International Journal of Industrial Ergonomics 54 (2016) 170–177

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

journal homepage: www.elsevier.com/locate/ergon

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

Majid Fallahi [a], Majid Motamedzade [b,*], Rashid Heidarimoghadam [c], Ali Reza Soltanian [d], Maryam Farhadian [e], Shinji Miyake [f]

[a] Department of Occupational Hygiene, Faculty of Public Health, Hamadan University of Medical Sciences, Hamadan, Iran
[b] Department of Ergonomics, School of Health and Research Center for Health Sciences, Hamadan University of Medical Sciences, Hamadan, Iran
[c] Department of Ergonomics, Faculty of Health and Medical Sciences Research Center, School of Public Health, Hamadan University of Medical Sciences, Hamadan, Iran
[d] Modeling of Noncommunicable Diseases Research Center, Department of Biostatistics and Epidemiology, School of Public Health, Hamadan University of Medical Sciences, Hamadan, Iran
[e] Department of Biostatistics and Epidemiology, School of Public Health, Hamadan University of Medical Sciences, Hamadan, Iran
[f] School of Health Sciences, University of Occupational & Environmental Health, Japan, 1-1 Iseigaoka, Yahatanishiku, Kitakyushu 807-8555, Japan

ARTICLE INFO

Article history:
Received 6 December 2014
Received in revised form
18 April 2016
Accepted 15 June 2016
Available online 24 June 2016

Keywords:
Mental workload
EEG
EOG
Simplified-subjective workload assessment technique
Traffic control center

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

* Corresponding author.
E-mail addresses: mjfllh@yahoo.com (M. Fallahi), motamedzade@yahoo.com (M. Motamedzade), a_sultanian@yahoo.com (A.R. Soltanian), maryam_farhadian80@yahoo.com (M. Farhadian), myk@health.uoeh-u.ac.jp (S. Miyake).

http://dx.doi.org/10.1016/j.ergon.2016.06.005
0169-8141/

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