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Original Article

Evaluation of trunk sway in sit-to-stand motion using a pressure distribution measurement system

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ABSTRACT
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Purpose: The majority of studies investigating sit-to-stand (STS) motion have focused on the analysis of motion in the sagittal plane. We conducted a study using a pressure distribution measurement system known as BIG-MAT (BM) to investigate the bilateral asymmetry of STS.

Method: Ten healthy men were asked perform STS movements while paying attention to their bilateral symmetry. We recorded the plantar pressure changes for both feet over the course of 15 rounds of STS. Based on the pressure sensitivity diagram obtained from the BM analysis, time-dependent changes in peak load pressure for both the left and right forefoot and hindfoot were evaluated.

Results: Temporal bilateral differences in forefoot peak load were below 0.2 s in 50.3 ± 12.8% of subjects, more than 0.2 s in 45.0 ± 14.1% of subjects, and the peak itself was absent in in 4.0 ± 0.5% of subjects.

Conclusion: Despite subjects attempting to remain aware of bilateral symmetry during STS movement, approximately 50% of STS motions were asymmetric. This study suggested the involvement of movements of the trunk, such as small rotations, lateral bendings, and lateral movements.

Key words: sit-to-stand motion, pressure distribution measurement system, trunk sway, motion analysis, BIG-MAT

Introduction

Sit-to-stand (STS) motion is a frequently used fundamental activity of daily life and has a key role in the sequential movements involved in rising from the supine position to a walking position [1]. Occurring at the moment of the lifting of the gluteal region from the surface of a seat, a STS motion is characterized by an instantaneous narrowing of the base of support from being a wide surface including the gluteal regions, to being a narrow surface comprising only the plantar surfaces. Since the gluteal region leaves the seat, the base of support shrinks into a narrow area comprising the areas of contact between the feet and the ground, while the center of gravity (COG) moves upward against gravity. In other words, only a muscular strength enough to move the body's COG upwards and a balancing action within the supporting surface are needed to achieve this motion. The necessity to control both the muscle force and the regulation of the COG during movement makes STS a difficult motion [2].

Numerous studies have analyzed STS motion, using a variety of noteworthy analysis methods, and kinematic analysis [3, 4] using three-dimensional motion analysis equipment with video cameras, and kinetic analysis [5−9] combining the use of surface electromyogram and force plates were used in those studies. Although these methods used in previous studies provided sufficient information, the tests used in those methods also had the disadvantage of being too time consuming and costly [7]. Other studies have reported simple evaluation of STS using a pressure distribution measurement system without a video camera or using only a ground reaction meter [10−13]. These studies have focused on total or partial changes in the center of pressure (COP) and ground reaction force and have revealed the presence of a uniform pattern of movement for the COP during STS. In either case, studies analyzing the mechanics of STS motion have mainly focused on movement of the sagittal plane [6, 14], and simplified methods must be developed in

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order to study STS more broadly. We previously conducted a study using the pressure distribution measurement system "BIG-MAT," enabling a relatively simple evaluation of the COP. We found that 1) the "extension of time from the beginning of STS until the forefoot load pressure reaches a peak", and 2) the "rate of change of load pressure values (increase in front and back sway) required for the forefoot", were useful as measurement indexes for "standing-up difficulty" [10]. We did not include the data when the bilateral temporal difference at the moment when the forefoot load reached its peak was more than 0.2 s, because we judged the data as outlier, and we asked the subjects to repeat the STS movements until the 4 data where the bilateral difference of less than 0.2 s was obtained. In the track of methods adopted in the previous studies, we evaluated STS movements as continuous movements restricted to the sagittal plane, and, as the result, the subjects had to perform the movement 10.20 ± 2.96 times (range, 6−14) in order to obtain the desired data 4 times. This condition was established to maintain consistency with previous reports; however, rejection of more than half of the data created a problem, leaving the question whether our hypothesis that STS is a bilaterally symmetric motion was valid or not. Moreover, a few additional reports [12, 15, 16] have claimed that STS is not a bilaterally symmetrical motion because of the influence of the dominant foot. Therefore, we examined the temporal bilateral differences in plantar load peaks during STS movements.

Methods

Study subjects included 10 healthy male volunteers with no history of motor system disorders. The subjects had a mean age of 34.7 ± 2.7 years (range, 30−38 years), mean height of 171.3 ± 4.5 cm, and mean weight of 70.1 ± 10.2 kg. Only 1 out of the 10 volunteers was left-foot dominant.

We used chairs with an adjustable seat height. The subject was instructed to sit in the chair, and both feet were positioned approximately at the center of the sensor sheet (BIG-MAT P3B 1300®, Nitta Industries) of the pressure distribution measurement system (BIG-MAT ver5.87®, Nitta Industries) placed on a flat floor. The seat height was adjusted such that the subject's hip joint was bent at an angle of 90°, the knee joint at 90°, and ankle joint at 0°. The standard seat height was 38.30 ± 2.50 cm. Both feet were positioned such that the distal tip of the first metatarsal bone and the calcaneal bone touched the ground. Both upper limbs were lightly crossed in front of the chest in order to minimize the effects of upper limb movements, and the subjects were told not to move their arms while observations were being made [4, 17]. The subjects were then asked stand up from their seats, facing the front, at their desired speed while paying attention to their bilateral symmetry. Recording was set to 50 frames per second. During STS motion, plantar surface pressure changes for both feet were recorded for 7 s. This series of tests was performed 15 times on each subject. Next, an 8-cm thick, low-repulsion urethane mat (low-repulsion cushion LE®, Bridgestone) was placed on the seat, and the test was performed again as before. To counter the increased thickness added by the urethane mat, the seat height was lowered such that the position of the feet mirrored that of the previous tests.

On the basis of the pressure sensitivity diagram obtained using BIG-MAT, the forefoot and hindfoot were separated at the mid-portion of the first metatarsal bone, and time-dependent changes in the left and right load peak pressure (2 × 2 cm^2) were evaluated (Fig. 1). Peak pressure was defined as the maximum pressure value within a specified area. A graph was plotted with the X-axis indicating time and the Y-axis indicating peak pressure value. The difference in the moment at which the load pressure values for each bilateral forefoot peak [10], , was categorized according to 3 observed patterns: 1) peaked in less than 0.2 s, 2) peaked in more than 0.2 s, and 3) no peak (Fig. 2). From the 15 STS motions performed by each subject, we calculated the percentage of subjects falling under each respective pattern category, and calculated the mean and standard deviation of the frequency. This process was performed using either a standard chair or a low-repulsion urethane mat, and the Wilcoxon rank-sum test was used to compare the frequency of each of the 3 patterns. With regards to the temporal bilateral difference of the forefoot being more than 0.2 s, The Chi-square test was conducted to investigate which

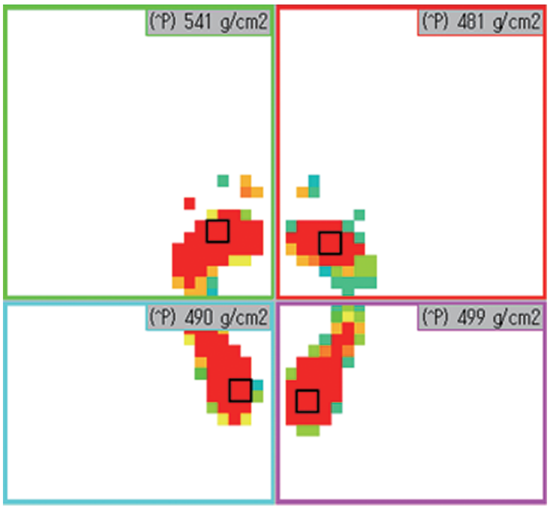

Figure 1. One case of plantar pressure sensitivity.
The forefoot and hindfoot were separated at the mid-portion of the first metatarsal bone, and the respective left and right load pressures (2 × 2 cm^2) are denoted by the numerical values in the upper right corner of each panel (g/cm^2).

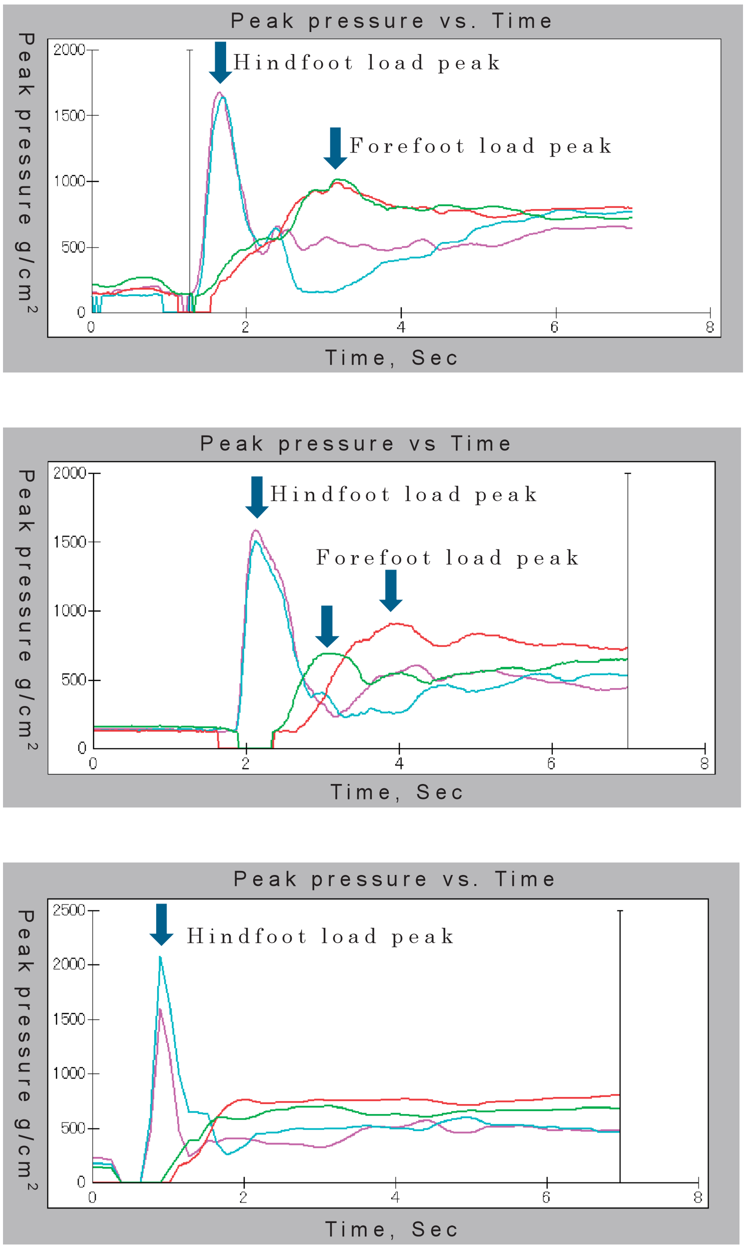

Figure 2. Successive changes in load peak pressure values.
Color coding used in the graph conforms to the rectangular colored boxes in Fig. 1 (🟩Left forefoot, 🟥Right forefoot, 🟦Left hindfoot, 🟪Right hindfoot). First, the hindfoot reaches load peak, and then the forefoot reaches load peak. The differences in the moment at which each bilateral forefoot load peak is observed are classified into High (less than 0.2 s), Med (more than 0.2 s), and Low (No peak).

foot (the dominant foot or the nondominant foot) reached load peak first. The statistical significance level of all experiments was set at 5%.

Results

A temporal bilateral difference of more than 0.2 s for the hindfoot load peak was not observed in any subject when the standard chair was used. However, the temporal bilateral difference in forefoot load peak was less than 0.2 s in 50.3 ± 12.8% of subjects and more than 0.2 s in 45.0 ± 14.1% of subjects, while no peak was observed in 4.0 ± 0.5% of subjects (Table 1). Similar results were obtained when the low-repulsion urethane mat was used, and no significant differences in the frequency of each pattern were found when comparing the 2 seating conditions. Moreover, the tests for investigating which foot (dominant foot or nondominant foot) first reaches load peak revealed a higher tendency of the dominant forefoot to precede

Table 1. Frequency of each of the 3 patterns of temporal changes in the forefoot load peak.

Temporal difference in forefoot load peak	Frequency <Normal chair> (range)	Frequency <Low-repulsion urethane mat> (range)	Wilcoxon rank-rum test (one-tailed)
Less than 0.2 s	50.0 ± 1.3% (33.3%−66.7%)	48.7 ± 1.8% (26.7%−80.0%)	*t* (9) = 13.5, no significant difference
More than 0.2 s	45.3 ± 1.3% (20.0%−66.7%)	44.7 ± 1.9% (13.3%−73.3%)	*t* (9) = 12, no significant difference
No peak	4.7 ± 0.5% (6.7%−53.3%)	6.7 ± 1.1% (0%−60.0%)	*t* (9) = 4, no significant difference

No significant differences between the 2 groups were found for any of the 3 patterns.

Table 2. Frequency of one foot preceding the other in STS movements where the temporal bilateral difference was more than 0.2 s at the moment when forefoot load was at peak.

	Dominant foot precedence (frequency)	Non-dominant foot precedence (frequency)
Normal chair	22	19
Low-repulsion urethane mat	39	28

the non-dominant foot when the low-repulsion urethane mat was used as compared to when the standard chair was used (odds ratio: 1.20; 95% confidence interval: 0.55−2.63) (Table 2). However, no statistically significant difference was found with regards to the influence of the dominant foot (χ^2 (1, N = 10) = 0.21, no significant difference).

Discussion

Previous studies investigating the changes in plantar pressure distribution during STS have demonstrated that, immediately after commencement of STS, the COP was 1) drawn towards the posterior calcaneal region, 2) rapidly moved to the anterior region of the forefoot, 3) shifted rearwards, and 4) finally reached a stable position, with minute adjustments according to changes in posture [11−13, 18]. In the current study, where STS was performed with awareness of bilateral symmetry, we found no temporal bilateral differences in the load peak of the posterior region of the foot, and a difference of more than 0.2 s in the forefoot was observed in nearly 50% of subjects. In previous studies investigating bilateral symmetry STS models, despite being told to stay aware of their bilateral symmetry, almost half of the subjects exhibited asymmetry in everyday STS movements, therefore, most of the sit-to-stand movements that they performed in daily life were believed to be asymmetric. Rodosky et al. investigated movement and angles of the foot, knee, and hip joints and reported that even a healthy person has a significant degree of bilateral difference [16]. Bear et al. have shown that movements of the trunk, such as small rotations, lateral bendings and lateral movements were also present in healthy subjects [15]. Tashiro et al. investigated changes in sway components of the COP and reported an absence of movement toward bilateral directions in only 16% of study subjects [12]. Similarly to our study, these previous reports support the asymmetrical nature of the STS motion. Despite the fact that none of the subjects showed a bilateral difference in load peak on the hindfoot, based on the studies of Bear et al. [15], we suspect that small rotations of the trunk, lateral bendings, and lateral movements during the forward movement of the COP may contribute to this asymmetry, and might be the reason that temporal differences between the two sides were found at a high frequency only in the forefoot.

The results of this study, showed no significant differences with regards to the influence of the dominant foot. However, when the low-repulsion urethane mat was used, the load to the forefoot of the dominant foot showed a tendency to shift anteriorly; and when the “degree of difficulty in standing up” was added among the conditions, the findings indicated the possibility of a stronger predominance of the dominant foot. More tests, with an increased number of subjects, are required to confirm this assertion.

The BIG-MAT sensor sheet is thin and can be rolled into a cylinder. Even with the USB connector, it weighs only 350 g (excluding the laptop computer). It is much lighter than the ground reaction force plate frequently used in previous STS studies. Furthermore, it can easily measure changes in the COP or specific parts of the foot, such as the bilateral differences in loads on both feet, and we expect that the BIG-MAT will have more clinical applications in the future.

Remarks

This study was performed with the approval of the medical research review committee at Showa University Fujigaoka Hospital.

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