THE IMPORTANCE OF THE GREAT TOE IN BALANCE PERFORMANCE

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ABSTRACT

The objective of this study was to evaluate function of the great toe in maintaining human static and dynamic balance. Correlation among the great toe length, body height and balance performance parameters were also investigated. Thirty female subjects (aged 22.1±1.87 years) were tested in two great toe conditions, unconstrained and constrained. Balance testing was done in the orders listed: 1) static balance, single leg stance with right/left foot, eyes open and closed; 2) static balance, both feet, eyes open and closed; 3) dynamic balance, rhythmic weight shifting, left/right and forward/backward; 4) dynamic balance, target reaching test, eight targets within 90% limit of stability (LOS). The results demonstrated significant differences in sway velocity between the two toe conditions with either eyes open or closed in single leg standing (p<0.05). No difference was found between the two toe conditions while standing with both feet. For the rhythmic weight shifting, significant differences in movement velocity were found both in toe conditions and in weight-shifting directions (p<0.05). Significant interaction was also found between the toe conditions and the weight-shifting condition. As to target reaching, significance was only noted in directional control scores but not in reaction time (p=0.689) and movement velocity (p=0.17). Correlation results revealed the great toe length was only linearly correlated with subject’s height (r=0.553, p<0.05) but not the others. Our results indicated that constrained great toe deteriorated the subjects’ single leg stance performance and worsened the directional control ability during forward/backward weight shifting. Great toe amputation individuals will be recruited in future testing for a more conclusive summary of the importance of the great toe in human balance.

KEY WORDS

Great toe, Balance, Foot, Sway velocity

Introduction

Balance is vital for people to accomplish daily tasks. Impairment in balance would interfere with the acquisition of motor skills, thus lead to deterioration in performance quality and cause higher incidence of falls and injuries. The plantar surface of the foot provides direct contact of human body to the surrounding environments. It is the most distal joint in the lower kinetic chain in maintaining standing balance [1]. During locomotion such as walking and running, the foot serves as a propulsive lever and a shock absorber. Therefore, proper arthrokinematics within the foot influences the body’s ability to attenuate these forces[1]. Dysfunction of foot biomechanics caused by diseases or injuries would interfere lower extremity biomechanics, posing extra pressure onto some other joints.

Within the foot structure, the great toe seems to play an important role in the biomechanical function of the foot. In standing, the great toe exerts more pressure than those of the five metatarsal heads and the heel 3. It also poses a pressure about twice of the total pressure of the other four toes [2]. During walking, as the great toe is passively dorsiflexed, the longitudinal arch of the foot is raised, the rearfoot supinated, the leg externally rotated, and the plantar aponeurosis tensed [3]. This so-called windlass mechanism is of great importance since it tenses the plantar fascia thus forming a rigid lever of the foot for push-off. If the mechanism is altered, the timing and effectiveness of push off would be affected. Therefore, disorders of great toe would cause inevitable changes in subject’s static and dynamic balance.

To the authors’ knowledge, none of the balance studies had directly evaluated the great toe influence onto balance performance. Tanaka et al., 1996[2], tested subjects’ single leg stance on a moving platform and measured their sway responses and the peak pressure under the toes. The results demonstrated that body sway was more significantly correlated with the peak anteroposterior sway component than with lateral sway, and the peak pressure value of the great toe was significantly greater than the sum of the peak values of the other four toes for both sides. Moreover, the maximal great toe pressure in the elderly group was significantly greater than that in the young group[6]. Similar results were found by Ducic et al. [4][5] in a group of patients with peripheral neuropathy. These results indicated that big toe may influence the balance performance.

Furthermore, Beyaert [6] analyzed children (aged 6.5-12.5 years) 5 years after removal of one or two second toes for digital reconstruction. They found maintenance of balance and rate of displacement of the center of pressure when standing on one foot with eyes closed were significantly altered for operated limbs compared with non-operated limbs. This result revealed...
the importance of the second toe in balance function. Since the great toe is the largest among all toes, it is likely to demonstrate an important function in maintaining balance.

Great toe amputation was also found to affect individual’s foot bone stress. Barca et al. (1995) [7] found that patients who received microsurgical reconstruction of the thumb with great toe transfer exhibited an overload of central and lateral metatarsal bones. This indicated great toe amputation significantly altered the weight distribution pattern within the foot structure. This alteration would inevitably affect subject’s balance.

Due to the scant information regarding the role the great toe plays in human balance performance, the purpose of this study is to evaluate the function of the great toe in maintaining human static or dynamic balance. It was hypothesized that subjects with unconstrained great toe would perform better during single leg stance in eyes open or eyes closed condition. For dynamic standing tasks, we predicted constraint of the great toe would deteriorate the subject’s balance performance parameters. In addition, the relationships among the length of great toe, body height and balance ability would also be investigated.

Material and Method

Thirty female aged 18-24 years volunteered for the study. The participation of subjects was in accordance with Institutional Review Board procedures at the Chang-Gung Memorial Hospital. Descriptive statistics regarding subjects’ age, height, body weight, and great toe length were listed in Table 1. Length of the big toe was measured from the first metatarsal joint line to the most distal part of the phalange. All subjects were right-leg dominant. Subjects signed the informed consents before their participation.

Table 1. The descriptive statistics of subjects age, height, body weight, and great toe length

<table>
<thead>
<tr>
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<th>MEAN ± SD</th>
<th>MINIMUM</th>
<th>MAXIMUM</th>
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<tbody>
<tr>
<td>AGE (years)</td>
<td>22.10 ± 1.87</td>
<td>18.37</td>
<td>24.88</td>
</tr>
<tr>
<td>HEIGHT (cm)</td>
<td>161.11 ± 4.78</td>
<td>152.00</td>
<td>170.00</td>
</tr>
<tr>
<td>BODY WEIGHT (kg)</td>
<td>57.02 ± 6.48</td>
<td>48.50</td>
<td>77.00</td>
</tr>
<tr>
<td>GREAT TOE LENGTH (cm)</td>
<td>6.48 ± 0.45</td>
<td>5.60</td>
<td>7.50</td>
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Subjects were tested in two great toe conditions, unconstrained or constrained. In condition of constraint, subject’s great toe was constrained in 30° dorsiflexion with a special designed splint to mimic the situation without great toe. In condition with two legs standing, both great toes were constrained. The splint held the great toe in a position so that it could not contact the ground. Fifteen subjects performed the unconstrained toe condition first and the others constrained toe condition first. The orders of the great toe conditions were randomly assigned.

Subject rode a stationary bike for three minutes and then performed designed lower extremity stretching exercises. The following testing conditions were recorded in the orders listed: 1) static balance, single leg stance with right/left foot, eyes open and closed; 2) static balance, both feet, eyes open and closed; 3) dynamic balance, rhythmic weight shifting, left/right and forward/backward; 4) dynamic balance, target reaching test, eight targets within 90% limit of stability (LOS). After the series of testing, subject sat and rested for ten minutes then performed the whole series of testing again with the next big toe condition.

Balance parameters were measured by a commercially available balance machine, the Smart Balance Master v5.0 from Neurocom International Inc, U.S.A. In condition of the static balance testing, subject stood with her eyes leveled with the computer screen. In single leg stance, subject placed her foot in the middle of the force plate. For the next condition, subjects stood with both feet about shoulder width apart (the actual width depended on the body height of the subjects). The recording time was 20 seconds. Both conditions were tested with eyes open and then eyes closed. Eyes open and eyes closed were treated as independent testing conditions. The sway velocity of center of pressure was recorded. Sway velocity was calculated by the averaged movement velocity between the 5%-95% movement distance.

Two-way analyses of variances were used with repeated measures on the two independent variables. The two independent variables were toe (unconstrained and constrained) and leg (left and right) for static single leg stance with eyes open or eyes closed; toe and direction (left/right and forward/backward) for weight shifting condition; toe and target (front, right front, right, right back, back, left back, left, left front) for target reaching test. Paired-t test of toe condition was used for static two leg stance with eyes open or closed. Pairwise comparison was used when a significant interaction was found between two independent variables. The significance level was set at 0.05. Pearson’s correlation coefficient was calculated to represent the correlation between great toe length and body height, great toe length and balance parameters, and the body height and balance parameters.

Results

Effects of great toe onto static balance

In condition with single leg standing, significant difference was seen in sway velocity between the two toe conditions with either eyes open or closed (p<0.05), but not between right and left legs. No interactions were shown between toe and leg conditions with eyes open or closed. The sway velocities were smaller with the great toe unconstrained than constrained (Fig 1). However, the sway velocity in static standing with both feet did not show significant differences between the two toe conditions (p=0.29) (Fig 2).
Fig 1. Sway velocity (degree/second) during single leg standing between the two toe conditions with both eyes open and closed.

Fig 2. Sway velocity (degree/second) during two leg stance between the two toe conditions with both eyes open and closed.

**Effect of great toe onto dynamic balance**

For the rhythmic weight shifting, statistical analysis revealed significant differences both in toe conditions and in weight-shifting directions (p<0.05). Subjects demonstrated a better directional control when the toe is unconstrained. Their directional control was better in left/right than forward/backward direction. A significant interaction was found between the toe conditions and the weight-shifting directions. Pairwise comparisons revealed that the sway direction in forward/backward was significantly different between different toe conditions (p<0.05), but not in left/right (Fig 3). This indicated the great toe played a significant role in forward/backward weight shifting balance. In addition, during the forward/backward weight shifting, subjects demonstrated a better directional control with their great toe unconstrained. Pairwise comparisons also revealed a significant difference between forward/backward and left/right sway regardless of the toe conditions.

As to the target reaching, there were no significant differences in the reaction time (p=0.689) or movement velocity (p=0.17) with the great toe either constrained or unconstrained. Significance was only noted in directional control scores (p<0.05). Paired t-test showed a significant difference between the two toe conditions in the directional control score in target position front, right front and left front (Fig 4). Subject demonstrated a better directional control when the great toe was unconstrained.

**Correlation between great toe length and body height / balance performance**

Person’s correlation coefficient was used to analyze the correlation of great toe length with subject’s body height, static balance performance with single leg support (eyes open or closed), static balance performance with both feet (eyes open or closed), dynamic left/right weight shifting, dynamic forward/backward weight shifting, dynamic target reaching reaction time, dynamic target reaching movement velocity, and dynamic target reaching directional control. The results indicated that great toe length was only linearly correlated with subject’s body height (r=0.553, p<0.01), but not the others.

**Correlation between body height and balance performance**

No significant correlations were found between the subject’s body height and the above listed balance parameters (p>0.05).
Discussion

The purpose of this study is to investigate the functional role of the great toe in maintaining static and dynamic balance. Results of our study revealed the importance of great toe in standing balance. The constraint status of the great toe did make a significant difference in subject’s sway velocity during single leg standing but not in standing with both feet. This supported our hypothesis that subjects demonstrated a better single leg stance performance with the unconstrained great toe. These results can be interpreted with the biomechanical (muscle function) point of view. In standing, body’s center of gravity passes through femoral greater trochanter and falls in front of the ankle joint. The gluteus maximus and the posterior shin muscles contract to hold the body in position. During single leg stance, the base of support is relatively smaller. In order for the body’s center of gravity to fall within the supported foot, more muscles need to join in to assist this task. Other than the activities from the above mentioned muscles, gluteus medius contracts to prevent the body from sideway leaning. Foot muscles are also of great importance while standing in this condition. Menz et al. [8] found that toe plantar flexor muscles are significant predictors of balance and functional ability. With a constrained great toe, the functions of great toe plantar flexors would be limited.

In addition, great toe is the biggest toe above all. It serves as the insertion for some of the foot extrinsic and intrinsic musculatures, and also the insertion of the arch maintaining structure-plantar aponeurosis. Malfunction of the great toe would inevitably cause foot function deterioration, therefore interfering with balance performance especially in challenging conditions such as single leg stance.

Our study also showed directional control deficits during forward/backward weight shifting in constrained great toe condition, but not during left/right weight shifting. Winter [9] indicated that during quiet standing, the center of pressure (COP) excursion in forward/backward direction is primarily controlled by the foot plantar- and dorsi- flexors, while the COP excursion in left/right direction is mainly adjusted by hip abductors and the foot invertors and evertors. The constrained great toe condition in our study limited functional control of foot, not hip; therefore the weight shifting performance in forward/backward direction might be deteriorated more obviously. Tanaka et al [10] also pointed out the amount of forward/backward sway during single leg stance is more obvious than the amount of left/right sway. This result again indicated that left/right sway, which is controlled by larger hip abductors, is more stable than the forward/backward sway—which is adjusted by foot dorsi- and plantar- flexors.

No significant difference was found in reaction time and movement velocity in the target reaching test regardless the conditions of great toe. This might be because the target reaching movement was mainly generated by the large lower extremity muscles in order to move the COP, and the muscles in great toe are primarily for fine motor control. Therefore, whether the great toe is constrained or not did not cause significant difference. Similar explanations apply to the findings of movement velocity. Since the COP movement velocity is mainly controlled by the contraction of large muscle groups, the conditions of great toe were not of great influence either.

On the other hand, significant differences were noticed in the directional control during target reaching between two toe conditions. When the great toe was constrained, subject demonstrated a worse directional control. The worse performance is directional specific to front, right front and left front target position. Limitation of foot dorsi- and plantar- flexors would affect subject’s forward/backward sway performance. In addition, considering plantar pressure distribution, the great toe itself sustains about 2.4% of the total load carried by the foot during regular stance[11]. According to the above, it is reasonable to infer that subjects with the great toe constrained in a dorsiflexed position would encounter difficulties while shifting forward—including the front, right front, left front target reaching tasks.

Test of correlation found that great toe length is highly correlated with the subject’s body height, but not with any other balance parameters. This indicated that in general, the ones who are tall have longer great toes; however the long great toes do not positively or negatively affect their balance performance.

Our results also found no correlations between the subject’s body height and the balance parameters measured. Different body characteristics would affect the balance ability differently; however the exact mechanism is not clear. Inconsistent results had been published regarding this issue. Era [12] pointed out that as the body height of subjects increases, the postural sway increases. In contrast, the study by Davis et al. [13] found that the older women who were shorter demonstrated a poorer balance ability and more prone to falls. On the other hand, Keironen et al [14] found no relationships between the subjects’ body height and their balance performance. Therefore, the mechanism of how body height influence balance performance remains unclear.

Conclusion

This study pointed out the importance of the great toe in static and dynamic standing balance. Constrained great toe interfered with subject’s balance performance during single leg stance. It also worsened the directional control ability during forward/backward shifting. Since the great toe flexors were restricted while the toe was constrained, they can not participate fully in balance adjustment. This might be one of the reasons why balance performance differs with a constrained great toe. Further research is
needed to clarify whether the balance deteriorations come from the deficits of foot supporting surfaces, great toe flexor muscle activities, or sensory functions. Individuals with great toe amputation will be recruited for testing in the future for a more conclusive summary of the importance of the great toe in human balance.

References