mental states, such as :

1. Fatigue (F)

$$F = \frac{\theta + \alpha}{\beta} \tag{1}$$

2. Immersion (I)

$$I = \frac{\theta}{\alpha} \tag{2}$$

3. Stress (S)

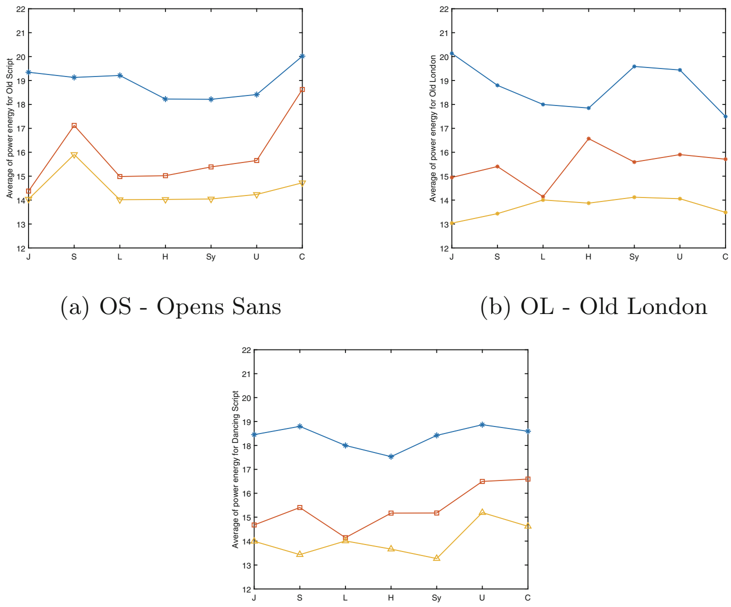
$$S = \frac{\beta}{\alpha} \tag{3}$$

The results are reported considering the minimum, maximum, average $\pm$ and standard deviation σ values. Significant level is reported at $p < 0.05$. The average of the parameters values were computed and compared. The three types of letters as well as the relation with the emotions words are analyzed.

3 Results and Discussion

Our study intended to address the following questions:

- Q_1 - Different words written in the same typeface present different energy levels? In what waves?
- Q_2 - The same words written in different typefaces present different energy levels? In what waves?
- Q_3 - Different words written in the same typeface present different levels of fatigue, immersion and stress? In what typefaces (OS, OL and DS)?
- Q_4 - The same words written in different typefaces present different levels of fatigue, immersion and stress? In what typefaces (OS, OL and DS)?



(a) OS - Opens Sans (b) OL - Old London

(c) DS - Dancing Script

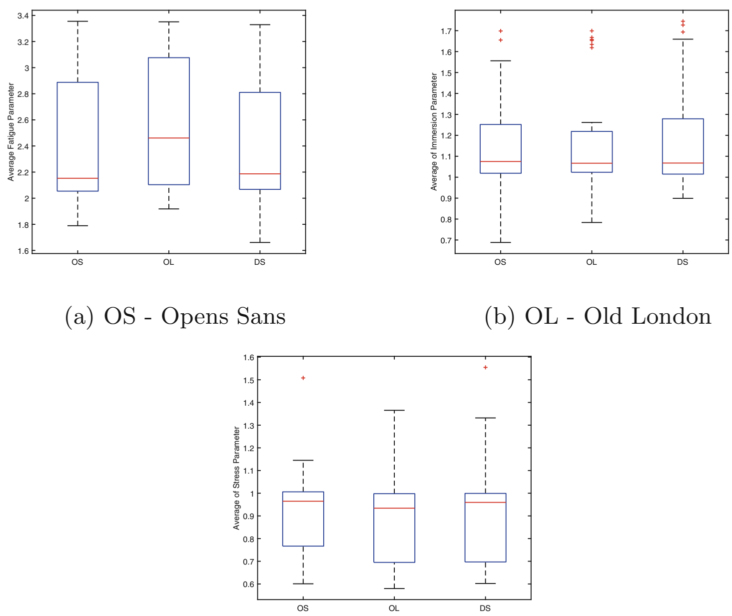
Fig. 3. Variability of the power energy of all participants considering three typefaces: OS - Opens Sans (a); OL - Old London (b) and DS - Dancing Script (c) for each emotional word (Joy (J), Sadness (S), Love (L), Hate (H), Sympathy (Sy), Unrest (U) and Calmness (C))

To answer the first question (Q_1) the levels of energy were compared, in the bands θ, α and β, between words of same typeface, as shown in Fig. 3. A confidence level of 95% was used, where some results stand out. Theta band power levels haven't got a significant statistical difference between all words when written in typeface DS. However, there were differences between H_{OS}-C_{OS} ($p = 0.036$), Sy_{OS}-C_{OS} ($p = 0.013$), J_{OL}-L_{OL} ($p = 0.028$), J_{OL}-H_{OL} ($p = 0.0229$), J_{OL}-C_{OL} ($p = 0.041$), Sy_{OL}-U_{OL} ($p = 0.0154$) and Sy_{OL}-C_{OL} ($p = 0.0154$) in typeface OL. Beta band energy levels show no statistically significant differences between words when written in OS and OL typefaces, but only one difference S_{DS}-U_{DS} ($p = 0.039$). Alpha band energy levels are those where there are most statistically significant differences between different words: J_{OS}-S_{OS} ($p = 0.083$), J_{OS}-C_{OS} ($p = 0.000121$), S_{OS}-L_{OS} ($p = 0.0215$), S_{OS}-H_{OS} ($p = 0.0212$), L_{OS}-C_{OS} ($p = 0.000015$), H_{OS}-C_{OS} ($p = 0.00041$), Sy_{OS}-C_{OS} ($p = 0.00091$) and U_{OS}-C_{OS} ($p = 0.000042$) when written in OS typeface, J_{OL}-H_{OL} ($p = 0.033$), L_{OL}-H_{OL} ($p = 0.0111$) and L_{OL}-U_{OL} ($p = 0.0313$) when written in OL typeface and J_{DS}-C_{DS} ($p = 0.0417$), L_{DS}-U_{DS} ($p = 0.019$) and L_{DS}-C_{DS} ($p = 0.0284$) when written in DS typeface. The word Calmness is the one with the most statistically significant energy differences over a large set of words written in the same typeface. To answer the second question (Q_2) the energy levels in the Theta, Alpha and Beta bands for each word written in different typefaces were compared. In general, there were no statistically significant energy differences in the Theta, Alpha and Beta bands in the various words when written in the different typefaces. The exceptions were the different energy levels for the word Calmness in all bands when comparing OS and OL typefaces (C_{OS}-C_{OL} Theta ($p = 0.0073$), Alpha ($p = 0.0045$) and Beta ($p = 0.025$)) and also in OS and DS typefaces (C_{OS}-C_{DS}) in Theta ($p = 0.016$) and Alpha ($p = 0.084$) bands. The word Sadness presented statistically significant energy differences in the Beta band when we compare this word written in the OS and OL typefaces (S_{OS}-S_{OL} ($p = 0.048$)) and in the OS and DS typefaces (S_{OS}-S_{DS} ($p = 0.014$)). Table 2 presents a descriptive statistical analysis of the values for each of the bands considering all the words grouped by typefaces. Theta band is the one with average values of higher energy. Comparing the various values of the Table 2 it is possible to conclude that there are no obvious differences, with however differences in the different words (as discussed earlier). To answer the $3rd$ question (Q_3) the levels of Fatigue, Stress and Immersion between different words written in the same typeface were compared, highlighting a few points. There are no statistically significant differences in the Immersion levels between words when written in typeface DS. In this typeface (DS), there is only a statistically significant difference in Fatigue L_{DS}-Sy_{DS} ($p = 0.0472$) and Stress S_{DS}-L_{DS} ($p = 0.0189$) levels. There are some statistically significant differences in Fatigue, Stress and Immersion levels in the various typefaces when comparing different words: in Fatigue levels, the pair of words S_{OS}-C_{OS} ($p = 0.0108$), L_{OS}-C_{OS} ($p = 0.0481$), H_{OS}-C_{OS} ($p = 0.0335$) and J_{OL}-L_{OL} ($p = 0.02$) and in Stress levels, the pair of words J_{OS}-C_{OS} ($p = 0.066$), S_{OS}-C_{OS} ($p = 0.0205$), H_{OS}-C_{OS} ($p = 0.033$), U_{OS}-C_{OS} ($p = 0.0464$), S_{OL}-L_{OL} ($p = 0.0189$), L_{OL}-H_{OL} ($p = 0.0034$) and L_{OL}-C_{OL} ($p = 0.0176$). As highlighted in previous analysis, the word Calmness was the one that presented the most statistically significant energy differences in relation to a large set of words, in the analysis of these 3 parameters, when written in the same typeface. According to Table 2, the Fatigue levels show higher mean values in typeface OL, the levels of Immersion and stress present mean values almost equal in all typefaces. Finally, and answering to Q_4, levels of fatigue Eq. 1, immersion Eq. 2 and stress Eq. 3 were compared to each word written in different typefaces. No statistically significant differences in levels immersion for the various words when written in the different typefaces was found. In general, the levels of fatigue and Stress for the various words when written in the different typefaces also did not present significant statistical differences, but only the following: Fatigue levels showed significant statistical differences for C_{OS}-C_{OL} ($p = 0.0363$), C_{DS}-C_{OS} ($p = 0.0051$), J_{DS}-J_{OL} ($p = 0.0325$). Stress levels showed significant statistical differences only for C_{OS}-C_{OL} ($p = 0.00029$).

Table 2. Minimum, maximum, average and standard deviation considering the frequency bands (θ, α and β) and each typeface (OS, OL and DS) respectively

		Min	Max	μ	σ
θ band	OS	12.00	23.82	18,93	3,41
	OL	12,14	23,91	18,70	3,69
	DS	11,45	23,45	18,51	3,59
α band	OS	10,90	23,60	15,88	3,58
	OL	10,39	23,93	15,42	3,53
	DS	10,16	23,88	15,50	3,52
β band	OS	10,22	23,94	14,42	2,71
	OL	9,84	23,73	13,69	1,86
	DS	10,37	23,94	14,06	2,30

Considering all the words grouped by typefaces, a variability analysis of the average values for fatigue, stress and immersion parameters are showed in Fig. 4. We can conclude that, globally, there are no significant differences in terms



(a) OS - Opens Sans

(b) OL - Old London

(c) DS - Dancing Script

Fig. 4. Variability of the average values: Fatigue values, (F), Immersion values, (I) and Stress values, (S) of all participants considering three types of letter: OS - Opens Sans (a); OL - Old London (b) and DS - Dancing Script (c)

of wave energy and the parameters analyzed. However, by performing a word analysis and considering the different typefaces, significant statistical differences are found, which leads to the conclusion that the analysis methodology as well as the signal acquisition equipment are very promising for the development of a BCI.

4 Conclusions and Further Work

Typography plays a key role in any graphic design, and readability is one of the main aspects to consider. There are several factors that influence the readability of a typeface, such as spacing, contrast, size, shapes, character color, background color, among others. Additionally, typography is a very dynamic communication tool, appealing to the imagination and communicating ideas without ever losing the purpose of what one wants to communicate. For communication to occur without interference it is important to choose the right typeface. This allows a reading to be very or little readable and a person to be quite attentive or not. Consequently, it is a fundamental component of any project. However, typographic fonts are more easily perceived and lead to higher levels of understanding, attention, immersion, stress or fatigue than others. Despite growing knowledge about how readers interact with texts, understanding how the brain processes this information is relatively limited. This multidisciplinary study (typography and cognitive neuroscience) examines how the brain processes typographic information using EEG technology and shows the value of neuroscience methodologies for readability research. It is considered that this is a preliminary study in this area and may be extended to another type of design characteristics: color, shape, contrast among others to better understand which are the way to promote the immersion, reducing the fatigue state. This study also sheds new light on the possibility of developing a metric for quantifying mental engagement and providing a real-time feedback on the dynamic change of mental engagement.

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