In-shoe pressures and subject comfort assessments for foam insoles in walking, stair climbing and hopping.

Authors:

David Tiberio, PT, PhD and
Timothy Hanke PT, MS - University of Connecticut, Storrs, CT , and
Scott S. Simpson – Associate Research Fellow - Rogers Corporation, Rogers, CT

Abstract:

The pressure reducing capability and comfort characteristics of eight foam insoles were studied during three activities: walking, stair-climbing, and hopping. Plantar pressures were measured using the F-scan in-shoe system at 120Hz. Subjective comfort ratings were determined using a visual analog scale for both in-shoe and hand-touch comfort. During walking, stair-climbing and hopping, the softer materials performed better than the firmer materials with regard to plantar pressure. During walking and stair-climbing the subjective comfort ratings demonstrated a strong preference for the softer materials. The pressure measurements and comfort ratings tend to correlate inversely: the lower the pressure, the higher the subjective rating. When hopping, although the softer materials had a low total contact pressure, the comfort ratings tended to favor firmer materials, eliminating the correlation between the pressure measurements and subjective comfort. It is apparent from the comfort ratings that subjects can detect small differences in pressure.

Purpose and Experimental Plan:

The purpose of this these experiments was to determine the relative ability of different insole materials to reduce pressure on the plantar surface of the foot during a variety of common weight bearing activities. In addition, determining the relationship between the perception of comfort and the actual forces experienced in the shoe was of interest.

The perception of comfort by touch can be a critical factor in purchasing decisions by consumers. The perception of comfort during a short walking period, as with in-store consumer evaluations, is also important. Whether these evaluations relate to the ultimate comfort experienced in more intense activities is of interest.

Measurement of the underfoot pressures was obtained using an F-Scan in-shoe system (Tekscan, South Boston, MA). A thin sensor (0.18 mm thick) in the shape of an insole allows in-shoe, underfoot pressure measurements to be continuously recorded during activities. Subjects participated in walking, stair-climbing and hopping, using different foam insole materials while in-shoe pressure levels were measured.

As part of each activity in this study the subjects were asked to rate each insole for comfort. Following the walking and hopping phases the subjects also rated each material by touch, while blinded, for their anticipated comfort.

Materials:

Eight different foam insoles materials were evaluated. All samples were nominally 4 mm in thickness. Table 1 lists physical properties for each material tested. In some cases substitutions with equivalent properties were made between experiments. All of the samples were foam only, i.e. no fabric covering.

Table 1
Physical Properties of Insole Materials

Material	SR-S	SR-F	S-15	S-20	F-15	F-20	PU	EVA
Thickness (mils)	155	160	156	157	158	158	161	165
Density (PCF)	14.8	14.6	15.3	19.7	15.8	18.9	11.5	4.7
Tensile Strength (psi)	94	104	75	101	139	189	54	138
% Elongation	191	190	133	133	148	148	73	121
Tear Strength (pli)	12	12.4	9.4	12.0	16.5	20.0	12.6	19.7
CFD (psi @ 25% compression)	4.4	4.8	5.9	10.5	10.2	16.1	12.2	20.3
Shore Resilience	6	8	20	22	12	12	40	31

Six of the materials were urethane foam grades produced by Rogers Corporation under the trademark PORON® Cellular Urethanes. The PORON materials included two slow recovery grades, SR-S and SR-F (Soft and Firm). A soft resilient grade was evaluated at two different densities, S-15 and S-20. A firm grade with intermediate resilience was also tested at two different densities, F-15 and F-20.

Note that the modulus, or firmness, of the S-20 and F-15 grades are similar as measured by CFD (compression force deflection at 25% compression). The change in hardness of the polymer is compensated by the difference in density.

In addition to the PORON cellular urethane materials, a commercially available, densified low density urethane foam (PU) was tested as well as a typical EVA foam used for footwear insoles (EVA).

For all subsequent bar charts the materials are ordered in the same way as in Table 1. In general this means that the modulus of the insole increases from left to right.

Subjects:

Volunteers were solicited among students and workers at the University of Connecticut. Subjects received a verbal description of the specific study and gave their written informed consent approved by the Institutional Review Board.

Eighteen subjects participated in the walking portion of the study, thirteen in the stair climbing and twelve in the hopping. All subjects used their existing footwear in the studies which were in all cases athletic shoes of various makes, styles and degrees of wear.

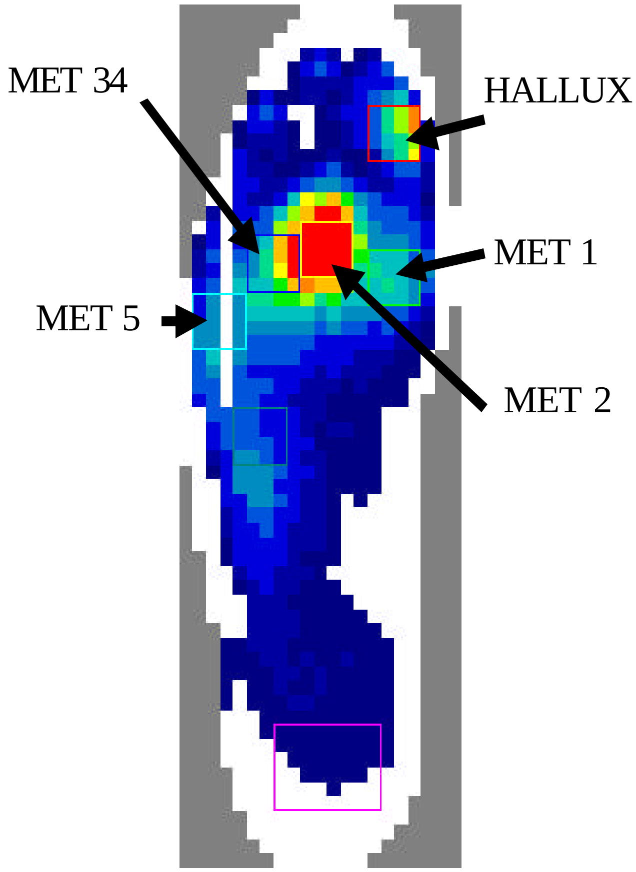
Equipment:

Figure 1 shows an example of a Tekscan pressure sensor and the connection of the pressure sensor to ankle cuffs that send the data to a computer via a 9.14 meter cable. The sensor contains small individual transducers (sensels) arranged in a grid so that each square centimeter contains 4 sensels. Prior to collecting data, the individual sensels were equilibrated by compressing the entire sensor at a pressure of 50 pounds per square inch. Then the sensor was calibrated to the individual subject weight by standing on one foot. In all cases the transducer was placed inside the shoe, under the foot and on top of any insole used. In each study the pressure measurements were gathered at a rate of 120 samples per second

Figure 1

Figure 2 is a typical force scan by location in which the pressure levels are color-coded. The data reported in the three studies is "average total contact pressure". This value is derived by dividing the force values by the area of contact (sensels under pressure). The highest contact pressure for each cycle (step, stair, or hop) was selected and averaged over a number of cycles to obtain a peak total contact pressure value for that trial. Data from individual subjects were averaged and then normalized by body weight for comparison.

Figure 2



Test Protocol - Walking:

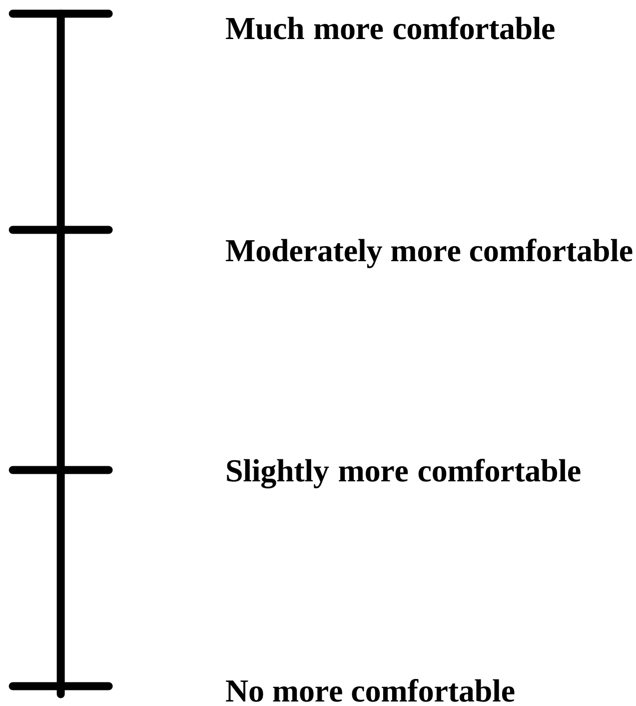
For this study the subjects walked on a treadmill to determine a comfortable walking pace. This pace was then set and kept constant throughout all of the material evaluations by that subject.

The different insole materials were then evaluated in random order as follows: The subject walked in a hallway with no insole followed by the insole to be tested. The subjects assessed the comfort of the material relative to no insole by marking the scale shown in Figure 3. The instructions ask the subject to rate the perceived comfort compared to walking with no insole. The rating scale is 9 cm long and the marks were measured with a ruler and recorded. The subjects then walked on the treadmill at their previously determined pace. After 30 seconds of acclimation time for the subject, 15 seconds of pressure data were recorded.

Figure 3

COMFORT RATING SCALE

Compared to my shoe without an insert, walking/stair climbing/hopping with this insert was…



The subjects walked on the treadmill with no insole before and after the eight randomly ordered materials producing a total of 10 trials. The first and last trials were averaged to get an accurate pressure reading with no insole in place, and to account for any drift in the pressure readings from the sensors.

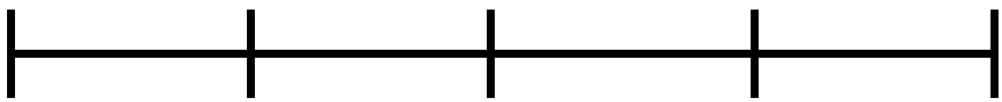
Following the walking trials, the subjects assessed the comfort value they would expect from the insole materials based on the touch/feel of each. This was performed using a blind box in a new random order. The subjects rated the materials by marking the scale shown in Figure 4. This scale is 10cm long and the results were also measured with a ruler and recorded.

Figure 4

COMFORT RATING SCALE
FOR BLIND TOUCHING

For the walking/hopping exercise I just completed, this material would substantially improve my comfort.

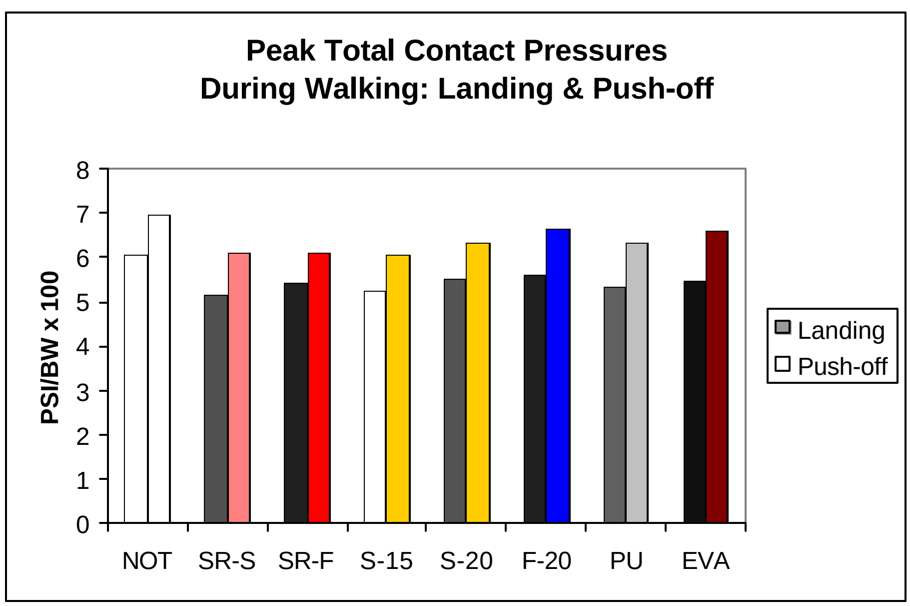
Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree



Results – Walking Study:

Figure 5 shows the peak pressures recorded for both landing and push off events during walking for each material. While the landing and push off values are quite distinct we found the peak pressure differences between materials to be quite small.

Figure 5



However, Figure 6 shows the average comfort ratings given by the subjects indicating distinct preferences. As will be shown later, the differences are more dramatic if compared using the frequency with which a material is selected in the top 3 choices for each subject. In this case, walking, the slow recovery and soft materials are clearly preferred.

Figure 6

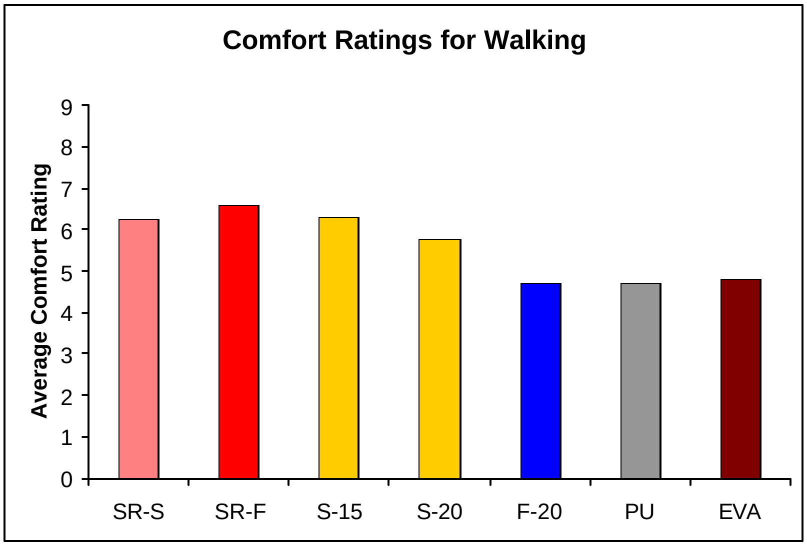
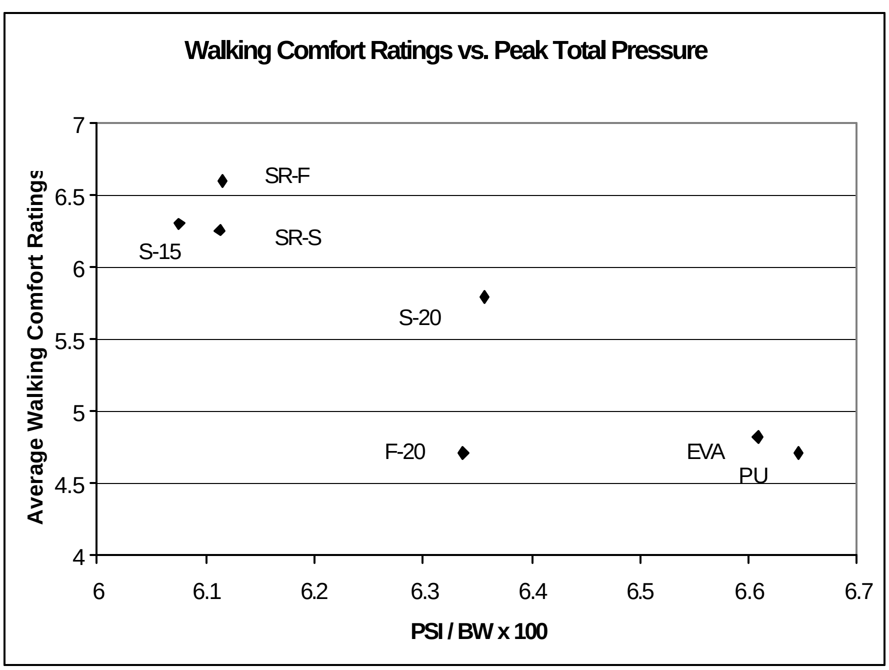


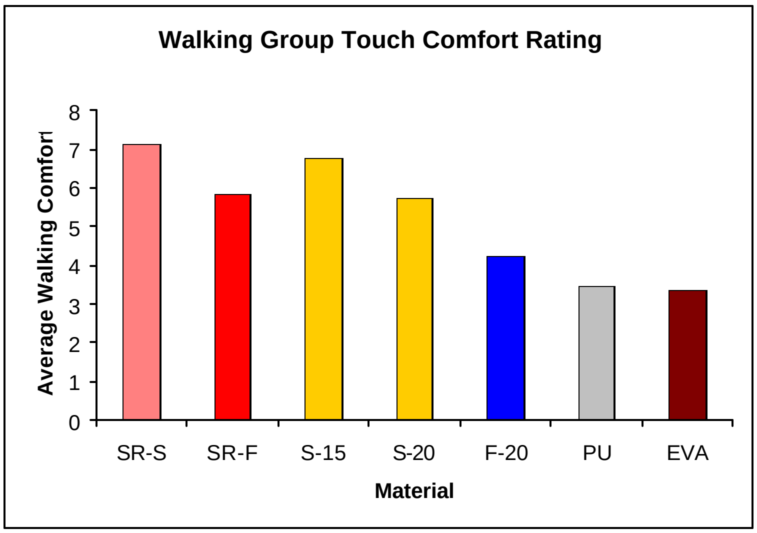
Figure 7 depicts the walking comfort ratings plotted against the peak total pressures for push off. The result indicates a relationship between the subjects' assessment of comfort and the peak total contact pressures. While a much larger number of subjects would be needed to be conclusive, the trend demonstrated in Figures 5-7 clearly shows that the slow recovery and soft grades do better in walking pressures and in subject comfort assessment during walking.

Figure 7



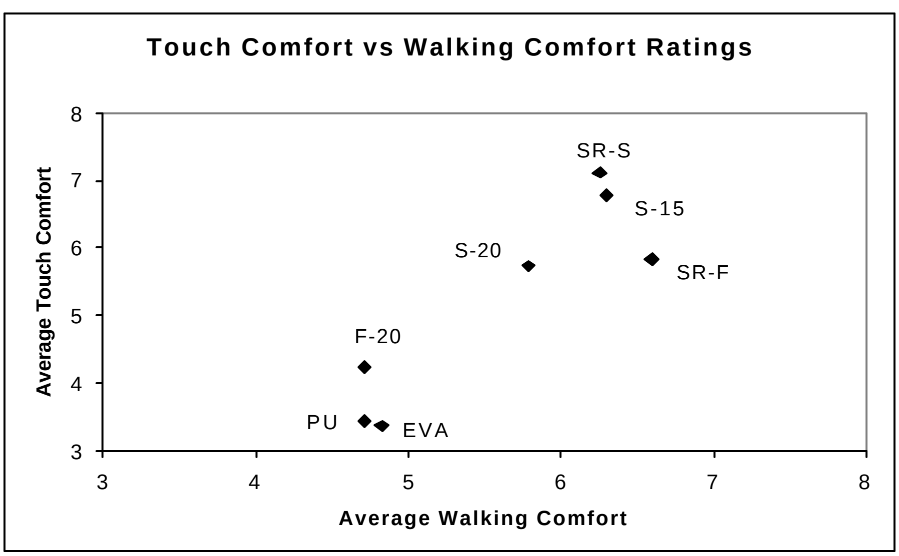
As described above, the subjects also provided blind touch evaluations of each material. These results are shown in Figure 8. Here also, the slow recovery and soft materials are preferred. The most significant difference is that the subjects rated the firmer slow recovery grade lower in touch assessment compared to its performance in both walking assessment and walking pressure values. The SR-F material does feel significantly firmer to touch compared to the SR-S. However, inspection of the physical properties (Table 1) and the pressure and walking comfort results (Figures 5,6 & 7) indicate that in fact it behaves closer to SR-S than touch assessment would indicate.

Figure 8



This can also be seen in Figure 9, which plots the touch comfort against the walking comfort ratings. The result indicates that subjects can predict their walking comfort, to a reasonable degree, by hand feel of the insole material. As above, the SR-F grade appears to be an exception in that it performs better in walking than touch would indicate.

Figure 9



Test Protocol – Stair-Climbing:

For the stair-climbing study each subject climbed at 80 steps per minute and then at 120 steps per minute for each randomly ordered material while the pressure was measured. The 120 steps per minute rate is close to the upper limit for 'normal' stair-climbing while the 80 steps per minute is a relatively leisurely pace. The subjects practiced climbing the stairs to the audible beat of a metronome set at the appropriate pace (80 or 120). As in the walking study, a trial with no insole was performed at the beginning and end of the material testing,

Data was collected for six seconds. The number of steps per trial that were averaged varied depending on the speed of the trial. The first step was excluded from measurement to allow the subjects to attain synchrony with the metronome. Subjects assessed the relative comfort of each material, following climbing at both rates, using the scale shown in Figure 3.

Results – Stair Climbing Study:

Figure 10 graphs the typical contact pressure cycles seen in stair-climbing. As with walking, the push off pressure exceeds landing by a considerable degree.

Figure 10

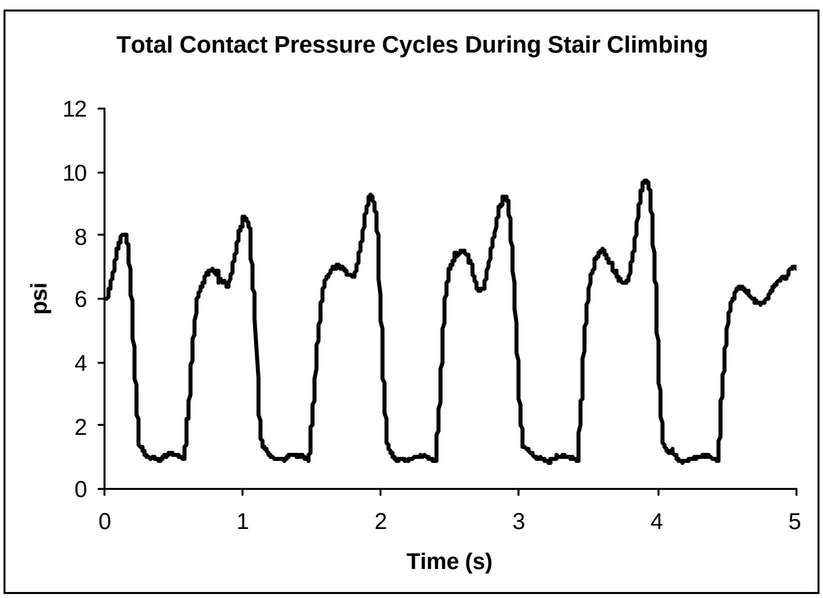
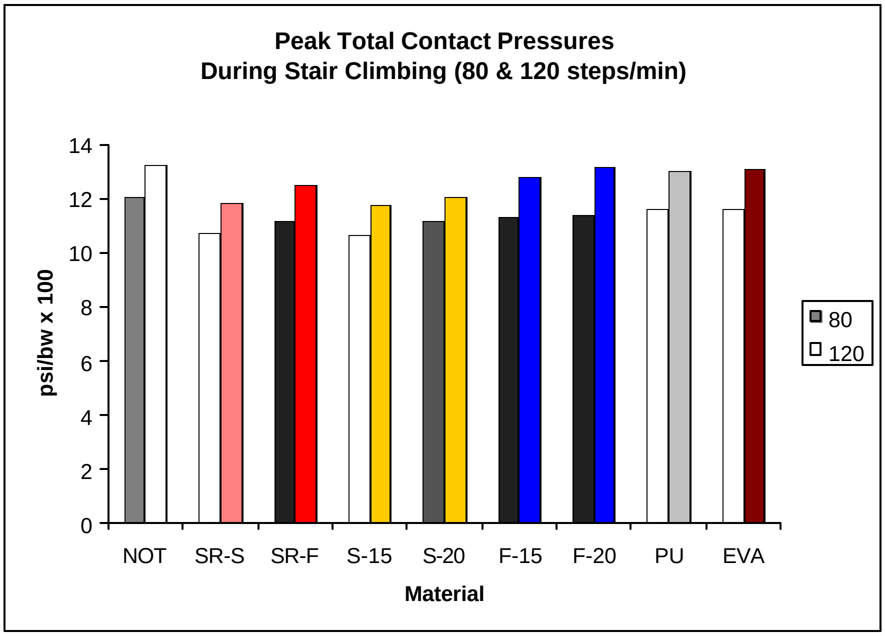


Figure 11 compares the average peak total pressures for the thirteen stair-climbing subjects, again normalized by body weight. As with the walking portion, the pressure differences between materials are relatively small.

Figure 11



However, Figure 12 indicates the subjects differentiate between materials and again generally prefer the softer grades.

Figure 12

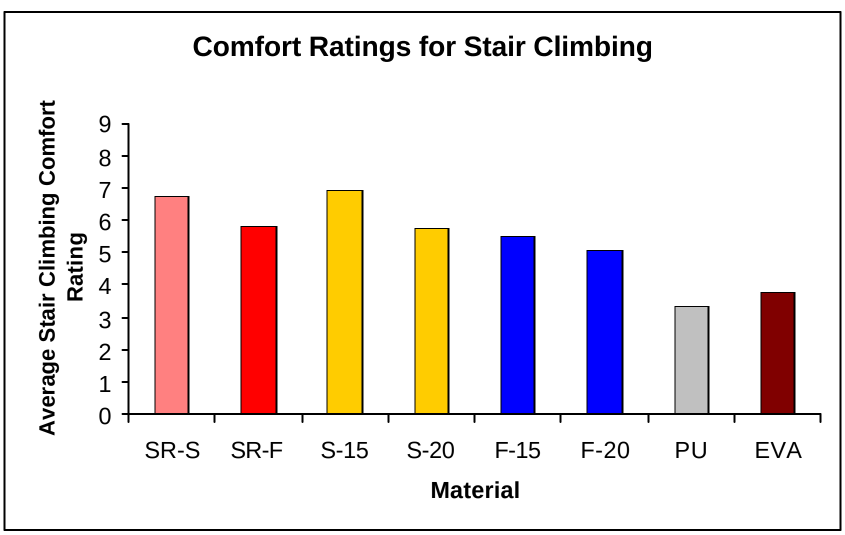


Figure 13 shows that, as with the walking, there is a good correlation between the subject comfort assessments and the measured peak total pressures in the shoe during stair climbing at 80 steps per minute.

Figure 13

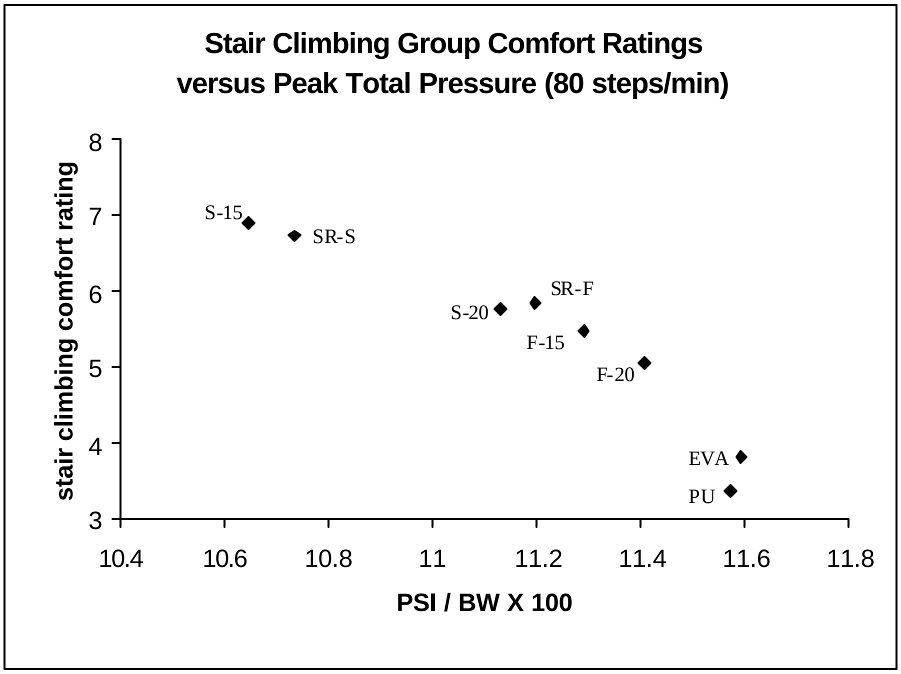
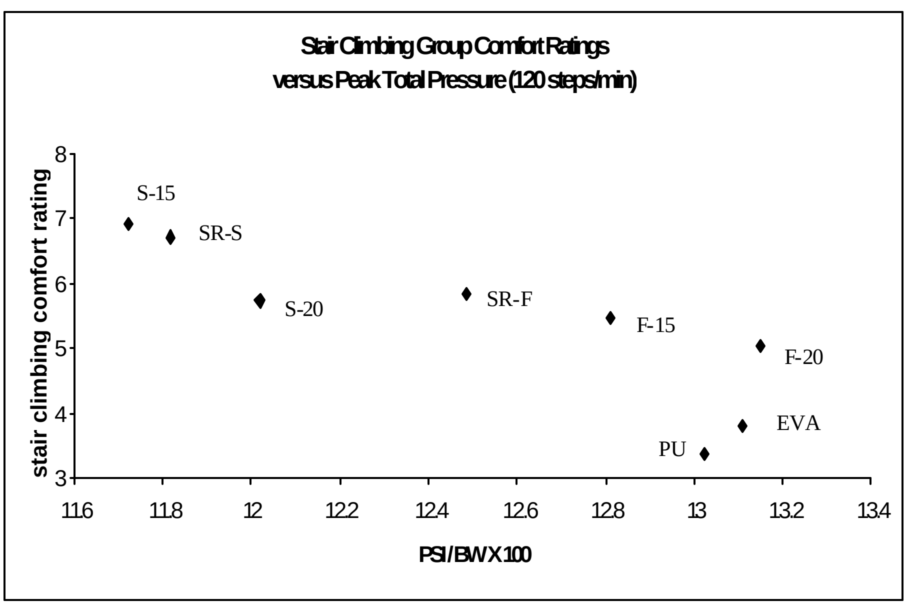


Figure 14 shows the same relationship for 120 steps per minute. As noted above, the subjects made only one comfort assessment after climbing at both rates.

Figure 14



Test Protocol - Hopping:

The hopping study was conducted in the same way as the walking and stair-climbing portions with no insert before and after the eight materials randomly ordered. The hopping was on one foot only and no control over hop height or frequency was imposed. Data was collected for 6 seconds, which allowed for the averaging of approximately10 hops per trial.

The comfort was assessed after hopping on each material and rated using Figure 3. As with the walking study the subjects then also blind-touch rated the materials using the scale in Figure 4 in a new random order.

Results – Hopping Study:

Figure 15 compares the average peak total pressures during hopping. The softer materials have the lowest values as with the walking and stair climbing portions.

Figure 15

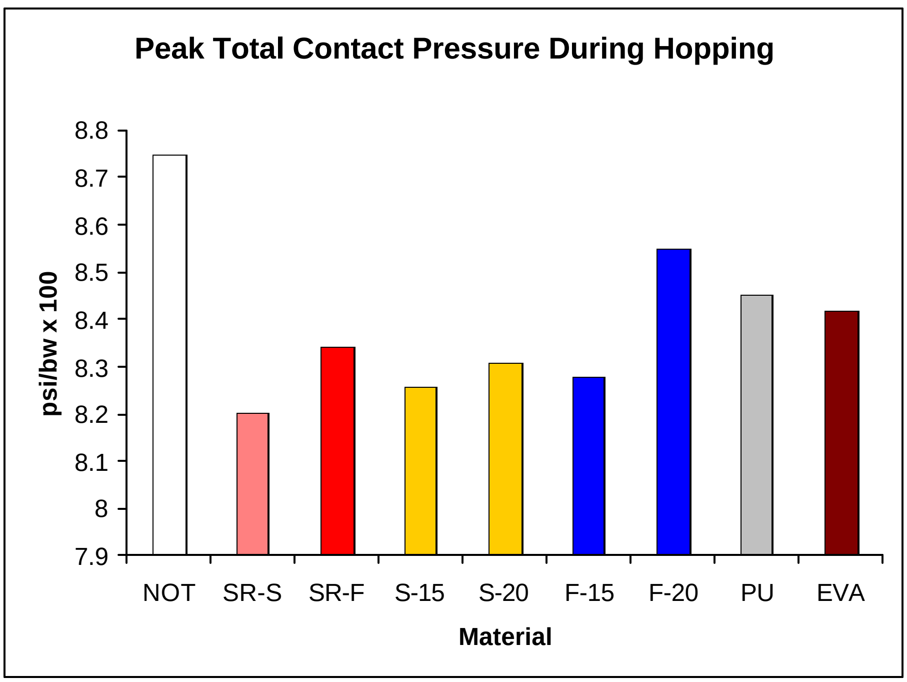
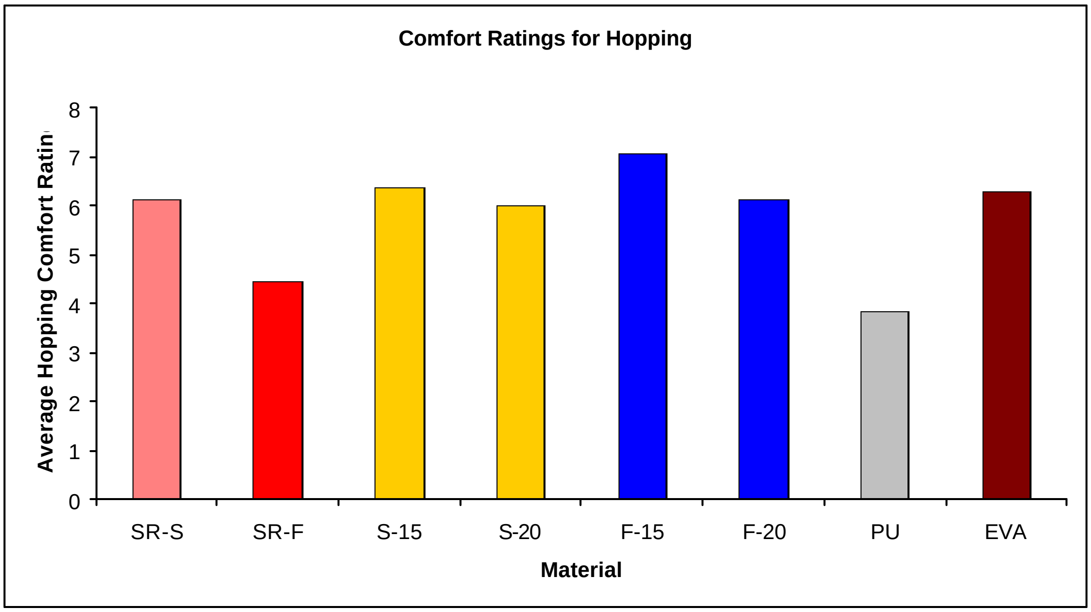


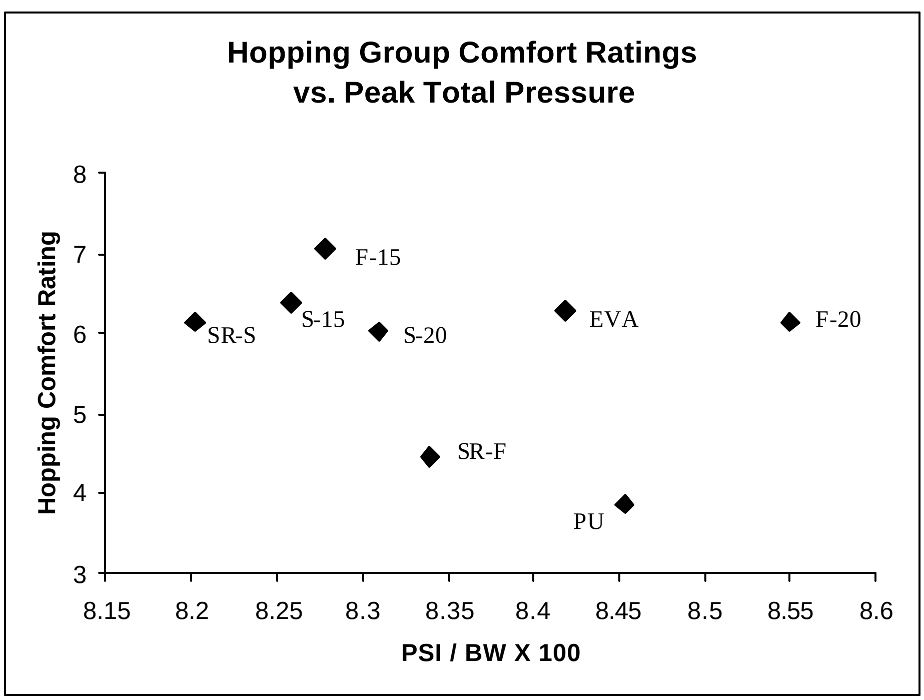
Figure 16 shows the average comfort ratings given by the twelve subjects following hopping. Note the increase in preference for the firmer materials grades compared to the walking and stair climbing.

Figure 16



The comfort assessments versus in-shoe pressures is plotted in Figure 17 where, unlike the walking and stair climbing studies, there is no apparent correlation between the two.

Figure 17



This lack of correlation is attributed to the fact that the hopping was uncontrolled in pace or intensity. Since the subjects were allowed to hop at their own rate and height the subjects adjust their hopping to each material such that the pressure values no longer correlate with subject comfort assessments. Note that the peak total pressures during hopping were less than those recorded during stair climbing.

Attempts to normalize the results by using data from a force plate on which the subjects hopped were unsuccessful in demonstrating better correlation. Using peak data from specific high pressure zones under the foot (e.g 1st or 2nd metatarsal) produced equivocal results.

Figure 18 shows the average touch comfort ratings given by the hopping group. Figure 19 graphs the relationship between the touch comfort and hopping comfort ratings. Again, unlike the walking and stair climbing groups, there was not a good correlation.

Figure 18

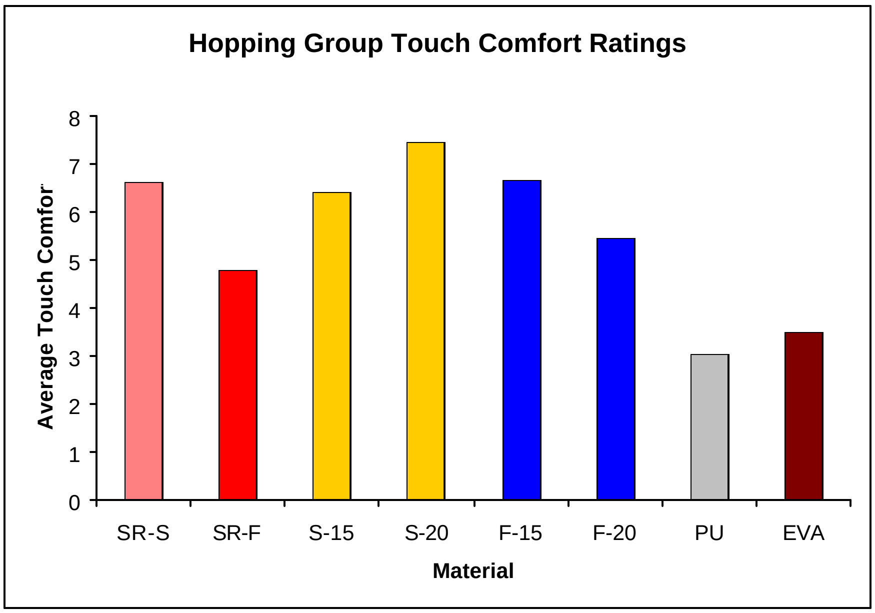
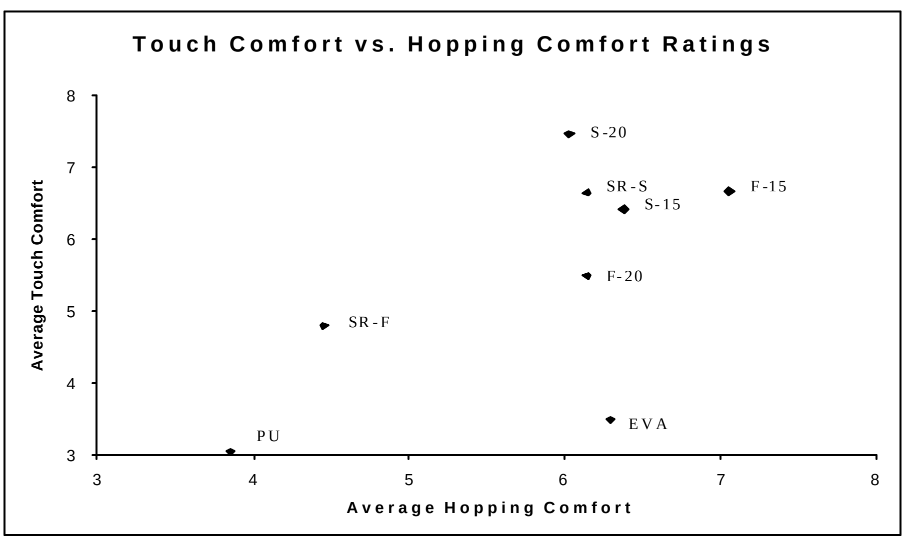


Figure 19

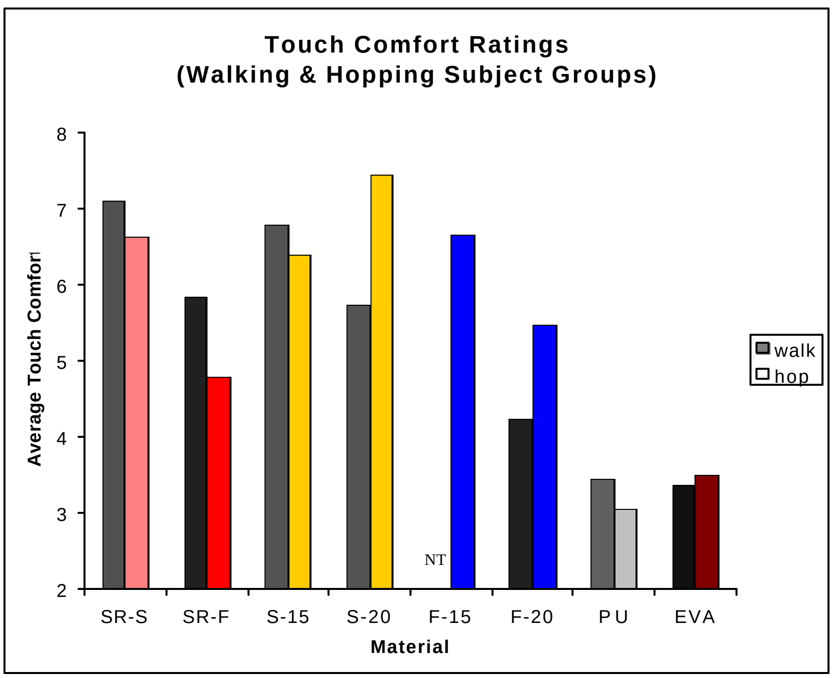


General Comparisons:

The subject comfort ratings were provided as perceived improvement over no insole. Since the subjects could differentiate between small increments of total pressure, and that in all cases no insole had measurably higher pressures than any of the insole materials used, we can conclude that foam insoles provide significant comfort advantages even in the athletic shoes used in these experiments which in most cases have significant midsole cushioning.

Figure 20 compares the touch comfort ratings given by the walking and hopping subject groups. It is interesting to note that the hopping group produced a slight preference for firmer materials than the walking group. This implies that subjects may inherently adjust their conception of touch response to the activity just completed. A much larger number of subjects would be needed to confirm this. Another possibility is that the softer foams may "bottom out" in high pressure areas while the total contact pressure remains low.

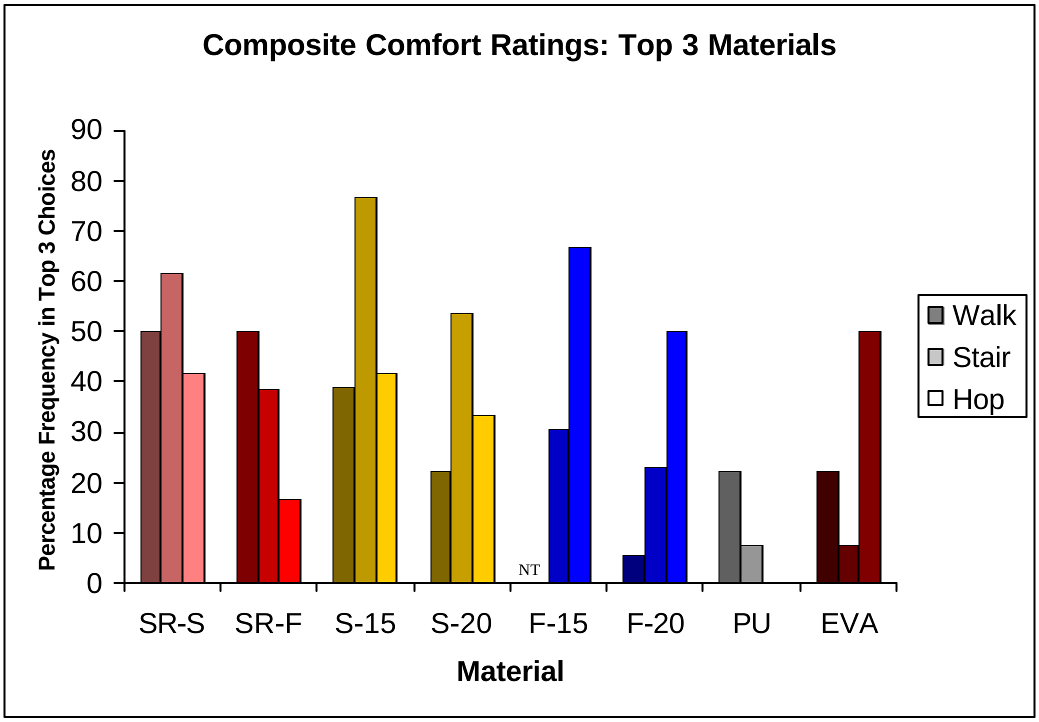
Figure 20



All PORON Cellular Urethane grades, regardless of modulus or resilience, were preferred in touch comfort over the PU and EVA materials.

Figure 21 uses the activity comfort ratings calculated in the form of the frequency with which each material was selected as one of the top three choices of each individual. This allows direct comparison of all of the activity groups despite the differences in number of subjects.

Figure 21



This chart clearly shows that as the activity level increases the preference frequency for the firmer materials also increases. Nevertheless, the soft grades, notably the SR-S and S-15 grades, continue to score well in comfort assessment.

While it seems empirically obvious, this study demonstrates the value of both in-shoe pressure measurements and subject comfort assessments in discriminating between materials.

Summary and Conclusions:

This study clearly demonstrates that subjects can differentiate between small total underfoot pressure differences.

The subject comfort assessments correlate well with average peak total pressure values normalized by body weight. This is true for activities in which the pace, or intensity, of the activity was kept constant for each subject (walk & stairs). This correlation does not appear to hold for activities in which the intensity was not controlled, as with the hopping portion of the study.

This study used only 4mm insoles. It is expected that if thinner insoles were used firmer materials might be preferred.

Subject preferences for touch and walking are for soft materials. Firmer materials are preferred more frequently as the intensity of the activity increases to stair climbing and hopping.

Subject assessments using hand touch/feel demonstrated better correlations during low intensity activities like walking compared to higher intensity activities like hopping, where firmer materials tend to be preferred.

The S-20 and EVA materials are currently being compared in a running study to assess long term wear performance using stair climbing pressures and subject comfort assessments taken at intervals during 500 miles of running.

School of Allied Health

About the UCONN School of Allied Health:

In 1972 the University of Connecticut initiated the School of Allied Health to be the primary educational resource for the preparation of selected health professionals within the state. Throughout its history, the School's mission has been to provide educational programs and leadership that will improve health care and the health care delivery system. Current programs offered to accomplish this mission are: Dietetics, Medical Laboratory Sciences, Physical Therapy, and the Master of Science in Allied Health.

David Tiberio Ph.D., PT, OCS is an associate professor at the University of Connecticut. He teaches in the areas of biomechanics, therapeutic exercise, and musculoskeletal rehabilitation. David has published articles on Physical Therapy, Clinical Biomechanics, Foot and Ankle, and Journal of Orthopaedic and Sports Therapy. His research interests are foot biomechanics and lower extremity function.

Timothy A. Hanke, MS PT is an assistant professor in the Physical Therapy Program at Midwestern University, Downers Grove, Illinois. He received his masters degree from Northwestern University. Tim is completing doctoral studies at the University of Connective where he was a graduate research fellow in gerontology in the Center on Aging and Human Development. He has several publications in refereed journals on topics such as balance rehabilitation following stroke, falls, posture and movement interactions in young and older adults, and reliability of biomechanical measurements.

Scott S. Simpson is an Associate Research Fellow at Rogers Corporation. He holds a BS degree in Applied Chemistry and an MS degree in Chemical Engineering from Columbia University. His experience includes polymer and surface chemistry, silicones, electronic connectors, flexible circuits, polyurethane foams and polyolefin foams. He is an inventor or co-inventor of 17 US patents.