Environmental Pollution xxx (2017) 1–10

Contents lists available at ScienceDirect

Environmental Pollution

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

Pulmonary exposure to metal fume particulate matter cause sleep disturbances in shipyard welders☆

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ARTICLE INFO

Article history:
Received 11 July 2017
Received in revised form
20 September 2017
Accepted 25 September 2017
Available online xxx

Keywords:
Cortisol
Lung function
$PM_{2.5}$
Serotonin
Wearable device

ABSTRACT

Sleep disorders may pose a risk to workers in the workplace. We aimed to investigate the associations between metal fume fine particulate matter ($PM_{2.5}$) and sleep quality in workers. We assessed the effects of personal exposure to metal fume $PM_{2.5}$ on lung functions, urinary biomarkers, and sleep quality in shipyard welding workers. In total, 96 welding workers and 54 office workers were recruited in the present study; office workers were exposed to 82.1 ± 94.1 μg/m^3 $PM_{2.5}$ and welding workers were exposed to 2166.5 ± 3149.1 μg/m^3. Welding workers had significantly lower levels of FEV25-75 than office workers ($p < 0.05$). An increase in 1 μg/m^3 $PM_{2.5}$ was associated with a decrease of 0.003 ng/mL in urinary serotonin (95% CI = −0.007–0.000, $p < 0.05$) in all workers and with a decrease of 0.001 ng/mL in serotonin (95% CI = −0.004–0.002, $p < 0.05$) in welding workers, but these were not observed in office workers. There was no significant association of $PM_{2.5}$ with urinary cortisol observed in any workers. Urinary serotonin was associated with urinary Cu, Mn, Co, Ni, Cd, and Pb. Urinary cortisol was associated with Cu, Mn, Co, Ni, Cd, and Pb. Sixteen subjects were randomly selected from each of the office and welding workers for personal monitoring of sleep quality using a wearable device. We observed that welding workers had greater awake times than did office workers ($p < 0.05$). Our study observed that exposure to heavy metals in metal fume $PM_{2.5}$ may disrupt sleep quality in welding workers.

1. Introduction

Sleep disorders are the most common health problems throughout the world (Institute of Medicine (US) Committee on Sleep Medicine and Research, 2006). Sleep disturbances, alteration in quality or timing of sleep and unusual behaviors or physiological conditions are considered to be associated with sleep disorders. In the US, 50–70 million people suffer from a chronic sleep disorder, which affects health and longevity (NHLBI, 2003). A report from a Korean study indicated that 17% of the general population had problems with sleep disturbances, and 37.3% of people suffered from sleep disturbances (Ohayon and Hong, 2002). Regarding sleep disturbance in workers, it has been reported that 30%–45% of workers had poor sleep quality (Doi, 2005). Such health problems of sleep disturbances among workers were linked to an approximate 2-fold increased risk of work injuries (Chau et al., 2004). Therefore, it is important to recognize sleep problems

☆ This paper has been recommended for acceptance by David Carpenter.

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https://doi.org/10.1016/j.envpol.2017.09.082
0269-7491/

among workers to prevent occupational accidents and injuries.

Pulmonary exposure of metal fume fine (<2.5 μm) particulate matter ($PM_{2.5}$) is an important occupational health issue for welding, soldering, and brazing machine setters workers (Bureau of Labor Statistics U.S. Department of Labor, 2015). Pulmonary exposure to metal fume $PM_{2.5}$ is able to induce flu-like metal-fume fever. Also, chronic exposure to metal fumes $PM_{2.5}$ can cause respiratory and systemic syndromes (Ahsan et al., 2009; American Welding Society, 2002; Fine et al., 1997). Recently, sleep disorders were observed in welding workers. A case report showed that workers exposed to welding fumes containing Mn presented with symptoms of sleep disturbances (Bowler et al., 2007a). Furthermore among 43 bridge welders, 79% had sleep disturbances (Bowler et al., 2007b). Although the effects of metal fume $PM_{2.5}$ exposure on sleep disturbances have been studied, more causal evidence is required to examine the association between metal fume $PM_{2.5}$ and sleep disturbances.

Serotonin, a neurotransmitter, plays important roles in regulating several physiological functions, including circadian rhythmicity, appetite, thermoregulation, nociception, emotions, and cognition (McGinty, 2009). High levels of serotonin are associated with wakefulness, whereas lower levels are associated with sleepiness (Portas et al., 2000). Notably, low serotonin levels can cause sleep disruption and sleep disorders. Cortisol is produced in the cortex of the adrenal glands, which is transported and released to the circulatory system. Generally, cortisol persists at high levels in the morning (Morris et al., 2012). Levels of cortisol begin to decrease in a fairly constant and regular fashion during the daytime. Regulation of serotonin and cortisol allow the body to maintain regular sleep patterns.

To reduce occupational accidents and injuries, new insights or approaches may be useful to improve/protect occupational health. Wearable devices, for example, are used to clinically evaluate sleep and constitute a practical direction in the development of health monitoring systems (Kuo et al., 2016; Puri et al., 2016). The accuracy of some commercial wearable devices has been validated with standard clinical approaches/equipment (Cook et al., 2017), which may provide an early warning or notice to prevent/reduce the occurrence of occupational injury/disease. The objectives of this study were: (1) to assess the hazard of and personal exposure to metal fume $PM_{2.5}$ in shipyard workers; (2) to examine pulmonary function in shipyard workers; (3) to detect sleep-related biomarkers of serotonin and cortisol in the urine of office and welding workers; (4) to evaluate urinary metal concentrations and their correlations with serotonin and cortisol; and (5) to evaluate the sleep quality of workers using a wearable device.

2. Materials and methods

2.1. Ethics

This study was approved by the Ethics Committee of the Taipei Medical University-Joint Institutional Review Board. All experiments were conducted in accordance with the approved guidelines. All study subjects received written and oral information prior to inclusion and provided informed consent.

2.2. Study population

This study was performed in a shipyard located in northern Taiwan. The method used for welding was Tungsten Inert Gas (TIG) in a semi-open area. The chemical profiling of the welding rods has reported previously (Lin and Pan, 2012). Lung function, urinary biomarkers and metals, and sleep time and efficiency (by wearable devices) were determined. There was 96 welding workers and 54 office workers recruited for this study as shown in Fig. 1a. Exclusion criteria for participants were an age younger than 20 years or older than 70, coronary artery disease, heart failure, diabetes mellitus, acute exacerbation within 1 month of the study, or chronic respiratory failure. The experimental procedure is shown in Fig. 1b. Urine samples from each subject were collected at the beginning of the work day (Monday; pre-exposure; baseline for 1-day exposure) and the beginning of the next work day (Tuesday; post-exposure; representing the previous 1-day exposure). Pulmonary function tests (PFT) were carried out on Tuesday (1 day post-exposure) using a Chestgraph (Chest, HI-701, Japan). PFT was conducted according to the guideline of spirometry (Miller et al., 2005). All tests were performed by a licensed respiratory therapist. Basic characteristic of the study population, including age, sex, body-mass index (BMI), smoking, alcohol consumption, and working characteristics, were collected.

2.3. Environmental monitoring

Eight-h continuous measurements were conducted between 09:00 and 17:00 from September to November 2015. A scanning mobility particle spectrometer (SMPS, TSI 3936, USA) was used to measure particles, ranging between 13.6 and 736.5 nm, in the welding and office areas. An AeroTrak 9000 (TSI) was used to investigate the lung-deposited surface area in units of micrometers squared per cubic centimeter ($\mu m^2/cm^3$). Particles introduced into the AeroTrak were charged, the voltage of which corresponded to the ICRP model (Human Alimentary Tract Model) based on alveolar lung deposition curves (Fissan et al., 2007; Leavey et al., 2013). Results indicated the fraction of any given particle size that was deposited in the alveolar region of the lungs, minus the fraction of

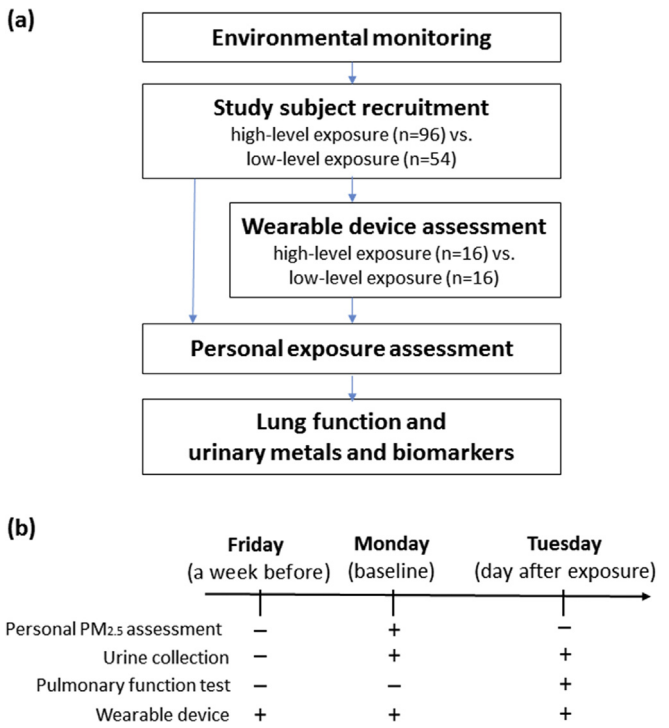

Fig. 1. Experimental design for investigating the effects of pulmonary exposure to metal fume fine (<2.5 μm) particulate matter ($PM_{2.5}$) on sleep disturbances in shipyard welders.

(a) Flowchart of exposure assessment and subject recruitment.
(b) Illustration of the experimental procedure for personal $PM_{2.5}$ assessment, urine collection, pulmonary function test, and wearable device assessment.

Please cite this article in press as: Chuang, H.-C., et al., Pulmonary exposure to metal fume particulate matter cause sleep disturbances in shipyard welders, Environmental Pollution (2017), https://doi.org/10.1016/j.envpol.2017.09.082