Analysis of Fluctuation in Repeated Handwriting Based on Psychophysiological Factors

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I. INTRODUCTION

During walking or running, we execute voluntary and repeated activities where repeated voluntary activities need a conscious mind [1,2]. In this study, we introduce the term *repeated voluntary movement* which refers to repeated movements during daily activities. These movements need a certain mental workload. By clarifying the correlation between repeated voluntary movement and mental workload, it becomes possible to improve the workers' well-being and safety at work. In order to confirm the correlation between repeated voluntary movement and mental workload, we selected handwriting as an everyday repeated activity which imposes a mental workload [3-7]. In our study three terms of *cognitive control, physical control* and *cognitive load* are going to be used in order to extract the features of repeated activities.

II. EXPERIMENTAL METHOD

Dual-task method was selected for the experiment's procedure in which two tasks are to be performed simultaneously (for our experiment, writing at a specific timeframe). The experiment's system is consisted of two PCs. These PCs control a pen tablet, generate an auditory stimulus, and measure biometric signals (ECG, EEG and also body temperature). There are three tasks of writing as shown in Fig. (1), in which each task was performed by the subject at three different writing speeds which is considered as the task difficulty (low, medium and high speed). The experiment was performed during 6 non-consecutive days so that on the first three days a set of tasks *WZ*, and on the last three days a different set of tasks *WL* were performed. In this report we have applied obtained data of one male student at the age of 24 for the analysis.

FIG. 1. Writing Tasks

III. EXPERIMENTAL PROTOCOL

The experimental protocol is shown in Fig. (2). First the subject fills in two questionnaires to measure the psychological factors, *Profile of Mood States (POMS) and State–Trait Anxiety Inventory (STAI)*. Then, the subject rests with closed eyes for 150s and performs a task of writing with a specific speed by 250 times. Finally, the subject rests with closed eyes for 150s and answers to the *POMS/STAI* questionnaires again.

FIG. 2. Experiment's Protocol

IV. ANALYSIS METHOD

Synchronization error between writing and audio-stimulus and spatial error tend to occur during performing each task. It means, depending on the task difficulty, the subject will find it difficult to synchronize repeated-handwriting with the audio-stimulus. Furthermore in each set, each writing task has different start and stop point. In this study we applied the Synchronization error between writing and audio-stimulus as a factor of our analysis and for simplicity we refer to it as *WSE (Writing Synchronization Error)* which is shown in Fig. (3) [8,9].

For the procedure of the analysis, first measured data was normalized to N (0, 1), then the autocorrelation coefficient was applied to the *WSE*:

$$c(i) = \sum_{k=1}^{L-i} \frac{\mathrm{N}[k]\times\mathrm{N}[k+1]}{L} \qquad (for\ i = 1,2,\dots,L-1) \qquad (1)$$

Where L is the length of the normalized data, N[k] and N[k+1] are K^{th} and $(K+1)^{th}$ term of the normalized data. After that, Fast Fourier Transform was applied to the autocorrelation coefficient in order to calculate the Power Spectral Density (PSD). Finally *Self-Similarity Feature* and *Natural Period Feature* were derived from the PSD.

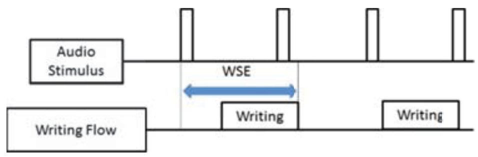

FIG.3. WSE (Writing Synchronization Error)

A. SELF-SIMILARITY FEATURE

The Power Spectrum Density of the *WSE* on a log-log plot is inversely proportional to the frequency. Generally this feature is referred to as *1/f noise*, Eq. (2) explain the general form of the *1/f noise* in which α has a range of -2 to 0.

$$S(f) \propto f^{\alpha} \quad -2 < \alpha < 0 \qquad (2)$$

We applied the least squares method in order to find the best fit line (linear regression) to the PSD where the gradient of this line represents the value of α in Eq. (2). Our results show that the value of α for each writing task is statistically self-similar. Fig. (4) shows the result of the experiment for the *Self–Similarity Feature* of WSE. The horizontal axis represents the writing tasks where W_Z is related to the writing task, *W* of the *WZ* set, and W_L is related to the writing task, *W* of the *WL* set. The vertical axis represents the value for α of each writing tasks. The red, brown and yellow bars are related to the highest, medium and lowest writing speeds, respectively. Obviously, the value of α in each set is dramatically proportional to the writing speed. When α has a more negative value, the task needs less mental workload and the *physical control* is dominant, and when α has a value near to zero, the task needs more mental workload and the *cognitive control* is dominant. The reason of this matter is that at the highest writing speed, the subject only performed a physical activity and found it difficult to synchronize his writing flow with the audio-stimulus. On the other side, at the lowest writing speed the subject has concentrated better on the task and easily has synchronized his writing flow with the audio-stimulus. For the medium speed of the writing task, both of the *cognitive control* and the *physical control* took part in controlling the writing activity. In this study, when α tends to approach to *-1* the case is called "*tendency to 1/f noise (pink noise)*" , this happened at the medium speed of the writing task in our experiment; and when α tends to approach to zero, the case is called "*tendency to the white noise*" which happened at the lowest speed of the writing task. But when we want to talk about the difficulty of writing letters not writing speed, we can't easily distinguish the difference between the writing tasks. For instance the writing task of *W* has more breaking points than the writing task of *L* and it would be more difficult to write, so the *cognitive control* should be dominant. Therefore we'd have expected that at the writing tasks of *W* the cognitive control would have more influence on the task but it wasn't satisfied. We conclude that one of the reasons of this problem is that the control of the writing task was influenced by other controls of different tasks on the mental workload during experiment.

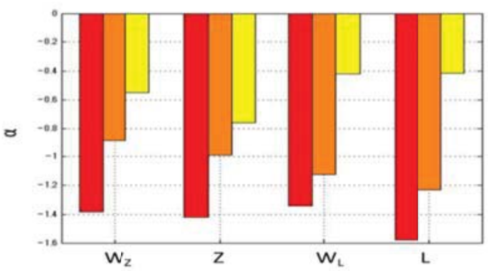

FIG.4. the Self–Similarity Feature of WSE

B. NATURAL PERIOD FEATURE

Difference between the PSD and the linear regression of the PSD (*DPower(f)*) is another factor that expresses the frequency characteristics. The mean value of the *DPower(f)* was defined as μ and the standard deviation of the *DPower(f)* was defined as σ. The number of points that the value of the *DPower(f)* exceeds $\mu + \sigma$ was defined as *Power(f)*. By dividing the *Power(f)* by the length of the *DPower(f)* a new term can be derived which we call it *PeakT*. In Fig. (5) we can see the value of the PeakT for each writing task. We can see that except for writing task of *L,* the other writing tasks at the lowest speed (yellow bars) have greater values for *PeakT* than of the highest speed (red bars). It means, the lowest speed of the writing task has a higher level of the *cognitive load* than the highest speed. At the highest writing speed (red bars), the values of *PeakT* are on their lowest values which means the *cognitive load* is at its lowest level. And finally for the medium speed, depend on the writing task the *cognitive load* has variable value and it is difficult to recognize the level of the *cognitive load* at this stage of the study and more experiments must be performed to make it more clear. The parameter "difficulty of writing letters" in this section is the same as what we have discussed in the previous section and to discover the detailed reasons of the misclassification problem, more experiments must be performed.

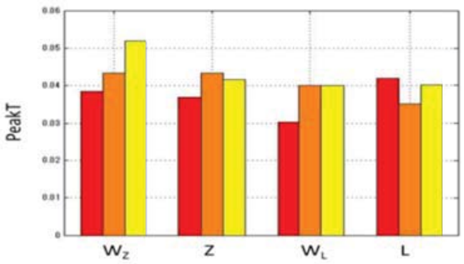

FIG.5. the Natural Period Feature of WSE

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