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ARTICLE

Ability of sit-to-stand with hands reflects neurological and functional impairments in ambulatory individuals with spinal cord injury

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Abstract

Study design A cross-sectional study.

Objectives To explore the need of upper limb contribution during sit-to-stand (STS) in ambulatory participants with spinal cord injury (SCI) and compare the lower limb loading during the sit-to-stand (LLL-STS) in those with SCI who performed the task with or without hands as compared to able-bodied individuals. In addition, the study assessed the correlation between the LLL-STS, and sensorimotor scores and functional ability in ambulatory participants with SCI.

Setting A tertiary rehabilitation center and community hospitals, Thailand.

Methods Forty-three participants with SCI who could perform STS with or without hands, and 10 able-bodied individuals were interviewed and assessed for their demographics, STS, and LLL-STS ability. Moreover, participants with SCI were assessed for SCI characteristics, sensorimotor scores, and functional ability relating to independent walking.

Results More than half of participants with SCI (58%) performed STS using hands. Their LLL-STS, sensorimotor, and functional ability were significantly lower than those with SCI who performed the task without hands. The LLL-STS of participants with SCI, particularly amount, was significantly associated with their sensorimotor scores and functional ability ($P < 0.05$).

Conclusions The findings indicated that those with marked lower limb muscle weakness and sensory impairments used their hands during STS. As such, the use of the hands during STS can be used as an indicator of neurological and functional impairments in ambulatory individuals with SCI.

Introduction

The sit-to-stand (STS) ability is at least equally crucial to other human mobility activities because rising from a sitting position is a prerequisite to conduct other daily activities, such as standing, transferring, and walking [1]. The task seems to be simple, but it is a complex and demanding motor activity that requires adequate joint torques to be developed in the joints of the lower extremities [2–4]. In addition, STS ability needs dynamic postural control to transfer their body weight from a stable three-point base of support with a low position of the center of mass to a two-point base of support with a high position of the center of mass [1, 5]. Thus, the task requires contribution from many-body systems such as lower extremity muscle strength, sensation, balance control, and psychological status [5–9]. With physical deterioration, therefore, some people such as

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those with neurological disorders or elderly perform the task using hands to reduce the task demands. It has been reported that using hands decreases the mean maximum hip moment during STS about 50% [3]. Alexander et al. [10] reported that the percentage of elderly who were unable to raise from a standard height chair decreased from 32 to 1% when hand use was allowed. Thus, ability of STS with hands is used as index for institutionalization, impaired activities in daily living, and impaired mobility in elderly [10].

Currently, there is little evidence regarding STS in ambulatory individuals with spinal cord injury (SCI). The researchers hypothesized that the sensorimotor deterioration following SCI affected their ability of body weight transfer or lower limb loading during sit-to-stand (LLL-STS), and a large proportion of them need the upper extremities to complete the task. Thus, the ability of STS with hands could be used to determine neurological and functional impairments of these individuals. Therefore, this study explored the need of ambulatory individuals with SCI to use their hands during STS, and compared LLL-STS among three groups of participants, including those with SCI who did and did not need their hands during STS as compared to able-bodied individuals. Furthermore, the study assessed the correlation of LLL-STS with sensorimotor scores and functional abilities of ambulatory participants with SCI. The findings would provide important clues for the incorporation of STS into rehabilitation practice for these individuals.

Methods

Participants

This cross-sectional study was conducted in independent ambulatory participants with SCI from a tertiary rehabilitation center and community hospitals in Thailand in the year 2016. The sample size was calculated to cover both objectives. For the comparison study, the data from a pilot study ($n = 10$) indicated that the mean difference of maximum LLL-STS between the groups was 5.75% of the body weight and standard deviation of 5.7, with set $\beta = 0.1$ and $\alpha = 0.05$, this objective required at least 17 participants with SCI/group. For correlation study using data from previous studies [11, 12], where $r = -0.63$, the power of the test $=$ 0.99 and $\alpha = 0.05$, this objective required at least 40 participants with SCI. Inclusion criteria were the ability to perform the STS independently with or without hands, and the ability to walk independently with or without a walking device for at least 10 m. Exclusion criteria were any signs and symptoms that might affect ambulatory and STS ability, i.e., pain in the musculoskeletal system with pain intensity of more than 5 out of 10 on a numeric pain rating scale, deformities of the spine and lower extremities, and other neurological or medical disorders. In addition, 10 able-bodied participants, gender and age matched (±5 years) with those of SCI, were invited to explain the finding on LLL-STS in relation to that of able-bodied individuals.

Able-bodied and SCI participants were interviewed for demographic data, including age, gender, and body mass index. Then, participants with SCI were evaluated for SCI characteristics (including etiologies, post-injury time, the level and severity of the injury), the sensorimotor scores according to the criteria from the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) [13], and the requirement of a walking device. Then the participants were assessed for their LLL-STS (the amount and duration) and ability relating to independent walking including walking speed, the timed up and go test (TUGT), and the five times sit-to-stand test (FTSST) [14–16]. Details of the tests are as follows.

STS ability and LLL-STS

This ability was assessed in both able-bodied and SCI participants using a digital load cell (Model L6E3-C, 200 kg-3G, with standard calibration method based on UKASLAB 14: 2006, the accuracy up to 0.1 kg and uncertainty of the measurement ±0.082 kg, patent application number 1701004050) [17]. Participants sat on an adjustable chair in a standard sitting position, with their back upright against the backrest of the chair, their feet placed flat on the digital load cell, and the arms on their sides or on the parallel bars. They were then instructed to stand up with the attempt to place most of their body weight on the lower extremities [14]. Then the data relating to LLL-STS (including minimum, first peak force, maximum, average, and duration) were recorded automatically by the digital load cell when the participants' back moved away from the backrest of the chair until they were in a steady standing position. The minimal force was the force reduction after lean forward during sitting that was recommended as an anticipatory postural adjustment into all strategies of STS movements. The first peak force was the greatest level of loading recorded that was followed by peak rebound force or the lowest force value after seat off. The maximum force was the highest loading that the participants could place their body weight onto their legs while standing. Normally, the first peak force and maximum force were the same point in able-bodied individuals, but they were different in some participants with SCI, especially in those who performed STS with hands. The average force referred to the average levels of loading from initiation to steady standing. The total time was the duration from the participants moved their back from the backrest of the chair until

Table 1 Demographics of able-bodied and SCI participants

Variable	Able-bodied participants ($n = 10$)	Participants with SCI	
		STS without hand ($n = 18$)	STS with hand ($n = 25$)
Age[a] (year)	46.3 ± 12.2 (37.6–55.0)	50.8 ± 8.8 (46.5–56.2)	50.4 ± 18.8 (41.8–56.9)
Weight[a] (kg)	62.6 ± 11.4 (54.5–70.7)	64.0 ± 11.2 (58.6–69.2)	57.7 ± 9.8 (53.7–61.7)
Height[a] (m)	1.6 ± 0.09 (1.6–1.7)	1.6 ± 0.09 (1.6–1.7)	1.6 ± 0.07 (1.6–1.7)
Body mass index[a] (kg/m ^{2})	23.9 ± 2.9 (21.8–26.0)	22.3 ± 4.4 (22.2–25.8)	20.8 ± 2.9 (20.4—23.3)
Post-injury time[a] (month)		70.9 ± 84.5 (34.4–107.4)	37.4 ± 67.1 (9.1–65.8)
Gender (male), *n*(%)	6(60)	12(67)	15(60)
Etiology (traumatic), *n*(%)		7(39)	8(32)
Level (tetraplegia), *n*(%)		3(17)	7(28)
Severity (AIS D), *n*(%)		18(100)	21(84)
Walking device use (yes), *n*(%)		5(28)	23(92)[b]
Walker, *n*(%)		1(6)	17(68)[b]
Crutches, *n*(%)		1(6)	4(16)
Cane, *n*(%)		3(16)	2(8)

STS sit-to-stand, *AIS* American Spinal Injury Association Impairment Scale.

Note: [a] The data are presented using mean ± SD (95% confidence interval)

[b] Indicated significant differences when analyzed using the χ^2-test

steady standing. Time to first peak force and time to maximum were the duration from initiation to the point indicated [18].

Gait speed

The findings reflect overall quality of gait [19, 20]. Participants walked along a 10 m walkway at a comfortable speed, and the time was recorded over the 4 m in the middle of the walkway in order to minimize acceleration and deceleration effects [15, 16]. The data were then converted to gait speed using a formula; gait speed = s/t, where s is distance (m) and t is time (s).

Timed up and go test

The test includes basic daily functions, such as standing up, walking, turning around, and sitting down. The outcomes reflect dynamic balance control, mobility, and risk of fall in ambulatory individuals with SCI [21, 22]. Participants stood up from a standard armrest chair, walked around a traffic cone that was located 3 m away from the front edge of the chair, and returned to sit down on the chair at the fastest and safest speed. The time was recorded from the command "go" until the participant's back touched the backrest of the chair [15, 16].

FTSST

The test quantifies functional lower extremity muscle strength that is necessitated for independent walking [9, 23, 24]. The participants sat on an armless chair, with their backs upright at 90° against the backrest of the chair, their feet placed flat on the floor at 10 cm behind the knees, and their arms at their sides. The time taken to complete five chair-rise cycles at a fastest and safe speed with or without a walking device was recorded for each participant [15, 16].

During the tests, participants were fastened a lightweight safety belt with an assessor being or walking alongside them to ensure their safety and the accuracy of the tests. The participants were allowed to use a walking device and take a period of rest between the trials and the tests, if needed. The average finding over the three trials for each test was reported.

Statistical analysis

The data were analyzed using SPSS® for Windows® version 17.0 (IBM Corporation, New York, USA, 2010). Descriptive statistics were used to explain demographics, SCI characteristics, and findings of the study. The Shapiro–Wilk test indicated that the data were normally distributed. Thus, the findings among the three groups were compared using the one-way analysis of variance for the continuous variables and the χ^2-test for categorical data. The post hoc analysis (Scheffe's test) and independent samples *t*-test were utilized to identify the differences of continuous data of every pairwise condition. The Pearson correlation coefficient (r) was applied to quantify the bivariate correlation between the LLL-STS, and the sensorimotor scores and functional ability of the participants. A value of correlation coefficient was considered as poor if it was ≤0.49, moderate

Table 2 The sensorimotor scores, functional ability, and LLL-STS of able-bodied and SCI participants

Variable		Able-bodied participants (n = 10)	Participants with SCI		P-value
			STS without hands ($n = 18$)	STS with hands ($n = 25$)	
Sensorimotor score	Upper extremity motor scores*		48.3 ± 4.5	45.1 ± 9.5	0.199
	Lower extremity motor scores*		41.2 ± 5.1	37.4 ± 7.9	0.001[a]
	Motor scores*		89.6 ± 6.2	79.3 ± 13.3	0.004[a]
	Sensory scores*		199.2 ± 20.2	179.1 ± 30.4	0.019[a]
Functional ability	Gait speed (m/s)		0.8 ± 0.2	0.3 ± 0.2	<0.001[a]
	Timed up and go test (s)		14.4 ± 8.1	40.8 ± 19.1	<0.001[a]
	Five time sit-to-stand test (s)		13.4 ± 2.7	19.7 ± 9.1	0.007[a]
LLL-STS					
Force during STS	Minimum (%)	14.5 ± 4.9	12.6 ± 3.1	15.4 ± 5.4	0.152
	Maximum (%)	100.8 ± 1.7	104.1 ± 3.5	97.7 ± 7.0 ^{W}	0.001[b]
	Average (%)	63.4 ± 7.8	66.5 ± 7.4	64.9 ± 10.0	0.739
	First peak force (%)	100.8 ± 1.7	104.1 ± 3.6	89.4 ± 14.8^{A,W}	<0.001[b]
Time during STS	Total time (s)	2.0 ± 0.2	2.1 ± 0.3	2.6 ± 0.7 ^{A,W}	0.002[b]
	Time to maximum force (s)	1.1 ± 0.1	1.1 ± 0.2	2.1 ± 0.9 ^{A,W}	<0.001[b]
	Time to first peak force (s)	1.1 ± 0.1	1.2 ± 0.3	1.3 ± 0.5	0.344

Superscripts indicate the group(s) with significant differences from the indicated groups where ^{A}indicated able-bodied participants, ^{W}indicated participants with SCI who performed STS without hands

STS sit-to-stand

Note: The data are presented using mean ± SD

* The data were assessed according to the International Standards for Neurological Classification of Spinal Cord Injury (ISNCSCI) with the total upper extremity motor scores of 50, lower extremity motor scores of 50, motor scores of 100, and sensory scores of 224

[a] Indicated significant difference between the groups. Data were analyzed using the independent *t*-test

[b] Indicated significant difference among the three groups. Data were analyzed using the one-way ANOVA, and every pairwise comparison was analyzed using the Scheffe's test

if between 0.50 and 0.69, and excellent if ≥0.70 [25]. The level of significant differences was set at $P < 0.05$.

Statement of ethics

All applicable institutional and governmental regulations concerning the ethical use of human volunteers were followed during the course of this research (HE581361, ClinicalTrial.gov ID: NCT02913911).

Results

Fifty-three participants completed the study, and 10 of them were able-bodied individuals. Most of them were middle-aged males with normal body mass index. There were no significant difference between able-bodied and SCI participants (Table 1). Most of participants with SCI had incomplete paraplegia (76%), with mild lesion severity (AIS D, 91%), and used a walking device (65%, Table 1).

All able-bodied participants (100%) could stand independently without using hands, whereas more than half of ambulatory participants with SCI ($n = 25$, 58%) needed their hands while standing up, and most of them (92%) used a walking device on a daily basis (Table 1). Their lower limb motor scores, sensory scores, and functional ability were significantly lower than those who stood up without hands ($P < 0.05$, Table 2). Figure 1 presents an example of amount (y axis) and duration (x axis) of LLL-STS in able-bodied ($n = 1$) and SCI participants who performed STS with ($n = 1$) and without hands ($n = 1$). Each participant performed the task for three trials, and each line represented the LLL-STS of the participants in each trial. The findings demonstrated that the first peak force and maximal LLL-STS of participants with SCI who performed the task using hands were significantly lower than those who did not use hands ($P < 0.005$, Table 2 and Fig. 1). These participants also took significantly longer time to stand up and to increase LLL-STS to the maximum levels as compared to the time taken by the other groups ($P < 0.005$, Table 2 and

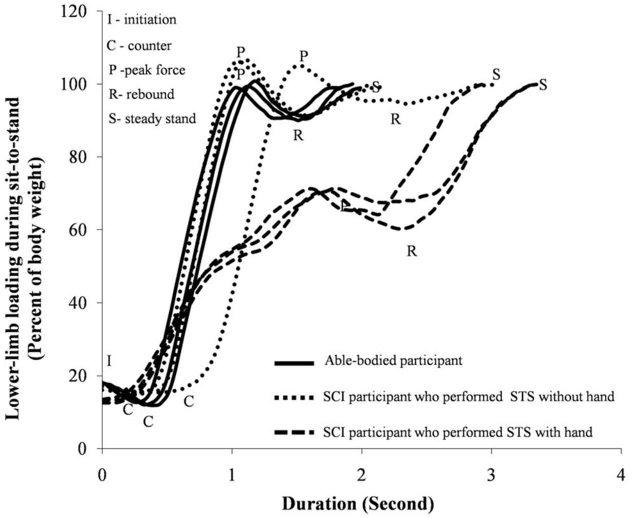

Fig. 1 Amount (y axis) and duration (x axis) of lower limb loading during sit-to-stand (STS) in able-bodied participant ($n = 1$) and participants with spinal cord injury who performed STS with ($n = 1$) or without hands ($n = 1$). Each participant performed the task for three trials and each line represents their ability in each trial

Fig. 1). In contrast, the LLL-STS of participants with SCI who did not use their hands was similar to that of able-bodied individuals ($P > 0.05$, Table 2 and Fig. 1). The differences between these participants were noticeable only for the consistency of the LLL-STS patterns among the trials, where the patterns of LLL-STS of able-bodied participant were rather consistent, whereas those of SCI participant showed some deviation among the trials (Fig. 1). The findings further demonstrated that the LLL-STS, particularly the maximum and first peak force, of ambulatory participants with SCI was significantly correlated to their sensorimotor scores and functional ability ($P < 0.05$, Table 3).

Discussion

This study investigated the need of upper limb contribution during STS, and compared the amount and duration of LLL-STS of ambulatory participants with SCI who performed the task with or without hands as compared to able-bodied individuals. Moreover, the study assessed its correlation with the sensorimotor scores and functional ability of participants with SCI. The findings indicated that more than half of participants with SCI needed their upper extremities while standing up. Their LLL-STS, sensorimotor scores, and functional ability were significantly lower than the other groups (Table 2 and Fig. 1), whereas the data of participants with SCI who stood up without hands were similar to those of able-bodied individuals, except the consistency of the patterns (Fig. 1). The duration and, in particular, amount of LLL-STS significantly associated with the sensorimotor scores and functional ability of the participants ($P < 0.05$, Table 3).

Ability of independent STS is very demanding that requires adequate motor activity, joint torques, and dynamic postural control to complete the task. With the reduction of lower limb motor scores, sensory scores, and functional ability, the participants needed contribution from the upper extremities to carry out the task (Table 2). The findings were coherent with a previous study that the amount of LLL-STS was directly associated with the amplitude of extensor muscle activation of the lower limbs [2]. Arborelius et al. [3] also reported that performing STS using hands reduced the mean maximum hip moment of elderly about 50%. Eriksrud and Bohannon [9] further indicated that the ability to perform an STS movement without hands increased contribution of knee extension force, compared to what could be achieved using hands. Aside from motor scores, sensory information is also important in determining the level of force generation and enables the continuous modification of motor behavior [26, 27]. With sensory reduction, the participants needed contribution of the upper limbs to supplementary control a movement while standing up ($P < 0.05$, Table 2). Lord et al. [8] also found that two sensory measures, lower limb proprioception and tactile sensitivity, augmented STS performance in the elderly. Although the patterns of LLL-STS of participants with SCI who performed the task without hands were similar to those of able-bodied individuals, the sensorimotor deterioration (Table 2) distorted their muscular endurance and ability of movement control. Thus, their LLL-STS patterns were inconsistent among the trials (Fig. 1). These findings may also explain the significant correlation of LLL-STS and sensorimotor scores of the participants (Table 3).

To increase the amount of LLL-STS within a short time, the participants need to adequately control the body center of mass from a stable and large base of support to a less stable and smaller base of support postures [1]. Such tasks require the ability of dynamic postural control, functional lower extremity motor strength, and sensorimotor scores that are also necessary for ability of walking in a good manner [9, 27]. Therefore, the LLL-STS showed significant correlation to the data of the gait speed, TUGT and FTSST (Table 3). However, the findings on duration of LLL-STS might be confounded by upper limb involvement during performing the task. Thus, they showed no clear correlation with sensorimotor scores of the participants (Table 3). Furthermore, the non-correlation between the duration of LLL-STS and data of the FTSST may reflect the different focuses of both tests ($P > 0.05$, Table 3). During the LLL-STS assessments, participants attempted to place most of their body weight on the lower limbs. In contrast, the FTSST required the participants to complete the five chair-rise cycles in the fastest and safest manner as possible, with

Table 3 The correlation between ability of LLL-STS and sensorimotor scores and functional ability of ambulatory participants with SCI

Variable	Sensorimotor score				Functional ability		
	UE motor scores	LE motor scores	Motor scores	Sensation scores	Gait speed	TUGT	FTSST
LLL-STS (%)							
Minimum (%)	−0.320*	−0.275	−0.375*	−0.284	−0.302*	0.197	0.321*
Average (%)	0.423*	0.188	0.389*	0.221	0.172	–0.227	–0.111
Maximum (%)	0.433*	0.339*	0.487*	0.509**	0.378*	–0.514**	–0.375*
First peak force (%)	0.209	0.495*	0.436*	0.541**	0.522**	−0.759**	−0.479*
Time (s)							
Total time (s)	0.125	0.020	0.069	−0.181	−0.438*	0.462*	0.167
Time to maximum (s)	0.050	−0.209	−0.094	−0.347*	−0.492*	0.602**	0.186
Time to first peak force (s)	−0.049	−0.005	−0.035	−0.210	−0.198	0.203	0.113

UE upper extremity, *LE* lower extremity, *TUGT* timed up and go test, *FTSST* five times sit-to-stand test

Note: The data are analyzed using the Pearson correlation coefficients.

*Indicate significant correlation with the P value < 0.05, and ** for the P value < 0.001

or without using hands. This assumption may also explain the moderate correlation between the FTSST and the muscle strength test in ambulatory individuals with SCI, as found in a previous report ($r = -0.630$, $P < 0.05$) [11].

Many studies used STS as an important task for rehabilitation training, assessments, and index of disability in many groups of participants [5, 10, 24]. Findings of the current study also suggest the use of STS with hands as an indicator for neurological and functional impairments in ambulatory participants with SCI. Moreover, the LLL-STS may be used to screen and monitor levels of independence of these individuals. For treatments, strategies to promote LLL-STS, such as the utility of external feedback relating to amount of LLL-STS, may promote levels of independence of these individuals. Nonetheless, the data were derived from participants with rather good functional ability, and cross-sectionally gathered. Thus, they may limit the generalization to a group with similar characteristics and cannot indicate causal relationship of the findings. In addition, levels of correlation ranged from poor to good that may be influenced by many factors such as upper limb involvement, muscle tone, muscle length, proprioceptive sensation, and psychological status of the participants. Nevertheless, the levels of correlation found in this study were higher than that found in a previous report in elderly populations [8]. A further study that recruits participants with various characteristics with the incorporation of these factors and assesses the effects of LLL-STS in rehabilitation practice would clearly confirm the clinical implication of LLL-STS in ambulatory individuals with SCI.

Data archiving

All relevant data are within this manuscript and raw data are archived by the authors.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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