Applied Ergonomics 65 (2017) 1–11

Contents lists available at ScienceDirect

Applied Ergonomics

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

Experimental study on visual detection for fatigue of fixed-position staff

Baisheng Nie [a, b, *], Xin Huang [a, b], Yang Chen [c], Anjin Li [a, b], Ruming Zhang [c], Jinxin Huang [a, b]

[a] School of Resources and Safety Engineering, China University of Mining and Technology (Beijing), D 11, Xueyuan Road, Haidian District, Beijing, 100083, China
[b] State Key Lab of Coal Resources and Safe Mining, China University of Mining and Technology (Beijing), D 11, Xueyuan Road, Haidian District, Beijing, 100083, China
[c] China Coal Information Institute, No.35, Shaoyaoju, Chaoyang District, Beijing, 100029, China

ARTICLE INFO

Article history:
Received 25 July 2016
Received in revised form
7 April 2017
Accepted 22 May 2017

Keywords:
Fatigue
PERCLOS
Image processing

ABSTRACT

Fatigue can lead to decreased work performance and poorer safety and health condition. Fatigue is ubiquitous in production and in life, while the research on it is mainly concentrated in the automotive driving, aircraft piloting and other fields, and it is insufficient to study on the fatigue of fixed-position staff. This paper puts forward a non-contact visual image method, which can monitor the extent of fatigue of fixed-position staff. Fatigue threshold used in judgment is obtained by processing the recorded data of visual images of the experimental subjects when fatiguing and by analyzing eye closure time, percentage of eyelid closure (PERCLOS) value, frequency and number of blinks. The results show that there is significant difference among the four indicators before and after experiment subjects undergo fatigue. The fatigue of experimental subjects is obvious when eye closure time is 3.5 s/min, PERCLOS value 6%, and blink frequency 0.4 times/s. This provides a reference for a wider range of detection of fatigue and a method for avoiding mistakes and accidents.

1. Introduction

Fatigue is a common, almost universal feature of modern life (Dawson et al., 2011). Although there has been a 100-years history of the study on fatigue, the definition of fatigue does not reach an agreement (Shen et al., 2006; Di Milia et al., 2011; Noy et al., 2011). Fatigue is a complex multi-dimensional phenomenon which relates to the physiology, psychology and others. It is difficult to define it theoretically by the researchers, and the phenomenon depends on individuals. In fact, fatigue, drowsiness and sleepiness are often synonymous (Wijesuriya et al., 2007).

Researches have proved that there is a close association between fatigue and the increasing of risk (Williamson et al., 2011; Dawson et al., 2012, 2014). Fatigue can impair cognitive function (Härmä, 2006), reduce working capacity and performance (De Vries et al., 2003; Swaen et al., 2003), and cause chronic diseases (Van Cauter et al., 2008; Smolensky et al., 2011). Fatigue can reduce the awareness of risk and result in accidents, particularly for the workers in specific positions. Fatigue affectation is related to a lot of areas, such as road traffic, shipping, machinery processing, construction, medical services (Akerstedt et al., 2002; Lockley et al., 2004; Fang et al., 2015; Wang and Xu, 2016; Filtness and Naweed, 2017), in which the fatigue of aviation and professional drivers is among the first (Lyznicki et al., 1998; Philip et al., 2003; Cabon et al., 2012; Jo et al., 2014; Butlewski et al., 2015). Fatigue can slow sensorimotor functions and impair information processing, impact on motorists ability to respond to sudden emergencies (Kaplan and Prato, 2012; Meng et al., 2016) and influence the attention and speed of response of the pilot and so on (Borghini et al., 2014).

The introduction of computers has led to dramatic changes in work practices for many people. This change has been accompanied by an increase in complaints about a number of health problems associated with working at video display terminals (VDT) (Helland et al., 2008; Pillastrini et al., 2010). The fixed-position staff need to analyze the information from the VDT with rapid eye movements called saccades. The quality of the information reproduced can

* Corresponding author. D 11, Xueyuan Road, Haidian District, Beijing, 100083, China.
E-mail address: bshnie@cumtb.edu.cn (B. Nie).

http://dx.doi.org/10.1016/j.apergo.2017.05.010
0003-6870/

sometimes be crucial for properly carrying out work tasks, especially if particular workstations are considered such as those used in mission critical control rooms (e.g. control rooms in airports, police stations, civil protection units and on offshore production platforms) (Walker et al., 2014; Leccese et al., 2016). Long-term exposure to video displays often leads to the fatigue, which is associated with visual cognitive overload. Fatigue has major effects on eye movement dynamics and increased time on task is linked to decreased saccadic velocity (Di Stasi et al., 2013). It can result in headaches and performance degradation (Park et al., 2017). Not only in the control room, the radiologists demonstrate decreased ability to focus and decreased accuracy with fatigue, and fatigued interpreters may neglect a portion of the image, with resultant search errors (Waite et al., 2017).

Fatigue may manifest in several forms, including sleepiness, mental, physical and muscle fatigue. Scholars have studied a variety of detection methods through different manifestations of fatigue, which mainly includes the following three ways. First, it detects physiological parameters (Correa et al., 2014; Meng et al., 2014; Chen et al., 2015; Sahayadhas et al., 2015), including heart rate, blood pressure, breathing rate, electroencephalogram, skin electricity and others. Second, it records directly observable acts, including eye movement, blink times, yawn, frequently nodding and so on (Azim et al., 2014; Cyganek and Gruszczyński, 2014; McIntire et al., 2014). The third observes the effect of behaviors (Forsman et al., 2013), including the rotation of steering wheel when driving, wheel path, gyroscope sensor and the like. Wherein, it is relatively accurate that the fatigue method involves the physiological index detected, but the main disadvantage of this technique is that it is intrusive, which will cause the experimental subjects aversion and may lead to inconvenience to work. So visual feature-based methods have emerged as the preferred avenue for research (Ji and Yang, 2002).

The past fatigue studies are mostly concentrated in road transport, shipping and other fields, and the study of fatigue of general fixed-position staff is less, such as dispatchers and visual display terminal operators. Fatigue threshold reflected in the research results does not apply to fatigue judgment of fixed-position staff, making it impossible to accurately judge and prevent the fatigue of fixed-position operators. Therefore, this paper adopts a fatigue detection method based on visual sense, using Matlab for image processing, which improves the method of calculating the pixels height of palpebral fissure, and counting eye closure, PERCLOS value, blink times and frequency visual detection indicators. Finally, threshold is obtained through analysis of experimental data and combined with fatigue classification, which provides the clue for fixed-position fatigue determination and early warning.

2. Method

2.1. Participants

To systematically, comprehensively and accurately grasp the variations in visual test of workers' sleep-related fatigue (SRF), and in considering the impact of gender, age, physical fitness and weight on fatigue, the experimental participants were selected according to the following principles:

(1) Good physical condition, no eye diseases;
(2) Regular schedule, having the siesta habit;
(3) Using a computer in a long time every day (more than 8 h);

Fourteen graduate students were selected as experimental subjects, whose basic information is shown in Table 1.

Table 1
Basic information of the participants.

No	Gender	Age	Height (cm)	Weight (kg)
1	Female	25	160	46
2	Female	27	158	43
3	Female	24	160	52
4	Male	26	168	56
5	Male	26	178	65
6	Male	27	178	62
7	Male	23	183	72
8	Male	26	164	56
9	Male	25	177	75
10	Male	23	182	68
11	Male	25	176	61
12	Male	26	175	66
13	Female	26	160	54
14	Male	23	180	73

2.2. Experimental equipment

The Logitech C310 high definition network camera was used in the experiment. This camera is equipped with the Right Light 2 technology, which can capture good quality images in dim light or dark conditions with its intelligently adjusting the light, and has the IM compatibility, which can be used with common instant messaging applications. Universal retaining clip is suitable for notebook computers, LCD or CRT monitors. Its specifications are shown in Table 2.

2.3. Procedure

(1) Check and calibration of the equipment

The Logitech C310 camera was checked to work correctly, and the shooting time, rate, pixel, size and other related parameters were set. The indoor light and temperature were adjusted.

(2) Preparation of participants

Experimental participants were allowed to maintain a normal daily routine which was keeping 8 h of sleep in the week before the experiment and was deprived of sleep on the day before the experiment, in which their sleeping time was adjusted to the schedule from 1:00 a.m. to 6:30 a.m. The participants came into the lab at 7:30 a.m. after breakfast, they chose comfortable sitting position and were ready to be tested. The experiment operator adjusted the camera position and camera angle. They did something quietly (such as browsing the web, reading and learning or working activities). In this period, any forms of sleeping, strenuous exercise, playing games, listening to music and other entertainment activities were banned totally, as well as alcohol, tea or coffee and other stimulating drinks. Laboratory was with temperature at around 25 °C and in daylight.

(3) Fatigue information capture

Table 2
Specifications of Logitech C310.

Type	C310
Sensor	CMOS
Pixel	5 megapixels
Video Resolution (Resolution)	1280 × 720
The maximum number of frames	30 Frames/sec
Interface	USB 2.0