Strategies Applied to Control Gait Initiation after Standing-up from a Seated Position

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Abstract:
In this study, we have investigated the combined task of sit-to-walk (STW) under different time constraints. STW can be viewed as gait initiation (GI) after/while rising from a seat (sit-to-stand: STS). Six healthy adults performed 100 STS and STW trials under different time constraints. Movements were initiated following a visual cue. Participants were instructed to change the final task from standing to walking or from walking to standing depending on a second visual cue which might be given after the first one. For all combined tasks including a GI component, it was observed that the anticipatory postural adjustment, which is a characteristic of GI from standing posture, was present after seat-off with some modifications. Comparison of different combined tasks with elementary tasks of STS and GI showed that, STW was not performed merely as a successive combination of two elementary tasks of STS and GI. Rather, some terminal characteristics of STS and some initial characteristics of GI were merged together. The merging scheme was to a large extent individual-dependent.

Key words: Sit-to-walk, gait initiation, combined task, anticipatory posture adjustment.

Introduction

Sit-to-walk (STW) is a combined task consisting of two elementary tasks of sit-to-stand (STS) and gait initiation (GI). Since these two tasks are different in nature, the Central Nervous System (CNS) has to apply sophisticated control strategies to provide a safe transition between them. Most researchers have studied gait initiation from a quiet standing posture [1]-[5]. Brenière *et al.* [1] have defined GI period to be the interval between onset of a backward and ipsilateral shift of centre of pressure (COP) towards the swing leg and the instant when the anterio-posterior (AP) velocity of centre of mass (COM) reaches its maximum value. Backward and ipsilateral shift of COP towards the swing leg causes at the same time a controlateral and forward movement of the COM towards the stance leg. In [1] the anticipatory postural adjustment (APA) phase has been defined as the time interval between

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onset of backward and ipsilateral shift of the COP, and heel-off of the swing leg. Brenière *et al.* [1] have shown that APA plays an important role in the creation of convenient conditions (*e.g.,* accelerating the COM) for progression. Their results show that both the progression velocity at the end of the first step and the acceleration of the COM at heel-off have significant covariation with the backward excursion of the COP during APA. There are also studies attempting to identify motor control programs and organization underlying GI [6]-[8]. On the other hand, there are numerous studies about STS transfer. Riley *et al.* [9] have defined three phases of the STS movement, which are flexion momentum phase, momentum transfer phase, and vertical extension phase. Pai and Rogers [10] have found that horizontal linear momentum in the AP direction remains almost constant under different ascent speeds. Based on this observation, they have concluded that the subjects might adopt a strategy of limiting the maximum horizontal linear momentum under different ascent speeds. Riley *et al.* [9] has also suggested that during STS, horizontal linear momentum is controlled in order to guarantee the stability of the movement after seat-off. Later Pai and Lee [11] have observed that maximum horizontal momentum increases significantly from the fast STS to the fast STS followed by a forward fall. That means the terminal constraints on STS can considerably affect the peak horizontal momentum of the COM and the corresponding propulsive impulse as well as the braking impulse that occurs after horizontal momentum reaches its maximum value. Magnan *et al*. [12] have reported that this braking impulse was still present during STW, but its magnitude was determined by the balance control strategy used by the subjects. They have observed that when the subject put priority to achieve first postural stability during transition phase, and then to initiate gait, the braking impulse was greater and the horizontal momentum was further reduced. They have concluded that the CNS overlaps the two tasks of STS and GI around seat-off to control the combined task of STW. However, Magnan *et al.* [12] did not record any data from GI for their participants or any data from STW under different time constraints. Hence, to develop a thorough understanding of the transition phase between STS and GI during STW, we have investigated sit-to-walk task under different time constraints and compared it with both STS and GI. To get a better understanding of the strategies applied to control the combined task of STW, we introduced some disturbances during the performance of the STW and STS. The chosen disturbance was altering the goal of the task. Participants were instructed to change the final task from standing to walking or from walking to standing depending on a visual cue which might be signaled after the subject began to perform the initially commanded task.

Protocols and Data

Six healthy adults have participated in this experiment. All subjects were asked to sit comfortably in a self-selected posture with upright back and arms crossed on their chest. The seat had no back and its height was adjusted for each subject to her/his knee height.

Participants were instructed to perform two tasks of STS and STW triggered by a visual command. In some trials, the initial light command changed at seat-off or 100 ms after the seat-off. Participants were told to perform the new task if the light command changes in between. Each subject performed 40 trials of STS and 40 trials of STW. In addition, they performed 5 trials in each condition when the light changed, including

STS to walk with the light change at seat-off (STSW) and light change at 100 ms after seat-off (STSWD), and STW to stand with light change at seat-off and 100 ms after seat-off (STWS and STWSD, respectively). For STWS and STWSD conditions, successful task performance was defined as standing without taking a step after seat-off. The sequence of trials was completely randomized. To reduce inter-subject variability, participants were asked to stand up as quickly as possible [10] and to initiate the gait always with the right leg. Each subject has also performed 10 trials of gait initiation which later were used as a group of control trials.

Seventeen active infrared diodes (IRED) were fixed on the following anatomical landmarks on both side of the body: 5th metatarsal, lateral malleolus, back heel, femur head, greater trochanter, iliac crest, clavicle, and ear lobe, and on xiphoid. The three-dimensional (3D) Cartesian coordinates of each diode have been recorded by three OPTOTRAK cameras. In addition, the seat reaction forces under buttocks and the ground reaction forces under each foot were collected. Kinematics and force-plate data were filtered by second order Butterworth filter.

From kinematic and kinetic data the AP and medio-lateral (ML) components of the whole body COP and 3D trajectories of COM were calculated. Horizontal (AP) and vertical linear momentum (HLM and VLM, respectively) of the whole body COM were also computed. For conditions including GI component (*e.g.*, STWS), important events were maximum ML deviation of COP to the right (MaxCOPz) and the corresponding time instant (TmaxCOP). *TmaxCOP is the beginning of the loading phase of the stance leg and the end of loading phase of the swing leg.* Polar coordinates of the COP-COM vector in the transversal plane (R, θ) were also calculated. COP-COM vector represents the magnitude and direction of COM acceleration [2].

One-way analysis of variances (ANOVA) for repeated measures with $\alpha = 0.05$ was used for statistical comparison between different mean values of different tasks (STS, GI, *etc.*).

Results

In sit-to-walk to stand (STWS and STWSD) trials, most of the participants failed to adjust their movement on time and had to take a step before stopping. Table 1 summarizes the information about successful and failed STWS and STWSD trails. In two cases of four successful STWSD, participant #6 finished the movement by using hip strategy to keep his balance [13] and thereby to avoid taking a step.

Table 1: Number of successful STWS and STWSD

	Number of successful STWS	Number of successful STWSD
SJ #1 to #4	1	0
SJ #5	4	1
SJ #6	5	4

Planar (ML versus AP) displacement of COP and COM for all conditions was investigated. Table 2 shows the polar coordinates of the COP-COM vector at TmaxCOP for all cases. Two types of planar displacement of COP for STW have been observed (figure 1-c and d). For participants #1 to #4 during STW, COP showed forward excursion after seat-off and during its shift towards the swing leg (figure 1-c). However, the ipsilateral shift of the COP before the loading phase of the stance leg has been observed constantly. On the other hand, for participants #5 and #6 in most of STW trials, COP moved backward during its ML excursion towards the swing leg (figure 1-d). Figure 1-a shows average planar displacement of COP and COM for successful STWS for participant #6. In this case, COP at the end of loading phase of the swing leg was in front of COM and thus, this participant could end his movement successfully. In other words the APA phase as the preparation phase before GI could be interrupted successfully. In unsuccessful STWS (figure 1-b), although COP at TmaxCOP was nearer to COM (see also table 2), but was not in front of COM and thus the participant could not brake his/her movement on time, and took a step before stopping. It was also observed that during STSW and STSWD, center of pressure at TmaxCOP moved more behind and to the right of COM when compared with COP during STW (see table 2).

Discussions

During STW for a group of the participants (#1 to #4), no backward excursion of COP after seat-off was observed (figure 1-c), although the loading and unloading of the swing leg (ipsilateral shift of the COP followed by its controlateral shift) before taking the first step was still present. This means that they gave priority to the continuation of the movement (*strategy 1*) during transition from STS to GI after seat-off. For other participants (#5 and #6) the backward displacement of the COP during its ML excursion was observed frequently (figure 1-d). This indicates that these subjects preferred mostly to adjust their posture after seat-off before they initiate the gait (*strategy 2*). This strategy can be interpreted as quasi-sequential performance of two elementary tasks of STS and GI. Table 2 indicates that θ_{STW} and R_{STW} have notably higher percentage of standard deviations ($\Delta\theta$ and ΔR, respectively) compared with θ_{GI} and R_{GI} (ΔR_{STW}=69.9%, ΔR_{GI}=24.3%, $\Delta\theta_{STW}$=154%, $\Delta\theta_{GI}$=20.5%). High variation in θ_{STW} and R_{STW} is due to different strategies used by our participants to perform the STW task whereas variations in θ_{GI} and R_{GI} are mainly as a result of differences in the participants' selected base of support, their body height, and their desired progression velocity. Comparing average maximum horizontal momentum for STS and STW for these two groups (#1-#4 and #5-#6) supports our inference about two strategies for performing STW. Average maximum horizontal momentum for participants #1 to #4 (MaxHM=48.1±1.94 Kgm/sec) was significantly higher than average maximum horizontal momentum for participants #5 and #6 (MaxHM=40.71±1.12 Kgm/sec). Average maximum horizontal momentum (over all participants) for STS was 40.26±11.71 Kgm/sec and was not significantly different from the maximum horizontal momentum of the second group of participants (#5 and #6). This means that these two subjects did not accelerate their body in the AP direction as much as the other four did. On the other hand, the analyzed data suggest that to perform STS to walk, participants accomplished to some extent first the originally instructed task of standing up and then initiated the gait. This observation proposes that there was less blending between two elementary tasks of STS and GI during STSW trials when compared with STW trials.

Conclusions

Our results indicate that the CNS uses a hybrid strategy to control the combined task of STW along with controlling body balance. This hybrid control strategy most probably consists of three essential regions. Movement begins in accordance with the beginning profile of the first task (STS) and ends/continues based on the second task (Walking). Between these two regions, there is a blending margin. Blending margin consists of the two final phases of the STS, i.e., momentum transfer and extension phases (after seat-off), and the anticipatory posture adjustment phase of GI. Our study shows that the blending margin is to a large extent individual-dependent. In other words, during STW the APA with some modifications (usually in the backward shift of the COP) began shortly after seat-off and during momentum transfer phase of STS (i.e., before maximum vertical momentum occurs). This study also indicates that "elementary" tasks like STS or GI are usually performed with less inter-individual differences than "combined" tasks such as STW. These differences become more pronounced when a typical task performance is interrupted by an external new demand or condition (*e.g.,* STS to Walk or STW to Stand).

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Table 2: Average values and standard deviations of polar coordinates of COP-COM vector (R and θ)

	STW	GI	STWS		STWSD		STSW	STSWD
			Failure	Success	Failure	Success		
R (cm)	8.14 (5.68)	11.6 (2.82)	7.66 (7.34)	4.94 (2.10)	6.58 (1.99)	9.69 (1.22)	12.65 (4.1)	12.9 (4.42)
(deg)	-24.1 (37.2)	-44.4 (9.1)	-0.6 (39.4)	23.2 (41.57)	-25.8 (21.2)	-21.8 (7.9)	-31.2 (10.3)	-32.4 (17.7)

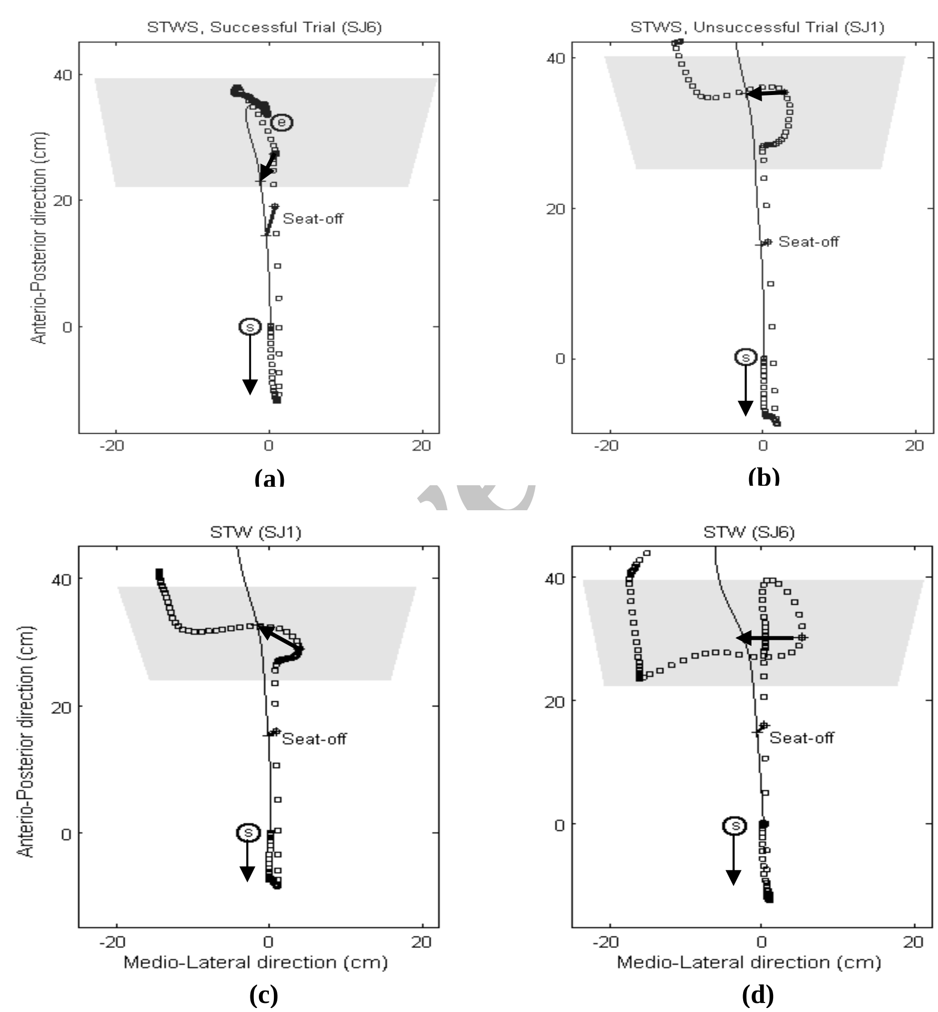

Figure 1: Planar displacement of the COP and COM for successful (a) and unsuccessful (b) STWS, and for two observed strategies of sit-to-walk (c and d). Gray regions on the figures show the base of support between two feet. Before seat-off there is a backward movement of the COP as shown on the figure. In all cases the COP-COM vector at TmaxCOP is shown by a bold arrow.