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Psycho Physiological and Subjective Responses to Mental Workload Levels during N-Back Task

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Abstract

The present study investigated the effects of mental workload levels on psychophysiological and subjective responses during n-Back task. Heart rate, heart rate variability, shoulder muscle activity, EEG and EOG were measured during performing four mental tasks by 32 males. NASA-TLX completed at the end of each mental task. Using NASA-TLX the subjects stated that the task demands of very high mental task were higher than those of low, medium and high mental tasks. By increasing mental workload LF/HF ratio, shoulder muscle activity, eye activity and alpha activity significantly changed. It suggests that mentioned indices have enough sensitivity to quantify mental workload. Future studies should implement to determine the long-term effects such as cardiovascular and mental disorders in both males and females which experience different levels of mental workload in daily working condition. To get better results suggested those parameters such as: cultural differences, anthropometric data, body mass index, alertness, shift work and menstrual cycle take into account.

Keywords: EEG; EMG; EOG; Heart rate; Heart rate variability; Mental workload; NASA-TLX

Introduction

Many ergonomists or researchers are trying to evaluate Mental Workload (MWL) quantitatively using different methods such as subjective and physiological measures [1]. At this time, the measurement of MWL is an important matter in the research and development of human-machine interfaces, in quest of higher levels of relief, pleasure, efficiency, and safety in the workplace. These are the great aims of ergonomics [2]. MWL cannot be measured directly, but must be appraised indirectly by measuring parameters considered to be related to it. In fact, MWL is a multidimensional idea with many facets and there is no single meter that can evaluate all its ingredients [3]. Methods for evaluating MWL have been reviewed and can be found in Cannon et al. study [4]. For evaluating of MWL there are three sets of methods: subjective, performance, and psycho physiological measurements [2,5-8]. In the last three decades, in ergonomics, using a combination of these three methods to evaluate user's MWL has been increased [6]. Performance-based and psycho physiological methods give in real time information about the objective situations of the interaction or the tasks' requirements for particular resources but subjective methods bid us information about user's feeling of the situations of task [9]. The first division of methods to evaluating MWL is with subjective techniques. A variety of tests and questionnaires has been grown to determine this subjective rating, such as the NASA-Task Load Index (TLX) [10] or the Subjective Workload Assessment Technique (SWAT) [11].

Lenneman and Backs [12] and Mehler et al. [13] have been represented that psycho physiological methods were more sensitive to initial changes in workload than performance-based methods. Psycho physiological methods are a non-invasive technique of characterizing relative MWL [14,15]. The techniques most often used in ergonomics applications are: cardiovascular activity (e.g., heart rate, heart rate variability, blood pressure, pulse wave velocity, and plethysmography), electroencephalography (EEG, event-related brain potentials, brain DC potentials, and event-related desynchronization), the electromyogram (to monitor the activity of specific muscles), skin activity (specific and non-specific responses with various methods), eye movements, body and skin temperature, and hormonal responses [16,17]. The electrophysiological or psycho physiological methods have advantages: (1) they are objective, and (2) they can be gathered in real time [18]. Moreover, psycho physiological signals are continuously available and can be obtained in a non-intrusive manner, pre-requisite for their use in operational environments [4]. In Europe and North America the importance of evaluating MWL has been well recognized [18]. Much research has been carried out to evaluate MWL using performance, psycho physiological and subjective methods [19-23]. Almost all of this research has been conducted in Europe and North America countries or in highly industrialized countries such as Japan [18] but in our country there is a large gap to implement such researches. Also avoiding of mental overload is important, because it increases emotional stress and declines critical human decision-making processes [14]. When MWL increased the operators may demonstrate delayed information processing, or even not react at all to the received information, because the amount of information outstrips their capacity to process it [24]. Thus, health problems such as chronic stress, depression, or burnout will be happen [25]. Therefore, this study aims to investigate MWL levels effects on pyschophysiological (shoulder muscles, brain activities, eye activity, heart rate and heart rate variability) and subjective responses during performing n-Back memory tasks.

Materials and Methods

Subjects

Thirty two university male students (M_{age}=27; SD=7; range=20-34) participated in the study. They were right handed with normal

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or corrected-to-normal vision, had no history of cardiovascular disease, did not take any medications which may influence their task performance and were not smokers. The protocol of this experimental study has been approved by the Research Ethics Committee of Hamadan University of Medical Sciences. All participants read and signed the consent form before the experiment. The experiment was designed to investigate different levels of MWL. Four tasks with low, medium, high and very high MWL were chosen. Each block consisted of a rest (5 min), workload (four sessions: 20 min) and recovery (5 min) period. Each subject performed all block on a defined day. It is necessary to mentioned that each subject rested for 5 min after performing each block.

Tasks

To induce different levels of MWL, we used the N-Back memory task [26]. N-Back tasks are continuous-recognition measures that present stimulus sequences, such as letters or images; for each item in the sequence, subject judge whether it matches the one presented n items ago (Figure 1). N-Back has face validity as a Working Memory (WM) task because subjects must maintain and update a dynamic rehearsal set while reacting to each item [27]. Performance in this task can be measured by recording the amount of missed targets, when the participants do not press the key for a target and through the amount of wrong responses, when the participants incorrectly identify a stimulus as a target [28]. Four variants of this task were used to impose low, medium, high and very high workloads which are likely to be present during operators of industrial process control room working day:

1. Position 1 Back (Low Workload; very easy task with visual stimuli): A square was appeared every 4.5 seconds in one of eight different positions on a regular grid on the screen. The subject has to respond by using the keyboard (press A button) if the position of the currently shown square is the same as the one that was presented just before. This kind of workload is comparable to monotonous monitoring tasks where the subject has to sustain his attention at the same level.

2. Position, image 1 Back (medium workload): In this mode, the two former position and image match tasks are combined. An undefined image was appeared every 4.5 seconds in one of eight different positions on a regular grid on the screen. If the position and image of the currently shown stimuli was the same as the one that was presented just before, subject has to press A and J button on the keyboard, respectively. This task reflects medium mental load since the subject has to memorize the position and image of a stimulus.
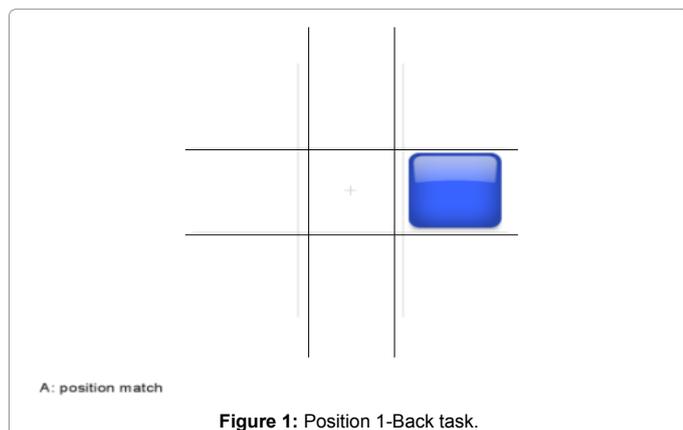
3. Position, color, image 1 Back (high workload): In this mode, the three former position, color and image match tasks were combined. An undefined colored image stimulus was appeared every 4.5 seconds in one of eight different positions on a regular grid on the screen. If the position, color and image of the currently shown stimuli were the same as the one that was presented just before, subject has to press A, F and J button on the keyboard, respectively. This task reflects high mental load since the subject has to memorize the position, color and image of a stimulus.

4. Position 2 Back (very high workload; very hard task with visual stimuli): A square was appeared every 4.5 seconds in one of eight different positions on a regular grid on the screen. The subject has to respond by using the keyboard (press A button) if the position of the currently shown square is the same as the one that was presented just two times before. This kind of MWL was comparable to complex monitoring tasks where the subject has to sustain his attention at the same level.

Procedure

Before the experiment, the subject took a 10 min rest in a quiet room in a relaxed condition to become adapted to the experimental situation and then wore the measurement apparatus. The experimenter explained in detail the experimental tasks and instructed the participants to operate the n-Back WM task. In order to let the subjects focus their attention on the n-Back memory task, the experimenter emphasized the importance of each task to them and also asked to avoid body movement during the experiment. They took about 10 min to practice the four n-Back tasks prior to the experiment. During experiment, they had to focus the task and complete a series of position, color, image matches, based on n-Back task, simultaneously. All experiments conducted between 9:00-13:00 which take 2 h for each subject. All of them did not take lunch. They completed the following blocks: a) rest with eyes open (5 min; Rest), b) Position, color, image, audio 1-Back task (5-min; high level), after that 5 min rest, c) Position, color, image, 1-Back task (5-min; medium level), after that 5 min rest, d) Position, image, 1-Back task (5-min; low level), after that 5 min rest, e) Position 1-Back task (5-min; very low level) after that 5 min rest and f) rest with eyes open (5 min; Recovery). The order of task difficulty level was not randomized but set in the same order, i.e., very high, high, medium and low to avoid spoiling the effects of the difficulty level by a learning effect. The psychophysiological indices were recorded during each block and the NASA-TLX questionnaire was completed after each block to evaluate the subjective MWL of different levels of task complexity. Also correct rate (%) of subjects after completing each n-Back task was recorded by experimenter.

Subjective ratings

The NASA Task Load Index (Hart and Staveland, 1988) was used to evaluate subjective workload of the participants. We used the paper & pencil version of NASA-TLX. The experimenter asked each subject to self-report his n-Back task MWL. The NASA-TLX technique includes six sub-scales (MD, mental demand; PD, physical demand; TD, temporal demand; OP, own performance; EF, effort; and FR, frustration). The mean (raw TLX) and weighted mean (WWL: weighted workload) of these six sub-scales were calculated.

Psychophysiolcal measurement

A NeXus from Mind Media B.V. was used for data collection. The NeXus is a psychophysiological monitoring and biofeedback platform

A: position match

Figure 1: Position 1-Back task.

that utilizes Bluetooth technology 1.1 class two wireless communication and flash memory techniques. This system allowed for the acquisition of signals, including raw EEG, ECG, EMG, EOG etc. The acquired signals were wirelessly transmitted, using Bluetooth wireless communication, for online monitoring and data storage. Online graphic presentations of the physiological parameters and retrieval of database, data processing, digital filtering, report of trends and statistical analysis functions were provided by compatible software (BioTrace+software®, Mind Media BV, Roermond-Herten, The Netherlands). Physiological parameters, heart rate (ECG) and muscle tension (EMG) were recorded using channels operating at a sample frequency of 1024 Hz. Muscle activity was recorded using EMG for shoulder muscles (upper-trapezius) on both sides of the shoulder using a bipolar recording montage. Root Mean Square (RMS) amplitude calculation was used to quantify the

muscle activity in the signal. The RMS data were calculated on the fly by the program software (Biotrace+software). The digital EMG band pass filter was set to 20-500 Hz. Biotrace+uses the ECG signal from the NeXus mostly to measure HR and HRV. The ECG was recorded using three Ag-AgCl electrodes. Electrodes were placed at the distal part of sternum and at the sixth rib in the left axilla. HRV, which refers to the beat-to-beat alterations in HR, was evaluated on the basis of ECG recordings during all six blocks. From the recorded ECG signals the following features were calculated: the mean value of the HR (Mean HR), the RMS of the successive difference of the RR intervals (RMSSD), and the ratio of the LF over the HF (LF/HF) (Figure 2). Channels operating at a sample frequency of 256 Hz were used to measure EEG (Figure 3) and EOG. For measuring these electrophysiological signals, NeXus uses carbon coated cables with active shielding. Effectively
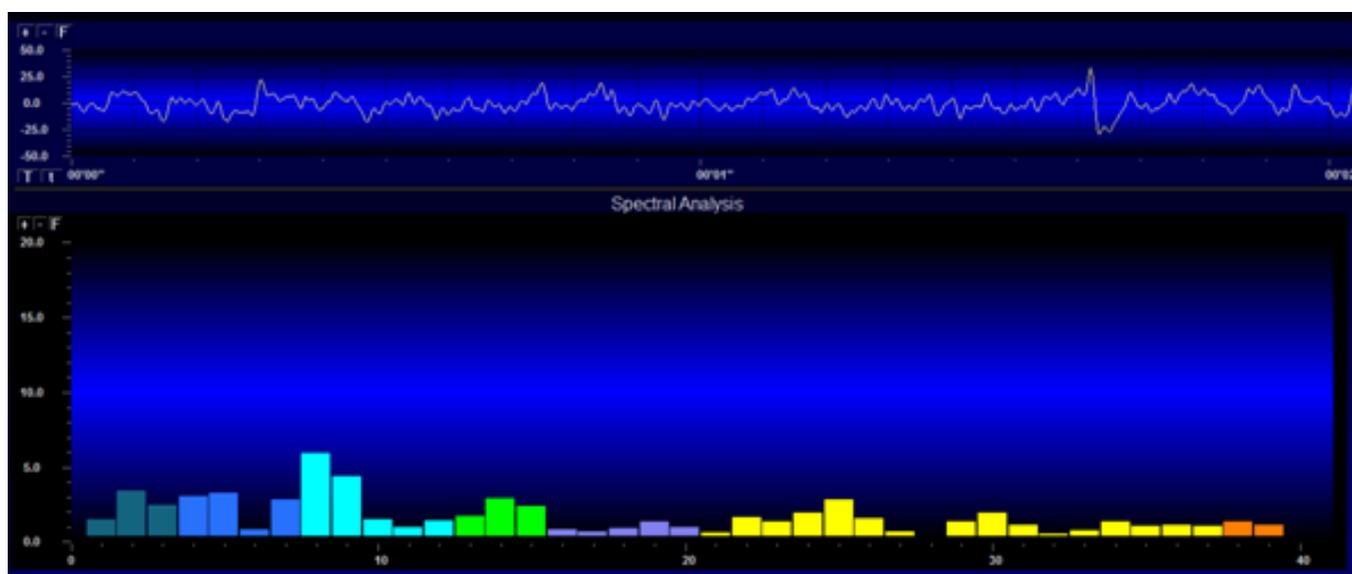

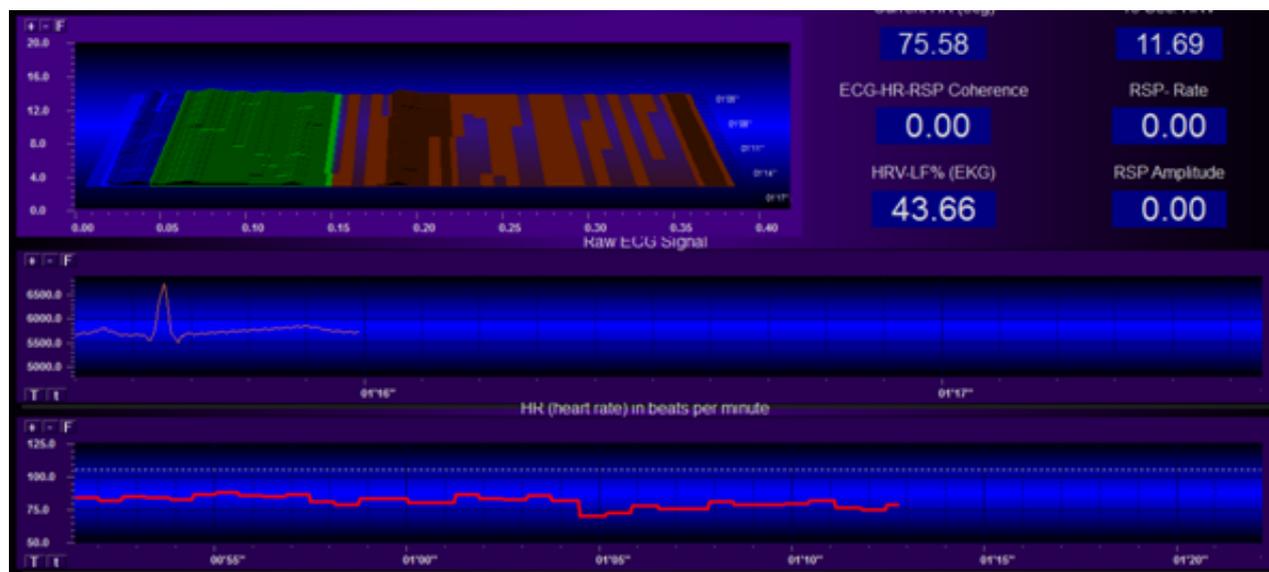**Figure 2:** EEG spectral analysis.

Figure 3: ECG spectral analysis.

that means very clean signals with virtually no movement artifacts. For electrode placement, we use the international 10-20 EEG system. We placed the EEG electrodes on the head using NuPrep (for skin preparation) and 10-20 EEG paste. We used input A of nexus for one channel of EEG. For a basic one channel EEG signal recording typically the left ear (or mastoid) was used for the reference electrode. The red electrode was placed on Cz and the ground electrode (white) was placed on the right ear. We optionally used the second channel (input B) for EOG checking (measuring eye blinks and movements). To record EOG (theta band), we placed one small ECG/EMG electrode above and one below the left eye (Vertical EOG).

Data analysis

The difference between subjective responses at four blocks for all sub-scales and overall workload of the NASA-TLX were analyzed using a one-way repeated measures analysis of variance (ANOVA). All psychophysiological parameters were analyzed by applying a one-way repeated measure ANOVA to examine the differences between measuring conditions (resting, low, medium, high, very high and recovery). The Greenhouse-Geisser correction was applied. The effect size index was reported and the Bonferroni multiple comparison method was used. The statistical analysis was conducted using SPSS software version 21.0. A 5% significance level was adopted in all tests.

Results

Subjective measure

The mean values including standard deviations of all NASA-TLX dimensions in four blocks have been illustrated in Table 1. All of NASA-TLX sub-scales except OP significantly increased by increasing MWL. An inconsistent change was observed for OP among subjects. For NASA-TLX (WWL) repeated measure ANOVA revealed a significant main effect for block ($F_{(2.625, 81.378)}=150.876$, $p<0.001$). Post hoc comparisons indicated that WWL during very high n-Back mental task was significantly greater than those during the low, medium and high mental tasks ($p<0.001$). Post-hoc analysis of the six dimensions of NASA-TLX except for OP ($F_{(2,39.20)}=42.719$, $p=0.066$) revealed significantly higher MD ($F_{(2,30)}=106.615$, $p=0.008$), higher PD ($F_{(2,30)}=31.618$, $p=0.035$), more TD ($F_{(2,30)}=66.561$, $p=0.022$), , greater EF ($F_{(2,30)}=67.194$, $p=0.041$) and higher FR ($F_{(2,30)}=63.810$, $p=0.021$) in very high n-Back task compared to low, medium and high mental tasks (Figure 4).

Performance measure

Figure 5 displays the correct rate (performance) for subjects. ANOVA revealed a significant main effect for block ($F_{(2.283, 70.779)}=34.685$, $p<0.001$). Post hoc comparisons indicated correct rate during very high n-Back mental task except for high mental task ($P=0.074$) was significantly higher than those during low and medium mental tasks ($p<0.001$).

Psychophysiological measures

The mean values including standard errors of psychophysiological indices among subjects in six blocks have been illustrated in Table 2. The results indicated that as MWL was increased; inconsistence changes were observed in HR, RMSSD, and θ and β band activity. By increasing MWL, LF/HF ratio, shoulder muscle activity, eye activity and α activity significantly changed. For HR, RMSSD, θ and β activity repeated measure ANOVA did not reveal a significant main effect for block ($F_{(4.303, 133.401)}=0.743$, $p=0.573$), ($F_{(3.34, 103.546)}=1.884$, $p=0.13$),

($F_{(2.017, 62.519)}=0.904$, $p=0.411$) and ($F_{(1.335, 41.395)}=0.429$, $p=0.573$), respectively. Figure 6 demonstrates the changes in LF/HF ratio among subjects. For LF/HF ratio repeated measure ANOVA revealed a significant main effect for block ($F_{(2.341, 72.572)}=19.344$, $p<0.001$). Post hoc comparisons indicated that LF/HF ratio during very high n-Back mental task was significantly greater than those during the rest period and low mental task ($p<0.001$), medium task ($p=0.001$) and recovery period ($p=0.040$) except for high mental task ($p=0.179$). Figure 7 illustrates the changes in shoulder muscle activity among subjects. For shoulder muscle activity repeated measure ANOVA revealed a significant main effect for block ($F_{(2.228, 69.069)}=23.218$, $p<0.001$). Post hoc comparisons indicated that shoulder muscle activity during very high n-Back mental task was significantly greater than those during the rest and recovery periods ($p<0.001$) and low mental task ($p<0.007$), except for medium and high mental tasks ($p>0.05$).

Figure 8 shows the changes in α band activity among subjects. For α band activity repeated measure ANOVA revealed a significant main effect for block ($F_{(2.984, 92.501)}=55.687$, $p<0.001$). Post hoc comparisons indicated that alpha activity during very high n-Back mental task was significantly lower than those during the rest and recovery periods, low and medium mental tasks ($p<0.001$) and high mental task ($p=0.005$). Figure 9 shows the changes in eye activity among subjects. For eye activity repeated measure ANOVA revealed a significant main effect for block ($F_{(2.074, 64.3)}=24.371$, $p<0.001$). Post hoc comparisons indicated that eye activity during very high n-Back
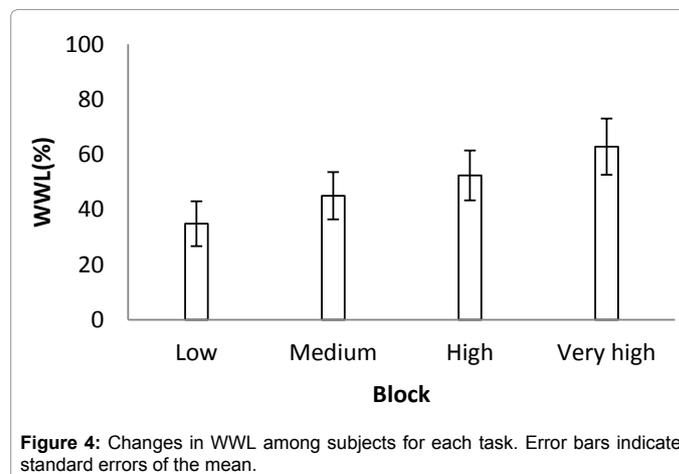

Figure 4: Changes in WWL among subjects for each task. Error bars indicate standard errors of the mean.
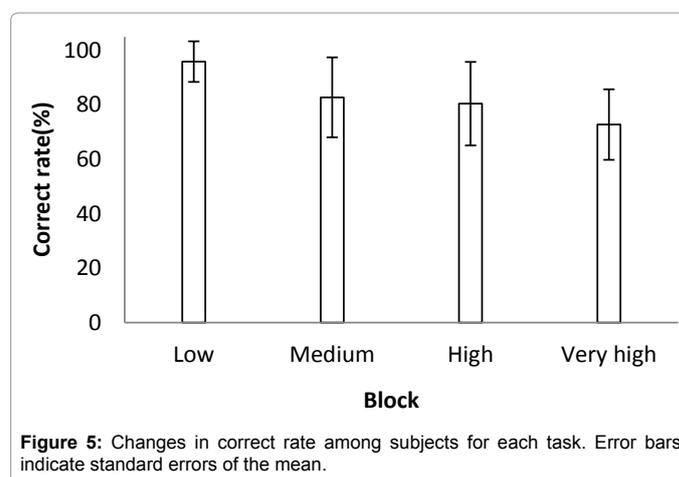

Figure 5: Changes in correct rate among subjects for each task. Error bars indicate standard errors of the mean.

Repeated Measures ANOVA Result						
NASA TLX	Low	Medium	High	Very High	p value	Effect Size
MD	26.5 ± 14.70	46.3 ± 16.13	50.5 ± 18.35	72.5 ± 16.49	0.008	0.671
PD	16.2 ± 13.69	26.5 ± 16.72	32.2 ± 22.38	41 ± 27.80	0.035	0.271
TD	23.5 ± 15.99	41.8 ± 16.89	46.8 ± 21.15	62.8 ± 20.9	0.022	0.394
OP	66.2 ± 27.06	58.7 ± 20.50	61.3 ± 21.10	55.0 ± 18.70	0.066	0.091
EF	36.0 ± 24.70	54.0 ± 19.80	58.3 ± 17.60	65.5 ± 19.80	0.041	0.198
FR	24.0 ± 16.50	35 ± 18.50	39.8 ± 22.50	46.7 ± 22.80	0.021	0.383
WWL	34.9 ± 8.14	45.0 ± 8.58	52.4 ± 9.05	62.8 ± 10.21	<0.001	0.830
MD: Mental Demand; PD: Physical Demand; TD: Temporal Demand; OP: Own Performance; EF: Effort; FR: Frustration; WWL: Weighted Workload						

Table1: Comparison of subjective variables Means ± S.D across four blocks among subjects.

Repeated Measures ANOVA Result									
Variables	Rest	Low	Medium	High	Very high	Recovery	P value	Effect size	ε
HR (beats/min)	76.66 ± 0.79	76.97 ± 0.85	77.05 ± 0.79	77.00 ± 0.75	76.51 ± 0.89	76.50 ± 0.84	0.573	0.023	0.861
RMSSD (ms)	127.24 ± 18.59	79.11 ± 13.69	123.06 ± 23.80	126.43 ± 25.22	121.53 ± 19.39	136.12 ± 20.69	0.13	0.057	0.668
LF/HF ratio	1.54 ± 0.26	1.87 ± 0.29	2.26 ± 0.29	2.69 ± 0.29	3.01 ± 0.28	2.52 ± 0.23	<0.001	0.384	0.468
EMG.amp (µv)	15.93 ± 0.63	23.44 ± 1.39	29.73 ± 2.13	31.21 ± 2.33	32.78 ± 2.75	17.83 ± 1.00	<0.001	0.428	0.446
Theta (µv)	12.17 ± 1.59	11.23 ± 1.08	11.19 ± 1.14	10.68 ± 0.79	12.37 ± 1.45	12.58 ± 1.37	0.411	0.028	0.403
Alpha (µv)	10.96 ± 0.42	10.05 ± 0.39	9.57 ± 0.36	9.10 ± 0.33	8.77 ± 0.30	10.86 ± 0.35	<0.001	0.642	0.597
Beta (µv)	4.36 ± 0.24	4.47 ± 0.28	4.39 ± 0.29	5.17 ± 1.16	4.23 ± 0.32	4.65 ± 0.38	0.573	0.014	0.267
EOG (µv)	18.87 ± 1.00	24.98 ± 1.39	31.50 ± 1.99	30.22 ± 2.86	37.46 ± 2.79	21.86 ± 1.45	<0.001	0.440	0.415

Table2: Psychophysiological variables Means ± S.E across six blocks among subjects.
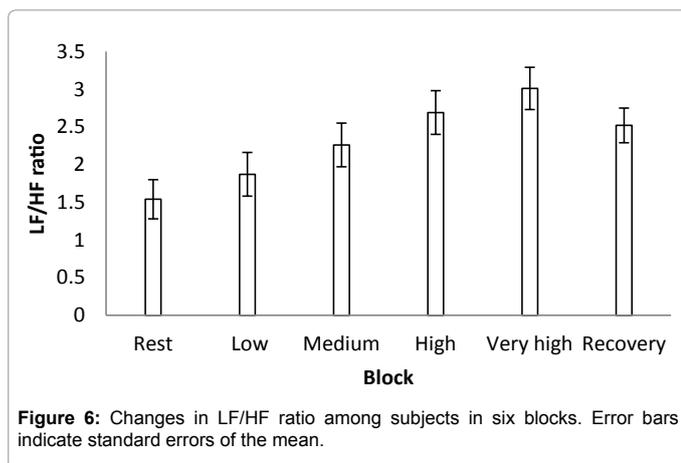

Figure 6: Changes in LF/HF ratio among subjects in six blocks. Error bars indicate standard errors of the mean.
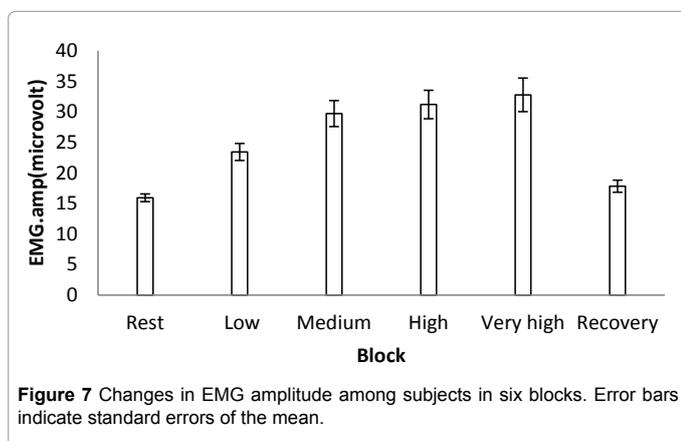

Figure 7 Changes in EMG amplitude among subjects in six blocks. Error bars indicate standard errors of the mean.

mental task was significantly greater than those during the rest and recovery periods, low and high mental tasks (p<0.001) and medium task (p=0.008).

Discussion

The present study investigates the cardiovascular indices, shoulder muscle activity, eye activity, EEG and subjective responses of subjects to their MWL in n-Back task. It is necessary to mention that the instructions to subjects may have affected subjective parameters such as NASA-TLX. Therefore, it is almost impossible to reject such an effect on subjective measures. Thus, besides NASA-TLX, we used psychophysiological measures to evaluate MWL. The findings suggest that an experimental MWL condition consisting of four n-Back task, as other types of mental work (arithmetic) applied in the laboratory; can effect on some psychophysiological indices and subjective responses.

Using NASA-TLX the subjects stated that the task demands of the very high n-Back task were higher than those of the low, medium and high blocks. In the low, medium and high mental tasks, OP was most important and at very high mental task MD was most important. This means that subjects tried to maintain their performance at the highest level in the low, medium and high mental tasks and when intensity of mental work increased MD increased as well. It seems that when intensity of mental work increased, subjects experienced more mental stress, which could lead to mental disorders under these circumstances. The study did not support the significant effect of n-Back mental tasks on HR. HR during mental arithmetic task was significantly higher than those during two rest periods and the modified mirror tracking task [29].

An inconsistence changes in HRV feature; RMSSD was observed among subjects while conducting four n-Back tasks compared to rest and recovery periods. It seems that this HRV feature is less sensitive to different n-Back tasks. Kuraoka et al. [30] suggested that HR was more affected by task characteristics (mental arithmetic and mirror tracing tasks) than other indices such as HRV parameters. Cinaz et al. [25] demonstrated the feature RMSSD significantly decreases with increased MWL.

The findings showed that by increasing MWL, LF/HF ratio, shoulder muscle activity, eye activity and α activity significantly changed. LF/HF ratio was increased as MWL increased. Cinaz et al. [25]
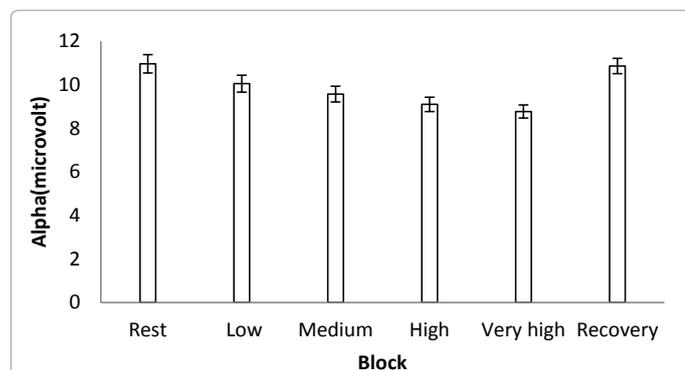
Figure 8: Changes in alpha band activity among subjects in six blocks. Error bars indicate standard errors of the mean.
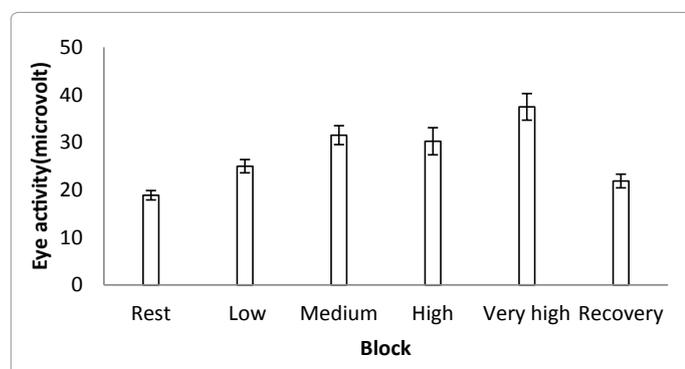

Figure 9: Changes in eye activity among subjects in six blocks. Error bars indicate standard errors of the mean.

indicated that LF/HF ratio significantly increases with increased MWL, the matter which observed in this study. Hwang et al. [7] demonstrated by increasing task complexity, HR and LF/HF ratio increased and HRV decreased for most of subjects. Billman [31] argued that the LF/HF ratio is an appropriate tool to evaluate cardiovascular autonomic regulation where increases in LF/HF are assumed to reflect a shift to "sympathetic dominance" and decreases in this index correspond to "parasympathetic dominance."

Shoulder muscle activity was higher during n-Back tasks compared to rest and recovery periods. The subjects used adjustable chair and same desk to do mental task. The experimenter asked them to adjust chair height before start the experiment. So it may be possible that the higher EMG amplitudes are due to the MWL rather than their posture. We did not measure subjects' anthropometric dimensions. It is suggested for future studies researchers measured subjects' anthropometric dimensions and if it was possible, all of them respond orally to induce mental task without using mouse. Kristiansen et al. [32] concluded that EMG amplitude increased in both dominant and non-dominant side in response to the mental work tasks. Also Mehta and Agnew [22] concluded that MWL has adverse effect such as tolerance reduction and fatigue on shoulder muscle.

In all n-Back tasks as intensity of mental task (or MWL) increased, time interval (4.5 seconds) of appearing undefined colored image stimulus for each n-Back task was identical. Thus all participants experienced time pressure with increasing MWL. Galy et al. [33] investigated the effects of task difficulty, time pressure and alertness in a WM task. Their results demonstrated additive effects of task difficulty and time pressure, and a modulation by alertness on behavioral, subjective and psychophysiological workload measures.

Comparison results of EEG and theta band activity for EOG showed significant differences for the α band and θ band for EOG activity. We used θ band activity for left eye to evaluate subjects' MWL while n-Back task performing. They must continuously focus their attention on PC monitor to identify correct targets. The results from the EOG showed that the θ band amplitude was higher during the very high mental task than the low, medium, high, rest and recovery blocks. It means that because of time pressure the subjects' eye blink duration was shorter while speed of eye blink was higher during the very high mental task compared to others. These results were similar to Doppelmayr et al. [34] study.

The results from the EEG showed that the α band activity was significantly lower during very high mental task than low, medium, high, and rest and recovery blocks. The decreased EEG α band amplitude indicates that the subjects experienced fatigue. According to the Ryu and Myung [24] study the α band suppression showed a systematic decrease, as the difficulty of the arithmetic task increased. α Band activity at the parietal sites has been demonstrated to decrease with increases in WM load [35].

Limitations

Some limitations of this study should be mentioned. All subjects were men. Thus the study did not address the effects of gender, nor did it report any gender differences while quantifying the effects of mental work intensity on psychophysiological responses. Future research should try to evaluate the MWL of humans in laboratory and real working condition with both men and women. Our results imply that increasing mental work intensity acutely significantly effect on the psychophysiological responses including: LF/HF ratio, α band activity and EMG amplitudes. Then impact of MWL should be further studied in individuals perform mental tasks on a real work condition to better understand its long term effect on health. Finally, in the present study we used n-Back task as mental work condition which is differ from Multi Attribute Task Battery [36], arithmetic task [34] and computer job tasks [37] what has been used in the literature.

Conclusion

These results support that MWL have significant effect on LF/HF ratio, α band activity, θ band activity of eye and shoulder muscle activity in healthy subjects and suggest that mentioned indices have enough sensitivity to quantify MWL. Future studies should implement to determine the long-term effects such as cardiovascular and mental disorders in both males and females which experience different levels of MWL in daily working condition. To get better results suggested those parameters such as: cultural differences, anthropometric data, body mass index, alertness, shift work and menstrual cycle take into account in future studies.

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