

The increase or decrease in the speed and accuracy of tasks is a measure of mental work performance in the aspect of mental fatigue

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Abstract

Problem Statement: It is assumed that an increase or decrease in the speed and accuracy of tasks with changing perception of threshold values of flicker fusion frequencies is the measure of mental work performance in the aspect of mental fatigue. **Approach:** Two tests of the Vienna Test System battery were used: the ALS mental work performance test and the FLIM test of emotional arousal in the aspect of mental fatigue. The study examined (N=58) university students. The participants were aged 18 to 25 years, they all were studying at the same university. **Purpose:** The analysis looked a measure of work speed, a measure of increase or decrease in work performance, the percentage of incorrect answers, a measure of work accuracy, and the frequency of light fusion and light flickering. **Results:** It has been observed that a decrease in mental work speed and accuracy is accompanied by the perception of a decrease in flicker fusion frequency at which image perception occurs. A high level of mental fatigue manifested by the perception of low threshold values of fusion and light flicker frequencies does not allow for the fast and accurate performance of mental work. These frequencies decrease as the level of mental fatigue increases. The standpoint of the main research problem concerning mental work performance and arousal responsible for mental fatigue a positive correlation was observed for mental fatigue with two indices of mental performance. There was a decline in the perception of threshold values of fusion and flicker frequencies as indices of an increase in mental fatigue that is accompanied by a decrease in work performance. **Conclusions:** An increase or decrease in the speed and accuracy of tasks is a measure of mental work performance. A high level of fatigue manifested by the perception of low threshold values of flicker fusion frequencies does not allow for the fast and accurate performance of mental work. These frequencies decrease as the level of fatigue increases.

Keywords: Task Performance, Measure of Accuracy, Fusion Light Frequency, Flicker Light Frequency

Introduction

People develop only part of their potential abilities to perform tasks, and only part of them is revealed through observation and measurement. Sternberg (1986) attributed rapid automation of cognitive processes to specific human abilities. This researcher argued that action performed repeatedly is automated, which in psychology means that its control shifts from the global level (that requires conscious control of the action performed) to the local level (associated with performing the action in an uncontrolled and automated manner). According to this author (Sternberg, 1986), automated cognitive processes are performed faster, without fatigue, and in a smooth manner. Conversely, when the mental workload is well above an appropriate level, there is a tendency to fatigue, which can lead to an increase in the number of errors during task performance (McClernon and Miller, 2011). Although the effects on people vary, psychological fatigue manifested by task aversion and/or deterioration in task performance is common. More specifically, in the case of a long time to complete the task, people often complete it more slowly, make more mistakes, and are less likely to correct them (Lorist and Jolij, 2012). It was also demonstrated (Boksem and Tops, 2008) that mental fatigue develops as a result of the assessment of the costs and benefits of the effort and can serve as a warning of reduced work performance. If the cost of performing a cognitive task outweighs the benefits of completing the task, subjective perception of mental fatigue, e.g. task aversion, increases whereas work performance deteriorates, e.g., reaction time increases and accuracy decreases. However, this warning system is not optimal. The study by (Zhang et al., 2011) showed that people are unable to accurately decide whether they can still successfully complete a task. The juxtaposition of mental work performance with measures of subjective fatigue showed that performance had been already declining before people were actually aware of fatigue.

One way to monitor work performance during a typical mental workday (Pimenta et al., 2014) is to install work performance meters on the computer keyboard to measure the speed and accuracy of typing during the workday. These researchers argued that these mental work performance indices can be used to monitor mental fatigue. Kalfaoğlu and Stafford (2014) examined the relationship between work speed and errors made. Their results indicated that these dimensions are variable and that they can be used to monitor mental fatigue.

Although measures of mental fatigue only describe its effect on behavior, fatigue is the final result of many different cognitive processes. Hopstaken et al. (2015) investigated the relationship between behavioral indices and underlying cognitive processes and demonstrated that the behavioral indices related to mental work can be used to monitor the effects of mental fatigue on specific cognitive operations. These authors argued that behavioral measures can help understand these cognitive processes, but they do not provide information about the processes directly, and thus their relationship to basic cognitive processes remains unexplored. There has been debate about these relationships for nearly 100 years since psychiatrist E. Kraepelin (1922) developed the mental work curve. Kraepelin's mental work curve takes into account the arithmetic sum of all the positive (drive to act) and negative (fatigue) effects that, according to this researcher, determine the level of a person's mental work performance at any moment of activity. Factor analysis of these variables showed (Sugimoto et al. 2010; Kashiwagi et al., 2007) that quantitative indices derived from test scores (Shinrigaku, 1985, 1995) measure six separate and independent factors: quantitative measures of performance, measures of energy and persistence, measures of quick adaptation and effort without self-restraint, measures of variability or stability, measures of accuracy and diligence, and measures of an uninterpreted factor that takes into account specific abilities and personality traits of an individual. It was observed (Hasler et al., 2010) that this can be linked to the experience of fluent addition and the difficulty in adapting to a new situation. In terms of fatigue, the most noteworthy measure is that of energy and persistence, which is directly related to performing work over long periods of time, because increases in speed and accuracy of tasks occur when an individual is not exposed to fatigue. However, with prolonged excessive mental load, his or her cognitive processes may slow down, or the person may not react at all to the stimuli received. Based on Kraepelin's mental work test, a procedure was developed to measure work performance (the Pauli test), which, just as it did 100 years ago on paper, presents successive addition and subtraction tasks on a computer screen to determine mental work capacity over a period of time.

Since the release of energy during mental work is reflected in the brain and there is a change in the level of emotional arousal during task performance, it is important to remember the effect of emotional arousal on mental fatigue. Mental work is accompanied by emotions that accelerate or delay the subjective feeling of fatigue. The lack of optimal emotional arousal (too low or too high) leads to negative emotions (apathy or tension), which have a direct effect on the decrease in mental performance. One criterion that is an indicator of the readiness of the central nervous system for activity is the perception of the frequency of a point source of light (Rodriguez et al., 2017; Quik et al., 2012). At this frequency, light is fused (flickering light source -> steady light source) or flickers (steady light source -> flickering light source). The fusion or flicker light frequency at which image perception occurs are referred to as the threshold frequencies (Truszczyński et al., 2012), whose values change (decrease) as the individual's level of fatigue increases. The perception of a decrease in threshold flicker fusion frequencies is considered an indicator of an increase in physiological fatigue (Clement, 2011; Truszczyński et al., 2009), while other authors (Seitz et al., 2005) considered the perception of flicker fusion threshold frequencies to be measures of an individual's total information processing. The threshold values for flicker fusion frequency can be considered the measures of the same phenomenon, and the results of the research by Curran and Hindmarch (Curran and Hindmarch, 1990) indicate strong positive correlations between them.

Thus, a relationship can be objectively inferred between the level of mental performance during the task and mental fatigue. Mental fatigue refers to a complex and multifaceted condition that can occur during or after an extended period of task performance. It is, therefore, reasonable to study and analyze these relationships because low or high levels of mental fatigue are more likely to result in an increase or decrease in the speed and accuracy of completed tasks as measures of mental performance.

Material and Method

Participation in the study was anonymous and voluntary. The study examined (N=58) male university students aged 18-25 years with secondary education and studying at the same university. The examination was the same for each person and lasted one hour. Each person attended one individual session in which material was obtained for the analysis. None of the tests were rejected. The experiments were undisturbed. The young people were willing to perform the tests and were interested in the results. All the participants gave their written informed consent to participate in the study. All procedures were approved in accordance with the standards of the Senate's Research Bioethics Commission and conducted in accordance with the Declaration of Helsinki of the World Medical Association. Both work performance measures and levels of emotional arousal that represented measures of mental fatigue were examined and analyzed using computer tests. Two tests of the Vienna Test System battery (Schuhfried, 2004 a, b) were used: the work performance test (ALS) and the flicker/fusion frequency test that records mental fatigue (FLIM).

• ALS work performance test

The work performance test (ALS) is a computerized version (presentation and evaluation) of the Pauli Test. The procedure was developed based on Kraepelin's work test and presents the consecutive tasks of addition aimed to determine the individual's ability to perform mental work over a specific time. The subject should add single-digit numbers (two at a time) as quickly and accurately as possible over a long period of time. The test is divided into two sections (subtests) to identify the development of abilities over time. According to the literature, the Pauli test measures "sustained concentration when performing mental tasks under time pressure." This

concept incorporates personality attributes such as constancy under conditions of distraction and interruption, and motivation, willpower, and the ability to focus attention on specific tasks. The computer version of the Pauli test consists of a standardized instruction and a practice phase followed by a 20-minute phase of the actual test. During this time, the subject is asked to perform as many additions of two elements as possible. The numbers are displayed on the screen one above the other. The subject should enter the result using the panel's numeric keypad. The execution time for the test is 20 minutes for the standard S1 form (used in the present study). Empirical indices: total tasks completed as a measure of the speed of work (ALS1), increase or decrease in tasks completed as a measure of increase or decrease in work performance (ALS2), percentage of incorrect additions (ALS3), sum of corrections as a measure of work accuracy (ALS4)

• FLIM frequency test: mental fatigue

Measurement of flicker fusion frequency is performed under stable conditions by placing the light source in a darkened body tube. The tube is applied tightly to the participant's eyes. There is a light source inside the tube with backlighting that provides adequate contrast. During the test, the flicker fusion frequency is automatically changed and the participant's task is to determine the threshold of fusion or flickering by pressing the appropriate button. The FLIM testing procedure makes it possible to determine the functional readiness of the central nervous system in terms of emotional arousal (fatigue). In the "increasing" version, the frequency of the flickering light source is gradually increased until the light appears to be steady (continuous). In the "decreasing" version, the frequency of the light source, initially so high that the participant recognizes the light as steady (non-flickering), gradually decreases until the subjective sensation of flickering. The participant should accept any change in the nature of the light (flickering -> steady or vice versa) by pressing the button. This critical frequency is stored in the system. The mean value of the critical frequency for the "increasing" and "decreasing" versions is the critical value and is called the fusion or flicker frequency, respectively. Empirical indices: fusion light frequency (FLIM1) - subjective perception of the transition from flickering light to steady light by the subject; flicker light frequency (FLIM2) - subjective perception of the transition from steady light to flickering light by the subject.

Statistical analysis of the data

After a series of measurements, the values of work performance measures and frequency thresholds were determined statistically using SPSS computer analysis, with the data from the Vienna Test System downloaded automatically. Next, descriptive statistics of the variables were performed in Statistical 13 software. Using one-way ANOVA, sigma-restricted parameterization and hypothesis decomposition were performed, and Wilks' lambda, eta squared effect sizes, and alpha power were calculated. Relationships between variables were examined using Spearman's correlation coefficient analysis.

Results

The increase or decrease in tasks performed as a measure of the increase or decrease in mental work performance is reflected by indices such as the sum of completed tasks as a measure of the work speed, the percentage of incorrect solutions, and the sum of corrections as a measure of the work accuracy. Table 1 shows the mean, minimum and maximum values for all the variables studied with standard deviations. The sum of completed tasks (ALS1) with the percentage of incorrect additions (ALS3) and corrections (ALS4) indicate the level of mental work performance (ALS2), while the perception of the fusion frequency threshold (FLIM 1) and flicker frequency threshold (FLIM 2) indicates the level of mental fatigue. The standard deviation of the mean M (ALS) represents an estimated sum of the completed tasks plus errors and corrections, while the standard deviation of the mean M (FLIM) is a control value to estimate the accuracy of the determination of the critical threshold for the transition between steady and flickering light and vice versa.

Table 1. Level of mental work performance indices and level of fatigue indices. N=58.

Variables	M	Min.	Max	SD
ALS1	444.81	295.00	733.00	88.46
ALS2	0.07	0.37	0.85	0.23
ALS3	17.84	2.00	82.00	14.47
ALS4	4.00	0.45	11.48	2.91
FLIM1	37.20	25.77	43.53	2.65
FLIM2	40.16	29.11	59.44	4.76

The one-way ANOVA for the factor 'job performance' in relation to three job performance indices (Schuhfried, 2004a): work speed measure (ALS1), error measure (ALS3) and work accuracy measure (ALS4) (Wilks' lambda=.468179; $F(4, 53)=15.051$; $p=.000$; eta squared= 0.531; alpha power = 0.999), shows an increase (1) or decrease (0) in mental work performance (ALS2). During an increase in mental work performance (1), as shown in Figure1, the sum of mathematical tasks completed increases as a measure of work

speed (ALS1) and there is a decrease in the percentage of incorrect solutions (ALS3) and a decrease in the sum of corrections as a measure of work accuracy (ALS4).

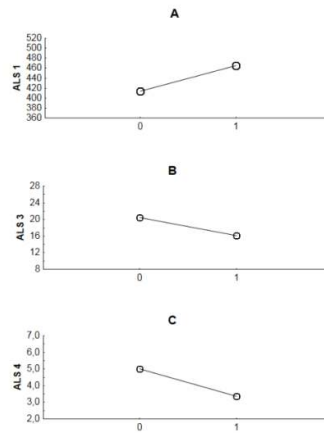


Figure 1. Indices of speed, errors, and accuracy of completed mathematical tasks against the increase (1) and decrease (0) in the level of mental work performance. N=58.

It is assumed (Schuhfried, 2004b) that in humans, the average thresholds of the perception of flicker fusion frequencies range from 40 Hz to 60 Hz. It should be noted that frequencies above 75 Hz are perceived by the vast majority of people only as a steady light. Fusion frequency (FLIM 1) and flicker frequency (FLIM 2) point to the level of mental fatigue. The one-way ANOVA for the factor 'work performance' in relation to mental fatigue indices (FLIM1 and FLIM2; Wilks' lambda=.97071, $F(2, 55)=.82990$; $p=.44148$; eta squared=.029; alpha power = 0.185073), shows average thresholds of frequency perception (Hz) of light fusion and flickering during an increase (1) or decrease (0) in mental work performance. An increase in work performance was observed (Figure 2) in 2/3 of the participants ($n=35$) whereas a decrease was found in 1/3 ($n=23$). Furthermore, it was shown (Figure 2A) that the mean threshold values of the perception of flicker frequency (FLIM1) are below average and the differences between the perception of flicker frequency at increase (37.54 ± 2.22 Hz) and decrease (36.66 ± 3.16 Hz) of mental work performance are not statistically significant ($p=.216$, $df=56$; variance $F=2.033$; variance $P=0.060$). The mean threshold values of the perception of flicker frequency (FLIM2, Figure 2B) are higher: with an increase in mental performance they are within the average range (40.39 ± 3.84) and with a decrease in performance, this range is 39.80 ± 5.97 Hz. The differences between the perception of these frequencies are also not statistically significant ($p=.646$, $df=56$; variance $F=2.412$; variance $P=0.020$).

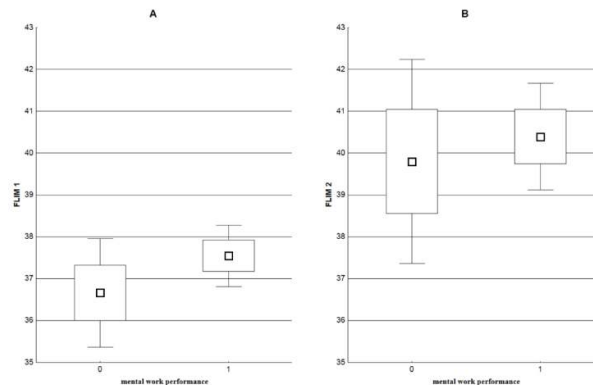


Figure 2. Thresholds of perception of fusion frequency (ALS1) and flicker frequency (ALS2) in relation to an increase (1) and decrease (0) in mental performance.

The detailed one-way ANOVA for fatigue (FLIM1, FLIM2) in relation to three measures of mental work performance: work speed measure (ALS1, Wilks' lambda=.00023; $F(80, 32)=25.963$; $p=.000$; eta squared=.098; alpha power = 1.000), error measure (ALS3, Wilks' lambda=.117; $F(56, 56)=1.916$; $p=.008$; eta squared=.065; alpha power = 0.996) and work accuracy measure (ALS4, Wilks' lambda=.496; $F(20, 92)=1.930$; $p=.018$; eta squared=.029; alpha power = 0.964) revealed the differences in the curves of these indices in comparison with the perception of the threshold of fusion frequency (FLIM1) and flicker frequency (FLIM2). The curves of the individual measures of mental performance demonstrate that faster mental work (ALS1) is accompanied by

the perception of higher fusion frequency (FLIM1) and flicker frequency (FLIM2), that is, fatigue occurs with the perception of fusion and flicker frequencies at low-frequency thresholds. A higher percentage of errors (ALS 3) is accompanied by a low fusion frequency (FLIM1) and a higher flicker frequency (FLIM 2), with larger standard deviations. A similar pattern is observed for the curve of a measure of mental work accuracy shown by error correction (ALS4) versus perception of lower thresholds of fusion frequency (FLIM 1) and versus perception of higher thresholds of flicker frequency (ALS 2).

The positive strong relationship (Table 2) between the percentage of incorrect additions (ALS3) and the sum of error corrections (ALS4, $r=0.962$, $p<0.010$) is a measure of the accuracy of task performance, while the positive relationship between fusion light frequency (FLIM 1) and flicker light frequency (FLIM 2, $r=0.482$, $p<0.050$) may be indicative of the level of emotional arousal in terms of mental fatigue. Fusing light frequency (FLIM1) is associated with the percentage of incorrect additions (ALS3) at the correlation level ($r=-0.319$, $p<0.050$) and the sum of corrections as a measure of work accuracy (ALS4), also at the correlation level ($r=-0.286$, $p<0.050$). This directly proportional correlation between the level of emotional arousal and mental work performance is indicative of a psychological regularity concerning the threshold of flicker frequency i.e. Measures of the level of fatigue with the errors and corrections during solving mathematical tasks.

Table 2. Associations of measures of mental performance (ALS) and mental fatigue (FLIM). N=58.

Variables	ALS1	ALS2	ALS3	ALS4	FLIM1
ALS2	0.266				
ALS3	0.164	-0.223			
ALS4	-0.066	-0.311	0.962**		
FLIM1	0.251	0.152	0.319*	0.286*	
FLIM2	0.051	0.047	-0.084	-0.057	0.482*

** $p<0.010$, * $p<0.050$.

Figure 4 shows the relationship of flicker frequency (FLIM 1) during recording the level of emotional arousal with the high score of the percentage of incorrect solutions of the mathematical task. The directly proportional relationship between these measures indicates that the percentage of errors (ALS3; Figure 3A) is higher when the perception of the threshold of transition from light flickering to fusion (FLIM 1) occurs faster. In contrast, the relationship of the perception of fusion frequency and the sum of corrections as a measure of mental work accuracy (ALS4, Figure 3B) confirms this relationship.

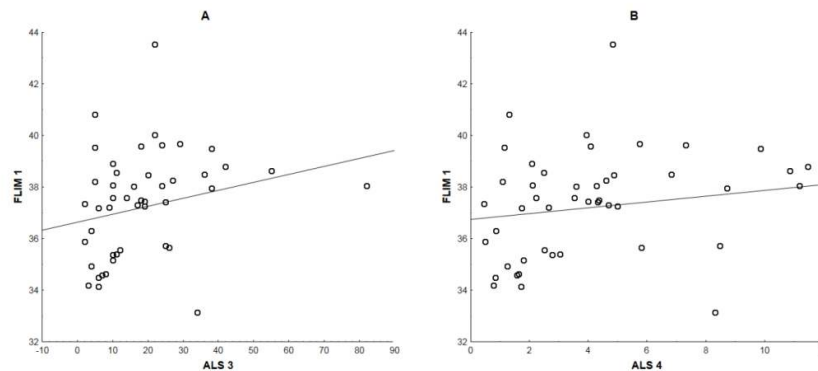


Figure 3. Associations of the percentage of incorrect additions (ALS3, Figure 3A) and the sum of corrections (ALS4, Figure 3B) with the perception of the threshold of fusion frequency (FLIM1). N=58.

Discussion

The interpretation of the results is based on the analysis of mental performance indices as a measure of speed, percentage of errors, and a measure of the accuracy of task performance, and mental fatigue indices as a measure of the perception of the threshold of flicker fusion frequency. The threshold values for flicker fusion frequency are considered the measures of the same phenomenon, and the results of the research by Curran and Hindmarch (Altavilla et al. 2013, Curran and Hindmarch 1990) indicate strong positive correlations between them. People tend to feel more comfortable after increasing their perception of flicker and fusion frequency to 60 kHz (Veicht, McColl, 1995), although it is accepted (Schuhfried, 2004b) that average threshold frequencies range from 40 Hz to 60 Hz. Perception of the threshold of fusion and flicker frequency, i.e. subjective perception by of the transition from flickering to steady light and vice versa, is significantly related to the level of mental performance indices. A decrease in task performance speed and accuracy is reflected by the perception of a

decrease in flicker fusion frequency (Rózanowski et al. 2012; Clement 2011; Truszczyński et al. 2009; Truszczyński et al. 2012, Gaetano and Rago 2014). The frequencies decrease as the level of fatigue increases, which can also result from starting work quickly. In this case, the respondent needs more time to adapt to new situations. However, after a period of adaptation, he or she is able to maintain the pace longer because they have energy reserves. Takigasaki (2006) conducted the Uchida - Kraepelin work curve test twice (Shinrigaku 1995; Brandstätter 1995), with the first test performed at rest, while in the second test, one group (mountaineers) was tested in the mountains after three hours of climbing. The control group (non-climbers) performed the test at rest. The climbers showed more abnormalities during the second test compared to controls. In order to reduce the effects of fatigue on task performance, good preparation is indispensable (Sienkiewicz-Dianzenza i Masz, 2019). That includes the right selection of loads and their distribution, as well as good planning of intermissions. The speed and accuracy of tasks would, of course, decrease with fatigue, so an accurate assessment of resistance to fatigue is of prime importance. According to Obmiński and Borkowski (2010) good training improves the performance under fatigue conditions and the reaction time may be crucial. The speed and accuracy of tasks to external stimuli were found to significantly decrease with mounting fatigue. This suggests that high levels of fatigue reduced the ability to cope with the task performed. Mental performance may also be related to attention (Mikicin 2013, 2014). A low percentage of errors and corrections indicates a natural and habitual tendency to work accurately, while a high percentage of corrections indicates that the subject is tense, nervous, and has difficulty paying attention.

Conclusion

An increase or decrease in the speed and accuracy of tasks is a measure of mental work performance. A high level of fatigue manifested by the perception of low threshold values of flicker fusion frequencies does not allow for the fast and accurate performance of mental work. These frequencies decrease as the level of fatigue increases.

Declaration of Conflicting Interests

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

These data have not been published before and are not submitted elsewhere.

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