The Characteristics of Walking with Different Types of Shoes as Viewed from the Ground Reaction Forces

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Abstract The characteristics of walking with different types of shoes were investigated from the viewpoint of ground reaction forces, as compared with those during walking barefoot. The shoes used in this experiment were three types for casual or business uses for men, which were on the market in Japan. The same shoes were worn by 4 male subjects of the same shoes sizes. It was concluded, from the analysis of variance and the mean difference test, that (1) the ground reaction forces during walking with shoes showed large differences between subjects, (2) the first peak value of the vertical ground reaction force had the tendency to increase while the polar minimum value of the vertical force had the tendency to decrease during walking with shoes, (3) the effect of shoes on the ground reaction forces appeared subject specific, and (4) the formal shoes with leather sole had less effect to enhance the acceleration.

Key Words Human walking, Ground reaction forces, Shoes, Barefoot

Introduction

The ground reaction forces during walking barefoot have been studied by numerous researchers (e.g., ENDO and KIMURA, 1969; CAVAGNA, 1985; CAVAGNA et al., 1976; KIMURA and ENDO, 1972; KIMURA et al., 1975; SUZUKI, 1987; YAMADA et al., 1988, 1989). However, there have been few studies on the forces during walking with shoes, and none using the same shoes for each subject. Because the effects of the shoes on the characteristics of walking may depend on the structural and mechanical features of the particular shoes, the same shoes should be used for all subjects in the experiment. We have investigated the ground reaction forces during walking with shoes in comparison with those during walking barefoot, using the same shoes and subjects of the same shoes size.

Subjects and Methods

Four male subjects whose shoe sizes were identical were chosen, based on the reason mentioned above. Their proper shoe size was '25-EEE' in JIS standard, which meant that the shoes were for the foot length from 248 mm to
Table 1. Age, stature and body weight of the subjects

| Subject | Age (years) | Stature (cm) | Body weight (kg) |
|---------|-------------|--------------|------------------|
| SY      | 36          | 175.5        | 67.2             |
| TO      | 36          | 168.8        | 69.6             |
| YT      | 41          | 168.6        | 63.8             |
| YM      | 44          | 168.4        | 64.3             |

The subjects were asked to walk on the level indoor track of 6 meters long, at the ordinary speed, stride, and cadence for each subject. The walking velocity of the subject was not controlled in order not to deform the natural walking. A force platform (120 cm long and 60 cm wide, Kyowa Dengyo Co.) was set in the middle of the track, and the ground reaction forces of right foot were recorded, which was repeated ten times under each of the four conditions, i.e. walking barefoot or wearing three different types of shoes. The ground reaction forces were normalized by the subject's body weight, and measurements were made on the following parameters (Fig. 1): peak value of the brake force (Fb), peak value of the acceleration force (Fa), the first peak value of the vertical force (Fv1), minimum value of the vertical force (Fvpm), and the second peak value of the vertical force (Fv2). The lateral force was not used in this analysis, because of its large inter-trial variation.

The shoes used in the experiment were three types for casual and business uses for men, which were on the market as the popular shoes for business men in Japan. The shoes type, upper and sole materials, sole patterns, shoe weight, sole length, toe-spring, and main character of these shoes are listed in Table 2. All these shoes sizes were '25EEE'. The shoes I were for casual use. They had heavy and thick polyurethane sole with radial ditches, which may enhance the brake and acceleration. The shoes II were for business use. They were the lightest among the three types, and had the soft rubber sole of rough surface with lattice pattern ditches, which made the shoes easy to be bent. The shoes III were for formal business use. They were heavy, and had the flat and hard leather sole,
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Table 2. Characteristics of the shoes used in the experiment

|                        | shoes I          | shoes II         | shoes III         |
|------------------------|------------------|------------------|-------------------|
| shoes type             | casual           | business         | business          |
| upper material         | buckskin         | leather          | leather           |
| sole material          | polyurethane     | rubber           | leather           |
| sole pattern           | radial ditches   | lattice ditches  | flat surface      |
|                        | (3-4 mm deep)    | (1 mm deep)      |                   |
| shoe weight (right shoe)| 396 g           | 276 g           | 395 g            |
| sole length (right shoe)| 273 mm          | 281 mm          | 275 mm           |
| sole thickness (tip)   | 15 mm            | 14 mm            | 6 mm              |
| (heel)                 | 26 mm            | 18 mm            | 30 mm             |
| toe-spring*            | 5 mm             | 16 mm            | 20 mm             |
| main character         | heavy and good to brake and accel | light, and brake and accel | to be bent quickly and lightly |

1) Toe-spring means the height of the shoe's front tip from the floor

Table 3. Results of the analysis of variance on the ground reaction force parameters by the subjects and the shoes

|                | sum of squares | degree of freedom | mean square | F-value | P  |
|----------------|----------------|-------------------|-------------|---------|----|
| Fb subjects    | 937.3          | 3                 | 312.4       | 127.1   | ** |
| shoes          | 7.9            | 2                 | 4.0         | 1.6     |    |
| Fa subjects    | 1541.2         | 3                 | 513.7       | 288.0   | ** |
| shoes          | 106.7          | 2                 | 53.4        | 29.9    | ** |
| Fv1 subjects   | 4056.5         | 3                 | 1352.2      | 74.3    | ** |
| shoes          | 464.9          | 2                 | 232.5       | 12.8    | ** |
| Fvpm subjects  | 1139.9         | 3                 | 380.0       | 49.5    | ** |
| shoes          | 131.0          | 2                 | 65.5        | 8.5     |    |
| Fv2 subjects   | 1599.5         | 3                 | 533.2       | 48.8    | ** |
| shoes          | 14.8           | 2                 | 7.4         | 0.7     |    |

**: P<0.01
Table 4. Mean and standard deviation of ground reaction force parameters during walking barefoot and with each type of shoes

| subj, SY | Fb       | Fa       | Fv1      | Fvpm     | Fv2      |
|----------|----------|----------|----------|----------|----------|
| barefoot | 16.38 ± 1.082 | 19.02 ± 1.343 | 98.79 ± 2.898 | 78.96 ± 1.686 | 107.78 ± 1.726 |
| I        | 15.48 ± 1.812 | 17.12 ± 0.753** | 109.29 ± 6.286** | 75.97 ± 4.246* | 109.21 ± 2.445 |
| II       | 16.69 ± 1.672 | 17.62 ± 1.173* | 111.17 ± 7.442** | 73.55 ± 4.805** | 110.35 ± 3.131* |
| III      | 15.22 ± 0.927 | 15.77 ± 1.152** | 105.12 ± 2.151** | 79.64 ± 1.381 | 110.62 ± 1.750** |

| subj, TO | Fb       | Fa       | Fv1      | Fvpm     | Fv2      |
|----------|----------|----------|----------|----------|----------|
| barefoot | 21.26 ± 1.745 | 22.18 ± 1.860 | 111.38 ± 5.203 | 75.96 ± 3.448 | 97.95 ± 4.271 |
| I        | 22.26 ± 1.985 | 25.19 ± 3.196* | 123.99 ± 5.068** | 71.62 ± 2.863** | 103.24 ± 3.636** |
| II       | 21.70 ± 2.175 | 24.13 ± 0.991** | 120.65 ± 5.318** | 71.20 ± 2.299** | 100.85 ± 1.889** |
| III      | 22.79 ± 1.891* | 22.19 ± 0.943 | 120.95 ± 3.001** | 70.97 ± 2.341** | 104.17 ± 1.354** |

| subj, YT | Fb       | Fa       | Fv1      | Fvpm     | Fv2      |
|----------|----------|----------|----------|----------|----------|
| barefoot | 13.92 ± 1.387 | 18.54 ± 0.815 | 109.57 ± 4.095 | 83.22 ± 2.326 | 106.35 ± 3.146 |
| I        | 16.43 ± 1.085** | 16.28 ± 0.717** | 118.22 ± 1.856** | 75.08 ± 1.548** | 105.43 ± 4.916 |
| II       | 13.83 ± 1.685 | 16.38 ± 0.690** | 114.87 ± 1.917** | 76.18 ± 2.442** | 109.11 ± 5.019 |
| III      | 14.95 ± 1.459 | 14.48 ± 1.351** | 112.88 ± 3.949* | 77.69 ± 2.443** | 105.36 ± 4.290 |

| subj, YM | Fb       | Fa       | Fv1      | Fvpm     | Fv2      |
|----------|----------|----------|----------|----------|----------|
| barefoot | 16.20 ± 1.149 | 21.53 ± 1.027 | 118.77 ± 5.203 | 71.99 ± 2.646 | 110.96 ± 4.194 |
| I        | 18.19 ± 1.115** | 24.25 ± 1.027** | 125.30 ± 3.392** | 68.36 ± 2.114** | 113.50 ± 3.240 |
| II       | 18.02 ± 1.267** | 22.81 ± 0.733** | 124.83 ± 3.510** | 68.89 ± 1.729** | 113.49 ± 1.947 |
| III      | 17.17 ± 1.142* | 21.62 ± 1.280 | 119.14 ± 3.066 | 70.94 ± 2.935 | 110.32 ± 3.424 |

1) Figures are expressed as % ratio against each subject’s body weight.
2) Significant differences of ground reaction force parameters between walking barefoot and walking with shoes are shown with asterisks; *: p<0.05, **: p<0.01.
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Fig. 2. The effect of each type of shoes on the ground reaction force parameters. The ordinate means the ratio of the ground reaction force parameters of the shoes against those during walking barefoot. ○ represents the shoes I, □ the shoes II, and △ the shoes III.

Results and Discussion

The analysis of variance revealed that difference of the normalized ground reaction forces between the subjects were significant (P<0.01) for all of the parameters measured (Table 3). Differences between the shoes were also significant for Fa, Fv1, and Fvpm (P<0.01).

The mean and standard deviation of each parameter of the normalized ground reaction force in each subject under each condition are listed in Table 4. The significant differences between walking with shoes and walking barefoot, examined by the unpaired t-test, are also shown in the table by the asterisks; the Fv1 significantly increased from the barefoot level with almost all types of shoes in all subjects while the Fvpm significantly decreased from the barefoot level with all types of shoes in all subjects, except for two cases. The Fb, Fa, and Fv2 showed no clear tendency by wearing the shoes.

Magnitude of the ground reaction forces during walking with shoes relative to those during walking barefoot in each subject are shown in Fig. 2. The figure shows that, irrespective of the shoes type, the increase or decrease of each force parameter against the barefoot level has characteristic pattern from subject to subject. A close examination of the figure, however, suggests shoes-specific effects on the ground reaction forces which are common to the subjects.

In Table 5 are compared the ground reaction force parameters between the shoes. In all subjects, the Fa is significantly greater for shoes I and II than for shoes III. A similar tendency, though not necessarily significant, is observed for the Fv1. An inverse trend seems to exist for the Fvpm, i.e. this parameter is greater for shoes III than for shoes I and II. The hard leather sole of shoes III appears to be responsible for these tendencies.
Table 5. Comparison of ground reaction force parameters between the shoes I, II, and III

| subj. SY | Fb  | Fa  | Fv1 | Fvpm | Fv2  |
|----------|-----|-----|-----|------|------|
| I vs. II | ▽  | ▽  | ▽  | ▽   | ▽   |
| I vs. III| △  | △**| △  | ▽*  | ▽   |
| II vs. III| △* | △**| △  | ▽** | ▽   |

| subj. TO | Fb  | Fa  | Fv1 | Fvpm | Fv2  |
|----------|-----|-----|-----|------|------|
| I vs. II | △  | △  | △  | △   | △   |
| I vs. III| ▽  | △* | △  | ▽   | ▽   |
| II vs. III| ▽  | △**| ▽  | ▽** | ▽   |

| subj. YT | Fb  | Fa  | Fv1 | Fvpm | Fv2  |
|----------|-----|-----|-----|------|------|
| I vs. II | △**| ▽  | △**| ▽   | ▽   |
| I vs. III| △* | △**| △**| ▽*  | ▽   |
| II vs. III| ▽  | △**| ▽  | ▽   | ▽   |

| subj. YM | Fb  | Fa  | Fv1 | Fvpm | Fv2  |
|----------|-----|-----|-----|------|------|
| I vs. II | △  | △**| △  | ▽   | ▽   |
| I vs. III| △  | △**| △**| ▽*  | ▽   |
| II vs. III| △  | △**| △**| ▽   | ▽*  |

△: I is greater than II, I is greater than III, or II is greater than III.
▽: I is less than II, I is less than III, or II is less than III.
Significant differences are shown by asterisks (*: P<0.05, **: P<0.01).

The results presented here have shown that the ground reaction forces during walking are basically subject-specific. Such an observation, reliable by using one and the same shoes for different subjects, suggests that each subject walks in a way unique to him, irrespective of the wearing conditions. Despite this, other results have demonstrated that there exist some effects of wearing conditions including the type of shoes. Possible factors causing these effects may include change in the walking speed and walking kinematics. Identification of the factor needs further study.

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抄 録

床反力値からみた裸足歩行に対する着靴歩行の特徴

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裸足歩行時と着靴歩行時の床反力値を比較し、着靴歩行時の特徴について考察を行った。実験に用いた靴は、市販されている3タイプの紳士用ビジネスシューズおよびカジュアルシューズであり、被験者は、36歳から44歳にわたる同じ靴サイズを有する日本人男性4名である。分散分析および平均値の差の検定の結果、(1) 着靴歩行時の床反力値には個人差が大きいこと、(2) 着靴歩行では垂直力第1ピークが高められ、垂直力極小値が低められる傾向がみられたこと、(3) 裸足歩行時に対する着靴歩行時の床反力値の変化の傾向は、靴の違いにかかわらず、被験者ごとにほぼ一定していること、(4) 跛行のフォーマル靴は他の靴と比較して推進力を高める効果が低いこと、が示された。

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