Effects of Anti-Fatigue Mats on Perceived Discomfort and Weight-Shifting During Prolonged Standing

Neal Wiggermann and **W. Monroe Keyserling**, University of Michigan, Ann Arbor, Michigan

Objective: The aim of this experiment was to investigate the effects of anti-fatigue mats on perceived discomfort and behavioral responses (weight-shifting between the feet) during prolonged standing.

Background: Prolonged standing is a common requirement in the workplace and is a well-known cause of discomfort. Anti-fatigue mats have been shown to reduce discomfort resulting from standing, but no study has identified a particular mat that performs better than others or examined the relationship between discomfort and weight-shifting.

Methods: Participants stood for 4 hours on four commercially available "anti-fatigue" mats and a hard surface (control condition). Subjective ratings of discomfort were measured, and in-shoe pressure was recorded and used to evaluate weight-shifting during standing.

Results: Compared to the control condition, after 4 hours of standing discomfort was reduced by three of the four mats, but discomfort ratings did not significantly differ among mats. However, significant differences among mats were found in the frequency of weight-shifting, and weight-shifting was positively correlated to discomfort.

Conclusion: These results suggest that subjective reports of discomfort were not sufficiently sensitive to detect differences among mats for the experimental conditions tested. Behavioral responses, specifically weight-shifting between feet, may provide a more sensitive alternative to subjective reports.

Keywords: weight-shifting, anti-fatigue mats

Address correspondence to Neal Wiggermann, Department of Industrial and Operations Engineering, University of Michigan, 1161 Tekulve Rd. #401-20, Batesville, IN 47006, USA; e-mail: newiggermann@gmail.com.

HUMAN FACTORS
Vol. 55, No. 4, August 2013, pp. 764-775
DOI:10.1177/0018720812466672

INTRODUCTION

Significance

Standing for prolonged periods of time is required for employees in many occupations, including health care workers (Baty & Stubbs, 1987; Cook, Branch, Baranowski, & Hutton, 1993; Meijsen & Knibbe, 2007), supermarket workers (Ryan, 1989), school teachers (Messing, Seifert, & Escalona, 1997), and inspection and assembly workers (Redfern, 1995; Van Deen & Oude Vrielink, 1998). While prolonged standing is common, its consequences are not trivial. Over the course of hours, standing has been shown to cause discomfort in the feet, legs, and lower back (Cham & Redfern, 2001; Jorgensen, Hansen, Lundager, & Winkel, 1993; Madeleine, Voigt, & Arendt-Nielsen, 1998). Regular exposure to prolonged standing has been associated with an increased risk of back pain (Macfarlane, 1997), leg and foot pain (Ryan, 1989), venous disorders (Tomei, 1999), and preterm births (Mozurkewich, 2000).

Anti-Fatigue Mats and Discomfort

Anti-fatigue mats are commonly used in industry to reduce discomfort resulting from prolonged standing. Several studies have evaluated mats by comparing at least one mat to a hard control surface. In these experiments, participants were asked to stand on each surface for sessions ranging from 1 to 4 hours in a laboratory (e.g., Cham & Redfern, 2001; Madeleine et al., 1998; Rys, 1989) or for one week at a worksite (King, 2002; Redfern, 1995). Nearly all of the studies recorded subjective ratings of overall discomfort after standing (e.g., Hansen, Winkel, & Jørgensen, 1998; Madeleine et al., 1998), and many also recorded discomfort ratings by body region (Cham & Redfern, 2001; King, 2002; Redfern, 1995; Zhang, Drury, & Woolley, 1991).

In the majority of studies (Cham & Redfern, 2001; King, 2002; Madeleine et al., 1998; Redfern, 1995; Rys, 1989), mats were found to be associated with lower ratings of discomfort when compared to hard flooring. Redfern (1995) and Cham and Redfern (2001) evaluated multiple mats and detected differences among mats themselves. These studies found that very soft mats (mats with a very low stiffness, defined later) were sometimes associated with higher discomfort than relatively harder mats. However, neither study was able to identify a particular mat that was more comfortable than other mats. The general conclusion that can be drawn from previous studies is therefore somewhat limited: that very hard surfaces are undesirable for standing and that very soft surfaces may also be undesirable. There is currently no method for predicting the effectiveness of a particular mat in mitigating discomfort.

Behavioral Responses to Standing

Part of the reason it is difficult to predict the ability of mats to reduce discomfort during prolonged standing is because there currently is no physiological explanation for differences in discomfort among flooring surfaces (Redfern & Cham, 2000). Without physiological measurements that can differentiate effects of different flooring surfaces, subjective ratings of discomfort represent the only measurement available. These subjective ratings have high variability, making them sensitive only to very large differences in discomfort between surfaces. For example, when comparing subjective ratings associated with standing on different surfaces, the coefficients of variation in Redfern (1995) were as high as .57. There is a need for a metric that can detect smaller differences in discomfort when comparing flooring designs.

Behavioral responses to standing such as weight-shifting between the feet may provide a measurement that is sensitive to differences in discomfort among flooring surfaces. The behavioral response to standing has not been thoroughly explored, but there is some initial evidence to suggest it may be related to discomfort. Gregory and Callaghan (2008) found that center of pressure (COP) shifts were predictive of lower back pain during standing but did not test for the effects of different flooring. Cham and Redfern (2001) found some significant differences in lateral COP shifts after 3 hours of standing, showing greater shifts for some surfaces associated with higher discomfort ratings. Using observational video analysis, Zhang et al. (1991) counted posture changes during standing. The study identified an increase in the frequency of changes with time, but not among surfaces.

Flooring Material Properties

Another impediment to predicting the ability of mats to mitigate discomfort is that the material properties of mats have not been adequately described in most previous studies. Studies that fail to measure and report material properties of flooring are difficult to reproduce, and the results cannot be used to predict the performance of other unstudied mats. When comparing anti-fatigue mats, some studies provide as little description as thickness and material composition (e.g., King, 2002; Zhang et al., 1991), neglecting additives, coatings, and geometric structure of mats that can drastically alter their attributes (Ciullo & Hewitt, 1999). The greatest detail was given by Cham and Redfern (2001) where mats were described using several flooring properties. However, no study has measured properties a priori to allow strategic selection of mats that include a range of values representative of the population of commercially available mats.

Material properties previously used to describe mats include stiffness and “work lost,” which appear to be connected to discomfort during standing (Cham & Redfern, 2001). Stiffness is a material’s resistance to deformation (compression) when an external load is applied. Work lost represents the energy absorbency of a material. When a material is compressed, and the compression force is graphed against displacement, stiffness is represented by the slope of the linear portion of the curve (Beer & Johnston, 2002). Work lost represents the area between compression and a curve measured during subsequent decompression (Duggan, 1965) (see Figure 1). Goonetilleke (1999) considered several material properties for shoes and found that stiffness was

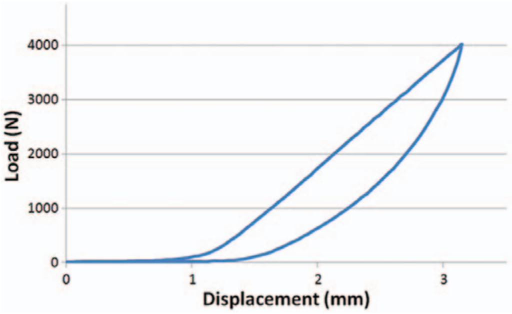

Figure 1. Graph of force versus displacement as an anti-fatigue mat is compressed and unloaded. The linear portion of the graph is generated as the compression load on the mat is increased. The slope of this line is the measure of the stiffness, in N/mm (Beer & Johnston, 2002). The curved portion of the graph is generated as the compression load is subsequently decreased. The area between the compression and decompression curves is the measure of work lost, in N × mm (Duggan, 1965).

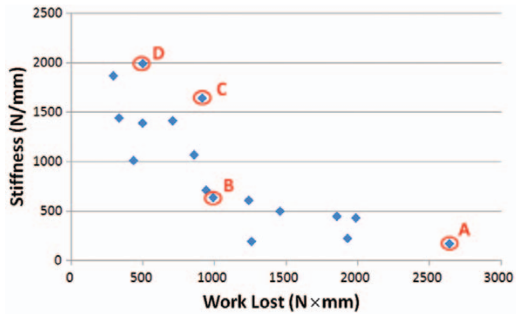

Figure 2. Stiffness and work lost values of commercially available mats considered for the study. Mats selected for the study are labeled.

most highly correlated to "perceived levels of cushioning" during standing. Cham and Redfern (2001) found trends in discomfort associated with flooring surfaces, stating that greater stiffness and lower work lost were associated with lower discomfort ratings.

Research Objectives

This study had two primary objectives. The first was to investigate the effect of flooring on discomfort by evaluating anti-fatigue mats with material properties that are representative of a range of contemporary commercially available mats. The second objective was to measure several behavioral responses to prolonged standing and to determine how these responses were affected by flooring surface and how they correlated to discomfort.

METHODS

In this study, participants stood for 4 hours on different flooring surfaces. During this time, pressure on the plantar surface of the foot was measured using in-shoe pressure sensors. These pressure data were used to assess the behavioral response to standing. Subjective ratings of discomfort were also measured.

Participants

A total of 10 participants (5 male, 5 female) were recruited from a student population. Informed consent was obtained prior to participation in the study using protocols approved by the Institutional Review Board. The mean age of participants was 23.5 years (*SD* = 4.1 years) and their mean body mass was 67.4 kg (*SD* = 12.6 kg). The women's shoe sizes (U.S. sizing) ranged from 6 to 10, and the men's ranged from 7.5 to 12. Individuals with a history of lower extremity disorders and those with an irregular foot arch height (Williams, McClay, & Hamill, 2001) were excluded.

Selection of Anti-Fatigue Mats

The independent variable in this experiment was the flooring surface. The material properties of stiffness and work lost were measured for 17 commercially available mats, from which 4 mats were chosen for the experiment. Material properties of the mats were measured using an MTS testing machine (model: Insight 10 SL; MTS Systems Corp; Eden Prairie, MN, USA) in which a sample of each mat was placed between two round aluminum plates 15.3 cm in diameter. Stiffness and work lost were calculated by taking the average of three compression cycles to 4,000 N.

Figure 2 shows a graph of the values of stiffness versus work lost for all 17 mats considered for the study. The selected mats (A through D) were chosen to represent the range of properties observed in the larger sample of 17 mats.

TABLE 1: Stiffness and Work Lost Values of Mats Chosen for the Study

Surface	Stiffness (N/mm)		Work Lost (N × mm)	
	Mean	*SD*	Mean	*SD*
A ("softest")	169	2.0	2,638	73.0
B ("softer")	711	65.9	942	68.0
C ("harder")	1,639	217.1	914	10.4
D ("hardest")	1,988	57.7	500	82.0

Experimental design considerations were also a factor in selection, such as the inclusion of mats B and C with similar work lost values in an attempt to isolate the effect of stiffness on experimental outcomes. The control surface was linoleum tile on concrete. While this surface could not be measured in the MTS machine, it was characterized by a very large stiffness and a very small work lost. Table 1 shows the material properties for the four mats included in the study.

Procedure

Each participant attended five experimental sessions, each lasting 4 hours. Using a full-factorial design, participants stood on a different surface for each session, and these surfaces were presented in a random order. To control for physiological time-of-day effects (e.g., Lericollais, Gauthier, Bessot, Sesbouumleacute, & Davenne, 2009), data collection for each participant occurred at the same time of day. For each participant, sessions were scheduled at least 72 hours apart to allow ample recovery from fatigue. Experimental sessions for all participants were completed within the same 8-week period. Participants were not given exercise or dietary restrictions but were asked not to engage in activities prior to experimental sessions that required them to stand for extended periods.

Participants were provided with standardized socks and cross-trainer athletic shoes (New Balance™ model MX602WN for men and the similar model WL493WF for women). Participants stood at an adjustable height work table in a 1.0 by 1.5 meter rectangular area and were instructed not to use the table to support any weight except that of the forearms. No instructions or constraints to standing were otherwise given. To standardize the demands on each participant, a rotation of work tasks was performed, which consisted of a light assembly task, a typing task, and a continuous monitoring task on a computer. After 110 minutes of standing, participants were given a 10-minute break during which time they were permitted to walk or sit as they wished.

Discomfort Ratings

Before the experiment and after each 55 minutes of standing, a discomfort survey was administered (see Figure 3). This survey used 10-centimeter visual analog scales (Capodaglio, 2001) for determining overall ("overall leg" and "overall body") and localized discomfort ratings (feet, lower legs, knees, thighs, buttocks, and lower back). A body diagram similar to Corlett and Bishop (1976) was used to define localized ratings (see Figure 3); no specific instruction was provided for defining overall ratings. The rating scale ranged from 0 to 100 millimeters and was determined by measuring the distance from the left side of the scale to a mark drawn by the participant.

Measurement of Behavioral Responses

Prior to data collection, .13-mm-thick F-Scan® pressure sensing insoles (Tekscan; Boston, MA, USA) were cut to fit and placed in the participant's shoes. These insoles are composed of a grid of .51 cm × .51 cm "sensels" that measure pressure by electrical resistance. Ten minutes of in-shoe pressure data were collected at 20 Hz during the computer monitoring task, which occurred near the end of each hour

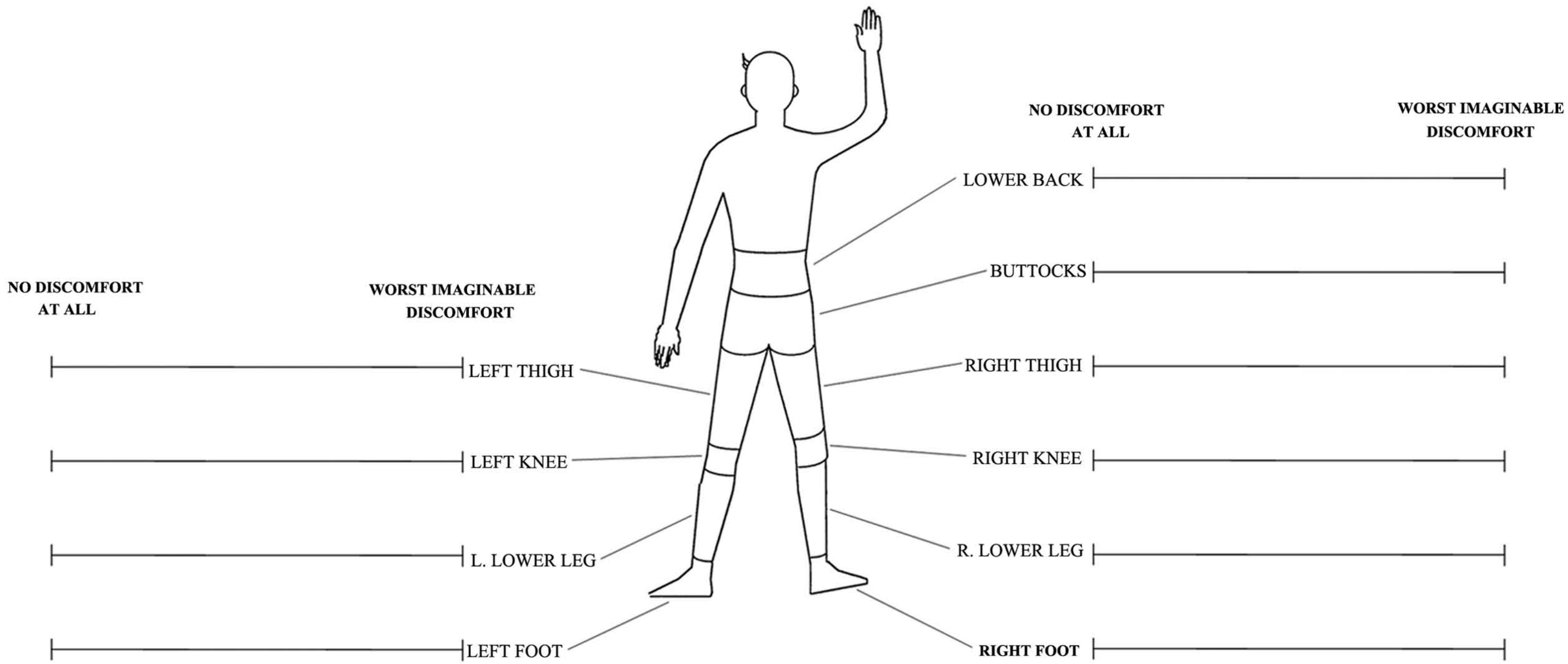

Figure 3. Survey used to measure discomfort at various body locations (not shown to actual scale).

of standing. The pressure data were used to determine several behavioral responses to standing, including weight-shifting, COP excursions, and distribution of body weight between the left and right foot.

Weight-shifting was defined as a change in distribution of load bearing between the two feet and consisted of a transition between any of the three conditions: (a) greater than 80% of body weight on left foot, (b) greater than 80% of body weight on right foot, (c) simultaneously, at least 20% of body weight on each foot. These shifts were counted during each 10-minute pressure recording. Changes that occurred less than 7.5 seconds after a previously counted weight-shift were considered part of a continuous shifting motion and were not counted as a separate shift.

COP excursions were the average travel rate (cm/sec) of the COP on a single foot during a standing experimental condition. Excursions were analyzed separately in the medial-lateral (ML) direction and the anterior-posterior (AP) direction and were calculated using only observations when the foot was loaded with at least 20% of body weight. COP excursions were measured within-foot rather than for the whole body to provide an estimate of more subtle movements of the foot and ankle, in contrast to weight-shifting, which measured whole-body postural movement.

The distribution of body weight between the left and right foot during standing was characterized as one of two stances: a predominantly single-foot stance (1FS) characterized by at least 80% of the body weight supported by one foot or a two-foot stance (2FS) with at least 20% of body weight simultaneously supported by each foot. The percentage of time in 1FS was determined from the proportion of 1FS to the total time standing.

Statistical Analysis

Subjective discomfort ratings and behavioral responses (weight-shifting, COP excursions, and percentage of time in 1FS) were analyzed independently using a repeated measures analysis of variance (Montgomery, 2005). Models for discomfort ratings were analyzed for each hour (Cham & Redfern, 2001) and also with all hours pooled. The effect of session number, duration of standing (by hour), surface, and participant (as a fixed effect) were included in the models. Discomfort ratings were analyzed as potential covariates for behavioral responses. Where floor surface was significant, Tukey pairwise comparisons were performed. Linear regression models were also generated to test for correlations among discomfort, behavioral responses, and mat material properties (e.g., stiffness and work lost).

Discomfort data were normalized by subtracting initial discomfort ratings from subsequent ratings obtained during the same testing session. Data from two sessions (less than 4% of observations) were considered outliers, and discomfort ratings and behavioral variables from these sessions were removed from the analysis. One session was removed because the participant reported that he slept in a chair the night before the experiment, experienced acute back pain during the testing, and the session was ended early. The second outlier occurred during a participant's initial session in the laboratory where he seemed to be confused by the discomfort rating system. Discomfort ratings for Session 1 were more than 200% higher than the discomfort ratings for subsequent sessions. At the end of the experiment, the participant did not claim to have experienced more discomfort in Session 1 than other sessions, so this session was not used in the analysis.

RESULTS

Discomfort Ratings

Of the eight body locations on the discomfort survey, only the lower leg was significantly influenced by surface across all hours of the experiment. Significant flooring effects only appeared in other locations when fourth-hour ratings were compared. For the "overall leg," the softest mats, A and B, demonstrated significantly ($p < .05$) lower discomfort ratings than did the hard linoleum-on-concrete control (see Figure 4). For the lower leg, surfaces A and D, the hardest and softest mats, showed significantly lower discomfort ratings than did the hard control (see Figure 5). For the feet, only the softest mat (surface A) showed a significant reduction in discomfort ratings over the hard

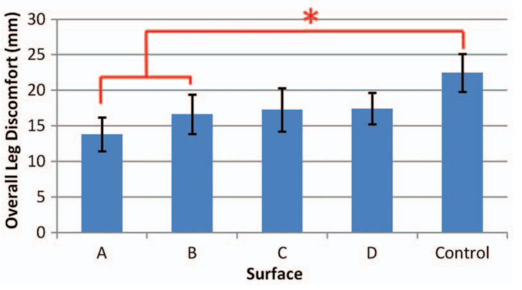

Figure 4. Mean overall leg discomfort for the different flooring surfaces after 4 hours of standing. Error bars represent standard error of the mean. *Significant difference in pairwise comparison.

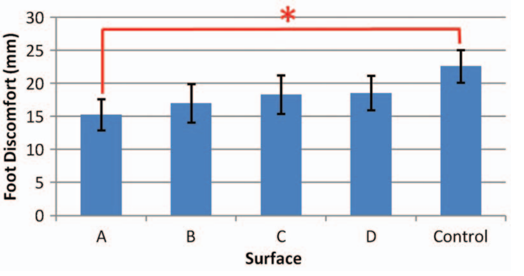

Figure 6. Mean foot discomfort for the different flooring surfaces after 4 hours of standing. Error bars represent standard error of the mean. *Significant difference in pairwise comparison.

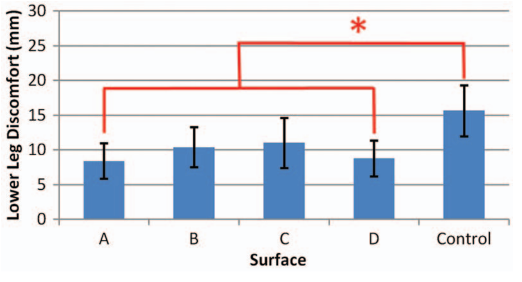

Figure 5. Mean lower leg discomfort for the different flooring surfaces after 4 hours of standing. Error bars represent standard error of the mean. *Significant difference in pairwise comparison.

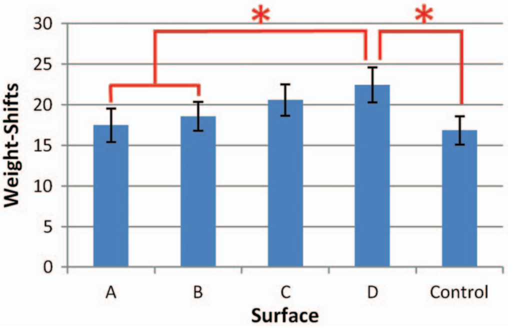

Figure 7. The mean frequency of weight-shifts (counted in a 10-minute period) for each surface. Error bars represent standard error of the mean. *Significant difference in pairwise comparison.

control (see Figure 6). For the lower back and knees, the hard control demonstrated greater discomfort than did the mats but did not achieve statistical significance (p = .07 for both locations) after 4 hours of standing. Flooring had no significant effect on discomfort for the overall body, buttocks, or thighs. Discomfort ratings were variable, with coefficients of variation ranging from .40 to .56 (overall leg), .56 to .75 (lower leg), and .36 to .52 (foot) after the fourth hour of standing. The properties of stiffness and work lost were not correlated to any ratings of discomfort except for the foot, where increasing stiffness and decreasing work lost corresponded to increased discomfort.

Behavior—Weight-shifting

The number of weight-shifts was significantly affected by the session number (p = .01), standing duration (p = .01), and surface (p < .01). Weight-shifting increased with session and elapsed hours standing, and the hardest mat (surface D) produced significantly more shifts than the soft mats (A, and B) and the hard control (see Figure 7). Weight-shifting was positively correlated with foot discomfort (p < .01, r = .30), lower back discomfort (p = .01, r = .35), and overall leg discomfort (p = .01, r = .24) and tended to increase with overall discomfort (p = .06). Figure 8 shows the trend of increasing weight-shifting associated with increasing foot discomfort. The material properties of stiffness and work lost were not related to weight-shifting.

An analysis of the weight-bearing between the left and right foot across all participants and all trials showed a trimodal distribution, in which standing tended to occur with either

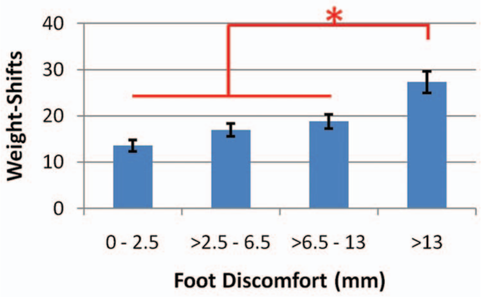

Figure 8. All normalized discomfort ratings were placed into quartiles ($n = 54$ for each bin). The means of the number of weight-shifts per 10-minute period are shown for each quartile of foot discomfort ratings (error bars represent standard error of the mean). *Significant difference in pairwise comparison.

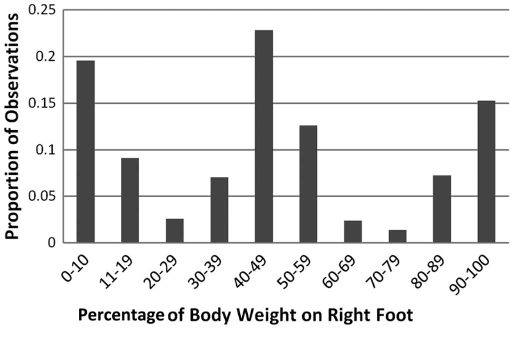

Figure 9. Distribution of body weight between feet during standing.

greater than 80% of body weight on a single foot (51% of observations) or relatively balanced with 40% to 60% of body weight on each foot (35% of observations). Figure 9 shows the proportion of observations for different relative loading between feet.

The percentage of single foot stance (1FS) increased with standing duration ($p = .03$) and was positively correlated with discomfort ratings ($p = .01$). Material properties of stiffness and work lost were not related to the percentage of 1FS.

Behavior—COP Excursions

ML and AP COP excursions also increased with discomfort ($p = .02$ and $p < .01$, respectively).

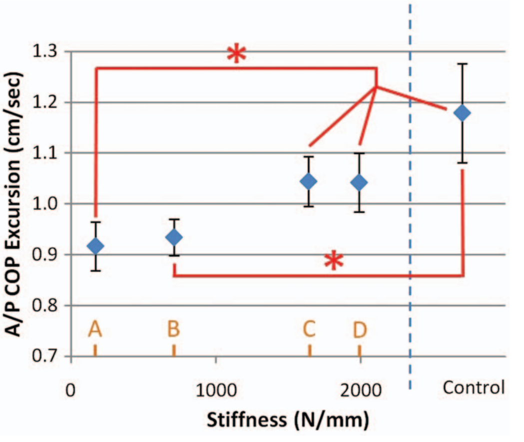

Figure 10. Mean anterior-posterior (A/P) excursions for each flooring surface graphed against the stiffness of the surface. Each surface is labeled above the *x*-axis. Error bars represent standard error of the mean. COP = center of pressure.*Significant difference in pairwise comparison.

The effect of surface was significant for both ML and AP excursions ($p < .01$ for both). For ML excursion, the soft mats (surfaces A and B) showed significantly less travel than did the harder mat (surface C) and the hard control. For AP excursions, the softest mat (surface A) demonstrated significantly less travel than did the harder mats (surfaces C and D) and the control, and the softer mat (surface B) had significantly less travel than the hard control. Figure 10 shows mean AP excursions by surface. Mean ML excursions by surface (not shown) followed very similar trends. Stiffness and work lost were both predictive of AP excursions ($p < .01$ and $p = .04$, respectively).

DISCUSSION AND CONCLUSIONS

Discomfort Ratings

The hard control surface was associated with significantly higher discomfort ratings than three of the mats. This reinforces the findings of other studies that also found differences in discomfort (Cham & Redfern, 2001; King, 2002; Madeleine et al., 1998; Redfern, 1995; Rys, 1989). With the exception of the lower leg, which was significant throughout all 4 hours of the experiment, significant differences in discomfort ratings did not emerge until the fourth hour. This is similar to the findings of Cham and Redfern (2001), who found significant differences only during the third and fourth hours.

This study did not find differences in discomfort among the mats themselves, which is in contrast to findings reported by Redfern (1995) and Cham and Redfern (2001). A possible explanation for the lack of differences among mats is that those included in this study were all contemporary commercially successful mats. It is possible that ineffective mats that could result in higher discomfort ratings, therefore making differences in discomfort easier to detect, have disappeared from the market. For example, some of the less comfortable mats in Redfern and Cham and Redfern studies were very soft and "bottomed out" when loaded. A surface that bottoms out is easily deformed when loaded and becomes much harder after it is compressed. The mats used in this study were similar in stiffness to those used in Redfern and Cham and Redfern studies, but did not bottom out when loaded.

Behavior

All of the behavioral responses measured in this study (weight-shifting, percentage time in 1FS, ML and AP excursions) were positively correlated with discomfort. Although these correlations were somewhat weak, this is not surprising given that discomfort ratings were so variable and that other factors such as differences among participants explain a large portion of the variability. Significant differences were observed among mats for weight-shifting and COP excursions. A post hoc statistical power analysis showed that behavioral response variables were better able to discriminate among mats than subjective ratings of discomfort. Given the differences in means observed in this study, for an alpha = .05 and a power of .90, 105 participants would be required to detect a difference among mats using discomfort ratings, 49 would be required for weight-shifting, and 25 would be required for COP excursions. Understanding the relationship between discomfort and behavior may help establish behavioral responses as a potential alternative to subjective ratings for evaluating discomfort and may also provide clues for how fatigue and discomfort develop during standing.

Weight-shifting seems to be a particularly promising response variable for evaluating flooring because of its likely connection to physiological mechanisms for discomfort. For example, it has been suggested that shifting weight temporarily relieves pressure on the feet (Goonetilleke, 1998), allows replenishment of synovial fluid in joint cartilage (Alexander, 1992), and decreases venous pooling in the lower extremities (Brantingham, Beekman, Moss, & Gordon, 1970). In this study, weight-shifting was positively correlated with discomfort. Weight-shifting generally seemed to increase as flooring stiffness increased, but this trend was not consistent for the hard control surface (see Figure 7). One possible explanation for why this trend was inconsistent and weight-shifting was relatively low for the control surface is that the increased COP excursions observed for the hard control surface compensated for the need to shift weight between the feet. The inconsistent trend in which weight-shifting for the control surface is unexpectedly low may also explain why weight-shifting was not correlated with stiffness or work lost.

Weight-shifting significantly increased with session number, with the increase occurring primarily between Sessions 1 and 3. This effect is most likely a result of accommodation by the participants to the test conditions presented in a laboratory experiment. During the weight-shifting measurements, participants monitored dials on a computer screen that moved at random speeds and directions. Participants used a mouse to respond when a displayed dial passed a certain threshold, and the response time was measured. As participants became more familiar with this task, they may have become more adept at identifying windows of time when they would not need to respond using the mouse, allowing them to switch their concentration from monitoring the dials to symptoms of discomfort in the lower extremities, thus increasing their weight-shifting behavior. Even though participants practiced this task on a separate day before the experiment, response times decreased significantly with session ($p < .01$). This result supports the possibility that as participants became more familiar with the task they could shift their attention to other sensory inputs. To test this hypothesis, future investigation of weight-shifting should consider task complexity as an independent variable. Regardless, because the order of the flooring surfaces was randomized, this effect of session on weight-shifting should not have a significant impact on the study findings.

COP excursion is another behavioral response variable that may be suitable for evaluating flooring. Like weight-shifting, COP excursions were correlated with discomfort and have a potential connection to physiological mechanisms for discomfort. Because fatigue of leg muscles has been shown to cause an increase in COP excursions (e.g., Vuillerme, Danion, Forestier, & Nougier, 2002), excursions may provide an indirect measure of leg muscle fatigue. COP excursions showed a consistent trend with respect to flooring stiffness, with increasing stiffness corresponding to larger AP excursions. It is possible that on these less comfortable, harder surfaces, individuals respond with COP excursions to alter the distribution of tension in muscles and pressure in cartilage. Additional research is needed to evaluate these relationships between COP excursion and flooring stiffness and COP excursion and discomfort.

Limitations

This study tested participants from a student population, which does not represent the demographics of the general workforce. Participants stood unconstrained in a small 1.0 by 1.5 meter area, and the results may have been different for purely constrained standing or for a mixture of standing and walking. While the standardized footwear used in this experiment helped to reduce unwanted variability, it is possible that different shoes or insoles may yield different results.

There are several possibilities for why differences in discomfort that may occur in the workplace were not detected in this experiment. The large variability of subjective ratings of discomfort makes it difficult to find significant discomfort differences between surfaces in trials of 4-hour duration. While the 4 hours of standing time in this study was longer than most previous laboratory studies, the time duration may not capture all of the outcomes that might otherwise be seen with consecutive days of exposure to 8- to 12-hour work shifts as could be experienced in industry.

Future Work

More work is needed to explain the physiological mechanisms for how mats intervene to reduce discomfort as compared to standing on a hard surface. The behavioral results from this study suggest that comfortable flooring may provide greater stability, reducing muscle requirements to maintain an upright posture. Electromyography of leg and lower back muscles during standing could be used to test the hypothesis that smaller COP excursions are associated with reduced muscle activation. To provide a biomechanical explanation for this phenomenon, a cadaveric foot could be used to test the hypothesis that a perturbation of a certain torque about the ankle for a loaded foot on a soft surface will generate a smaller COP excursion than the same level of torque for a loaded foot on a hard surface.

More comfortable flooring may also enable discomfort-relieving movements while standing. Using motion capture or goniometers to measure movement of the ankle, knee, hip, and lumbosacral joint will test the hypothesis that softer flooring enables greater changes in joint angles while standing. This result could then be linked to venous pooling, previously associated with discomfort (Kraemer et al., 2000), by testing the ability of these joint movements to reduce leg circumference, a measure of venous pooling. These movements may also identify an alternate compensatory strategy that explains the inconsistent weight-shifting result that was observed on the hard control surface in this study.

Implications for Industry

This study did not detect differences in discomfort between four commercially available mats, but our results confirm that mats are indeed capable of mitigating discomfort during prolonged standing. There are many reasons why differences in discomfort between mats may exist but are not detectable (e.g., variability in discomfort ratings, difference in individual preference, etc.). However, these findings do suggest that for standing workstations, the selection of mats can be based more on criteria such as safety, durability, and cost and less on perception of comfort.

The results also show that while mats reduce discomfort, the effect of hours spent standing is much greater than the effect of flooring surface. This means that eliminating standing work, using sit/stand stations, or rotating seated and standing tasks will provide greatest comfort to the worker, regardless of flooring surface.

ACKNOWLEDGMENTS

The authors of this publication were partially supported by Training Grant No. T42 OH 008455 from the Centers for Disease Control and Prevention/National Institute for Occupational Safety and Health (NIOSH). The contents are solely the responsibility of the authors and do not necessarily represent the official views of the National Institute for Occupational Safety and Health. U.S. Mats Inc. (Michigan, USA) and Wearwell (Tennessee, USA) supplied some of the mats tested in this study. The authors would also like to thank Benjamin Pokorney for his assistance with data collection, as well as Eyvind Claxton and Charles Wooley for their help in preparing laboratory equipment. Finally, gratitude is owed to the participants for their cooperation and commitment to the study.

KEY POINTS

- After 4 hours of standing, three of the four anti-fatigue mats were associated with lower discomfort than with the hard control surface. However, subjective ratings of perceived discomfort were incapable of discriminating among mats.
- Behavioral responses to standing (i.e., weight-shifting and center of pressure excursions) were sensitive to differences among mats and may provide an objective alternative to subjective reports of perceived discomfort. These behavioral measurements were positively correlated with discomfort ratings and had smaller coefficients of variation.
- Weight-shifting and center of pressure excursions generally tended to increase with flooring stiffness.
- To more effectively evaluate mats, a better understanding is needed of the physiological mechanisms that cause discomfort during prolonged standing and the relation of these mechanisms to behavioral response variables such as weight-shifting.

REFERENCES

Alexander, R. (1992). *The human machine*. New York, NY: Columbia University Press.

Baty, D., & Stubbs, D. (1987). Postural stress in geriatric nursing. *International Journal of Nursing Studies*, *24*, 339–344.

Beer, F. P., & Johnston, R. E. (2002). *Mechanics of materials*. New York, NY: McGraw-Hill.

Brantingham, C., Beekman, B., Moss, C., & Gordon, R. (1970). Enhanced venous pump activity as a result of standing on a variable-terrain floor surface. *Journal of Occupational Medicine*, *12*, 164–169.

Capodaglio, E. (2001). Comparison between the CR10 Borg's Scale and the VAS (Visual Analogue Scale) during an arm-cranking exercise. *Journal of Occupational Rehabilitation*, *11*, 69–74.

Cham, R., & Redfern, M. (2001). Effect of flooring on standing comfort and fatigue. *Human Factors*, *43*, 381–391.

Ciullo, P. A., & Hewitt, N. (1999). *The rubber formulary*. Norwich, NY: Noyes Publications.

Cook, J., Branch, T., Baranowski, T., & Hutton, W. (1993). The effect of surgical floor mats in prolonged standing: An EMG study of the lumbar paraspinal and anterior tibialis muscles. *Journal of Biomedical Engineering*, *15*, 247–250.

Corlett, E., & Bishop, R. (1976). A technique for assessing postural discomfort. *Ergonomics*, *19*, 175–182.

Duggan, T. V. (1965). *Stress analysis and vibrations of elastic bodies*. New York, NY: American Elsevier Publishing.

Goonetilleke, R. (1998). Designing to minimimize discomfort. *Ergonomics in Design*, *6*(3), 12–19.

Goonetilleke, R. (1999). Footwear cushioning: Relating objective and subjective measurements. *Human Factors*, *41*, 241–256.

Gregory, D., & Callaghan, J. (2008). Prolonged standing as a precursor for the development of low back discomfort: an investigation of possible mechanisms. *Gait & Posture*, *28*, 86–92.

Hansen, L., Winkel, J., & Jørgensen, K. (1998). Significance of mat and shoe softness during prolonged work in upright position: Based on measurements of low back muscle EMG, foot volume changes, discomfort and ground force reactions. *Applied Ergonomics*, *29*, 217–224.

Jorgensen, K., Hansen, L., Lundager, K., & Winkel, J. (1993). Low back muscle reactions to constrained standing in relation to shock absorbing properties of floor and shoes. In R. Nielson & K. Jorgensen (Eds.), *Advances in industrial ergonomics and safety V* (pp. 279–283). London, UK: Taylor & Francis.

King, P. (2002). A comparison of the effects of floor mats and shoe in-soles on standing fatigue. *Applied Ergonomics*, *25*, 477–484.

Kraemer, W., Volek, J., Bush, J., Gotshal, L., Wagner, P., Gomez, A. L., . . . Selle, B. J. (2000). Influence of compression hosiery on physiological responses to standing fatigue in women. *Medicine & Science in Sports & Exercise*, *32*, 1849–1858.

Lericollais, R., Gauthier, A., Bessot, N., Sesbouumleacute, B., & Davenne, D. (2009). Time-of-day effects on fatigue during a sustained anaerobic test in well-trained cyclists. *Chronobiology International*, *26*, 1622–1635.

Macfarlane, G. T. (1997). Employment and physical work activities as predictors of future low back pain. *Spine*, *22*, 1143–1149.
Madeleine, P., Voigt, M., & Arendt-Nielsen, L. (1998). Subjective, physiological, and biomechanical responses to prolonged manual work performed standing on hard and soft surfaces. *European Journal of Applied Physiology*, *77*, 1–9.
Meijsen, P., & Knibbe, H. (2007). Prolonged standing in the OR: A Dutch research study. *AORN Journal*, *86*, 399–414.
Messing, K., Seifert, A., & Escalona, E. (1997). The 120-second minute: Using analysis of work activity to prevent psychological distress among elementary school teachers. *Journal of Occupational Health Psychology*, *2*, 45–62.
Montgomery, D. (2005). *Design and analysis of experiments*. New York, NY: John Wiley and Sons.
Mozurkewich, E. L. (2000). Working conditions and adverse pregnancy outcome: A meta-analysis. *Obstetrics and Gynecology*, *95*, 623–635.
Redfern, M. (1995). Influence of flooring on standing. *Human Factors*, *37*, 570–581.
Redfern, M., & Cham, R. (2000). The influence of flooring on standing comfort and fatigue. *AIHAJ*, *61*, 700–708.
Ryan, G. (1989). The prevalence of musculoskeletal symptoms in supermarket workers. *Ergonomics*, *2*, 570–581.
Rys, M. a. (1989). An evaluation on floor surfaces. In *Proceedings of the Human Factors Society 33rd Annual Meeting* (pp. 517–520). Santa Monica, CA: Human Facotrs and Ergonomics Society.
Tomei, F. B. (1999). Chronic venous disorders and occupation. *American Journal of Industrial Medicine*, *36*, 653–665.
Van Deen, J., & Oude Vrielink, H. (1998). Evaluation of work-rest schedules with respect to the effects of postural workload in standing work. *Ergonomics*, *41*, 1832–1844.
Vuillerme, N., Danion, F., Forestier, N., & Nougier, V. (2002). Postural sway under muscle vibration and muscle fatigue in humans. *Neuroscience Letters*, *333*, 131–135.
Williams, D., McClay, I., & Hamill, J. (2001). Arch structure and injury patterns in runners. *Clinical Biomechanics*, *16*, 341–347.
Zhang, L., Drury, C., & Woolley, S. (1991). Constrained standing: Evaluating the foot/floor interface. *Ergonomics*, *34*, 175–192.

Neal Wiggermann oversees ergonomics research for Hill-Rom Company. He received his PhD in industrial and operations engineering from the University of Michigan in 2011.

W. Monroe Keyserling is a professor in the Department of Industrial and Operations Engineering at the University of Michigan. He received his PhD from the University of Michigan in 1979.

Date received: March 4, 2012
Date accepted: October 9, 2012