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Ergonomic Evaluation of Three Types of Inner-Room Floor Mats by Using In-Shoe and Platform Type Pressure Measurement Systems

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Abstract : Prolonged work in upright postures (standing and walking) is common in industry and in daily living activities, and is one possible risk factor for low back pain and leg problems. This study compared the reaction forces of four different floor surface conditions (three inner-room floor mats and no-mat) during gait. The reaction forces were measured by both the in-shoe and platform type pressure measurement systems. Six male subjects (average weight = 72.4 ± 7.5 kg) walked barefoot on the four floor conditions and the data from the two measurement systems were recorded simultaneously. The mean reaction force, two peak forces (heel strike and toe off), and the maximum reaction force measured by the in-shoe type system showed significantly different values according to the floor surface conditions ($P < 0.05$). The no-mat condition induced the largest mean reaction force of 828.9 ± 114.2 N. However there was no difference in the reaction forces measured from the platform type system ($P > 0.05$). All three floor mats induced smaller reaction forces than no-mat, but the mean reaction force and maximum reaction forces (maximum and two peak forces) showed different results due to different thickness and materials. Thus, an appropriate selection of inner-room floor mat according to the biomechanical properties may be useful for reduction of fatigue and discomfort in industrial settings.

Key words : foot pressure, reaction force, gait, floor mat, floor surface condition.

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Introduction

Prolonged work in upright postures (standing and walking) is common in industry and in daily living activities, and is one possible risk factor for low back pain and leg problems [1, 2]. Health problems associated with prolonged standing and walking include lower extremity discomfort and fatigue, lower extremity swelling and venous blood pooling, low back pain and entire body fatigue [3].

Soft floor surface mats are used to reduce fatigue during prolonged standing and walking in many situations. Much research has tried to find out the influence of various floor mats on fatigue and discomfort. According to a literature review paper by Rys and Konz [4], floor surface mats are able to diminish discomfort associated with prolonged standing work. Also, the benefits of using floor mats can include reduced fatigue, enhanced balance, and the potential for reduced back and leg disorders, especially when employees spend a considerable amount of time on their feet [3, 5, 6].

In a series of research, Rys and Konz [7, 8] and Konz *et al.* [9] compared concrete and industrial carpet or mats using physiological criteria (foot volume, skin temperature and heart rate) and subjective rating. They found that body comfort decreased on all body parts with time, but the decreasing level was different according to the body parts. It was also found that carpet or mats were more comfortable than concrete. Similar results were also found in other studies [5, 6, 10]. These studies focused on physiological responses or subjective feelings induced by different floor conditions.

However, mechanical properties such as shock absorption or plantar pressure distribution can give a useful and quantitative indication of the profound effects of floor mats on fatigue and discomfort. Ground reaction forces or plantar pressure distribution are used widely in gait analysis and in the evaluation of various floor mats or shoes [1, 11]. There are two types of pressure measuring systems: one uses platform type sensors, the other uses in-shoe type sensors. Platform type sensors are located below the floor mats, while in-shoe type sensors are located between the mats and the foot. Barnett *et al.* [12] compared the in-shoe type system with a force platform. In most cases, comparisons of the data recorded by the two systems provided good evidence for the accuracy and reliability of temporal measurements.

Most previous studies investigated the influence of the floor mats in industrial settings where subjects wore shoes and industrial mats were used. However, ergonomic evaluation of floor mats in inner-room setting is also important, particularly in Korea and in some other Asian countries. Korean people usually spend much time without shoes in rooms covered with inner-room mats. According to the Korean Women's Development Institute[13], Korean housewives spend about 7 hours a day at home without shoes. Also, in traditional Korean restaurants or other small-size companies such as the sewing industry, people work on floor mats without shoes.

The objective of this study was 1) to investigate the effects of the different floor mats for inner room (without shoes) on the reaction forces, and 2) to compare the different measures (mean reaction forces and peak reaction forces, *et al.*) in evaluating the floor mats by using the in-shoe and platform type pressure measurement systems.

Materials and Methods

Six male subjects participated in the experiments. Their mean age, height, weight and barefoot size were 23 ± 3 years, 174.8 ± 4 cm, 72.4 ± 7.5 kg and 273 ± 6.8 mm, respectively. None of the subjects reported a history of foot or ankle musculoskeletal/neuromuscular trauma or disease.

The subjects walked barefoot on each floor surface condition 5 times, and the sequence was fully randomized. The subjects chose their own walking speeds and step widths. There were four floor surface conditions. First, 'E' was the baseline condition with no mat. 'A' was a 2 mm thick normal polyvinyl chloride (PVC) mat used in inner rooms. 'B' was a 6.5 mm thick mat used in offices or in trains with shoes. 'C' was a 4 mm thick cushion mat, which has been recently developed to be used barefoot in inner rooms. The three mats were products of one chemical company in Korea and had different thickness, materials and other physical characteristics (unrevealed outside the company).

The subjects walked on the gait way about 5 m (Fig. 1) with an in-shoe type pressure sensor system (Pedar, Novel Co., Germany) inside their socks. Pedar is a pressure measuring device, composed of 2.6 mm thick insoles, containing a force sensing matrix of 99 capacitance sensors, with a spatial resolution of approximately 10 mm. In the gait way, there was a platform type pressure measuring device (Emed, Novel Co., Germany) installed beneath the gait-way surface. The Emed system contains 38×72 force sensing matrix. The data were collected simultaneously from the Emed and Pedar systems, with a sampling frequency of 50 Hz on the right foot.

Fig. 1. The layout of experimental setup.

Four dependent variables were mean reaction force, two peak forces (heel-strike and toe-off), and maximum reaction forces. All reaction forces were summed up during foot contact and the mean reaction forces were calculated by dividing the sum by the time of foot contact. One-way analysis of variance (ANOVA) procedures were conducted on the four reaction forces to evaluate the effect of the floor surface conditions on the reaction forces. The independent variable was the floor surface condition (four levels) with five repetitions in each subject. The average value of the five repetitions in each condition was used in the analysis. Also, further post hoc SNK (Student Newman-Keuls) comparison tests ($\alpha = 0.05$) were conducted to see the difference among the floor surface conditions.

Results

Temporal gait pattern

One example of the reaction force profile obtained from the platform type and in-shoe type is presented in Fig. 2. The first peak is induced during heel contact, and the second peak corresponds to the plantar extension (toe off). In Fig. 2, the first peak forces showed higher values than the second peaks, but the magnitude order of the two peak forces was not consistent throughout the subjects, and the mat conditions.

Fig. 2. One example of reaction force profiles collected by the in-shoe and platform type measurement systems. $\blacklozenge$: in-shoe type, $\circ$: platform type.

Foot contact time

Table 1 shows the times of foot contacts. The in-shoe type measurement system showed shorter contact times (mean difference = 0.04 sec) than the platform type. However, there was little time difference among the four floor surfaces.

Table 1. Foot contact times (mean $\pm$ S.D.) of the two measurement types (sec)

Floor surface condition	Platform type	In-shoe type
E	0.76 $\pm$ 0.04	0.71 $\pm$ 0.07
A	0.75 $\pm$ 0.04	0.71 $\pm$ 0.07
B	0.76 $\pm$ 0.04	0.72 $\pm$ 0.07
C	0.76 $\pm$ 0.05	0.72 $\pm$ 0.07

Mean reaction forces

The effect of the floor surface condition on the mean reaction force (in-shoe type) was found to be statistically significant ($P < 0.001$) from ANOVA procedure (Table 2), but the effect was not statistically significant for the platform type ($P = 0.18$).

Table 2. ANOVA results of mean reaction forces

Source	DF	SS	MS	F-value	P-value
FSC	3	195591	65197	82.18	<0.001
Sub	5	240396	48079	.	.
FSC $\times$ Sub	15	11900	793	.	.

FSC: Floor surface condition, Sub: Subject

The mean reaction forces of the four surface conditions are shown in Fig. 3. The SNK (Student Newman-Keuls) comparison test ($\alpha = 0.05$) for the mean reaction forces of the in-shoe type revealed significant differences among the floor surface conditions (three groups: G1, G2 and G3). The mean reaction forces of the no mat ('E') condition showed the highest value of 828.9 ± 114.2 N (group 1), and the mean reaction forces of the 'A' and 'B' mats were 715.5 ± 115.1 N and 697.9 ± 90.1 N, respectively, and grouped together (group 2). The 'C' mat induced the lowest reaction force of 619.9 ± 101.7 N (group 3).

Fig. 3. Mean reaction forces (mean $\pm$ S.E.) of the different floor surface conditions. $\square$: in-shoe type, $\blacksquare$: platform type. Student Newman-Keuls (SNK) test ($\alpha = 0.05$) grouped the four floor surface conditions into three different groups (G1, G2, and G3) for the in-shoe type.

First (heel strike) and second (toe off) peak forces

The first and second peak forces measured from the in-shoe type showed statistically different values in different floor conditions ($P < 0.001$ from ANOVA test). Figure 4 shows the first and second peak forces of the in-shoe type with the results of the SNK test. The SNK grouping results in the first and second peak forces were different from those of the mean reaction forces. The no mat ('E') condition revealed the highest peak forces (first peak force: 1320.7 ± 145.6 N, second : 1348.7 ± 234.4 N, group 1) and the 'A' mat revealed the mean peak values of 1064.4 ± 250.8 N for the first peak and 1081.2 ± 150.8 N for the second peak (group 2). The 'B' and 'C' mats showed low peak forces (first peak force : 893.9 ± 167.6 N for the 'C' and 844.3 ± 172.8 N for the 'D', second : 909.3 ± 125.0 N for the 'C' and 905.6 ± 115.1 N for the 'D') and grouped together (group 3).

Fig. 4. The first and second peak reaction forces (mean $\pm$ S.E.) of the in-shoe type according to the different floor surface conditions. $\square$: first peak force (heel strike), $\blacksquare$: second peak force (toe off). Student Newman-Keuls (SNK) comparison test grouped the four floor surface conditions into three different groups (G1, G2, and G3).

However, the platform type didn't show different peak forces according to the four floor conditions ($P = 0.79$ for the first peak and $P = 0.43$ for the second peak, respectively) as shown in Fig. 5.

Fig. 5. The first and second peak reaction forces (mean $\pm$ S.E.) of the platform type according to the different floor surface conditions. $\square$: first peak force (heel strike), $\blacksquare$: second peak force (toe off).

Maximum reaction force

The maximum reaction forces during the foot contact were also analyzed and the results were the same as those of the two peak forces. The effect of the floor surface condition on the maximum reaction forces measured by the platform type was not statistically significant ($P = 0.42$), but the mat effect showed a statistically significant effect on the maximum reaction forces for the in-shoe type ($P < 0.001$). The maximum reaction force (in-shoe type) of the no mat ('E') condition showed the highest value of 1469.9 ± 145.4 N (group 1), and the 'A' mat revealed 1179.8 ± 141.2 N (group 2). The 'B' and 'C' mats induced low values of 961.0 ± 130.7 N and 928.8 ± 106.1 N, respectively (group 3).

Because reaction forces can be highly correlated with the subject's weight, we normalized the reaction forces by subject weights. However, the results showed the same trend.

Discussion

In this study, reaction forces of four floor surface conditions during gait were compared using both the platform and in-shoe type pressure measurement systems. The reaction forces of the three mats were smaller than the no mat condition when measured by the in-shoe type measurement system. Thus, the three mats can diminish the biomechanical load on the various joints and muscles, and this could help reduce fatigue during gait.

The foot contact times of the in-shoe type were shorter than those of the platform type. The two systems used the same sampling frequency of 50 Hz (one sample at every 20 ms), so this time difference might be caused by the different attachment configuration of the sensors. The sensors of the platform type were arranged parallel on a flat panel, but those of the in-shoe type were placed along the curvature of the foot. Thus, the in-shoe type detected the heel strike later and detected the toe off earlier than the platform type. This different attachment configuration might also affect the sensitivity of the two measurement systems.

The reaction forces measured by the platform type were not affected by the floor surface conditions ($P > 0.05$), but the reaction forces measured by the in-shoe type showed different values according to the floor surface conditions ($P < 0.05$). This result indicates that in-shoe type is more sensitive than platform type in evaluating the reaction force induced by inner-room floor mats. The reason might be attributable to the different placement of sensors in addition to the sensor attachment difference, as discussed earlier. While platform sensors are placed under the floor surface, in-shoe sensors are placed between the foot and floor surface. Because of this difference, the platform type can not detect minute differences of the floor surface condition.

When the reaction force was evaluated using the in-shoe type measurement system, the floor surface condition had a significant effect on the mean reaction forces, first (heel strike) and second (toe off) peak forces and maximum reaction forces. The four dependent variables showed a similar trend except 'B' mat. The 'B' mat produced relatively high mean reaction force but relatively low peak values (maximum reaction force and two peak forces). This might be due to the property of 'B' mat. 'B' mat is usually used in an office or train, and is relatively thick and hard. Thus, 'B' may have absorbed higher forces rather than lower forces. Therefore, both the mean

reaction force and maximum reaction forces (maximum or the two peak forces) need to be analyzed to evaluate floor mats' properties.

In this study, mean, two peak forces, and maximum reaction forces were used to evaluate four floor surface conditions. Other measures could also be used to evaluate floor surfaces. Barnett *et al.* [12] compared temporal parameters (e.g., first peak force, mid peak low, second peak force, duration, peak to peak, impulse), which were obtained from both a force measuring platform (Kistler) and a pressure measuring system (Pedar). Therefore, further research needs to be performed to evaluate floor surface conditions using the temporal parameters obtained from in-shoe and platform types.

The subjects who participated in this study were all male students. However, there can be gender or racial differences in gait pattern [14], so that the effect of different gait pattern caused by different gender, race, or pregnancy should be investigated further.

Conclusions

This research compared four floor conditions (no-mat and three inner-room floor mats) using reaction forces measured from both the in-shoe and platform type pressure measurement systems. The conclusions of this research can be summarized as follows.

- 1) Floor mats induced smaller reaction forces (mean, two peak forces, and maximum reaction forces) than the hard floor (no mat) condition.
- 2) The mean, maximum reaction force, and two peak forces measured by the in-shoe type pressure measurement system were sensitive enough to differentiate inner-room floor mats, but the platform type used in this study was not sensitive in evaluating inner-room floor mats.
- 3) The mean reaction force and three maximum reaction forces (maximum and two peak forces) showed different results in SNK comparison tests. Thus, these measures should be considered together in evaluating inner-room floor mats.

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靴内装着型および固定型足底圧計測システムを用いた3種類の室内フロアマットの人間工学的評価

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要 旨：立位姿勢(直立ないし歩行)での長時間の作業は、就業時や日常の活動においても普通であり、腰痛や下肢障害の危険因子の一つである。本研究では異なる4種類の床面状態(3種類のフロアマットとフロアマットなし)で歩行時の床反力の比較を行った。床反力は靴内装着型および固定型足底圧計測システムの両者によって測定した。6名の男性被験者(平均体重 = 72.4 ± 7.5 kg)は4種類の状態の床を裸足で歩行し、2種の測定システムで足底圧を同時に記録した。平均床反力、2つの極大値(踵接地および足趾離床)、および靴内装着型足底圧計測システムにより測定された最大床反力は床表面状態により有意に異なる測定値を示し($P < 0.05$)、床材がない場合が 828.9 ± 114.2 N で最大の床反力であった。しかしながら、固定型足底圧計測システムによる測定では有意な差は得られなかった。フロアマットがない場合と比較すると3種のフロアマットすべてが床反力を減少させたが、平均床反力および最大床反力(最大値と2つの極大値)はマットの厚さと材質の違いにより違いがあった。以上のことから、バイオメカニカルな特性に従った適切なフロアマットの選択を行うことが作業時での疲労と不快感の減少に有効であると考えられる。

キーワード：足底圧, 床反力, 歩行, フロアマット, 床表面状態.

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