



## Comparisons of tibial accelerations when walking on a wood composite vs. a concrete mezzanine surface



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### ABSTRACT

Mezzanine surfaces can be made from concrete, bar grate, or composite materials. Anecdotal data indicate that mezzanines in distribution centers made from composite materials, due to their increased compliance, may be a more comfortable working surface. Prior research suggested that a measure of tibial shock, peak tibial acceleration, could potentially discriminate the biomechanical differences between these surfaces. The objective of this study was to quantify differences in tibial accelerations as 27 people walked on mezzanines constructed from concrete and a wood composite material. Accelerometers were attached bilaterally to the shins of volunteers, and data were collected as they walked 30.5 m on each surface at their normal walking speed, a faster-than-normal walking speed, and a slower-than-normal walking speed. Peak acceleration values obtained from the leg with the highest values were compared. On average, the peak acceleration values were 5% higher on the concrete mezzanine as compared with the wood composite mezzanine ( $p = .036$ ). These findings suggest that individuals working on mezzanines in distribution centers constructed from composite surfaces would potentially experience less discomfort associated with long exposure periods on these surfaces.

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### 1. Introduction

Prolong standing at work has been associated with lower extremity pain (Chandrasakaran et al., 2003; Hou and Shiao, 2006), which, in turn, is predictive of early retirement (Rice et al., 2011). Cham and Redfern (2001) showed that the level of discomfort was affected by the type of surface upon which one stands. Specifically, “softer” surfaces have been associated with less subjectively measured discomfort than harder surfaces (Redfern and Cham, 2000). Likewise, Orlando and King’s (2004) study found reduced reports of discomfort among assembly line employees when working on floor mats or using shoe insoles for a week, compared to when they stood on a woodblock floor for the same length of time. Beyond matting and insoles, these findings suggest that workers walking on more compliant flooring materials should also experience less discomfort. One manufacturer of a wood composite material used for mezzanine construction gathered anecdotal reports from customers that are consistent with the above-referenced reports. The basic research question addressed in this

paper is whether specific mezzanine construction materials can impact biomechanical exposures in the lower extremity.

Selected studies in the gait analysis literature have focused on quantifying “tibial shock” using accelerometers affixed to the lower leg (Higginson, 2009; Whittle, 1999). Signals from skin-mounted accelerometers have been shown to provide reliable measures of the initial peak acceleration at heel strike (Liikavainio et al., 2007) and have been used to document the effectiveness of cushioned insoles during running (Lake, 2000; O’Leary et al., 2008). For example, O’Leary et al. (2008) reported that the use of cushioned insoles reduced the peak tibial accelerations during the initial foot contact by an average of nearly 16 percent.

These findings suggest that measurements of the peak tibial accelerations may also be sensitive to the differences in flooring material used in the construction of mezzanines. The aim of this work was to obtain a valid measure that could differentiate biomechanical exposures as people walked on different mezzanine surfaces. Specifically, this investigation compared the peak tibial accelerations as people walked on concrete and wood composite mezzanines. Specifically, our hypothesis was that peak tibial accelerations would be significantly lower when walking on the wood composite (ResinDek, Cornerstone Specialty Wood Products, LLC) surface relative to those measured when walking on concrete.

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## 2. Methods

### 2.1. Experimental design

A repeated measures design was used in which participants walked on mezzanine surfaces constructed of concrete and a wood composite material. The walking sequence on surfaces was counterbalanced across subjects. On each surface the participants were asked to walk at three speeds: their “normal” walking speed, “faster than normal”, and “slower than normal”. While the normal speed condition was always the first performed on each surface, the sequence of the faster and slower speeds was randomized for each participant. There were two replicates of each experimental condition.

### 2.2. Participants

Twenty seven volunteers, 16 males and 11 females between the ages of 21 and 64 (mean = 41 years, s.d. = 13 years), participated in this study. All were employees working at an apparel distribution facility. Mean height and weight were 1.73 m (s.d. = 0.09 m) and 86 kg (s.d. = 20 kg). Based upon BMI, 22 percent of the sampled individuals were normal weight, 33 percent were overweight, and 45 percent were obese. None expressed any current lower extremity symptoms at the time of the study. All participants signed an Institutional Review Board (IRB)-approved consent document. Participants were tested in this protocol in whatever footwear they were wearing at the time, which was primarily either some type of athletic shoe or a work boot.

### 2.3. Instrumentation

A single axis accelerometer (Vernier, model LGA-BTA) was attached to the shin of each participant's lower legs using a self-adhesive wrap (Fig. 1). The sensors were connected to a data recorder and computer mounted on a cart that followed the participant as he or she walked.

Walking speed is an important covariate in this study; it was quantified by measuring the time required to the 15.25 m test distance. An auditory alarm, triggered through the use of photo beams, was used to signal the timing process (Fig. 2).

### 2.4. Procedures

The accelerometers were positioned on the anterior or anterior lateral aspect of each tibia. The exact position was determined by

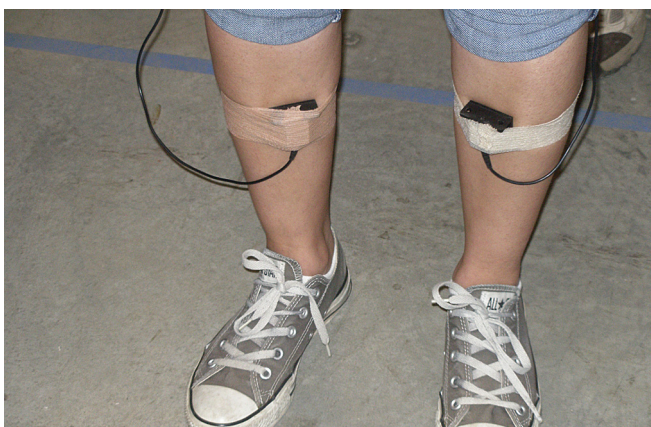


Fig. 1. The accelerometers positioned on one of the participants using the self-adhesive wrap.

where the investigator responsible for instrumentation believed the most rigid attachment to the bone could be attained. The type of shoes worn by each participant was noted.

Participants were instructed to walk at three different speeds on each flooring type:

1. At their normal walking pace;
2. At a slower-than-normal but comfortable pace (i.e. “a walk through the shopping mall”); and
3. At a faster-than-normal pace (i.e. “when you need to work quickly to finish a job”).

Each condition was repeated twice, first walking away from the original starting point and then returning to the original starting point. Prior to collecting data on each surface, participants did a practice walk in which they walked the full distance away from and returning to the starting point. This practice was used to familiarize the participants with the feel of the instrumentation.

### 2.5. Data analysis

This approach yielded two trials in which data were obtained from each heel strike within the 15.25 m walking zone (~10 steps per side), for each combination of walking speed and flooring condition. At each walking speed, the high and low tibial accelerations were removed in case unusual steps were taken, and the remaining accelerations were averaged. These averaged tibial accelerations, two from each walking speed, were used to develop a regression function for each individual and flooring condition combination. The purpose of these regression functions was to obtain the tibial accelerations for a specific floor surface and walking speed for each individual participant that could be used in the overall data analysis using an ANOVA. For each participant, the average normal walking speed across the two flooring conditions was then entered in these subject and surface specific regression functions to obtain the tibial accelerations values for each surface at the specified walking speed. This way the floor type comparisons of the tibial acceleration data were independent of any potential differences in the walking speed across the two surfaces.

Using the same subject and flooring condition specific regression models, the tibial acceleration values when walking 10 percent faster than the subject's average normal walking speed were obtained, to evaluate the effect of more hurried working conditions. The ten percent value was selected because every participant walked at least 10 percent faster when instructed to walk “faster than normal” and therefore was within the range of each subject specific regression functions relating walking speed to tibial acceleration.

In many cases the bilateral tibial acceleration values were compatible, however, as Fig. 3 shows this was not true for all subjects. This could be due to better positioning of the accelerometer on one side versus the other, or due to idiosyncrasies in individual gait patterns. Given these differences were relatively large in a small proportion of the sample (Fig. 3), there is no reason to suspect this was due to any inherent bias in the accelerometers which were zeroed prior to collecting data for each flooring condition. However, on account of these differences, we analyzed the leg showing the largest tibial acceleration values at the average normal walking speed, irrespective of flooring surface. We believe this represents the leg with the greatest biomechanical load and, thus, presents the greatest risk of developing discomfort, pain, or tissue damage over time. The resulting tibial acceleration data were analyzed using a within-subjects two-way ANOVA procedure (floor type and walking speed) using IBM SPSS (version 19).

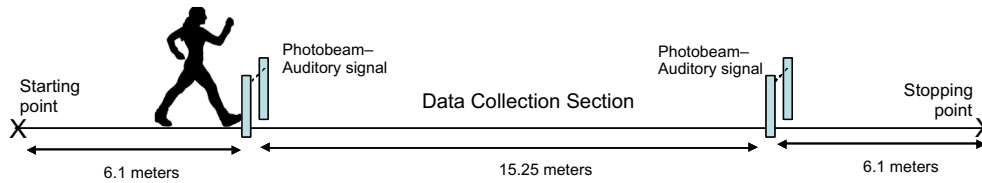


Fig. 2. The data collection process had participants walk each direction at three walking speeds on each flooring surface. Auditory signals were used for timing and calculating the walking speeds.

### 3. Results

The walking speeds at a normal pace and at a ten percent faster-than-normal pace were not statistically different ( $p > .05$ ) across the two surfaces. The means of the peak tibial accelerations as a function of floor surfaces when walking at normal speed and when walking 10 percent faster than normal speed, are shown in Fig. 4. Significant ( $p < .05$ ) reductions in mean tibial accelerations were observed when walking on the wood composite mezzanine material relative to a concrete mezzanine surface. The reductions were 5.2 and 5.4 percent for the normal speed and the 10 percent faster-than-normal walking speed conditions, respectively (Fig. 4).

A secondary analysis that included a factor for shoe type explored the interaction between shoe type and floor surface. This interaction effect was not statistically significant ( $p > .05$ ), largely due to the small number ( $n = 4$ ) of people wearing “flat” soled shoes (which includes athletic shoes without cushion, see Fig. 1). The trends in the data suggest that, while individuals who wore athletic shoes and work boots experienced a decline in tibial acceleration when walking on wood composite surface as compared with concrete mezzanine surface, the individuals wearing flat soled shoes did not experience any biomechanical benefit when walking on the composite surface (Fig. 5).

### 4. Discussion

The tibial acceleration findings presented here support the use of wood composite material surfaces for mezzanine construction over using concrete surfaces. Because the changes are small, it is important to consider their practical significance. Thus, they need to be viewed in context of daily exposure. In a pilot study we found that a sample of product selectors ( $n = 9$ ) working in a direct sales distribution center walked, on average, approximately 21,000 steps per day (with a range of about 17,000 to 24,000 steps). The five percent tibial shock reduction found here with wood composite material, across this quantity of steps, could represent a significant reduction in cumulative lower extremity biomechanical exposures. Epidemiologic investigations will be required to determine if these results correlate with differences in lower extremity discomfort

and pain associated with extended walking on mezzanine surfaces during the workday.

One question is whether the participants are dynamically adapting their gait given the differences in compliance between the surfaces. Previous investigators have reported that people alter their gait patterns based upon surface stiffness (Hardin et al., 2004). Stiles and Dixon (2007) found the impact forces measured during tennis moves on to a forceplate covered with surfaces of varying compliance were lowest for the least compliant surface, therein suggesting their participants adapted their movements. Modeling efforts by Nigg and Liu (1999) suggest that people adapt the stiffness of their muscle response according to the surface conditions, which, in turn, affects the impact forces experienced (Nigg and Wakeling, 2001). In sum, this literature suggests that people are likely dynamically adapting their gait to these different surfaces, which would reduce the differences measured with our instrumentation.

While a non-significant difference was found for persons wearing “flat” soled shoes, the trend in the shoe type data suggest a similar phenomenon. We found that those wearing flat shoes had the highest tibial accelerations, which were generally insensitive to the mezzanine surface type. The higher response would be expected based on the lack of cushioning; however, for the same reason we had anticipated the effect of the flooring type would have been stronger in this component of the sample.

We also expected that the compliant soles of the athletic shoes would potentially mask differences across floor types. Instead, it was the athletic shoes, followed by the work boots, that resulted in the largest differences across flooring materials. We had no way to assess the level of wear of these athletic shoes. Given that participants worked in these athletic shoes on a daily basis, the effectiveness of the cushioning may be reduced relative to when the shoes were new, therein yielding similar tibial acceleration values to those found with the work boots.

Clearly, one of the limitations of this study is the unbalanced sample with regards to shoe type. The study was conducted in a work environment and volunteers were sampled in the footwear they chose to wear the day of the study. In designing this study we considered providing standardized footwear to each of the

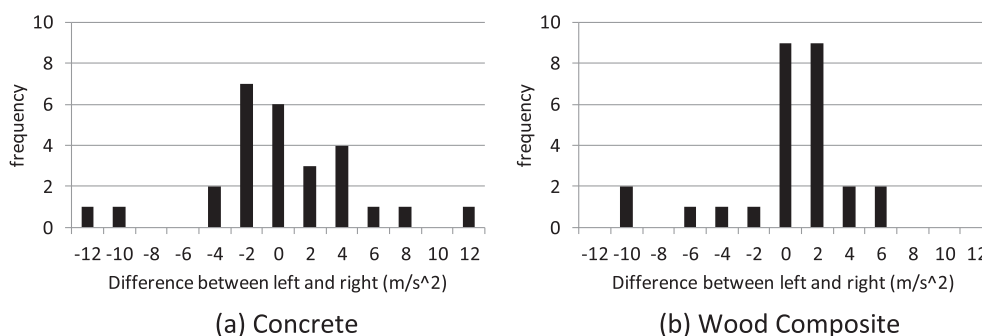


Fig. 3. Frequency distributions of the bilateral differences between the tibial accelerations obtained from the left and right legs on the concrete (a) and wood composite (b) surfaces.

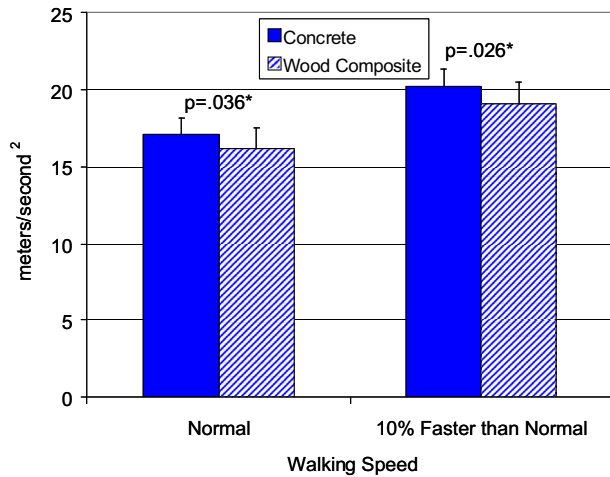


Fig. 4. The peak tibial accelerations measured on the concrete and wood composite mezzanine surfaces at normal and 10% faster than normal walking speeds.

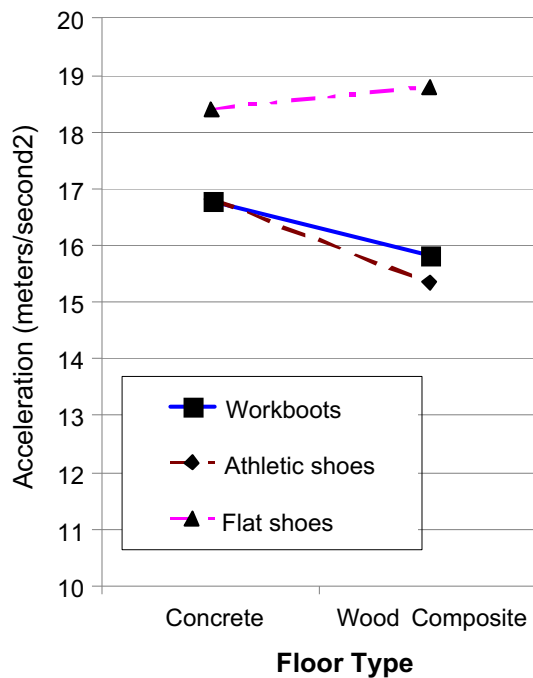


Fig. 5. The non-significant interaction effect suggesting the floor type trends were potentially moderated by shoe type.

participants. We opted not to pursue this approach given that people may walk differently in unfamiliar shoes. By collecting data from participants in their normal footwear we believe this approach preserves ecologic validity of the study and shows the magnitude of the effect that would likely be experienced in distribution environments where people are able to choose footwear

they find comfortable. Another limitation of this study is that no data were obtained regarding the participants' history of knee pain symptoms. Such data may have provided insights into bilateral differences in the tibial shock values.

## 5. Conclusions

Overall, these data supported our hypothesis that peak tibial accelerations would be reduced when walking on a wood composite mezzanine surface relative to those measured when walking on a concrete mezzanine surface. These lower accelerations would translate to lower tibial shock forces, therein suggesting the potential for reduced cumulative loading of the lower extremities for individuals working on wood composite mezzanine surfaces. Further study is needed to determine if these findings would translate to reduced lower extremity discomfort or other ailments and to further explore how these differences across flooring surfaces could be impacted by different choices in footwear.

## Acknowledgement

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