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Influence of Footwear on Individual Performance during Prolonged Standing

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Abstract
Standing is a normal posture during working in industries, some jobs even make it mandatory to stand while working. Standing is natural and itself doesn't pose a specific health risk. But standing for a very long duration has an immense share in many health complications. The aim of this study is to determine which type of footwear is healthier to wear while standing for long periods. Five physically fit participants ($n = 5$) were chosen from lthe ive industrial environment. All the five participants participated in this study without disturbing their usual work as ma achine operator. Photo-plethysmography (PPG) was used to collect continuous heart rate information from each participant. Each participant was observed for six hours each day for two consecutive days, wearing different footwear each day. The information collected was used to calculate total energy expenditure during the experimentation period. In this study, it was observed, that standing for longer duration when wearing floaters ($M = 1699.5$, $SD = 451.5$) and when wearing shoes ($M = 1288$, $SD = 140$), have alternaan tive hypothesis. It was observed that there is signifia cant difference ($t(4) = 2.095, p < 0.1; CI_{90\%}$) in energy expenditure while different footwear type was used. Participants were more physically exerted when wearing floaters than that when wearing shoes. Thus, it can be concluded that wearing shoes while standing for longer duration is the best choice. This study shows that the average energy expenditure among the group while using shoes is 22% less than that while using floaters. This makes wearing shoes a good choice while standing for longer duraa tion.
Keywords: *prolong standing, energy expenditure, heart rate, shoes, floaters*

Introduction

Standing is a normal posture during working in industries, some jobs even make it mandatory to stand while working. Standing is natural and itself doesn't pose a specific health risk. But standing for a very long duration has an immense share in many health complications. Immediate effect of standing for longer duration are pain, discomfort and fatigue, while long-term effects are work-related musculoskeletal disorder, chronic venous insufficiency, postural kyphosis, varicose veins, joint- compression, muscle fatigue, problems in pregnancy, preterm birth, spontaneous abortion, carotid atherosclerosis, etc.… (A.S Shaikh *et al.,* 2016).

As per, Walter F. Stewart *et al.,* (2003), pain is an extremely common and disabling condition in the workforce which makes it expensive to the employer. It leads to loss of productive time and reduced performance.

In today's modern industrialized world there is a demand to enhance human well-being as well as overall system performance. This study is to analyze the physical exertion of the participants when wearing a different type of footwear (i.e. floaters and shoes). This study also determines which type of footwear saves more energy when compared to another. It will directly impact worker's efficiency which leads to an impact on performance and productivity.

The aim of this study is to see which type of footwear is healthier to wear while standing for a longer duration. This work is concerned with the understanding of interactions among humans and footwear and applies the theory, principles, data, and methods to design to enhance human well-being and overall system performance.

Literature Review

Isa *et al.,* (2013), investigated fatigue, while the participants stood on the metal stamping process and handwork section, using sEMG. He concluded that muscle activity of the workers was determined by the work load and duration of standing. This study suggests that anti fatigue mat and micro breaks should be provided to the workers to reduce muscle fatigue.

Javad Aghazadeh *et al.,* (2015), investigated pain, while the participants stood on polyurethane foam 14.5 mm mat and concrete floor, using EMG & VAS. He concluded that anti-fatigue mat may be useful in reducing the low back pain although it objectively didn't significantly change the gluteus medius co-activation pattern related to the lower back pain.

Jeremy Brownie & Bernard J. Martin (2015), investigated fatigue, while the participants stood on linoleum tiles, rubber mat & sole insert, using sEMG. He concluded that standing work induces lower limb muscle fatigue with long-lasting effects not consciously perceived. Floor mats or sole inserts do not appear to mitigate muscle fatigue. Age effects are not conspicuous in this context of low level sustained exertion.

Lauranna Li & Mardon B. Frazer (2001), investigated fatigue and discomfort, while the participants stood on a softer floor mat, softest floor mat, and concrete floor, using sEMG and Likert scale. He concluded that a strong interaction of surface compressibility and standing duration was observed in the variables studied. Overall, the presence of anti-fatigue mat resulted in less discomfort, tiredness, fatigue compared to a concrete surface. However, standing duration was also shown to be a critical component. Also, the compressibility of the surface was a significant factor.

Pascal Madeleine *et al.,* (1998), investigated discomfort, while the participants stood on 14.5 mm polyurethane mat and aluminum plate, using iEMG, skin temperature, and leg volume. He concluded that the experimentally induced pain influenced postural activity, underlining central interactions between proprioceptors and nociceptors. The results highlighted a higher feeling of comfort when standing on the soft surface. In addition, postural activity was lower when standing on the soft surface, but the activity was sufficient to prevent swelling of the lower legs.

Phyllis M. King (2002), investigated fatigue and discomfort, while the participants stood on the hard floor, floor mat, shoe insoles and shoe in-soles with floor mat, using Likert scale. He concluded that no significant difference in fatigue or discomfort was found on comparing the overall effects when using the floor mat and wearing the shoe in-soles or in the combined condition.

Rakié Cham & Mark S. Redfern (1999), investigated fatigue and discomfort, while the participants stood on floor mat placed over a force plate and vinyl tile floor, using COP, sEMG, skin temperature, and leg volume measurement. He concluded that the hard floor and floor mat consistently yielded worse performance. The relationships between the mat material properties and fatigue measures suggest that floor performance increased with greater elasticity and stiffness, and lower energy absorption (Hidayat & Budiatma, 2018; Yunita *et al.,* 2019).

Yen-Hui Lin, *et al.,* (2012), investigated discomfort, while the participants stood on (1) 12.5 mm thick mat and force plate, using COP & Likert scale. (2) 12.5 mm thick mat and concrete floor, using shank circumferences and Likert scale. He concluded that subjective discomfort ratings were related to floor type, shoe condition, and standing time. Common ergonomic interventions, such as modifying the flooring on which workers stand might somewhat alleviate legerdemain for workers standing for 4-h shifts in laboratory and field settings. Prolonged standing for even 1 h without rest showed negative effects and should be avoided when possible (Dewi *et al.,* 2018; Martini & Suardana, 2019).

Objective

This work is concerned with the understanding of interactions among humans who stand for a longer duration while working and their footwear to enhance human well-being and overall system performance. Determination of heart rate of individuals when wearing floaters and when wearing shoes and subsequent determination of energy expenditure are the important aspects of this study.

Instruments Used

Photo-plethysmography (PPG): When the heart beats, capillaries expand and contract. Photo-plethysmography device or optical heart rate monitors LED lights to reflect off the skin to detect this change to measure heart rate automatically and continuously. Fitbit Charge HR™, used as a photo-plethysmography device, was worn on the wrist by participants of this experiments, for continuous and automatic heart rate tracking. It has a comfortable design to wear during the experiment. Instructions were provided to participants regarding the use of Fitbit Charge HR™ wrist placement before starting the experimentations as per recommendation provided on Fitbit Charge HR™ website (As of 23 October 2016, Fitbit Inc.,(2016) "www.fitbit.com").

Shoes: All the participants used the same brand and similar type of standard industrial safety shoes for experimental purpose.

Floaters: All the participants used the same brand and similar type of floaters for experimental purpose.

Physical Examination

All the participants of this study are Indian males, having age within the range of 23±3 Years.

All the participants of this study have BMI ($BMI = Weight\ (kg)/Height^2\ (m^2)$) greater than $18.5\ Kg/m^2$ and lower than $24.9\ Kg/m^2$, i.e. within the normal standard range (As of 23 October 2016, Indian Health Organisation (IHO), "www.indianhealthorganisation.com").

All the participants of this study have WHR ($WHR = Waist/Hip$) lower than 0.95, i.e. low risk

All participant's physical measurements were within the limits of Indian anthropometric dimensions data (Debkumar Chakrabarti, 1997).

It was also ensured that all the participants of this study are free from any neurological and musculoskeletal impairment that might influence their ability to perform the standing work tasks.

Method

All the participants of this experimentation were machine operators who worked in standing posture during the experiment. The experimentation was carried out without affecting their usual work. Each participant was examined in two conditions: (1) standing on the concrete floor wearing shoes for six hours and (2) standing on the same concrete floor wearing floaters for six hours. Each day only one participant was examined in one condition. During the period of experimentation, all the participants wore Fitbit Charge HR™ on their wrists like a wristwatch for collection of heart rate data. The data collected was used to calculate energy expenditure.

Statistical Analysis

Mixed-model analysis equation as suggested by Keytel, *et al.*, (2005), was used to calculate the energy expenditure of the individual.

The t-test statistical analysis method was used to analyze this study. In this study, it was observed that there is a significant difference in energy expenditure when using a different type of footwear (i.e. floaters and shoes) when standing for a long duration (i.e. 6 hours). The following values were derived:

Total Number of the participant in the study:

$$n = 5$$

Energy expenditure (kcal) when wearing floaters:

$$M = 1699.5 \pm 451.5$$

Energy expenditure (kcal) when wearing shoes:

$$M = 1288 \pm 140$$

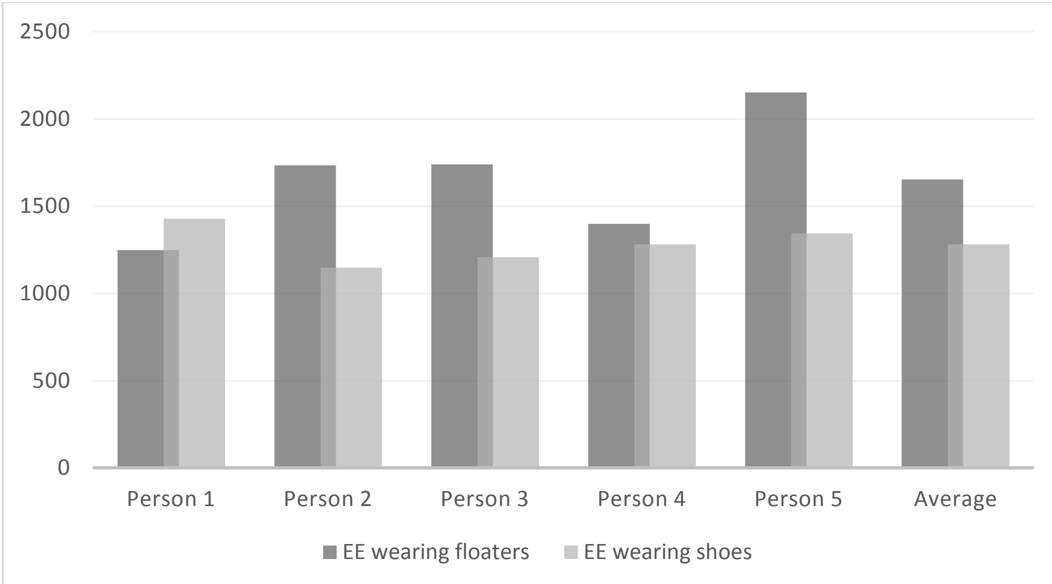
$$\propto = 0.1$$

$$t_{Critical}^{(df=4,\ 1-tailed)} = 1.5332$$

$$t(4) = 2.095, p < 0.1; CI_{90\%}$$

where: n: population; M: mean; SD: standard deviation; t: value; df: degrees freedom; p: significance; CI: confidence interval.

Comparison of energy expenditure of participants [floaters versus shoes on the hard concrete floor]: From the collected data, we conclude that the energy required to perform the same task differed due to the use of different footwear on the same type of floor. The average energy expenditure of participants was 22% more when wearing floaters on the hard floor than that when wearing shoes on a hard floor. This shows that wearing shoes is more comfortable and energy saving.



Graph 1. EE of participants wearing floaters versus wearing shoes on a hard floor

Discussion

As per the literature review, it was concluded that individual responses investigated in earlier studies were based on pain, fatigue and discomfort (Isa *et al.,* 2013; Javad Aghazadeh *et al.,* 2015; Jeremy Brownie & Bernard J. Martin 2015; Lauranna Li, & Mardon B. Frazer, 2001; Pascal Madeleine *et al.,* 1998; Phyllis M. King, 2002; Rakié Cham & Mark S. Redfern 1999; Yen-Hui Lin *et al.,* 2012). Though as per Oxford Dictionary (As of 23 October 2016, English, Oxford Living Dictionaries – Oxford Dictionaries (2016), "www.en.oxforddictionaries.com") the terms discomfort, pain, and fatigue are defined as (1) Discomfort: slight pain. (2) Pain: highly unpleasant physical sensation caused by illness or injury. (3) Fatigue: extreme tiredness resulting from mental or physical exertion or illness; a lessening in one's response to or enthusiasm for something, caused by overexposure; a reduction in the efficiency of a muscle or organ after prolonged activity. Based on these definitions, it was observed that it is inappropriate to determine individual performance using term discomfort or pain. Fatigue too is a by-product of mental or physical exertion. Moreover, only discomfort, pain and fatigue doesn't affect the overall performance of an individual. Hence, the assessment of energy expenditure or physical exertion during a specific task can deliver more accurate results. As per Nurhayati Mohd Nur *et al.,* (2015), working with an energy expenditure rate that is either equal to or above the maximum energy expenditure rate of the tasks results in decreased work productivity performance.

As per, Olli Tikkanen *et al.,* (2014), heart rate is a superior method of predicting energy expenditure, whereas accelerometer is most accurate for level loads at the population level. As per, Keytel *et al.,* (2005), it is possible to estimate physical activity energy expenditure from heart rate in a group of individuals with a great deal of accuracy, after adjusting for age, gender, body mass, and fitness. As per, Kirsten L. Rennie *et al.,* (2001), a combination of simple measurements and heart rate monitoring produces estimates of energy expenditure that are highly correlated with those obtained using full individual calibration.

As per, Massimiliano de Zambotti *et al.,* (2016), Fitbit Charge HR™ showed good agreement with Polysomnography (PSG) and Electrocardiography (ECG) in measuring heart rate. As per, Matthew P. Wallen *et al.,* (2016), Fitbit Charge HR™ device accurately measure heart rate. As per, Sarah E. Stahl *et al.,* (2016), wearable activity trackers provide an accurate measurement of heart rate during walking and running activities.

Objective methods used in earlier studies include some very cost intensive methods like electromyography and required high degree of expertise to use them, whereas in this study, optical heart rate monitor [Photo-Plethysmography (PPG)] has been used which is simple, low-cost, easy, non-invasive and reliable optical measurement technique to collect the data. It is not based on individual perception but on scientific data.

This complete analysis shows that shoes are the best choice while working. On the contrary, floaters have an adverse effect on individual energy expenditure. Average energy expenditure of the group when using floaters is

22% higher than that while wearing shoes. This frightening indicator is a point of concern for floater users while standing for a prolonged period.

Conclusion

The following conclusions were drawn from this analytical study:

1) Heart rate is one of the best tools to evaluate energy expenditure.
2) Physical exertion or energy expenditure is one of the best methods for assessing individual performance.
3) Average energy expenditure among the group standing for a longer period is 22% higher when wearing floaters than that when wearing shoes.

Thus, from this study, it is concluded that wearing shoes and standing on a firm, hard floor when standing for a longer duration while working is more health friendly. This study needs to be repeated on a large population and for longer duration and using different types of footwear to further understand and estimate the effects of footwear on health and individual performance.

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