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Effects of Directional Change on Postural Adjustments during the Sit-to-walk Task

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Abstract. [Purpose] The purpose of this study was to clarify the effects of directional change on postural adjustments during the sit-to-walk (STW) task. [Subjects] Fifteen healthy young men participated in this study. [Methods] Subjects were required to stand up from a chair and walk toward a target. The first step was limited to the right limb only. Three conditions of target direction (straight, ipsilateral and contralateral) were set. For the ipsilateral and contralateral conditions, the target was placed at an angle 45° clockwise and 45° counterclockwise from straight ahead, respectively. Trials were recorded by a motion capture system and force plates. The forward momentum of the body, time of events, center of pressure (COP) and center of gravity (COG) displacement were measured and compared between conditions. [Results] In the contralateral condition, the fluidity index was significantly lower than that in the straight condition. In the contralateral condition, COP displacement toward the swing limb was larger than in the other conditions. [Conclusion] The present results indicate that a directional change during the STW task affects fluidity and postural adjustments. When the STW direction was changed to diagonal, the lateral component of postural control became more important.

Key words: Sit-to-walk, Fluidity, Postural control

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INTRODUCTION

Standing up from a chair and walking are basic parts of daily activities. These motions are frequently executed as a series of tasks. Sit-to-stand and gait have been studied and reported in various fields. However, studies that deal with these two tasks as sequential activities are limited. Standing up from a chair and starting to walk is referred to as the sit-to-walk (STW) task or rise-to-walk task. Concerning the STW task, Kerr[1, 2)] examined the STW task using a three-dimensional motion analysis system and ground reaction force plates. In their study, they defined the phases of the STW by the movement of center of gravity (COG) and ground reaction force. They showed that seat off and gait initiation (GI) are simultaneously executed. Magnan[3)] analyzed STW with body forward momentum and timing of events. They also showed that GI started before completion of standing and concluded that the STW task is a transitional activity. In other words, standing up and GI are not simply continually performed but are blended and performed at the same time. This is supported by the balance system. According to other studies using electromyograms, muscle strength, especially from the knee extensor, contributes to STW performance. This information added to our knowledge of the risk of falls in the elderly and suggested muscle strengthening as a preventative measure[4)]. In comparisons between younger adults and the elderly, the COG speeds in forward and vertical rising during STW are significantly slower in the elderly compared with younger adults[5)]. In the elderly, the progressive elements from the ground reaction force are decreased due to learned anticipatory postural control (which involves smaller forward movement because of aging and declining physical function). During STW and sit-to-stand, it has been often reported that gait initiation merges sequential component tasks. Only a few clinical studies based on patients have been reported. For example, stroke patients require more time for such tasks as compared with healthy subjects. For stroke or Parkinson's disease patients who have impaired coordination, STW is difficult to perform smoothly and requires more time[6, 7)]. These results come from analysis of the focused ground reaction force and relationship between the COG and center of pressure (COP).

Dion et al.[8)] defined the ability of an individual or strategy used by an individual with regard to performance of transitional activities (for example, a series of standing up and initiating gait) as "fluidity" or "fluid strategy." They developed an assessment scale for fluidity known as the Fluidity Index (FI) and Fluidity Scale (FS). With the FI and FS, they assessed the ability of hemiplegia patients and showed decreasing fluidity among such patients. These strategy assessments follow a task-oriented assessment model[9)] and bring with them the possibility to incorporate new concepts.

Strategy is chosen by considering body function and sur-

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rounding conditions[10]. However, when we assess a patient's strategy, we should set the conditions while taking into consideration possible influences. Previous studies of STW have been limited by the condition of a destination direction that is straight ahead. In day-to-day life, gait is initiated in not only the straight ahead condition but also in diagonal directions. At gait initiation, non-straight steps may represent 35–45% of all steps during the day[11]. During STW, a similar trend may be adopted. The direction of and side of the first limb swing are important. When the destination direction is to the right, and if the first swing leg is also on the right side, the first step is thrown straight. On the other hand, if the required direction is to the left, the first step limb and stance limb will cross. In other words, the target direction determines whether the ipsilateral or contralateral limb will make the first step. These two conditions require different functions that control the COG and COP to efficiently lead the body to the destination. The purpose of this study was to clarify the influence of changing the direction of STW by observing fluidity, COG, and COP trajectory.

SUBJECTS AND METHODS

The subjects were fifteen healthy young men (mean age 26.3 ± 4.5 years). Their heights and weights were 170.7 ± 6.7 cm and 66.5 ± 7.5 kg, respectively. None of the subjects had a disability that restricted performance of STW. This study was approved by the Ethics Committee of the Gunma University Faculty of Medicine. Each subject was informed of the purpose of this study, and they all gave their consent to participate in the study.

The STW conditions were based on Malouin's[12] study. The subjects were seated on a chair without a back support or armrests with a seat height standardized to 100% of leg length. The chair was set on two force plates, and one foot was placed on each of the force plates with a neutral width. The subjects were initially instructed to look forward, fold their arms on their chest, and remain in a stationary position for 10 seconds. After hearing an auditory cue, they were required to stand up and walk at a comfortable speed toward a target placed 2 m away. During STW, they were instructed to keep their arms folded. For all subjects and trials, the first swing limb side was limited to the right side. For the purpose of this study, three target direction conditions were set. For the straight condition, the target was set just in front of the subjects. For the ipsilateral condition, the target was set rotated 45° clockwise from straight ahead. In this condition, the target was placed to the right side of the subjects, ipsilateral to the side of the swing limb. For the contralateral condition, the target was set rotated 45°counterclockwise from straight ahead. In this condition, the swing leg was the contralateral side. The subjects practiced these tasks enough to be able to reproduce them smoothly and naturally. After practicing each condition, trials were recorded.

Each trial was recorded simultaneously by a digital video camera and a motion capture system (Vicon612) with 10 infrared cameras and 4 force plates (AMTI). The sampling frequency was 60 Hz. Reflective markers were attached to the acromion, greater trochanter, knee joint, lateral malleolus, and metatarsal head of the 5th toe as landmarks on both sides. Kinematic and kinetic data were filtered using a Butterworth low-pass filter with a cut-off frequency of 6 Hz. Coordinates of the COG were calculated from these markers by applying Dempster's 4 linked model[13].

As outcome measures, the body's forward momentum (mass × COG velocity) was used to assess the fluidity of the motor strategy. In a fluid motor strategy, the body forward momentum is maintained or slightly decreased after the first peak, whereas in a less fluid strategy the momentum drops after the peak. The degree of fluidity was calculated with the FI, which corresponds to the percent change in the body forward momentum (ratio of the bottom to the peak)[12]. A larger FI indicates more fluidity; conversely, a lower FI indicates less fluidity (separating standing up and GI). Several events in STW were analyzed including the onset of the ground reaction forces, the time of seat off, toe off, and the highest vertical position of COG after starting the task. As COP-related parameters, the mediolateral (ML) distance and time to the inflection point from a stationary position were measured. The inflection point was defined by the point of maximum lateral displacement or the slowest velocity of the COP movement. ML and anteroposterior (AP) distances of the COP to the COG projected on the ground were calculated at the time of seat off, toe off, and the maximum COP-COG distance. Each event's timing was standardized with the time to the highest vertical COG. ML distances were standardized with the width of the markers on the bilateral metatarsal heads of the 5th toe. AP distances were standardized to the distance of the lateral malleolus to the 5th metatarsal head.

Statistical analysis was performed using IBM SPSS Statistics 21. These variables were analyzed by a one-way repeated-measures ANOVA. Post hoc analyses were performed using Bonferroni corrections for multiple comparisons. The threshold of statistical significance was set at $p<0.05$.

RESULTS

The transition of the forward momentum of the body was the same as has previously been reported[8, 12]. Figure 1 shows two patterns of COP trajectories that were observed in this study. All trials were applied with these two patterns. Common movements were seen in both patterns: the COP moved slightly backward at the start of the task and then moved forward. During the forward movement phase, the pattern was distinguished. Regarding the swing limb direction pattern, the COP started moving toward the swing limb side and through the inflection point, and then it changed direction towards the stance limb. In the stance limb direction pattern, the COP moved immediately toward the stance limb. In the straight condition, the swing limb direction pattern was seen in the majority of subjects (n=12). In the contralateral condition, the swing limb direction pattern was observed in 14 subjects. On the other hand, in the ipsilateral condition, the stance limb direction pattern was seen in the majority of subjects (n=8). Figure 2 shows the ML transitions of the COG and COP. When subjects remained

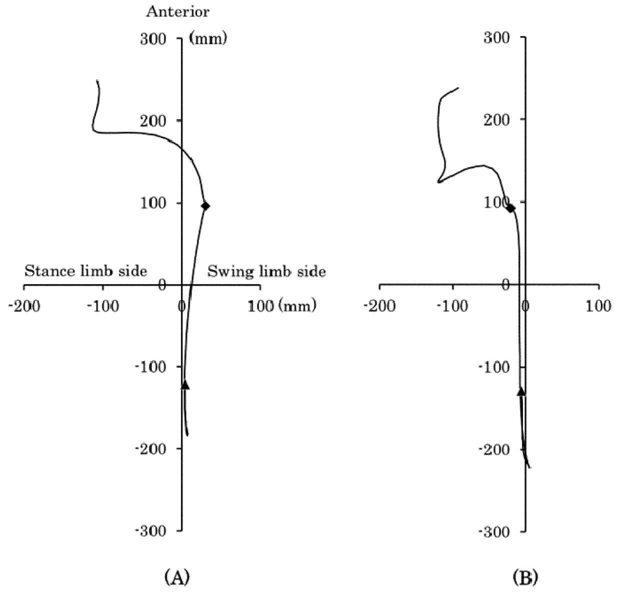

Fig. 1. Two patterns of center of pressure trajectories
(A) Swing limb direction pattern, (B) stance limb direction pattern
▲ Start
◆ Inflection point

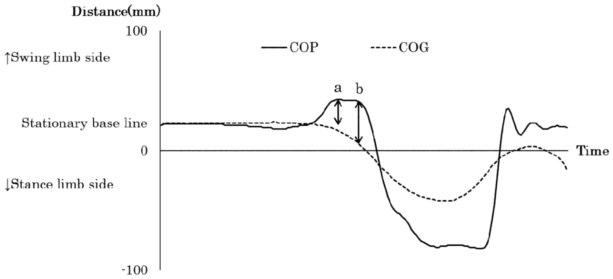

Fig. 2. Displacement of the center of pressure (COP) and center of gravity (COG)
a: COP ML displacement. Distance of the inflection point from a stationary baseline.
b: Maximum ML separation. Maximum distance between the COP and COG.

in the stationary position, the COG was on the COP. But once STW was initiated, ML movement of the COP stared, and this was not seen in the COG.

Table 1 shows the results of each measurement. There were no significant differences in peak value of the forward momentum of the body between the three conditions. However, regarding the bottom value, the contralateral condition was significantly lower than the straight condition ($p<0.01$), as was the FI value ($p<0.01$). Regarding the time of toe off, it occurred earlier in the ipsilateral condition than in the straight condition ($p<0.05$). With regards to the distance of ML COP displacement from the starting point to the inflection point, there were significant differences between conditions ($p<0.01$). In the contralateral condition, ML COP displacement was significantly larger than in the other conditions ($p<0.01$). In addition, there were significant differences in time to the inflection point between conditions ($p<0.01$). In the straight and contralateral conditions, the inflection point was reached after seat off, but in the ipsilateral condition, it was reached before seat off and significantly earlier than in the contralateral condition ($p<0.05$). At seat off, the COG was close to the stance limb side rather than the COP. After seat off, the COG and COP distance (COG-COP separation) at seat off differed significantly among conditions ($p<0.01$). In the contralateral condition, it was larger than in the other conditions ($p<0.01$). At toe off, in the straight and ipsilateral conditions, the COG was close to the swing limb side compared with the COP. In the ipsilateral condition, it was significantly larger than in the straight condition ($p<0.01$). On the other hand, in the contralateral condition, the COG was close to the stance limb side. This was different from the other two conditions. The maximum ML COG-COP separations also significantly differed among conditions ($p<0.01$). The contralateral condition had a larger separation than the other conditions ($p<0.01$). In the straight and contralateral conditions, the maximum separation appeared during seat off to toe off. But in the ipsilateral condition, it appeared before seat off. There were significant differences between all conditions ($p<0.01$). In sagittal measurements in the contralateral condition, COG-COP separation at toe off was significantly lower than in the straight condition ($p<0.05$).

DISCUSSION

The FI, the ratio of bottom to the peak, was about 60–70%, and fluidity was observed in each condition. But the contralateral condition brought about a decrease in FI as compared with the straight condition. This is thought to be a result of the strategy of taking the first step across the stance limb by swinging the limb. Analysis of the COP and COG trajectories during STW reveals the mechanisms and particularities of each type of movement.

A noteworthy phenomenon is ML movement of the COP. In most trials, the COP moved toward the swing limb side. This is also observed in the GI, and depends on inverse fluctuation. It is said that accelerations of the COP, according to the laws of mechanics, are proportional to the gap existing between the COP and COG[14, 15]. In the contralateral condition, this inverse fluctuation of COP displacement is increased. On the other hand, in the ipsilateral condition, the displacement decreased, and different patterns of movement of the COP towards the stance limb side were observed. This phenomenon is the same as that reported in Corbeil's[16] study, which analyzed the COP at GI. They found that when the target is changed to the contralateral direction, the COP ML displacement toward the swing limb becomes larger. On the other hand, in the ipsilateral direction, the COP ML displacement shortens, and in some trials, the COP moves toward the stance limb side.

When the swing and stance limb cross during the first step, the lateral components of postural adjustments increase. Compared with the straight condition, these postural adjustments induce a greater lateral acceleration of

Table 1. Comparison of the conditions

	Straight	Ipsilateral		Contralateral		Rep ANOVA
COG momentum (kg • m/s)						
Peak	36.1 ± 8.3	37.4 ± 5.3		35.6 ± 4.9		
Bottom	25.8 ± 7.0	23.8 ± 4.9		21.6 ± 5.0	a*	**
Fluidity index (%)	71.6 ± 14.2	64.3 ± 13.7		61.3 ± 15.0	a*	**
Time of events (%)						
Seat off	58.6 ± 4.4	57.2 ± 7.7		57.4 ± 4.1		
Toe off	89.2 ± 8.0	81.4 ± 9.6	b*	89.0 ± 11.4		*
Highest vertical position of the COG† (s)	1.3 ± 0.2	1.4 ± 0.3		1.3 ± 0.3		
Inflection point (%)						
Distance	2.9 ± 6.5	0.1 ± 5.2		10.7 ± 8.3	a**c**	**
Time	63.1 ± 8.0	51.5 ± 14.0		66.4 ± 11.9	c*	**
COP trajectory pattern						
Swing limb direction/stance limb direction	12/3	7/8		14/1		
COG-COP separations (%)						
Seat off ML	–5.1 ± 2.0	–0.9 ± 7.0		–12.2 ± 4.9	a**c**	**
AP	21.6 ± 22.6	–10.3 ± 10.5		–17.8 ± 4.9		
Toe off ML	15.4 ± 8.1	34.3 ± 18.0	b**	–2.1 ± 5.0	a**c**	**
AP	137.7 ± 11.1	91.4 ± 11.6		90.8 ± 6.7	a*	*
Maximum ML	–8.7 ± 3.3	–6.2 ± 9.1		–24.4 ± 7.8	a**c**	**
Time	64.3 ± 13.3	35.5 ± 20.6	b**	72.7 ± 10.6	a**c**	**
Maximum AP	128.4 ± 30.5	151.9 ± 48.1		129.5 ± 23.0		
Time	36.4 ± 5.1	34.3 ± 10.5		37.8 ± 6.1		

Values: mean ± SD, Rep ANOVA: repeated measures ANOVA, *: $p<0.05$, **: $p<0.01$
Post hoc tests
a*: significant difference versus straight ($p<0.05$) a**: significant difference versus straight ($p<0.01$)
b*: significant difference versus straight ($p<0.05$) b**: significant difference versus straight ($p<0.01$)
c*: significant difference versus ipsilateral ($p<0.05$) c**: significant difference versus ipsilateral ($p<0.01$)
† Complete trunk and lower limb extension, with the COG in the highest position
ML: mediolateral. ML distance was standardized with the distance of both 5th metatarsal heads
AP: anteroposterior. AP distance was standardized with the distance of lateral malleolus to the 5th metatarsal head

the COG toward the stance limb. This strategy ultimately leads to a reduced lateral acceleration of the COG toward the swing limb that is sufficient to orient the COG in the desired direction.

Conversely, on analysis of GI, in the ipsilateral condition, in order to control the COG movement toward the stance limb, lateral acceleration of the COG is initially reduced. Thus, when the swing limb is lifted and the COP shifts underneath the stance limb, the COG is redirected toward the desired direction of gait with a greater acceleration. In order to initiate gait in the desired direction, the lateral component plays an important role. These mechanisms could be adapted to STW.

Unlike GI, STW includes the sit-to-stand task. With STW, subjects have to control the COP and COG not only in terms of ML movement but also in terms of AP movement with simultaneous adjustment of the transforming base of support. This necessity makes control difficult and leads to exposure to more unstable conditions. For this reason, when elderly people (especially with fear of falling) or patients with Parkinson's disease attempt STW, the COP ML movements are small[7, 17, 18]. This means that subjects pay attention to stability: they complete the sit-to-stand task and then start the gait task. As a result, the entire task is performed with a non-fluid strategy. In the present study, healthy young adults could integrate sit-to-stand and GI with fluidity of movement. This was the result of appropriate anticipatory postural control[5]. But the contralateral condition that requires large ML control influenced the fluidity. Considering this, when the elderly or patients who have hemiplegia or mobility dysfunctions attempt this task, their results may be greatly influenced by these conditions. For example, it may be difficult for hemiplegia patients, and so in the contralateral condition, patients may use their paretic side as the stance limb. Because the stance limb in the contralateral condition requires more dynamic balance control.

Fluidity during STW involves an efficient strategy in terms of time and space, and occurs as a result of higher mobility. This study attempted to show the influence of changing the target direction during STW. Performing this task while changing direction in a clinical setting is a good way to assess a patient's mobility. It can also be a valuable task in therapy to increase locomotion if therapists are aware of the difficulty and ability needed to perform the task in each condition.

A limitation of this study is that the subjects were healthy young adult volunteers. Thus, how patients with laterality dysfunction would perform the STW in practice is only an inference. Trials with such patients could clarify their strategy and lead to more concrete applications in therapy. For clinical evaluation, a briefer assessment without equipment is needed. Malouin's FS12) was developed as a simple assessment scale. Modifying this assessment scale by changing the target directions could possibly produce a tool that can be used to assess the risk of falling.

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