PROCEEDINGS OF THE HUMAN FACTORS SOCIETY

36th ANNUAL MEETING

October 12-16, 1992
Atlanta, Georgia

Volume 1

INNOVATIONS FOR INTERACTIONS

Hosted by the Atlanta Chapter

Human Factors Society

SHOE CUSHIONING AND RELATED MATERIAL PROPERTIES

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This study investigated the effect of dynamic material properties on the Perceived Level of Cushioning (PLC) in shoes. An Impact Tester was used to characterize the material properties. Three pairs of shoes were used in the two experiments conducted. Experiment 1 was aimed at establishing the effects during standing while experiment 2 was an attempt to relate the effects during walking. A 7-point scale was used to rate PLC. The results showed that during standing, PLC may be related to stiffness of the material, compression, and the time to reach maximum deceleration. However, during walking, PLC appears to be related to the maximum deceleration as measured by the Impact Tester.

INTRODUCTION

Researchers have investigated the effect of floor surfaces during standing work (e.g. Rys and Konz, 1990; Redfern and Chaffin, 1988). Others have evaluated the effect of insoles in reducing back, leg, and foot pain during standing work (Basford and Smith, 1988).

During standing work, a number of "mechanical" systems of different stiffnesses may be present between the foot and the ground. All these systems tend to act in series. Two of these are the floor surface and the foot-"ground" interface or the shoe. When fatigue and discomfort are studied in an industrial setting, it becomes necessary to look at the series effect of all elements between the plantar side of the foot and the ground. Traditionally, the cushioning characteristics of shoes have been ignored and components such as insoles, floor surfaces etc., have been studied and the most used element, the shoe, has been neglected. In real life, the series effect of the shoe alters the overall system characteristics thereby posing a serious problem to the practical implications of these results.

Rys and Konz (1990) did not find any significant changes in the subject physical dimensions. They concluded that the comfort vote was the most sensitive criterion. The physiological changes observed were consistent with the comfort vote results. Mat comfort was inversely related to mat compression with the floor mats. They also found that floor mats were significantly more comfortable than a concrete surface. The last two conclusions suggest that comfort is related to the compression by an inverted-U curve, thus making it necessary to locate the point of optimum comfort. Basford and Smith (1988) concluded that subjects strongly preferred the use of insoles of different durometer (on the Shore Hardness Scale) over their shoes alone. Redfern and Chaffin (1988) found similar results using a psychophysical approach. They found that the effectiveness of a floor in relieving fatigue is a function of the floor hardness and that viscoelastic insoles help relieve perceived discomfort in different body parts.

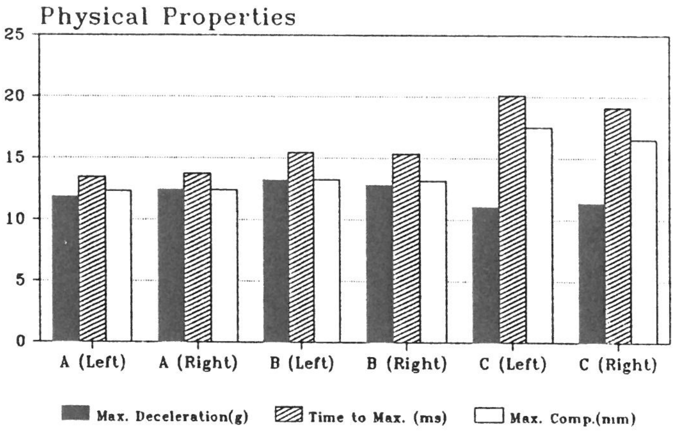
With the development of man-made materials, it becomes important to characterize the static and dynamic (or "quasi-static") properties of human interfaces appropriately. The Instron Universal instrument and similar machines have been standard measuring devices for compression testing where forces are applied to the test samples at a preselected rate. These machines cannot load the specimens as quickly as a drop or free fall tests. As a result, they are not as useful for the dynamic characterization of materials. The response characteristics of many cushioning systems depend on the rate of loading. Previous research on floor surfaces (Redfern and Chaffin, 1988; Rys and Konz, 1990) have used the material compression as an objective measure. However, with the use of viscoelastic materials for surfaces, other material properties may play an important role in comfort or cushioning.

Even though the term "cushioning" is ubiquitous, it lacks a good technical definition. The objective of the study reported here was to establish the material properties related to PLC. It was hypothesized that these material properties are activity dependent. Hence two activities were chosen: standing and walking. Each activity was investigated in one experiment.

METHOD

Apparatus

Dynamic cushioning characteristics and curves have been used for shock control in the packaging industry for many years (Arimond, 1987). A similar procedure was used in this study to evaluate the cushioning characteristics of shoes. The impact tester concept first appeared in a 1980 Runner's World magazine (Cavanagh, 1980). The Impact Tester used to quantify the shoe material properties was designed to simulate the impact between the human heel and a cushioning system. The impact test device consists of an electromechanically operated impact head of mass 7.8 kg and head diameter of 2.5 cm, which is dropped onto the test sample. Computer-linked force, velocity and displacement transducers allow the impact dynamics to be measured, recorded and analyzed. The material properties that can be obtained from the tester are the maximum deceleration (measured in g's), time taken to reach maximum deceleration (ms), maximum compression (mm), energy dissipated through the material during impact (i.e. resilience measured using the hysteresis loop in the force-deflection curve) and the stiffness of the material calculated from the loading portion of the force-defection relationship. Impact velocity of the head was set at 1.2m/s.



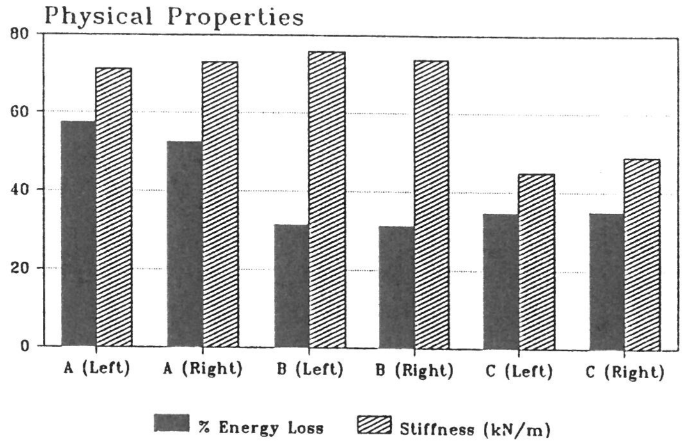


Figure 1. Material Properties

Materials

Three pairs of shoes with different midsole characteristics were used. The first two pairs (A and B) were the experimental shoes, while the third pair served as a control shoe (C). The same three pairs of shoes were used in the two experiments, standing and walking. The physical characteristics of the left and right sides of each shoe pair were matched as closely as possible in terms of the compression, resilience, stiffness, maximum deceleration and the time required to reach the maximum deceleration values (Figure 1). i.e. For each measured property,

$X(\text{Left}) \sim X(\text{Right}) \qquad \text{where } X = A, B, \text{ or } C$

Subjects

A total of 40 subjects were used. Twenty (20) of them participated in experiment 1, while the other twenty (20) were subjects in experiment 2.

Procedure

In experiment 1, the subjects rated the perceived level of cushioning for the three pairs of shoes on a 7-point Likert scale during standing. One (1) represents "very poor" cushioning while a seven (7) represents "very good" cushioning (Figure 2). One pair of shoes, e.g. A(Left) and A(Right), was presented to each of the subjects at one time. During the test, the subjects were allowed to change their lower extremity limb positions without stepping.

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1      2      3      4      5      6      7
|------|------|------|------|------|------|
very                                    very
poor                                    good
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Figure 2. PLC Scale

The subjects rated the level of cushioning on the left and right shoe separately. Two trials (trial 1 and trial 2) were presented to each of the 20 subjects. Ten of the subjects rated the shoes in the order C-A-C-B, while the other ten rated in the order C-B-C-A. To distinguish the two presentations of shoe C, the orders were labeled as C1-A-C2-B and C1-B-C2-A. The presentation order was the same in both trials 1 and 2 for each subject.

In experiment 2, the test procedures were the same as experiment 1 except that the perceived level of cushioning was rated during walking after a predetermined amount of time.

At the end of each experiment, verbal protocols of subjects were recorded and analyzed. The protocols addressed the "perceptual meaning of cushioning". Hence these protocols are indicative of what cushioning is or they may used to explain the mechanisms by which cushioning is perceived.

Statistical Analyses

The SAS statistical package was used for all statistical analyses. A battery of statistical tests were performed on the dependent variable, the PLC score. The nonparametric test (Wilcoxon rank-sum test) gave similar results as the Analysis of Variance. The statistical comparisons were as follows:
1. Experimental shoes (A vs. B) and
2. Each experimental shoe against the control shoe.

RESULTS

Verbal Protocols

The subject responses revealed interesting results. The protocols partially explain the different mechanical properties that are required for good cushioning. Interestingly, all protocols had a measurable physical quantity associated with it.

Representative examples of how subjects described cushioning in the standing experiment are as follows:

1. "Softness under the foot."
2. "The ability of a material to ... provide shock absorbance, comfort, softness, ... (and) bounce."
3. "Something that feels soft and comfortable under my feet."

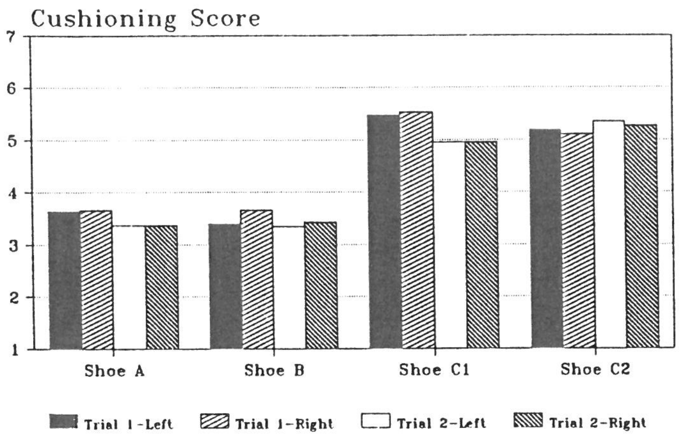

Figure 3. Mean PLC during standing

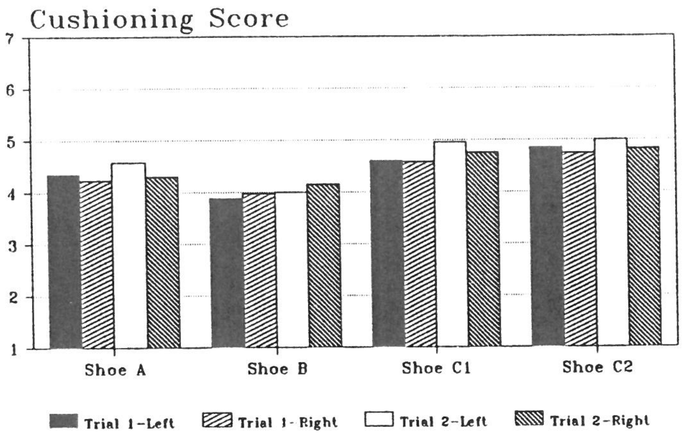

Figure 4.' Mean PLC during walking

Some examples of how cushioning was described by subjects participating in the walking experiment are given below:

1. " Cushioning is the sensation or even the lack of or the non-sensation of having your heel ... strike the ground."
2. "The softness ... of the foot striking the shoe, how far your foot goes down, or how far it presses."
3. "The ability of the shoe to absorb the shock from the impact."
4. "... it's a slowing of the rate of descent."
5. "Cushioning is when it's not too soft, but still stable at least for walking; it doesn't have to absorb a lot of shock."
6. "... soft enough for you not to feel the ground too much, but still prevents your feet from rolling side to side."

To summarize, the subjects viewed "cushioning" in various ways. Some of these are:

1. Level of shock absorption
2. Softness/hardness of a material
3. Deflection that the material undergoes
4. Rate of descent
5. Stability offered by the material
6. Stiffness or Rigidity
7. "Comfort" provided
8. Amount of medio-lateral roll
9. Amount of bounce provided by the material

<u>Experiment 1 - Standing</u>

The mean PLC scores for each shoe during standing are shown in Figure 3. The statistically significant ($p < 0.05$) results are as follows:

1. Shoe C was significantly better ($p < 0.001$) than either shoe A or shoe B.
2. A correlation analysis showed significant correlations of the PLC score and some impact tester measurements. The magnitudes of these correlations are as follows:
   a. PLC & maximum deceleration ($R^2 = 0.73$; $p < 0.03$)
   b. PLC & time to reach maximum deceleration ($R^2= 0.88$; $p < 0.005$)
   c. PLC & maximum compression ($R^2 = 0.94$; $p < 0.001$)
   d. PLC & stiffness of material ($R^2= 0.99$; $p < 0.001$)

<u>Experiment 2 - Walking</u>

The mean PLC scores during walking are shown in Figure 4. The statistically significant ($p< 0.05$) results are as follows:

1. When the two trials were pooled,
   a. Shoe C was significantly better than shoe B.
   b. A(Left) was significantly better than B(Left).
   c. C2(Right) i.e. second presentation of the right of shoe C, was significantly better than A(Right).
2. In trial 2, C(Left) was significantly better than B(Left). In trial 1, the second presentation of shoe C (i.e. C2) was significantly better than shoe B (both feet).
3. A correlation analysis showed significant correlations of the PLC score and
   a. Maximum deceleration ($R^2= 0.99$; $p < 0.0001$) and
   b. Stiffness of material ($R^2= 0.84$; $p < 0.01$)

DISCUSSION

The above results can be analyzed further when the following assumptions are made:

1. PLC is physical property dependent. i.e., significant differences in PLC are due to one of the physical properties, as measured by the impact tester.
2. PLC is magnitude dependent. Differences in PLC are due to differences in the magnitudes of the physical property.
3. PLC is sign independent. i.e., positive and negative differences in the physical property are perceived to be the same.

Table 1. Differences between shoe properties

Material Property	Left			Right		
	B-A	A-C	B-C	B-A	A-C	B-C
Max. Accel.	1.37	0.77	2.14	0.35	1.09	1.44
Time to max. (ms)	2.0	-6.7	-4.7	1.6	-5.4	-3.8
Max. Penetra. (mm)	0.9	-5.2	-4.3	0.7	-4.1	-3.4
Energy Loss (%)	-26.0	22.8	-3.2	-21.2	17.6	-3.6
Stiffness (kN/m)	4.7	26.1	30.8	0.8	24.0	24.8

Table 1 gives the absolute values of the differences in impact test results between shoes. The results can be easily interpreted using the above assumptions and Table 1.

Experiment 1:

In experiment 1, a strong correlation exists between the perceived level of cushioning and the maximum deceleration. However, the significant differences that exist between the shoes are not supported by this correlation. For example, a maximum deceleration difference of 1.09 (Table 1) between shoe A (Right) and shoe C (Right) is perceivable. However, a larger difference of 1.37 between shoe A (Left) and shoe B(Left) is not perceivable. Hence it may be concluded that during standing, the PLC in viscoelastic materials could be caused by the differences in

a. time to reach maximum deceleration
b. maximum compression
c. stiffness of material

Experiment 2:

The correlations seen in experiment 2 are different from those in experiment 1. In experiment 2, a strong correlation exists between the PLC score and the stiffness. However, stiffness is not a causal factor of the perceived differences in cushioning. This is because the significant differences seen in the ANOVA or the Wilcoxon rank-sum test are not supported by the strong correlation. For example, a stiffness difference of 4.7 kN/m between shoe A (Left) and shoe B(Left) is perceivable, but a larger difference of 26.1 kN/m between shoe A(Left) and shoe C(Left) is not perceivable. The maximum deceleration value on the other hand seems to support the significant differences between the shoes. Therefore, during walking, a lower peak deceleration magnitude on the impact tester is a good indicator of an improved level of perceived cushioning.

CONCLUSIONS

Based on the two experiments performed, it may be concluded that the material properties affecting PLC are different during standing and walking. In addition, it may be stated that:

1. Dynamic characterization of materials is important when evaluating cushioning or comfort.
2. Deceleration properties of a material play an important role during walking. A lower peak deceleration magnitude on the impact tester is a good indicator of an improved level of perceived cushioning.
3. Perception of cushioning during standing seems to be related to the following impact test data: material stiffness, time to reach maximum deceleration and maximum compression.

REFERENCES

Arimond, J. (1987). Shock Control. Machine Design, May 21, pp. 109-112.

Basford, J. R. and Smith, M. A. (1988). Shoe Insoles in the Workplace. Orthopedics, 11 (2), 285-288.

Cavanagh, P.R. (1980). The Running Shoe Book. Mountain-View, CA: Anderson World, Inc.

Redfern, M. S. and Chaffin, D. B. (1988). The Effects of Floor Types on Standing Tolerance in Industry. In F. Aghazadeh (Ed.), Trends in Ergonomics/Human Factors V (pp. 401 - 405). North-Holland: Elsevier.

Rys, M. and Konz, S. (1990). Floor Mats. In Proceedings of the Human Factors Society 34th Annual Meeting (pp. 575-579). Santa Monica: Human Factors Society.

AUTHOR INDEX

*Abstract only

**Manuscript not submited for publication