International Journal of Industrial Ergonomics 64 (2018) 1–7

Contents lists available at ScienceDirect

International Journal of Industrial Ergonomics

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

Influence of mental workload on detecting information varieties revealed by mismatch negativity during flight simulation

Xiaoru Wanyan [a, b], Damin Zhuang [a], Yingzi Lin [b, *], Xu Xiao [c], Jin-Woo Song [d]

[a] School of Aeronautics Science and Engineering, Beihang University, Beijing 100191, China
[b] Intelligent Human-Machine Systems Lab, Mechanical and Industrial Engineering Department, College of Engineering, Northeastern University, Boston, MA 02115, USA
[c] China Academy of Electronics and Information Technology, Beijing 100041, China
[d] Department of Aerospace Engineering, College of Engineering, University of Illinois at Urbana-Champaign, IL 61801, USA

ARTICLE INFO

Article history:
Received 3 August 2016
Received in revised form
16 June 2017
Accepted 18 August 2017

Keywords:
Mental workload assessment
Mismatch negativity (MMN)
Pre-attentive processing
Eye blink rate
Flight simulation

ABSTRACT

Behavioral and physiological measures indexed by frontal mismatch negativity (MMN), temporal MMN and eye blink rate derived from electrooculogram (EOG) were used to assess the mental workload related to flight simulation tasks. A total of 14 healthy flying cadets carried out flight simulation tasks under high and low mental workload conditions respectively. The mental workload conditions were manipulated by the complexity of abnormal attitude identification task presented on the head-up display (HUD) during the cruise phase. In this experiment, the increasing mental workload was associated with decreased accuracy rate of detecting abnormal information and longer reaction time. The frontal MMN was enhanced under the high mental workload condition whereas the temporal MMN was decreased, reflecting different information processing mechanisms. In addition, the eye blink rate, an additional assessment of mental workload, also showed high sensitivity and decreased significantly with the increase of mental workload. These results suggested that high mental workload might influence operator's pre-attentive change detection.

1. Introduction

It is generally considered that mental workload is a multidimensional concept, involving task demand, time pressure, operator's ability and effort, behavioral performance as well as some other influencing factors (BorBorghini et al., 2014; Di Stasi et al., 2011). It is well known that during flight, the pilot is sometimes required to deal with a large amount of information within a relatively short time, thereby resulting in the increased mental workload. Often during times of urgency, mental overload occurs and can affect the pilot's operation performance. In some instances, pilots forget to perform critical tasks or omit important information (e.g. flight altitude) under the high mental workload condition (Noel et al., 2005; Wanyan et al., 2014). Worldwide data shows that, in the period 1993–2007, 46% of the contributing factors that led to fatal accidents were cockpit crew related, and that pilot operation errors, caused by ineffective mental states (e.g., peak workload, mental underload, lack of situation awareness, fatigue), account for the majority of them (BorBorghini et al., 2014). In-depth exploration of pilot's mental workload measurements can be applied to the early phases of design and evaluation of pilot-cockpit system. Event-related potential (ERP) extracted from electroencephalograms (EEGs) is considered as the sensitive technical means of measuring mental workload with the unique advantage of mirroring the brain's information processing activity in a non-invasive, real-time and high precision manner (Lv et al., 2010b; Ying et al., 2011).

As the inverse relationship exists between mental workload and attentional reserve, the efficient resources allocation is crucial while individuals perform mentally demanding tasks (Miller et al., 2011). The exhaustion of attentional reserve can be expected to limit cognitive processing for any additional demands, resulting in performance decrement (Miller et al., 2011; Wickens and McCarley, 2008). In some studies, mental workload was even viewed as the attentional capacity which is required to satisfy the performance expectations (Young and Stanton, 2001). Therefore, it is feasible

---

* Corresponding author. Intelligent Human-Machine Systems Lab, Dept. of Mechanical and Industrial Engineering, College of Engineering, Northeastern University, 360 Huntington Avenue, Boston, MA 02115, USA.
E-mail address: yi.lin@northeastern.edu (Y. Lin).

http://dx.doi.org/10.1016/j.ergon.2017.08.004
0169-8141/

that by investigating the variances of the operator's attentional status under different mental workload conditions, the results can be indirectly applied to their mental workload assessment. Currently, several attention-related ERP components, such as P1, N1, P2, N2, P3a, P3b, have been already adopted for assessing operators' mental workload (Allison and Polich, 2008; Miller et al., 2011; Wester et al., 2008; Ying et al., 2011; Zhao et al., 2012). However, the existing studies on pilot attention activities are mainly confined to voluntary attention behavior up to now, revealing only the significant effect of mental workload change on pilot's voluntary attention, such as the ‘attention narrowing phenomenon’ under the high mental workload (Cai and Lin, 2012a, b; Steelman et al., 2017; Wanyan et al., 2011b; Wickens and McCarley, 2008; Wickens et al., 2002, 2003). The pilot's pre-attention, which refers to the mental process of determining whether or not to attend to a stimulus before focusing on it and reflects the detection of the transient changes in the environment under non-attentional condition, has not been investigated widely (Yang et al., 2013). According to the studies of the causes for aviation accidents, it is believed that aviation accidents caused by mental workload have a close relationship with the flight operational errors resulting from the deterioration of pilot cognitive functions of information automatic detection, attention orienting and alertness (BorBorghini et al., 2014; Steelman et al., 2017; Wickens and McCarley, 2008). As it is generally known that mismatch negativity (MMN) has been an important objective indicator of pre-attentive change detection and that the noninvasiveness nature of MMN also makes it particularly suitable for testing under special conditions, such as complicated and dangerous flight missions (Naatanen et al., 2007; Yang et al., 2013), the present study investigated the pilot's pre-attentive processing under different mental workload conditions by recording MMN accordingly.

In previous mental workload studies, workload levels are generally manipulated by controlling task difficulty and measuring consequential operation performances (BorBorghini et al., 2014; Di Stasi et al., 2011; Kramer et al., 1995; Lin and Cai, 2009; Muller-Gass et al., 2006). Similar studies that have been carried out mainly investigated the effect of task difficulty on auditory MMN under the single or dual task conditions (Dittmann-Balcar et al., 1999; Harmony et al., 2000; Kathmann et al., 1999; Kramer et al., 1995; Lv et al., 2010a; Muller-Gass et al., 2006; Restuccia et al., 2005; Song and Zhang, 2011; Wanyan et al., 2011a; Yang et al., 2013; Yucel et al., 2005a, 2005b; Zhang et al., 2006). The majority of these studies indicated that task difficulty did not affect auditory MMN (Dittmann-Balcar et al., 1999; Harmony et al., 2000; Kathmann et al., 1999; Muller-Gass et al., 2006). For example, Muller-Gass et al. (2006) assessed the effect of visual task difficulty on the passively elicited MMN. In their experiment, subjects were instructed to ignore the auditory stimulation and engage in an easy and difficult visual discrimination task, and the results demonstrated that the MMN did not significantly vary with visual task difficulty, in spite of the fact that the easy and difficult tasks showed a wide variation in performance. However, some investigators suggested a decrement mental workload effect on auditory MMN (Kramer et al., 1995; Yang et al., 2013; Yucel et al., 2005a, 2005b). For example, Kramer et al. (1995) recorded MMN from 10 radar operators when they performing simulated radar-monitoring tasks and the MMN amplitude decreased with the introduction of mental tasks as well as decreased further under the high-load condition were observed. Yang et al. (2013) also found that MMN amplitudes at the frontal-central electrode sites were significantly decreased in subjects after 2 h mental arithmetic tasks and indicated that mental fatigue impaired pre-attentive processing. In contrast, there were also evidences that the amplitude of auditory MMN increased under the higher task difficulty (Lv et al., 2010a; Restuccia et al., 2005; Song and Zhang, 2011; Wanyan et al., 2011a; Zhang et al., 2006). For example, while subjects were performing the visual attentive tracking task, Zhang et al. (2006) recorded the amplitude of MMN and found it increased with increasing attentional load. Similarly, study carried out by Lv et al. (2010a) also showed an enhanced MMN under the high working memory load condition, which implicated a more engaged change detection process.

The above discrepancies could be due to the different experimental conditions. For instance, the tasks used for controlling mental workload differed from each other in the previous studies, however, it has been pointed out that the distractor processing depends critically on the level and type of load involved in the processing of goal-relevant information (Lavie, 2005). In addition, if the visual task and auditory task require the use of different sensory channels based on the multiple resource model (Wickens, 2002; Wickens and McCarley, 2008), this would explain why the visual task difficulty has little impact on auditory MMN. In particular, few studies have explored directly the mental workload effect on auditory MMN during simulated flight. Therefore, in this study, we recorded the auditory MMN in the cruise phase of simulated flight under different mental workload conditions. In addition, in recent years, the eye-tracking method of assessing mental workload has received a lot of attention, and one of the most popular eye-related indices mapping mental status is blinking (Di Stasi et al., 2011; Fairclough et al., 2005; Ryu and Myung, 2005; Ahlstrom and Friedman-Berg, 2006; Lin et al., 2003). Considering that the current research results related to blink rate were inconsistent, as the blink rates either increased or decreased depending on the different task demands (Marquart et al., 2015), we collected the eye blink rate from electrooculogram (EOG) simultaneously as an additional indicator for mental workload assessment.

2. Materials and methods

2.1. Subjects

Fourteen highly trained, healthy flying cadets from Beihang University participated in the present study. All subjects (male, ranging in age from 22 to 28 years with a mean age of 25.6 years) were right-handed, and possessed normal or corrected to normal vision and normal hearing. No subject had a history of neurological problems. Written informed consent was provided before the experiment.

2.2. Abnormal attitude identification task and oddball task

A whole dynamic process of flight simulation, including three phases of take-off (2min40s), cruise (6min0s) and landing (4min20s), was performed by the subject in a flight simulator. Except for accomplishing the normal flight operations in the take-off and landing phases, each subject was instructed to constantly monitor the flight indicators presented on the Head-Up Display (HUD) during the cruise phase. According to programming, abnormal information could be produced from several flight indicators, including airspeed, barometric altitude, pitching angle, rolling angle, heading angle, etc, as shown in Fig. 1. When abnormal information (any one of the indicators went out of range; i.e., visual target) was detected, the subject was required to pressed the prescribed different keys on the keyboard to recover the pointer back from the ‘alarm’ area into the ‘normal’ area as quickly and accurately as possible. The mental workload of the subject was manipulated by varying the quantity of flight indicators needed to be monitored and the occurrence frequency of abnormal information. All subjects conducted two flight