Differences in Biomechanical Characteristics of Sit-to-Walk Motion between Younger and Elderly Males Dwelling in the Community

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Abstract. [Purpose] The purpose of this study was to clarify the difference in sit-to-walk (STW) motion between young adults (YG) and an elderly persons (EG). [Subjects and Methods] Twenty-seven subjects (9 in YG and 18 in EG) were instructed to perform STW and to walk 3 m at a comfortable speed and at maximal speed. Data were obtained using a 3D motion capture system for kinematic data, and two force plates for kinetic data. [Results] The time required for STW was similar for both groups at both comfortable and maximal speeds, but the forward velocity of the center of gravity of the whole body (COG-WB) was higher for YG, and upward COG-WB at the time of the first heel contact was faster for YG. Ground reaction force analyses showed many differences between the groups. For YG, COG-WB moved forward and the first swing side was longer than for EG. [Conclusion] Forward and lateral COG-WB movements before the toe-off generate a progressive force. We suggest that YG subjects may have sufficient muscle power in their lower extremity to bear the progressive force, or that EG subjects may have learned anticipatory postural control which has shorter forward movement due to aging and declining physical function.

Key words: Sit-to-Walk, Young and elderly people, Biomechanical analysis

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INTRODUCTION

Few researchers have examined the biomechanical characteristics of sit-to-walk motion (STW), although STW is frequently seen in our activities of daily living. In a previous study, Wall et al.¹⁾ divided the Timed Up and Go (TUG) test²⁾ into six phases, and analyzed the difference in the duration of each phase between young adults, healthy older adults and older adult fallers. That study pointed out that the sit-to-stand and gait initiation phases were difficult to discern clearly because subjects initiated gait before standing up completely. Kerr et al.³⁾ divided STW into four

phases by using ground reaction forces (GRFs) and center of gravity of the whole body (COG-WB). This study defined four phases: flexion momentum, extension, unloading and stance. Magnan et al.⁴⁾ clarified the difference between STW and sit-to-stand (STS) by biomechanically analyzing healthy men. In our previous study of STW⁵⁾, we compared the biomechanics of STW to STS or gait initiation (GI). We found that the maximal horizontal velocity of COG of the trunk (COG-T) before seat-off was significantly faster in STW than in STS. The peak value of backward GRF at the first heel contact was significantly greater in STW than in GI. We suggested that it was important in STW to

develop forward momentum by bending the trunk quickly, and to brake the forward motion by heel contact.

Generally, elderly people show declines in physical function compared to the young, and elderly fallers show declines in physical function compared to healthy elderly people. The TUG test²⁾ is useful for evaluating dynamic balance and predicting falls⁶⁻⁸⁾. Although the TUG test includes STW, the biomechanical characteristics of STW in elderly people have not been clarified much. However, there are many comparative studies of gait, STS and GI, which are motions similar to STW⁹⁻¹⁴⁾. Previous studies have pointed out that there are some differences in STS and GI between the young and elderly, so some differences will also be indicated in STW. If we could clarify the differences between the young and elderly, it would give us a clinical interpretation of the result of the TUG test, and provide a means of clinical intervention for patients who can not achieve STW smoothly.

SUBJECTS AND METHODS

The subjects were nine healthy young men (young group: YG, mean age 21.8 ± 2.5 years) and 18 elderly men (elderly group: EG, mean age 73.9 ± 5.3 years) living at home. Their mean height was 170.3 ± 4.9 cm for YG, and 160.0 ± 4.7 cm for EG; and their mean weight was 65.1 ± 6.8 kg for YG, and 56.6 ± 7.8 kg for EG. No subject had a disability which restricted his achievement of STW. All elderly subjects were able to do light outdoor work such as cleaning and gardening. Each subject was informed of the purpose of this study, and they all gave their consent to participate in the study. This study was conducted after receiving approval from the ethics committee of Prefectural University of Hiroshima.

The subjects were instructed to perform STW at both comfortable and maximal speeds. STW was initiated from sitting in a chair, and included walking 3 m. A chair without a backrest or armrest was used, and the seat's height was adjusted to match the length of the subject's lower leg. STW was started with the knee flexed at 90 degrees and the feet, shoulder width apart. Subjects started their motion upon hearing a beep emitted by a sound device. The subjects practiced the task until they were able to perform it smoothly and naturally, and

Fig. 1. Measuring system and the three dimensional coordinates.

one trial was adopted for the analysis.

An outline of the experiment is shown in Fig. 1. Kinematic and kinetic data were obtained by a three-dimensional motion capture system (Vicon 512, Oxford Metrix, Ltd.) and two force plates (Kistler force plate 9287BA, 900 mm $\times$ 600 mm). Kinematic data were obtained by measuring the trajectories of 10 reflective markers (RMs) on landmarks on each subject's body using six infrared cameras. RMs were attached to each landmark on both sides: the acromions, greater trochanters, knee joints, lateral malleoluses, and the metatarsal heads of the fifth toe. Kinetic data were obtained by measuring forces and their coordinates created by both feet on each force plate.

Sampling frequency was 120 Hz for the infrared cameras and 600 Hz for the force plates, and force plate data were re-sampled at 120 Hz by using a Vicon Workstation (ver. 4.6). Kinematic and kinetic data were synchronized after second-order Butterworth low-pass filtering (6/50 Hz). Then, the data were converted to DIFF (Data Interface Format File) using a Vicon Workstation; and DIFF data were converted to Microsoft Excel data (Microsoft Corp.) using "diff gait" and "wave eyes", software produced by The Clinical Gait Analysis Forum of Japan. Coordination of space and GRF defined the x axis as right-left, y -axis as forward-backward and z -axis as vertical (Fig. 1). Excel data included coordination of RMs and COP, velocity (V_y , V_z) of COG-WB and COG-T, and GRFs (F_y , F_z). When

Table 1. Comparison of the required motion time and the velocity of COG-WB and COG-T

		Comfortable speed condition			Maximal speed condition		
		YG	EG		YG	EG	
time required ^a	[s]	1.43 ± 0.33	1.29 ± 0.23	n.s.	1.09 ± 0.13	1.01 ± 0.10	n.s.
V_y COG-T ^b	[m/s]	0.72 ± 0.11	0.71 ± 0.08	n.s.	0.99 ± 0.20	0.90 ± 0.16	n.s.
V_z COG-WB ^c	[m/s]	0.67 ± 0.12	0.62 ± 0.09	n.s.	0.70 ± 0.15	0.65 ± 0.12	n.s.
V_y COG-WB ^d	[m/s]	0.37 ± 0.18	0.36 ± 0.12	n.s.	0.89 ± 0.23	0.66 ± 0.23	*

V_x, y, z : components of velocity; COG-T: center of gravity of the trunk, COG-WB: center of gravity of the whole body.

a: the time required from the start of movement of both acromions to the first heel contact; b: maximal V_y of COG-T before seat-off; c: maximal V_z of COG-WB while standing up; d: V_y of COG-WB at the maximal V_z of COG-WB while standing up.

n.s.: not significant.

*: $p < 0.05$.

Table 2. Upward and anterior velocity of COG-WB while first leg swing

			Comfortable speed condition			Maximal speed condition		
			YG	EG		YG	EG	
V_y COG-WB	loading before swing ^a	[m/s]	0.46 ± 0.15	0.45 ± 0.11	n.s.	0.76 ± 0.13	0.65 ± 0.10	*
	toe-off ^b	[m/s]	0.47 ± 0.16	0.43 ± 0.10	n.s.	0.91 ± 0.17	0.67 ± 0.14	***
	heel-contact ^c	[m/s]	0.72 ± 0.16	0.83 ± 0.12	n.s.	1.30 ± 0.16	1.05 ± 0.18	**
V_z COG-WB	loading before swing ^a	[m/s]	0.35 ± 0.13	0.32 ± 0.14	n.s.	0.27 ± 0.09	0.22 ± 0.11	n.s.
	toe-off ^b	[m/s]	0.38 ± 0.24	0.42 ± 0.21	n.s.	0.63 ± 0.14	0.58 ± 0.10	n.s.
	heel-contact ^c	[m/s]	0.04 ± 0.16	-0.03 ± 0.12	n.s.	0.29 ± 0.19	0.08 ± 0.15	**

V_x, y, z : components of velocity; COG-WB: center of gravity of the whole body.

a: maximal loading on the first swing leg before swing; b: first toe off; c: first heel contact.

n.s.: not significant.

*: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

forward velocity of both acromions was generated continuously for 0.05 seconds or longer, the start of STW was defined as the time when the motion began.

To compare YG and EG, a non-paired t test was adopted using SPSS ver. 14.0 for Windows (SPSS Japan). The level of statistical significance was set as $p < 0.05$.

RESULTS

Comparisons between the YG's and EG's required time and velocity of COG are shown in Table 1. The time from the start of STW to the first heel contact was the same for both groups. V_y of COG-WB at maximal V_z of COG-WB while standing up was significantly faster for the YG than the EG during the maximal speed ($p < 0.05$).

To obtain detailed results about the velocity, V_y and V_z of COG-WB were compared at the time of maximal loading of the swing leg before the first swing, the first toe-off and the first heel-contact

(Table 2). At a comfortable speed there were no significant differences between the two groups. At the maximal speed, V_y of COG-WB was higher for YG than for EG at all times, and V_z of COG-WB was higher for YG than for EG at the time of the first heel contact.

GRF analysis showed many significant differences in the groups' maximal GRFs (Table 3). At a comfortable speed there were significant differences in all analyzed timings. At the maximal speed, the maximal F_y (forward component) was significantly larger for YG on the first and second stance legs, and the maximal F_z was significantly larger for YG at the time of loading the first swing leg before the first swing and the first stance leg.

The distance (dx, dy, dz) between COG-WB and COP at the time of the first toe-off was compared between the groups (Table 4). dx was indicated as the first swing side to COP. The results showed no significant differences at comfortable speeds. At the maximal speed, dx and dy were significantly longer for YG than EG, and dz was significantly

Table 3. Comparison of GRFs between YG and EG

			Comfortable speed condition			Maximal speed condition		
			YG	EG		YG	EG	
Fy	1st stance leg ^a	[%BW]	21.59 ± 3.69	15.57 ± 4.98	**	25.91 ± 4.36	16.23 ± 4.81	***
	2nd stance leg ^b	[%BW]	-10.41 ± 3.02	-7.06 ± 4.02	*	-5.28 ± 2.37	-5.94 ± 3.35	n.s.
	2nd stance leg ^c	[%BW]	23.24 ± 5.05	15.74 ± 5.93	**	29.79 ± 6.95	17.85 ± 6.94	***
Fz	1st swing leg ^d	[%BW]	65.24 ± 5.09	50.64 ± 10.15	**	68.31 ± 12.68	54.03 ± 11.81	*
	1st stance leg ^e	[%BW]	108.92 ± 7.02	80.81 ± 16.71	***	104.93 ± 10.68	74.04 ± 15.7	***
	2nd stance leg ^f	[%BW]	103.45 ± 9.14	86.82 ± 16.41	***	102.75 ± 8.42	92.37 ± 18.58	n.s.

a: maximal forward GRF on the first stance leg;

b: maximal backward GRF on the second stance leg;

c: maximal forward GRF on the second stance leg;

d: maximal upward GRF on the first swing leg before swing;

e: maximal upward GRF on the first stance leg;

f: maximal upward GRF on the second stance leg.

n.s.: not significant.

*: p<0.05, **: p<0.01, ***: p<0.001.

Table 4. Distance between COG-WB and COP

		Comfortable speed condition			Maximal speed condition		
		YG	EG		YG	EG	
dx	[%BH]	5.07 ± 0.56	4.30 ± 1.10	n.s.	5.48 ± 1.03	4.56 ± 1.09	*
dy	[%BH]	6.68 ± 2.06	5.50 ± 1.73	n.s.	9.71 ± 9.59	7.50 ± 2.15	*
dz	[%BH]	53.9 ± 3.24	52.8 ± 3.30	n.s.	47.2 ± 3.77	49.9 ± 2.76	*

dx, y, z: components of distance between COG-WB and COP.

n.s.: not significant, *: p<0.05.

longer for EG than YG.

DISCUSSION

This study analyzed biomechanical STW characteristics between YG and EG. The time required did not differ significantly between the groups at comfortable and maximal speeds (Table 1). Maximal V_y of COG-T before the seat-off, and maximal V_z of COG-WB while standing, did not differ significantly between the groups. Mourey et al.¹²⁾ reported, in their STS study, that maximal forward velocity and maximal composite velocity of COG-WB during the seat-off were larger in YG than EG at both comfortable and maximal speeds. This study found no difference in the velocity of COG before the seat-off and while standing up between the groups because this study included subjects in EG who had better physical functions.

At the maximal speed condition, V_y of COG-WB at all analyzed times was faster for YG than EG (Table 2), although the required time from the

starting movement to the first heel contact didn't differ significantly between the groups. It therefore seems that the difference in the required time might become larger after the first heel contact. V_z of COG-WB at the first heel contact was significantly faster for YG than EG at the maximal speed. At this time YG continued standing up, while EG had already achieved an upright standing position. It seems that initiating gait before achieving an upright standing position was difficult for EG.

This study found many significant differences in GRFs between YG and EG. All components of GRFs which differed significantly between the groups showed a higher value for YG (Table 3). At a comfortable speed, although no significant differences were shown in the vertical and forward velocities of COG-WB and COG-T between the two groups (Table 2), the results do show significant differences in all vertical and forward-backward GRFs between them (Table 3). This inconsistency may have occurred because of quick and effective force generation of the leg, followed

by smooth force transmission to the COG. In previous studies, patients with Parkinson's disease stood up with GRF values lower than those of age-matched healthy adults, although the required time did not differ between the two groups¹⁵⁾. Tokumo et al.¹⁶⁾ reported that people who had had a stroke initiated their gait with forward-backward GRF value lower than healthy older adults, although their motion was adjusted and performed at the same speed. In this study, it seems that YG could perform the STW motion by extending their legs quickly.

In the relationship between COG-WB and COP at the first toe-off, COG-WB moved farther forward and to the first swing side in YG. In contrast, COG-WB moved farther upward in EG (Table 4). On gait initiation, COG-WB movement before the first toe-off was important for anticipatory postural control¹⁷⁾. If the speed of initiating gait is changed, the movement of COG-WB as a predictor of postural control is changed¹⁸⁾. So it is thought that EG can /do not have to move COG-WB forward, and their first swing side is farther. Forward and lateral COG-WB movement before toe-off makes the movement a progressive force. It can be said that YG have sufficient muscle power in their lower extremities to bear the progressive force, or that EG subjects may have learned an appropriate anticipatory postural control in which they move forward a shorter distance due to aging and declining physical function.

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