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Can a simple balance task be used to assess fitness for duty?

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ABSTRACT

Human fatigue, caused by sleep loss, extended wakefulness, and/or circadian misalignment, is a major cause of workplace errors, incidents and accidents. In some industries, employees are required to undertake fitness for duty testing at the start of a shift to identify instances where their fatigue risk is elevated, so that minimisation and/or mitigation strategies can be implemented. Postural balance has been proposed as a fitness for duty test for fatigue, but it is largely untested. Therefore, the purpose of this study was to examine the impact of sleep loss, extended wakefulness and circadian phase on postural balance. Fourteen male participants spent 10 consecutive days in a sleep laboratory, including three adaptation days and eight simulated shiftwork days. To simulate a quickly rotating roster, shiftwork days were scheduled to begin 4 h later each day, and consisted of a 23.3-h wake episode and a 4.7-h sleep opportunity. Every 2.5 h during wake, balance was measured while standing as still as possible on a force platform with eyes open for one minute, and eyes closed for one minute. Subjective sleepiness was assessed using the Karolinska Sleepiness Scale. Core body temperature, continuously recorded with rectal thermistors, was used to determine circadian phase. For measures of postural balance and subjective sleepiness, data were analysed using three separate repeated measures ANOVA with two within-subjects factors: circadian phase (six phases) and prior wake (nine levels). For subjective sleepiness, there was a significant effect of prior wake and circadian phase. In particular, sleepiness increased as prior wake increased, and was higher during biological night-time than biological daytime. For the eyes open balance task, there was no effect of prior wake or circadian phase. For the eyes closed balance task, there was a significant effect of circadian phase such that balance was poorer during the biological night-time than biological daytime, but there was no effect of prior wake. These results indicate that postural balance may be a viable tool for assessing fatigue associated with time of day, but may not be useful for assessing fatigue associated with extended hours of wake.

1. Introduction

Human fatigue, caused by sleep loss, extended wakefulness, and/or circadian misalignment, is a major cause of workplace errors, incidents and accidents (Dinges, 1995). In some industries, employees are required to undertake fitness for duty testing at the start of a shift to identify instances where their fatigue risk is elevated, so that minimisation and/or mitigation strategies can be implemented. Individuals who undertake shiftwork at night are particularly at risk of these types of events because they are often exposed to high levels of work-related fatigue (Dorrian et al., 2008). This is largely due to the sleep restriction and sleep disruption associated with sleeping during the daytime, being awake during the normal sleep period, and working through the circadian nadir (Åkerstedt, 2003). Work-related fatigue is an important issue because it can result in reduced alertness and performance, as well as more serious consequences such as greater risk of injury and accident (Dinges, 1995; Dinges et al., 1997). For these reasons, suitable preventive and protective strategies are required to mitigate the adverse effects of work-related fatigue (Costa, 2003). In some industries, fitness for duty testing is used to detect instances where employees may have elevated fatigue risk, so that minimisation and/or mitigation strategies can be employed. However, such tests are only useful if they are sensitive to the major factors that contribute to work-related fatigue, namely disturbed or restricted sleep, sustained wakefulness, and time of day (Folkard and Tucker, 2003).

One particular assessment that has been proposed as a suitable fatigue-related fitness for duty test is postural balance. Maintenance of the upright posture is a fundamental homeostatic mechanism governed by input from the eyes, inner ears, joints, and muscles (Schlesinger et al., 1998; Swift, 1984). The degree to which this system operates efficiently and effectively can be determined from measurements of postural sway or standing steadiness.

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Such measurements are usually obtained during quiet standing on a computerised force platform (Yim-Chiplis and Talbot, 2000). Using this technique, several studies have shown that postural sway increases with age (Røgind et al., 2003), alcohol consumption (Nieschalk et al., 1999), and sedative drug use (Norris et al., 2005). More recently, there is some evidence to suggest that postural balance is sensitive to sleep loss, sustained wakefulness, and time of day (Forsman et al., 2008; Liu et al., 2001; Morad et al., 2007; Nakano et al., 2001).

A number of studies have employed a total sleep deprivation protocol to examine the impact of sleep loss, sustained wakefulness and time of day on postural sway (Forsman et al., 2008; Liu et al., 2001; Morad et al., 2007; Nakano et al., 2001). In this type of protocol, participants are subjected to a period of sustained wakefulness across the night (i.e. 24 h) and assessments of postural balance during quiet standing are made at regular intervals. In general, these studies have shown that postural balance deteriorates throughout a night without sleep and is at its worst around the early hours of the morning (i.e. 04:00–08:00 h). These findings have been taken as evidence that postural balance is a suitable fatigue-related fitness for duty test. However, there are limitations of these studies that must be taken into account when interpreting their results. First, in each of these studies, the effects of sustained wakefulness and time of day on postural balance were confounded. Consequently, it is unclear whether balance is independently affected by time of day or sustained wakefulness. Second, assessments of balance were made following a night of total sleep deprivation, thus it is unclear whether balance is sensitive to sleep restriction (i.e. 4–6 h of sleep per night). This second limitation is particularly important given that most shift workers are not exposed to total sleep deprivation, but rather, experience repeated days of restricted sleep (Åkerstedt, 2003). The aim of the present study was to examine the independent effects of prior wake and circadian phase on postural balance under conditions of sleep restriction.

2. Methods

2.1. Participants

Fourteen male volunteers with a mean (±SD) age of 21.8 (±3.8) years and a mean body mass index of 22.4 (±2.3) kg/m^2 gave written informed consent to participate in this study. Participants were free of neurological, psychiatric, endocrine, and sleep disorders and did not consume large doses of caffeine (i.e. >300 mg per day) or alcohol (i.e. >14 standard drinks per week). Participants were non-smokers, medication free, and had not undertaken shift work or transmeridian travel in the 3 months prior to the study. Participants were instructed to maintain consistent sleep-wake schedules with ~8 h sleep per night in the week prior to the study, which was verified using wrist activity monitors in conjunction with self-report sleep diaries. The study was approved by the University of South Australia Human Research Ethics Committee and the research methods conformed to the guidelines established by the National Health and Medical Research Council of Australia.

2.2. Apparatus and measures

Postural balance was assessed using an Accusway computerised force platform (AMTI, Watertown, MA) in conjunction with Swaywin software (AMTI, Watertown, MA) loaded on a Toshiba laptop computer. The force platform measured the three dimensional forces (F_x, F_y, F_z) and the three dimensional moments (M_x, M_y, M_z) involved in balance. These provide centre of pressure (COP) coordinates, which allow postural sway to be calculated. Two postural balance tasks were performed – one with eyes open and one with eyes closed. In both tests, participants stood on the force platform with their feet shoulder-width apart and their arms by their sides. To ensure accurate and repeated foot placement, a paper template was made for each participant in the correct standing position, and attached to the platform. For the eyes open task, a target was placed at eye level on a wall two meters from the force platform. Participants were instructed to focus on the target and to stand as still as possible for 60 s. Following a 1-min rest period, participants resumed the same position on the force platform for the eyes closed task. Participants were instructed to focus on the same target, and then to close their eyes and stand as still as possible for 60 s. For both versions of the task, the dependent measure was the area of the 95% confidence ellipse enclosing the COP (Area 95, cm^2). A larger Area 95 value indicates greater deviation in the COP and poorer postural balance (see Fig. 1). This measure has been used to quantify postural balance in healthy adults and the elderly (Røgind et al., 2003), and in response to drug administration (Norris et al., 2005) and circadian disruption (Sargent et al., 2010).

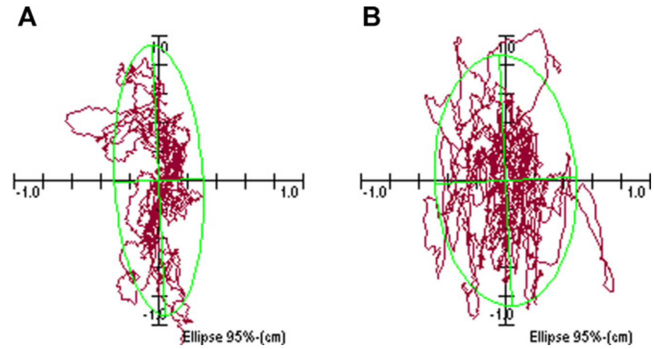

Fig. 1. The area of the 95% confidence ellipse enclosing the centre of pressure (Area 95, cm^2) for two participants during an eyes open balance trial. Panel A represents relatively good balance (i.e. small Area 95). Panel B represents relatively poor balance (i.e. large Area 95).

Participants' subjective sleepiness was assessed using the Karolinska Sleepiness Scale (KSS) (Åkerstedt and Gillberg, 1990). This is a 9-point scale, which ranges from 1 (very alert) to 9 (very sleepy).

Sleep was assessed using standard polysomnography techniques (PSG). The electroencephalogram (EEG) was recorded during all sleep episodes using a standard montage of electrodes (C3, C4), referenced to contralateral mastoids (M1, M2). In addition to the EEG, two electrooculograms (left outer canthus, right outer canthus), and two electromyograms were recorded (placed 2 cm below the inferior edge of the mandible and 2 cm to the left and right of the midline). Electrodes were applied 30 min prior to each sleep episode and were removed at the end of each sleep episode. PSG data were recorded directly to a data acquisition, storage and analysis system (Compumedics E-Series EEG/PSG system; Melbourne, Victoria). Sleep data were scored visually in 30-s epochs in accordance with standard criteria by a trained technician (Iber et al., 2007).

Core body temperature (CBT) was continuously sampled at 1-min intervals with a rectal thermistor (Steri-probe 491B; Cincinnati Sub-Zero Products, Cincinnati, OH) connected to a datalogger (Minimitter, Bend, OR). CBT data were used to generate circadian phase estimates for each participant. CBT data from six forced desynchrony days (2–7) were used to generate circadian phase estimates for each participant. The generation of phase estimates from CBT data was a five-step process: (i) clean the raw CBT data to account for erroneous or missing values due to downloading of the data, slippage of the thermistor, or malfunction of the equipment, (ii) de-mask for physical activity using a purification by intercepts approach (Waterhouse et al., 2000), (iii) de-mask for sleep/wake