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Analysis of the mental workload of city traffic control operators while monitoring traffic density: A field study

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ABSTRACT

Introduction: It is important to evaluate when and why the mental workload of operators increases during system operation. The city traffic control center (TCC) is a complex work system, and it is important to describe MW as a condition related to this. The purpose of this study is to evaluate the mental workload of operators while monitoring traffic loads in the city TCC.
Methods: Electroencephalography and electrooculography data were collected from 16 operators while performing their daily work, in four conditions: resting state, low traffic density, high traffic density, and recovery. The Simplified-Subjective Workload Assessment Technique (S-SWAT) was used to evaluate the subjective workload of operators.
Results: The findings indicate that operators experience a larger mental workload during high traffic density than during low traffic density ($p < 0.001$). TCC stressors led to significant changes in EEG bands, such as theta, alpha, and eye activity. Significant differences were observed for subjective ratings of MW ($p < 0.001$).
Conclusion: Although the working situations of TCC operators are repeated daily, their mental fatigue and stress level gradually increase, leading to deterioration in their mental health. It may be necessary periodically to monitor their mental health and to consider their organizational behavior during traffic density monitoring.
Relevance to industry: complex work systems have increased the requirement for many operators to conduct mental tasks in real work conditions such as city traffic density monitoring. When evaluating such workplaces, it is important to identify situations requiring increased mental workload that might impose additional stress on operators, decreasing their performance. Based on the results, the traffic control center director would be aware of the MW condition of the operators.

1. Introduction

To design and evaluate an occupational task, it is important to analyze its mental workload (MW) (Didomenico and Nussbaum, 2011). The concept of MW has become a dominant issue for all kinds of industry after 1960s (Kum et al., 2007). MW has been considered an important factor in human performance in complex systems and both under-stimulation as well as mental overload is associated with decreased performance (Lysaght et al., 1989), increased errors (Desmond and Hoyes, 1996) and decreased operator wellbeing (Johnson and Widyanti, 2011). With the rapid development of technology, complex work systems have

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progressed, in which operators must adapt their decision-making and performance in the face of dynamic, ever-changing environments, concurrent task demands, time pressure, and tactical constraints (Moray, 1997).* MW—or just workload—"is the general term applied to describe the mental cost of executing task requirements" (Hart and Wickens, 1990; Wickens, 1992). It is difficult to match task demands and human capabilities (Lai et al., 2014). When a human operator experiences different workload demands in response to a task, his capacity to deal with those demands is crucial (Hopkin, 1995). High degrees of workload occur when task demands surpass operator capacity (Loft et al., 2007). It is crucial to understand the information processing of mental tasks imposed on humans (Johnson and Widyanti, 2011). If human operators experience extensive MW in their daily work, with insufficient rest time, health problems, such as chronic stress, depression or burnout will ensue (Cinaz et al., 2013). It is also important to evaluate when and why operator MW increased during system operation (Jo et al., 2012). The assessment and prediction of the MW related to operating such complex systems has long been recognized as important (Moray, 1997).

MW may be subjectively or objectively assessed. Subjective evaluations, such as the NASA-Task Load Index (TLX), are inexpensive and easily administered, but are unable to provide precise reports, because of individual bias, and often require a large number of samples (Lean and Shan, 2012). The most widely employed subjective rating scales are the subjective workload assessment technique (SWAT) and the NASA-TLX (Dey and Mann, 2010). Objective measures require a relatively small number of samples and can provide more accurate reports than subjective measures, but they are more complex, requiring technical skill and operational experience (Lean and Shan, 2012).

Most studies apply information from the frequency bands of the EEG to analyze MW and fatigue (Käthner et al., 2014). To record physiological indices, physiological electrodes must be applied to the human body (using electroencephalography (EEG)). Popular physiological devices have some disadvantages, such as interfering with natural body movements, lack of comfort, the impracticality of wearing devices for a long period of time, and interference of bodily fluids, such as sweat (Tran et al., 2007). EEG is widely applied to evaluate MW. MW will lead to changes in EEG measures: alpha band, beta band, theta band, and delta band (Lean and Shan, 2012). EEG has sufficient time resolution, to allow the tracking of changes in mental status as complex behaviors are revealed. Furthermore, EEG signals can be acquired outside specialized laboratory environments, because of the compactness of the associated technology (Ryu and Myung, 2005).

In the workplace, the movement of operators can create artifacts and good quality EEG recordings are impossible. The EEG signal recording may be collected during real work tasks, at least in jobs in which most work is performed at a computer in an office-like environment. In some professions, such as traffic control or industrial work, operators work in various shifts for 24 h. It is critical to evaluate their MW. The city TCC is a complex work system, in which the evaluation of MW is important. Yet research on this area is lacking.

The city of Mashhad is comprised of an area of approximately 275 square kilometers (Irannezhad et al., 2010) and is one of the 163 most populated cities in the world, with 2.63 million citizens in 2007 (Azari and Arintono, 2012). It is the second largest city in Iran (Shad, 2013), which accepts more than 32 million pilgrims a year (Irannezhad et al., 2010) and thus faces traffic problems (Shad, 2013). To solve these problems, the city implemented an Intelligent Transportation System (ITS). The ITS consists in a wide range of electronic technology, and wired and wireless communications based information. It includes a major subsystem called the Advanced Traffic Management System (ATMS). The ATMS can control traffic density in real time, and aims to minimize traffic load while maximizing movement of people and goods, to improve traffic density, and to focus on and manage travel demand (Samadi et al., 2012). To reach these goals, operators of TCC often face difficult task conditions when non-recurrent, non-predictable traffic density occurs (e.g., due to an incident or unexpected weather conditions). In these cases, in addition to local measures, an intervention at the network level is usually necessary to manage traffic density and to reinstitute a normal traffic situation. This involves TCC operators redirecting traffic density in a larger part of the network to decrease its effects. The operator has to assess the severity of the traffic density, predict the most probable evolution of the state of the network, and select the most appropriate actions. This complex task requires particular knowledge and a great deal of experience; each operator requires extensive training. Therefore, operators at the TCC continuously monitor traffic densities, which are unstructured and generally different (Hegyi et al., 2001).

It is important to analyze MW in real work conditions to prevent mental disorders and maintain mental health, but most research has focused on distinguishing different levels of MW in laboratory conditions (Cinaz et al., 2013). If the same scientific assessment tools and methods are used in the field, the findings might be more generalizable (Oron-Gilad et al., 2008). This information can be used to promote good ergonomics, by optimizing work demand level so that the risk to mental health is decreased. In this study we utilize approaches such as the subjective workload assessment technique (SWAT) and neurophysiologic assessment (EEG and EOG) to analyze the MW of operators under real working conditions at a city traffic control center.

2. Methods

2.1. Participants

Sixteen healthy male operators (mean age 29.4 ± 2.61 years) participated in this study. They were paid for their participation. They were right-handed, with normal or corrected-to-normal vision and hearing and had no diseases. All operators read and signed the consent form before the experiment. The experiment was designed to investigate MW in resting, low traffic density (LTD), high traffic density (HTD), and recovery conditions.

2.2. Procedure

The TCC (Fig. 1) operates 24 h a day, Saturday to Friday, with an on-call team available 24 h a day, seven days a week. The operators almost permanently monitor the traffic density of intersections from morning to night, including on weekends, and if an accident or special event occurs, they try to reestablish a normal traffic pattern in the city. There is a hierarchical environment at this TCC. During each shift, at the first level, four operators with less work experience perform the monitoring task. Three operators with more work experience work at the second level, and the third level is allocated to the shift supervisor, who typically has the most experience. Therefore, the supervisor usually manages the activities of seven operators in each work shift. The supervisor superintends car accidents/incidents and camera and sensor failures at intersections. In the TCC, 28 large LED monitors continuously indicate traffic load at the main intersections, highways, and ring roads of the city. Furthermore, during his work shift, each operator uses two monitors at his desk and continuously monitors the video images of at least 30 cameras at the intersections. Using such a system, the operator will be able to manage traffic signal timing and phasing for each intersection. He continuously moderates the signal timing to

Fig. 1. Mashhad traffic control center.

reduce traffic density and diminish delays. Operators usually have to resolve problems individually and without assistance. Such problems might be detected by the system itself or reported by the public or even local maintenance crews; all must be solved as soon as possible. The cameras are located at the most critical intersections in the city of Mashhad. Currently, 200 intersections are equipped with traffic cameras, with additional cameras installed on a continuous basis. The traffic cameras can pan, tilt, and zoom, and when special events occur the operators can observe video images of traffic conditions for all approach directions, adjacent intersections, and corridors.

In the center we studied, 23 operators worked for 12 h in two shifts, continuously. There was a morning shift from 6:00 to 18:00, and a night shift from 18:00 to 6:00. Each operator worked for 12 h and rested for 24 h (work-rest schedule: 12–24 h). The interval between shifts was 24 h, and all operators worked both morning and night shifts. The measurement time for the rest and recovery period at the beginning and end of the experiment was conducted exactly before or after of LTD (or HTD) condition for operators A-B and operators C-D (Fig. 2). First, we wanted to conduct an experiment among all TCC operators, but some of them did not cooperate. We explained the aim of the study and, thereafter, 16 operators agreed to participate in the study. We interviewed the operators and supervisors and asked them to characterize their real working conditions. We recognized that they experienced two different conditions during each work shift: situations with low traffic density, and situations with high traffic density in the city. Based on their statements, both LTD and HTD occur during both morning and night shifts, particularly on Saturdays, Wednesdays, and Tuesdays. Based on this information, measurements related to traffic conditions were conducted between 9:00 and 14:00and 18:00 and 23:00. Environmental conditions, such as workplace lighting and temperature, were suitable in the TCC. The average background noise levels during the morning and night work shifts were 48 dB and 43 dB, respectively. Furthermore, there were no accidents or severe changes in climate that would have evoked rapid MW change during the experiment. The experimenter specified a day with LTD and HTD conditions for each operator, during which the following steps were performed:

1. Before implementing the experiment, each operator was provided with the necessary information and descriptions, mainly about the EEG and EOG measurements, and how to complete the SWAT questionnaire. The dominant working posture of operators was sedentary, in that they had continuously to monitor the traffic load of their assigned intersections. To prevent errors and failure during the measurement procedure, the experimenter asked operators to make the least possible number of movements and to avoid talking to their colleagues while physiological indices were recorded.
2. After wearing EEG and EOG electrodes, EEG and EOG signals for each operator were recorded for five minutes in a resting condition with open eyes in a quiet room. For those five minutes, the operator's colleagues carried out his traffic monitoring for him.

Fig. 2. An example of experimental procedure. *The measurement is only for 5 min in Rest and Recovery period.

3. For each operator, while he monitored the LTD (or HTD) condition, EEG and EOG signals were recorded for one hour. There after, the experimenter asked each operator to complete the SWAT questionnaire.
4. For each operator, EEG and EOG signals were recorded for five minutes at the end of the shift with open eyes in a quiet room.

2.3. Subjective ratings

The subjective workload assessment technique (SWAT; Reid and Nygren, 1988) is a multidimensional scale, including three dimensions: Time Load (TL), Mental Effort Load (MEL), and Psychological Stress Load (PSL). For each dimension, the levels have descriptors that represent the lowest MW (level 1) to the highest MW (level 3). De Winter (2014) suggested that the NASA-TLX is the dominant scale in workload measurement and that other questionnaires, such as the SWAT, have gained modest popularity. He stated that the NASA-TLX is not the most sensitive or predictive-valid questionnaire available, but has been become popular because it has reached sufficient escape velocity and is now the clear choice for researchers. The SWAT has been criticized for having low sensitivity owing to its only having three-point scales (low, medium, and high) when measuring lower levels of MW (Cain, 2007) and for having a long pre-task sorting procedure (Cain, 2007; Luximon and Goonetilleke, 2001). Luximon and Goonetilleke (2001) conducted a study to evaluate five variations of the SWAT in an attempt to improve sensitivity as well as reduce pretesting time. They stated that variations in continuous scales were more sensitive than those that used discrete scales, and that variation with continuous dimensions that used an unweighted average of the three SWAT dimensions (TL, MEL, and PSL) measured workload with the highest sensitivity. This variation of the SWAT, the Simplified-SWAT (S-SWAT; Luximon and Goonetilleke (2001)), has been shown to hold the same statistical power as the SWAT technique, with increased sensitivity to lower levels of workload, and has no pre-task procedures. Morgan and Hancock (2011) conducted a driving simulation task containing demand transitions and evaluated perceived workload throughout the experiment with the S-SWAT. They suggest that the S-SWAT may be able to gather subjective workload data unobtrusively while participants perform a vigilance task. Based on the above explanation, the S-SWAT was chosen. After recording EEG and EOG signals for the LTD (or HTD) condition, each operator completed the S-SWAT questionnaire. All operators rated the three dimensions—TL, MEL, and PSL—on a scale ranging from 0 to 100, in increments of ten units. An unweighted average of the three scores was used to quantify the overall subjective workload levels. Furthermore, beside the S-SWAT score, three dimensions of the SWAT were calculated from 1 to 3.

2.4. Physiological measurement

A NeXus-4 from Mind Media B.V. was used for data collection. The NeXus-4 is a four-channel physiological monitoring and biofeedback platform 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, etcetera. 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 from EEG and EOG were recorded for this study. Channels operating at a sample frequency of 256 Hz were used to measure brain activity (EEG) and eye activity (EOG). NeXus is one of the few systems that has implemented active noise cancelation for physiological signals. To measure these electrophysiological signals, NeXus uses carbon-coated cables with active shielding, yielding clean signals with no movement artifacts. NeXus uses active noise cancelation technology, which reduces (movement) artifacts and external interference and provides good quality EEG signals. Environmental noise is electronically subtracted from the EXG signal, resulting in clean signals with few artifacts. Movement artifact is virtually absent; 50/60 Hz noise is low. For electrode placement, we used the international 10–20 EEG system. We placed 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).

2.5. Data analysis

The difference between subjective responses in LTD and HTD conditions during morning and night shifts for all dimensions and overall SWAT scores were analyzed using two-way analysis of variance (ANOVA). All physiological parameters were analyzed applying a two-way (2×4) repeated measures ANOVA to examine the differences between shift work and interactions with measuring conditions (rest, LTD, HTD, and recovery). The Greenhouse–Geisser correction was applied. The factor of shift included the factor between subjects. 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.

3. Results

3.1. Subjective workload

The age and work experience of operators were 29.44 ± 2.61 (SD) and 3.37 ± 2.28 (SD) years, respectively. The results of subjective ratings of workload measured by SWAT across LTD and HTD conditions are summarized in Table 1. SWAT score ranged from 0, representing no demand, to 100, representing maximum demand. According to SWAT scale norms, 0–40 is considering low MW, 41–60 moderate, and 61–100 high. Scores for the HTD and LTD conditions fell into the moderate (41–60) and low MW (0–40) categories, respectively. The operators reported higher task demand across the two different conditions of traffic control tasks. The results showed that, from the subjects' perspective, the degree of difficulty varied based on traffic density for each condition. In the LTD condition, mental effort loads (MEL) and in HTD condition time

Table 1
Comparison of subjective variables Means ± SD across LTD and HTD conditions.

	LTD condition	HTD condition
SWAT-score	24.53 ± 13.17	54.85 ± 12.48
SWAT-TL	1.56 ± 0.51	2.75 ± 0.44
SWAT-MEL	1.87 ± 0.71	2.62 ± 0.50
SWAT-PSL	1.62 ± 0.62	2.43 ± 0.63

SWAT: Subjective Workload Assessment Technique, TL: Time Load, MEL: Mental Effort Load, PSL: Psychological Stress Load.

load (TL) were most important. The results of subjective ratings of workload measured by SWAT across three conditions based on shift work are summarized in Table 2. In both morning and night shift work, operators reported progressively higher task demand across the two different conditions of traffic control tasks. In the LTD condition in morning and night shift work, MEL was more important than other dimensions. In the HTD condition, TL was more important than other dimensions in the morning shift work and MEL in the night shift work. A two-way ANOVA of the three SWAT dimensions revealed a significantly higher TL ($p < 0.001$) and MEL ($p < 0.001$), and more psychological stress load (PSL) ($p < 0.001$), and a SWAT score ($p < 0.001$) at HTD, compared to the LTD condition. Furthermore, significant shift-MW interactions were not found for all dimensions of SWAT (Table 2). Changes in SWAT scores between shifts across the two traffic densities are plotted in Fig. 3.

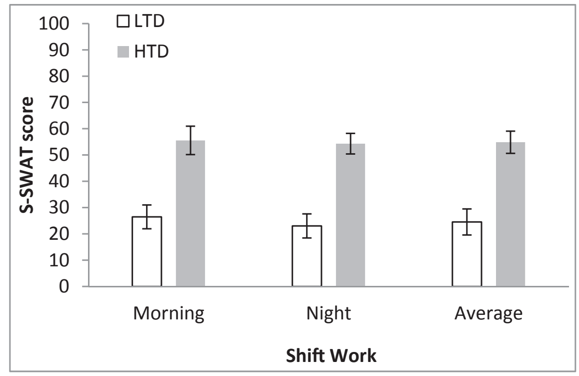

Fig. 3. Changes in S-SWAT score between shifts across two traffic density. Error bars indicate standard errors of the mean.

3.2. Physiological measures

The mean values including the standard errors of all operators' physiological indices in the rest, LTD, HTD, and recovery conditions are illustrated in Table 3. While traffic density increased, operators' alpha band values decreased and their eye activity increased. The results of the 2 × 4 repeated measures ANOVA indicated that increasing traffic load or MW had a significant main effect on the following features: theta, alpha bands of EEG and eye activity.

A 2 × 4 repeated measures ANOVA revealed a significant main effect of MW on theta band activity (F(2.341, 35.115) = 51.807, $\varepsilon = 0.780, p < 0.001$). A Bonferroni post-hoc test showed that there was a significant difference for mean theta band between rest and HTD ($p = 0.001$), rest and recovery ($p = 0.001$), LTD and recovery ($p = 0.001$) and LTD and HTD ($p = 0.003$). A 2 × 4 repeated measures ANOVA showed a significant main effect of MW on alpha band activity (F(1.577, 23.653) = 14.474, $\varepsilon = 0.526$, $p = 0.001$). Bonferroni post-hoc comparison revealed no significant difference for mean alpha band between recovery and LTD ($p = 0.872$). There was a significant difference between rest and HTD ($p = 0.001$), LTD and HTD ($p = 0.001$), HTD and rest ($p = 0.001$) and rest and recovery ($p = 0.015$). A 2 × 4 repeated measures ANOVA revealed a significant main effect of MW on eye activity (F(2.192, 32.885) = 81.089, $\varepsilon = 0.731$, $p < 0.001$). A Bonferroni post-hoc test indicated a significant difference for mean eye activity between rest and LTD ($p = 0.001$), rest and HTD ($p = 0.001$), and LTD and HTD ($p = 0.001$). No significant difference for mean eye activity between LTD and recovery ($p = 0.320$) and rest and recovery ($p = 0.170$) was observed.

The changes in physiological indices among TCC operators between shifts are plotted in Fig. 4. The mean values, including standard errors of all variables and results of statistical analysis in the resting, LTD, HTD, and recovery conditions are illustrated for both morning and night shift work, in Table 4. The results indicate that shift work did not have any effect on the following features: theta, alpha bands of EEG, and eye activity. Thus, the main effect of shift-MW interaction was not significant for the mentioned indices during the four conditions (Table 4).

Table 3
Comparison of physiological variables Means ± SE across rest, LTD, HTD and recovery conditions.

Variables	Rest	LTD condition	HTD condition	Recovery
Theta (μv)	16.73 ± 0.93	18.13 ± 1.48	26.83 ± 1.46	10.82 ± 0.36
Alpha (μv)	12.47 ± 0.35	11.48 ± 0.40	9.90 ± 0.32	10.66 ± 0.34
Eye activity (μv)	17.70 ± 094	25.00 ± 0.91	42.08 ± 2.01	21.65 ± 1.60

4. Discussion

In the current study, the brain and eye activity of operators at a TCC was investigated in real working conditions, while monitoring low and high traffic density congestion. Eye activity was recorded using EOG; brain activity was recorded using EEG. There have been few studies on MW using EEG and EOG in actual working conditions, especially in TCC operators. Findings of SWAT indicated that task demand was higher for operators in the HTD condition than in the LTD condition (moderate MW). MEL was dominant in the LTD condition; TL in the HTD condition. Operators reported needing more MEL compared to other dimensions in the LTD condition during both morning and night shifts. In the HTD condition, TL in morning shift work and MEL during night shifts were more important than the other dimensions. The findings indicate that operators try to maintain their performance at the highest level in both LTD and HTD condition during both morning and night shifts. However, an increase in traffic load during the HTD condition in morning and night shifts increases time pressure and mental

Table 2
Comparison of subjective variables Means ± SD across LTD and HTD conditions in the morning and at night shift work.

Two way ANOVA result									
Variables		LTD condition	HTD condition	Shift p value	MW p value	Shift × MW p value	Shift effect size	MW effect size	Shift × MW effect size
SWAT-score	morning	26.44 ± 11.98	55.55 ± 14.34	0.684	<0.001	0.769	0.012	0.832	0.006
	night	23.03 ± 14.55	54.31 ± 11.71						
SWAT-TL	morning	1.71 ± 0.48	2.85 ± 0.37	0.312	<0.001	0.710	0.073	0.901	0.010
	night	1.44 ± 0.52	2.66 ± 0.5						
SWAT-MEL	morning	1.85 ± 0.69	2.42 ± 0.53	0.509	<0.001	0.290	0.032	0.646	0.079
	night	1.88 ± 0.78	2.77 ± 0.44						
SWAT-PSL	morning	1.71 ± 0.48	2.57 ± 0.78	0.478	<0.001	0.819	0.037	0.621	0.004
	night	1.55 ± 0.72	2.33 ± 0.5						

MW: Mental Workload, SWAT: Subjective Workload Assessment Technique, TL: Time Load, MEL: Mental Effort Load, PSL: Psychological Stress Load.

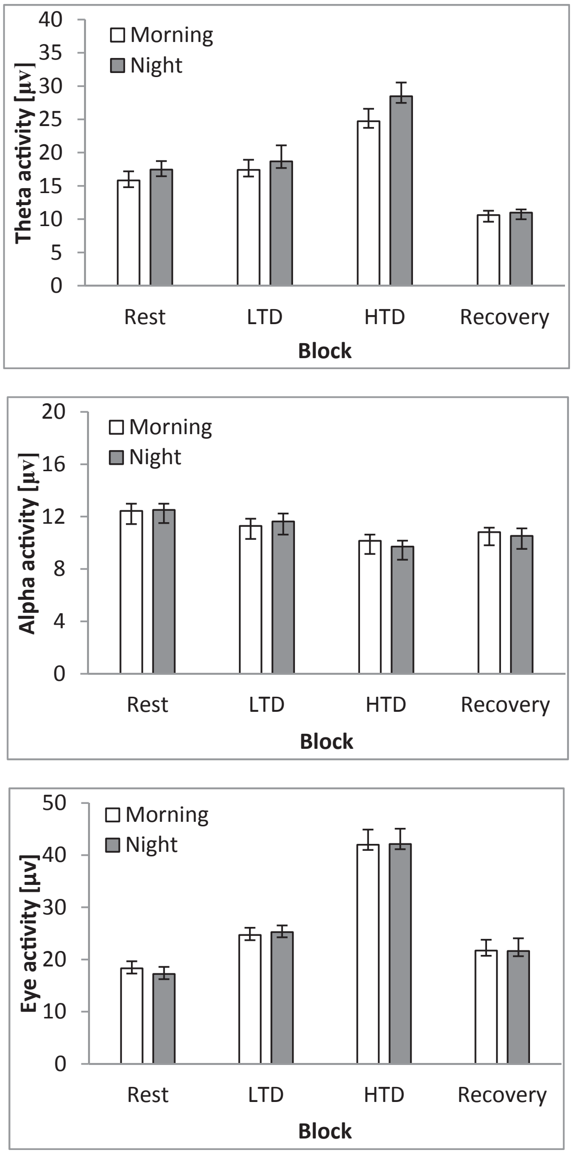

Fig. 4. Changes in physiological indices across four conditions between shifts. Error bars indicate standard errors of the mean.

demand, which may increase the stress experienced by operators while performing their work.

We used EOG activity for the left eye to evaluate MW in operators while monitoring traffic density. They must continuously focus their attention on visual displays to monitor the traffic density of intersections. The results from the eye activity showed that the electrical activity amplitude was higher during the HTD than the LTD condition. This means that eye blink duration was shorter during HTD during LTD conditions. In HTD conditions, operators need continuous focus and spend more time watching the monitors, shortening blink duration. These results were similar to previous studies (Doppelmayr et al., 2008; Wilson and Russell, 2003a; 2003b; Veltman and Gaillard, 1998; Wastell and Newman, 1996).

In this study, it was observed that by increasing traffic density and more visual information processing EEG theta band activity increased. Similarly, during a flight scenario investigated by Hankins and Wilson (1998), the theta band of the EEG increased in mental calculation conditions. In addition, Fairclough et al. (2005) reported that theta activity increased in parietal areas in response to increased task demand. This result confirms the findings of studies on working memory load (Gevins et al., 1998; Smith et al., 2002), visual search task (Yamada, 1998), multiple attribute task battery (Fournier et al., 1999), and flight simulations (Smith et al., 2001) in which EEG theta activity in frontal areas reportedly increases with increasing task demand.

The EEG results indicate that the EEG alpha band amplitude was lower during the HTD than the LTD condition. These differences were statistically significant. The graph showed that the mean amplitude of the EEG alpha band tended to decrease as traffic density increased. The decreased EEG alpha band amplitude indicates that the operators experienced fatigue. This finding confirms the results of prior studies demonstrating the inverse relationship between alpha band activity and task difficulty (Gevins et al., 1998; Sterman and Mann, 1995). According to the Ryu and Myung (2005) study, alpha band suppression indicated a systematic decrease, as the difficulty of the arithmetic task increased. Klimesch et al. (1997) indicated that alpha band activity is especially sensitive to memory demand. Alpha band activity at parietal sites decreases with increases in working memory load (Fairclough et al., 2005; Fournier et al., 1999; Gevins et al., 1998; Smith et al., 2001; Sterman and Mann, 1995). Thus, this study indicates that traffic control center stressors lead to changes in EEG bands and eye activity. Significant differences were observed in the subjective experience of MW.

4.1. Limitations

The study included some limitations. All TCC operators were males, with a mean age of less than 30 years. Thus the study did not address the effects of gender, nor did it report any gender differences while quantifying the effects of traffic density on physiological responses. Most studies have not directly compared the physiological response to MW of males and females. Dittmar et al. (1993) concluded that females experience MW as more difficult than males. Sato and Miyake (2004) suggested the possibility that females have an advantage over males with respect to MW levels. Another recent study suggested that gender does not affect the physiological response induced by the cognitive demand of similar

Table 4
Comparison of physiological variables Means ± SE across rest, LTD, HTD and recovery conditions in the morning and night shift work.

Variables		Rest	LTD	HTD	Recovery	Repeated measures ANOVA result: Shift p value	MW p value	Shift × MW p value	Shift effect size	MW effect size	Shift × MW effect size	ε
Theta (μv)	morning	15.81 ± 1.38	17.40 ± 1.52	24.71 ± 1.87	10.61 ± 0.66	0.314	0.001	0.585	0.033	0.417	0.006	0.775
	night	17.44 ± 1.29	18.69 ± 2.41	28.48 ± 2.06	10.98 ± 0.48							
Alpha(μv)	morning	12.43 ± 0.55	11.29 ± 0.55	10.15 ± 0.48	10.81 ± 0.35	0.886	0.001	0.655	0.005	0.753	0.038	0.511
	night	12.50 ± 0.48	11.63 ± 0.60	9.71 ± 0.45	10.53 ± 0.57							
Eye activity (μv)	morning	18.31 ± 1.34	24.69 ± 1.39	42.00 ± 2.91	21.70 ± 2.08	0.956	0.001	0.935	0.091	0.803	0.018	0.724
	night	17.22 ± 1.36	25.25 ± 1.28	42.14 ± 2.93	21.62 ± 2.45							

mental tasks (Pérusse-Lachance et al., 2012). Experimenters found that shift work probably did not have affect physiological response; the limited number of operators working each shift might explain this. In this study, the work-rest cycle of operators was between 12 and 24 h. Investigating the MW of a larger number of operators with eight to 16 work-rest cycles might yield more robust results.

4.2. Conclusion

Many studies have been conducted in laboratory settings. The findings and conclusions of such studies on MW and its health effects on human operators cannot necessarily be applied in real workplaces. For this reason, we conducted this study in a TCC under working conditions. The findings show that traffic congestion has a significant effect on physiological variables and that shift work was not significantly related to shift work. Although subjective responses to HTD conditions were moderate, MW should be considered appropriate, but changes in EEG bands such as alpha, theta and eye activity demonstrate that, when the work experience of operators increases mental fatigue and stress might be detrimental to the mental health of operators. Thus, on the results reveal that if the responsible stakeholders are aware of the MW of TCC operators, human resources for LTD and HTD conditions can be organized to sustain appropriate MW as well as to improve city traffic control management.

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References

Azari, K.A., Arintono, S., 2012. Congestion pricing scheme in Mashhad, Iran: overview description, impacts and behavioural responsiveness. World Appl. Sci. J. 20, 1484–1492. http://dx.doi.org/10.5829/idosi.wasj.2012.20.11.1516.

Cain, B., 2007. A Review of the Mental Workload Literature. Defence Research And Development Toronto, Canada (NATO Report No. RTO-TR-HFM-121-PART-II).

Cinaz, B., Arnrich, B., La Marca, R., Tröster, G., 2013. Monitoring of mental workload levels during an everyday life office-work scenario. Pers. Ubiquitous Comput. 17, 229–239. http://dx.doi.org/10.1007/s00779-011-0466-1.

Desmond, P.A., Hoyes, T.W., 1996. Workload variation, intrinsic risk and utility in a simulated air traffic control task: evidence for compensatory effects. Saf. Sci. 22, 87–101. http://dx.doi.org/10.1016/0925-7535(96)00008-2.

De Winter, J.C.F., 2014. Controversy in human factors constructs and the explosive use of the NASA-TLX: a measurement perspective. Cognition. Technol. work 16 (3), 289–297. http://dx.doi.org/10.1007/s10111-014-0275-1.

Dey, A., Mann, D.D., 2010. Sensitivity and diagnosticity of NASA-TLX and simplified SWAT to assess the mental workload associated with operating an agricultural sprayer. Ergonomics 53, 848–857. http://dx.doi.org/10.1080/00140139.2010.489960.

Didomenico, A., Nussbaum, M.A., 2011. Effects of different physical workload parameters on mental workload and performance. Int. J. Ind. Ergon. 41, 255–260. http://dx.doi.org/10.1016/j.ergon.2011.01.008.

Dittmar, M.L., Warm, J.S., Dember, W.N., Ricks, D.F., 1993. Sex differences in vigilance performance and perceived workload. J. Gen. Psychol. 120, 309–322. http://dx.doi.org/10.1080/00221309.1993.9711150.

Doppelmayr, M., Finkenzeller, T., Sauseng, P., 2008. Frontal midline theta in the preshot phase of rifle shooting: differences between experts and novices. Neuropsychologia 46, 1463–1467. http://dx.doi.org/10.1016/j.neuropsychologia.2007.12.026.

Fairclough, S.H., Venables, L., Tattersall, A., 2005. The influence of task demand and learning on the physiological response. Int. J. Psychophysiol. 56, 171–184. http://dx.doi.org/10.1016/j.ijpsycho.2004.11.003.

Fournier, L.R., Wilson, G.F., Swain, C.R., 1999. Electrophysiological, behavioral, and subjective indexes of workload when performing multiple tasks: manipulations of task difficulty and training. Int. J. Psychophysiol. 31, 129–145. http://dx.doi.org/10.1016/S0167-8760(98)00049-X.

Gevins, A., Smith, M.E., Leong, H., Mcevoy, L., Whitfield, S., Du, R., Rush, G., 1998. Monitoring working memory load during computer-based tasks with EEG pattern recognition methods. Hum. Factors J. Hum. Factors Ergon. Soc. 40, 79–91. http://dx.doi.org/10.1518/001872098779480578.

Hankins, T.C., Wilson, G.F., 1998. A comparison of heart rate, eye activity, EEG and subjective measures of pilot mental workload during flight. Aviat. Space Environ. Med. 69, 360–367. PMID:9561283.

Hart, S.G., Wickens, C.D., 1990. Workload Assessment and Prediction. Manprint. Springer, pp. 257–296.

Hegyi, A., De Schutter, B., Hoogendoorn, S., BABUŠKA, R., Van Zuylen, H., Schuurman, H., 2001. A fuzzy decision support system for traffic control centers. In: Intelligent Transportation Systems, 2001. Proceedings. IEEE, pp. 358–363.

Hopkin, V.D., 1995. Human Factors in Air Traffic Control. CRC Press, pp. 1–498.

Irannezhad, E., Mousavi, S.H., Zangiabadi, M., 2010. Air Pollution Zoning Based on Land Use and Traffic of Vehicles, pp. 372–378.

Jo, S., Myung, R., Yoon, D., 2012. Quantitative prediction of mental workload with the ACT-R cognitive architecture. Int. J. Ind. Ergon. 42, 359–370. http://dx.doi.org/10.1016/j.ergon.2012.03.004.

Johnson, A., Widyanti, A., 2011. Cultural influences on the measurement of subjective mental workload. Ergonomics 54, 509–518. http://dx.doi.org/10.1080/00140139.2011.570459.

Käthner, I., Wriessnegger, S.C., Müller-Putz, G.R., Kübler, A., Halder, S., 2014. Effects of mental workload and fatigue on the P300, alpha and theta band power during operation of an ERP (P300) brain–computer interface. Biol. Psychol. 102, 118–129. http://dx.doi.org/10.1016/j.biopsycho.2014.07.014.

Klimesch, W., Doppelmayr, M., Schimke, H., Ripper, B., 1997. Theta synchronization and alpha desynchronization in a memory task. Psychophysiology 34, 169–176. http://dx.doi.org/10.1111/j.1469-8986.1997.tb02128.x.

Kum, S., Furusho, M., Duru, O., Satir, T., 2007. Mental workload of the VTS operators by utilising heart rate. Int. J. Mar. Navig. Saf. Sea Transp. 1, 145–151.

Lai, V., Theppitak, C., Makizuka, T., Higuchi, Y., Movahed, M., Kumudini, G., Izumi, H., Kumashiro, M., 2014. A normal intensity level of psycho-physiological stress can benefit working memory performance at high load. Int. J. Ind. Ergon. 44, 362–367. http://dx.doi.org/10.1016/j.ergon.2013.11.015.

Lean, Y., Shan, F., 2012. Brief review on physiological and biochemical evaluations of human mental workload. Hum. Factors Ergon. Manuf. Serv. Ind. 22, 177–187. http://dx.doi.org/10.1002/hfm.20269.

Loft, S., Sanderson, P., Neal, A., Mooij, M., 2007. Modeling and predicting mental workload in en route air traffic control: critical review and broader implications. Hum. Factors J. Hum. Factors Ergon. Soc. 49, 376–399. http://dx.doi.org/10.1518/001872007X197017.

Luximon, A., Goonetilleke, R.S., 2001. Simplified subjective workload assessment technique. Ergonomics 44, 229–243. http://dx.doi.org/10.1080/00140130010000901.

Lysaght, R.J., Hill, S.G., Dick, A., Plamondon, B.D., Linton, P.M., 1989. Operator Workload: Comprehensive Review and Evaluation of Operator Workload Methodologies. DTIC Document. TR-2075-3.

Moray, N., 1997. Models of models of... mental models. Perspect. Hum. Control. 271–285.

Morgan, J.F., Hancock, P.A., 2011. The effect of prior task loading on mental workload an example of hysteresis in driving. Hum. Factors J. Hum. Factors Ergon. Soc. 53 (1), 75–86. http://dx.doi.org/10.1177/0018720810393505.

Oron-Gilad, T., Ronen, A., Shinar, D., 2008. Alertness maintaining tasks (AMTs) while driving. Accid. Analysis Prev. 40, 851–860. http://dx.doi.org/10.1016/j.aap.2007.09.026.

Pérusse-Lachance, E., Tremblay, A., Chaput, J.-P., Poirier, P., Teasdale, N., Drapeau, V., Sénécal, C., Brassard, P., 2012. Mental work stimulates cardiovascular responses through a reduction in cardiac parasympathetic modulation in men and women. Bioenergetics S1:001, 1–6. http://dx.doi.org/10.4172/2167-7662.S1-001.

Reid, G.B., Nygren, T.E., 1988. The subjective workload assessment technique: a scaling procedure for measuring mental workload. Adv. Psychol. 52, 185–218. http://dx.doi.org/10.1016/S0166-4115(08)62387-0.

Ryu, K., Myung, R., 2005. Evaluation of mental workload with a combined measure based on physiological indices during a dual task of tracking and mental arithmetic. Int. J. Ind. Ergon. 35, 991–1009. http://dx.doi.org/10.1016/j.ergon.2005.04.005.

Samadi, S., Rad, A.P., Kazemi, F.M., Jafarian, H., 2012. Performance evaluation of intelligent adaptive traffic control systems: a case study. J. Transp. Technol. 2, 248–259. http://dx.doi.org/10.4236/jtts.2012.23027.

Sato, N., Miyake, S., 2004. Cardiovascular reactivity to mental stress: relationship with menstrual cycle and gender. J. Physiological Anthropol. Appl. Hum. Sci. 23, 215–223.

Shad, R., 2013. Cooperating mobile GIS and wireless sensor networks for managing transportation infrastructures in urban areas. Sensors Models Photogrammetry Remote Sens. 2, 469–474.

Smith, M.E., Gevins, A., Brown, H., Karnik, A., Du, R., 2001. Monitoring task loading with multivariate EEG measures during complex forms of human-computer interaction. Hum. Factors J. Hum. Factors Ergon. Soc. 43, 366–380. http://dx.doi.org/10.1518/001872001775898287.

Smith, M.E., Mcevoy, L.K., Gevins, A., 2002. The impact of moderate sleep loss on neurophysiologic signals during working-memory task performance. Sleep 25 (7), 784–794.

Sterman, M., Mann, C., 1995. Concepts and applications of EEG analysis in aviation performance evaluation. Biol. Psychol. 40, 115–130. http://dx.doi.org/10.1016/0301-0511(95)05101-5.

Tran, T.Q., Boring, R.L., Dudenhoeffer, D.D., Hallbert, B.P., Keller, M.D., Anderson, T.M., 2007. Advantages and disadvantages of physiological assessment for next generation control room design. In: Human Factors and Power Plants and HPRCT 13th Annual Meeting, 2007 IEEE 8th. IEEE, pp. 259–263.

Veltman, J., Gaillard, A., 1998. Physiological workload reactions to increasing levels of task difficulty. Ergonomics 41, 656–669. http://dx.doi.org/10.1080/

001401398186829.
Wastell, D., Newman, M., 1996. Information system design, stress and organisational change in the ambulance services: a tale of two cities. Account. Manag. Inf. Technol. 6, 283–300. http://dx.doi.org/10.1016/S0959-8022(96)90017-X.
Wickens, C.D., 1992. Virtual reality and education. Systems, man and cybernetics. In: IEEE International Conference on, 1992. IEEE, pp. 842–847.
Wilson, G.F., Russell, C.A., 2003a. Operator functional state classification using multiple physiological features in an air traffic control task. Hum. Factors J. Hum. Factors Ergon. Soc. 45, 381–389. http://dx.doi.org/10.1518/hfes.45.3.381.27252.
Wilson, G.F., Russell, C.A., 2003b. Real-time assessment of mental workload using physiological measures and artificial neural networks. Hum. Factors J. Hum. Factors Ergon. Soc. 45, 635–644. http://dx.doi.org/10.1518/hfes.45.4.635.27088.
Yamada, F., 1998. Frontal midline theta rhythm and eye blinking activity during a VDT task and a video game: useful tools for psychophysiology in ergonomics. Ergonomics 41, 678–688. http://dx.doi.org/10.1080/001401398186847.