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Effect of safety shoes type, lifting frequency, and ambient temperature on subject's MAWL and physiological responses

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ABSTRACT

Objective: The purpose of this paper is to evaluate the lifting capabilities of individuals while wearing safety shoes in a hot environment and to investigate the behavior of the physiological responses induced by the lifting process associated with those variables.
Methods: In order to achieve the objectives of this research, two sequential studies were conducted. The first part was an acclimatization and training program followed by a psychophysical experiment. Seven male workers participated in this experiment from the university. A three-way repeated measures design, with three independent variables and seven response variables, was utilized in this study. The independent variables studied in the psychophysical experiment were: 1) environmental temperature (20 and 30 °C WBGT), 2) lifting frequency (1 and 5 lifts/min), and 3) safety shoes (light-duty, medium-duty and heavy-duty). The response variables for this experiment were: 1) maximum acceptable weight of lift (MAWL), 2) heart rate, 3) aural-canal temperature, 4) muscle electromyography (EMG) of four muscle groups (biceps brachii, anterior deltoid, trapezius, and erector spinae), 5) rating of perceived exertion, 6) rating of thermal sensation and7) safety shoes discomfort rating.
Results: The psychophysical experiment results showed that the weights selected by participants at higher levels of the independent variables were significantly less than those selected at lower levels of the independent variables. Some of the interaction effects were also significant.
Conclusion: This study found evidence that – in addition to lifting frequency, which is well reported in the literature – heat stress increases the workload intensity in manual lifting tasks influencing the psychophysical selection of MAWL and the physiological responses of the human body represented in aural-canal temperature, heart rate and muscular activities. The study findings demonstrated the necessity of accounting for work environmental temperature and type of worn safety shoes, which is a safety requirement by most employers, when calculating the recommended weight limits.
Practitioner summary: Most of the manual materials handling studies had investigated worker's capacity to perform lifting tasks in different environmental conditions not considering the effect of wearing safety shoes. This research fills the gap by presenting safety guidelines regarding lifting tasks in a hot environment while wearing safety shoes.

1. Introduction

It has been estimated that more than a quarter of all injuries related to industrial work are directly associated with Manual Materials Handling (MMH) activities (Ciriello, 2005). Hazards of MMH especially manual lifting continue to exist in manufacturing and services industries. The fifth European working conditions survey reported that 33% of European workers carry heavy loads at least a quarter of their working time (Eurofound, 2010).

Overexertion – while lifting, pulling, holding, carrying or throwing of an object – was the number one cause for workplace injuries in the United States in 2002 and was ranked among the top five during the preceding years (Liberty Mutual Research Centre for Liberty Mutual Research Institute for Safety, 2004). Exposure to MMH tasks, especially manual lifting, is recognized as a major cause of injury in general and an important contributor to the etiology of low-back disorders in particular (NIOSH, 1981; Ayoub and Mital, 1989; Riihimaki, 1991; Skovron, 1992; Mirka and

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Marras, 1993; Burdorf and Sorock, 1997; Xiao et al., 2004).

The medical condition of low-back pain (LBP) poses economic burden on those injured due to its high costs (Gore et al., 2012). In industry, job physical exposure is among the factors contribute to the etiology of LBP (Garg et al., 2014a, 2014b). The National Institute for Occupational Safety and Health (NIOSH) recognized the growing problem of work-related back injuries and published the Work Practices Guide for Manual Lifting (NIOSH, 1981), which investigated the relationship between LBD and occupational lifting factors based on summarized lifting-related literature before 1981. This report was reviewed and updated by the Application Manual for the Revised NIOSH Lifting Equation (Waters et al., 1994).

Ferguson et al. (2014) suggested that higher job physical demands had an effect on higher job turnover rate among warehousing workers, implying workers escape from jobs that may lead to low-back disorders. Variation in worker characteristics (age, sex, body dimensions, muscle strength, physical fitness), task requirements (load location, vertical height range, lifting frequency, lifting speed, size and shape of container) and environmental conditions (temperature and humidity) raise the issue of the complexity of determining a reliably safe permissible weight to be lifted by each individual. Therefore, those variables should be considered in determining that safe permissible weight limits (Hafez, 1984; Hafez and Ayoub, 1991).

Rapid fatigue and increased risk of musculoskeletal injury associated with work in hot and/or humid environment was reported by many studies (Snook and Ciriello, 1974; Hafez, 1984; Hafez and Ayoub, 1991; Ramadan, 1988; Harkness et al., 2004; and Powell et al., 2005). Extremes of temperature are considered as one environmental risk factor (HSE, 2003). For lifting tasks in a hot environment, it was found that self-selected workload was significantly reduced by 20%. In addition, the heart rate and rectal temperature were significantly increased by 9–10 beats per min and 0.2–0.3 °C, respectively (Hafez, 1984; Hafez and Ayoub, 1991; Ramadan, 1988).

Reduction in workload was not sufficient to reduce heart rate and rectal temperature to levels found in the moderate environment (Hafez, 1984; Hafez and Ayoub, 1991; Ramadan, 1988). The physiological responses to workload reduction under hot environment conditions reflected an adaptation of the human body in the form of heat stress under which it is prepared to work. Hence, heart rate and rectal temperature increases may be used to define permissible weight limits to be lifted (Hafez, 1984; Hafez and Ayoub, 1991; Ramadan, 1988).

Powell et al. (2005) reported that humidity has a significant effect on physiological strain when manual handling in hot thermal environments so air temperature alone is not a good indicator of physiological strain. Liang et al. (2011) showed that working in hot and humid environments increases core body temperature, heart rate, and blood pressure. Recently, Maresh et al. (2014) investigated the effects of environmental temperature on repetitive box lifting performance. They found that repetitive box lifting capability was reduced in 38 °C when compared to the 23 °C trial.

Aghazadeh and Lu (1994) investigated the effect of changes in posture caused by wearing different heeled shoes heights (e.g., flat, 5 cm and 7.6 cm) on the maximum lifting capacity. The results showed that a significant difference exists between maximum acceptable weight of lift with flats and that with 7.6 cm heels for both lifting heights (floor to knuckle and knuckle to shoulder), the weight lifted increased by 21.5% when using flats compared to 7.6 cm heels. Aghazadeh and Lu (1994) concluded that high-heeled shoes might affect the lifting capacity and cause back injury when performing lifting tasks. Barton et al., 2009 evaluated the effects of in-shoe 20 mm high bilateral heel lifts on trunk muscle activity. The results indicated that the heel lifts altered muscle activity reactively around heel strike.

Li et al., 2010 studied the effect of three footwear applied in four lifting and lowering conditions of manual material handing tasks. They found significant effects of lifting loads from the floor to the knuckle on the heart rate, MAWL, and VO2. Moreover, Kim et al. (2011) investigated the characteristics of the EMG and the kinematics of the trunk and lower extremity during the sit-to-stand task while wearing 1-, 4-, and 8-cm high-heeled shoes. They found that during a sit-to-stand task, wearing 8-cm high-heeled shoes alters the muscle activation patterns (i.e., EMG amplitude and onset latencies) of the lumbar and upper leg musculature. In addition, Mika et al., 2013 identified whether heel height alters lumbar and hip extensor muscle timing characteristics during a standardized trunk flexion task. They reported that wearing shoes with 10-cm heels alter trunk and hip extensor muscle coordination patterns.

In spite of the extensive research in this area, recommendations regarding safe permissible weight to be lifted are still not sufficient especially while wearing safety shoes and working in a hot environment. The objective of this paper is to investigate the effects of manual lifting in a hot environment while wearing safety shoes on lifting capacity, human body physiological responses and the reported level of stress. Therefore, research hypotheses of this study was lifting frequency, environmental temperature and worn safety shoes have significant effect on MAWL, heart rate, aural-canal temperature, perceived exertion, and muscles' activities (EMG).

2. Material and methods

2.1. Participants

Seven males from King Saud University's workers population participated in this experiment with average age of 29.28 years and standard deviation of 3.9 years. Participants' average mass was 70.7 kg with standard deviation of 4.2 kg; and average stature was 166.1 cm with standard deviation of 3.3 cm. None of the participants had previously experienced low back and/or lower limbs disorders, had any cardiac symptoms, been on prescriptions for any medication that might had altered their muscles' functions, or had heat intolerance. All participants were informed about the experiment's purpose and experimental procedures, then, signed consent forms approved by the Human Participants Review Sub-Committee, Institutional Review Board. Afterwards, participants went through medical screening. None of the participants was trained in a hot environment prior to the tests; therefore, all participants were considered heat-un-acclimatized (Hafez, 1984; Hafez and Ayoub, 1991; Ramadan, 1988; Hidalgo et al., 1997; Kellett et al., 2003). All tests were performed during April and May and participants were compensated for their time.

2.2. Measured responses and used equipment

2.2.1. Heat chamber

All acclimatization and experimental sessions were performed inside a 3.2 m × 2.2 m × 2.2 m self-controlled heat chamber manufactured by Cliphyco Company, China. In addition, an HT30 heat stress meter by Extech was used to ensure temperature consistency at the heat chamber corners.

2.2.2. Anthropometric measures

A SiberHegner GPM Anthropological Instrument (DKSH Switzerland Ltd., Zurich, Switzerland) with an adjustable stool was used for measuring participants' anthropometric dimensions. This instrument consists of the following: fixed anthropometer (0–2100 mm with straight probes and curved measuring