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Body Sway and Muscle Activity during Assisted One-and Two-leg Stances in the Elderly

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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ABSTRACT

One-leg stance (OLS) training is recommended to prevent falls in elderly people. However, most elderly have difficulty in performing OLS for an extended period of time. Hence they need to use hand help when performing OLS training. The effects of hand help on body sway and leg muscle activity during OLS have been not been adequately investigated. This study aimed to compare the body sway and leg muscle activity during a two-leg stance (TLS) and OLS with front and lateral hand helps. Eleven elderly adults who were unable to perform OLS for 1 min (mean age, 79.6±5.3 years) participated in this study. Subjects wore electrodes on the gastrocnemius medialis, soleus, and tibialis anterior muscles of the supporting leg during TLS test, and one-leg stance with front support (OLS–FS) and lateral support (OLS–LS) for 1 min on a stabilometer. Muscle activity (mean %RMS and maximum %RMS) and body sway (total path length and X and Y axes path length) in the first, middle, and last periods were calculated and the differences among time periods (factor 1) and test methods (factor 2) were examined. All muscle activity and body sway variables showed significantly greater values during OLS–FS than during TLS. Gastrocnemius medialis and soleus muscle activity and Y axis path length during OLS–LS were significantly greater than during TLS, in a part of three time periods. Tibialis anterior muscle activity and X axis path lengths were

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significantly smaller during OLS–LS than during OLS–FS. In conclusion, regardless of hand help position, activity of the gastrocnemius medialis and soleus muscles during OLS with hand help is greater than during TLS. Tibialis anterior muscles activity and body sway in the left–right direction are greater during OLS–FS than during TLS and OLS–LS.

Keywords: Balance; elderly; electromyography; postural sway.

1. INTRODUCTION

One-leg stance (OLS) training is used to prevent falls and locomotive syndrome in the elderly [1,2]. This is a very simple training method in which the person stands on one leg for 1 min three times a day. OLS training is very practical and accessible because it does not require a specific place or time, and it is free and can be easily performed by most people. OLS training using a hand as support is recommended for the safety of elderly people who cannot perform OLS or those who have poor balance [1]. Lightly resting one's hand on a desk or a wall can stabilize body sway while standing [3-5].

During OLS training, individuals must support their entire body weight with only one leg, which is a narrow supporting base. Hence, it is safe to assume that leg strength and balance ability are required, and the benefits of training depend on exertion ability. In other words, reduction of the burden on the leg during OLS using one's hand (hand help method) for balance may also reduce the training benefits. There are several rules about the hand help method during OLS. In the Locomotive Syndrome Pamphlet 2013 [1], the following instructions are described: "If you require something to lean on, carefully place your hands or fingers on a table. You can use either one or both hands."

Sakamoto et al. [6] stated that it is not necessary that people perform OLS without hand help and recommended a method in which elderly patients place one or both hands on parallel bars at their right and left sides. Differences in hand help position may also affect body sway during OLS. Bove et al. [7] examined body sway changes using light touch (LT) in the front or lateral directions during standing, whereas anteroposterior or lateral body sway was induced via vibration to the back or lateral neck muscles. They reported that when using LT in the front direction, anteroposterior body sway markedly decreased, and when using LT in the lateral direction, lateral body sway markedly decreased.

In addition, Rabin et al. [8] examined the change in body sway during tandem stance using LT and reported that hand help toward the direction of a short support base notably enhanced postural stability. From these findings, it can be concluded that body sway during OLS depends on the position of hand help. Hence, hand position should be taken into consideration when performing OLS training.

This study aimed to compare body sway and leg muscle activity during two-leg stance and OLS with front and lateral hand help in elderly people who were unable to perform OLS for 1 min.

2. MATERIALS AND METHODS

2.1 Subjects

Eleven elderly adults who could not perform OLS for 1 min (n = 11; mean age, 79.6±5.3 years; mean height, 154.2±9.9 cm; mean weight, 53.9±9.3 kg) participated in this study. Their mean OLS time was 18.5±14.5 s (maximum 41.1 s). All subjects were able to independently perform activities of daily living and did not have any serious leg disorders. Based on the dominant leg survey reported by Demura et al. [9], the right leg was assumed to be the dominant leg in all subjects. The aim and procedures of this study were explained to all subjects, and informed written consent was obtained from them. This study was approved by the Ethics Committee on Human Experimentation of the Faculty of Human Science, Kanazawa University (2012-04).

2.2 Measurement Method

All subjects wore electrodes on the gastrocnemius medialis, soleus, and tibialis anterior muscles of the supporting leg and performed a two-leg stance (TLS), a one-leg stance with front support (OLS–FS), and lateral support (OLS–LS) for 1 min (one trial each). Electromyography (EMG) signals and body sway during each test were recorded. The order of the tests was random. To normalize EMG signals, the muscle activities during maximum voluntarily isometric contraction during plantarflexion and dorsiflexion were measured using surface EMG after each test.

2.2.1 TLS tests

Subjects stood on the stabilometer under the following conditions: eyes open, looking forward, with upper limbs at the sides of the body. After the start signal, subjects were instructed not to move, and 5 s later, a 1-min measurement of the center of pressure (COP) path and EMG signals was initiated.

2.2.2 OLS using one hand as a help (OLS–FS and OLS–LS tests)

Subjects assumed the same posture as for the TLS test. According to tester's instructions, subjects placed a hand on a table, which was set forward (OLS–FS) or sideward (OLS–LS) of their supporting leg. The height of the button was adjusted according to their height and arm length. After the start signal, subjects placed a hand on the table, flexed one knee at 90°, and stood with only one supporting leg. We measured COP and EMG signals for 60 s, after 5 s from the start signal. Taking the burden of the OLS tests on the elderly body into consideration, each test was conducted only once. The order of the tests was random. If the lifted leg touched the floor or the supporting leg or if the supporting leg moved from the start position, the trial was regarded as void.

2.2.3 Maximum voluntary isometric contraction

The subjects sat on the floor with legs extended and back against the wall. The tester held the subject's instep (during plantarflexion) or the upper part of the sole (during dorsiflexion) with his/her hands. Subjects were then asked to perform the maximum voluntary isometric contraction during plantarflexion or dorsiflexion for 5 s. During both measurements, EMG signals were also recorded. Each measurement was performed three times. Root mean square values (RMS) were calculated for each trial, and the maximum value was used as the representative value.

2.3 Surface EMG

For all tests, surface EMG was measured using a multichannel telemetry system (Nihon Kohden, Tokyo, Japan) with a band pass filter of 20–500 Hz and a sampling frequency of 1000 Hz. A stable posture is mainly maintained by the activity of the ankle when maintaining a static standing position, and leg muscle groups related to plantarflexion and dorsiflexion are activated. Although many muscles are involved in posture control in addition to the above stated muscle groups during one-leg standing, in this study, we selected the gastrocnemius medialis, soleus, and tibialis anterior muscles as the target muscles as these are assumed to be the most active muscles during one-leg standing. Measured EMG was translated into a 1-s RMS every 0.1 s.

2.4 Body Sway

Body sway was measured by a stabilometer (Gravicorder GP-5000; Anima Co., Ltd., Tokyo, Japan). This device comprises three vertical load cells that translate the action center point of vertical loads to COP and import this data to a personal computer through an analog-to-digital converter. In this study, the COP path was recorded with a sampling rate of 20 Hz.

2.5 Evaluation Variables

2.5.1 Muscle activity variables (mean %RMS and maximum %RMS)

EMG data were divided at 20-s intervals into first, middle, and last periods. Mean and maximum RMS was calculated for each period and divided by the maximum RMS during maximum voluntary isometric contraction during plantarflexion or dorsiflexion. The calculated values were used as the mean and maximum %RMS.

2.5.2 Body sway variables (X and Y axes path lengths and total path length)

In this study, path lengths in the X and Y axes and the total path length, which are typical and reliable body sway variables [10], were calculated for each period. These variables can assess body sway on the coronal and sagittal planes and the overall sway, respectively.

2.6 Statistical Analysis

Muscle activity (maximum %RMS and mean %RMS) and body sway variables (X and Y axes path lengths and total path length) calculated for each time period were used as dependent variables, and test methods (TLS, OLS–FS, and OLS–LS) and time periods (0–20 s, 20–40 s, and 40–60 s) were used as independent variables. A two-way repeated measures analysis of variance (test methods × time periods) was used to examine differences among the means of each variable. Greenhouse-

Geisser corrections were applied to significant F ratios that did not meet Mauchly's sphericity assumption. Tukey's HSD test was used for multiple comparisons if a significant interaction or main effect was found. The significance level was set at $p < 0.05$.

3. RESULTS AND DISCUSSION

Table 1 shows the basic statistics for the mean %RMS in each test and the results of the two-way ANOVA. A significant interaction was observed for the tibialis anterior muscle, and the post hoc analysis showed that muscle activity was greater during OLS–FS than during TLS for all time periods. In addition, muscle activity during OLS–LS was not significantly different than that during OLS–FS and TLS in any time period. Muscle activity during the first period was greater than that during the last period during OLS–LS. A significant main effect was found for the test method factor with regard to the gastrocnemius medialis and soleus muscles. The post hoc analysis showed that gastrocnemius medialis muscle activity was greater during OLS–FS than during TLS in the first period and greater during OLS–FS than during OLS–LS and TLS in the middle and last periods. In addition, the soleus muscle means were larger for OLS–FS and OLS–LS than for TLS for all time periods.

Table 2 shows the basic statistics for the maximum %RMS in each test and the results of the two-way ANOVA. A significant main effect was found with regard to the test method factor for all muscles. The post hoc analysis showed that the tibialis anterior muscle activity was greater during OLS–FS than during TLS in the first period and greater during OLS–FS than during OLS–LS and TLS in the middle and last periods. In addition, gastrocnemius medialis muscle activity was greater during OLS–FS than during TLS in the first period and greater during OLS–FS and OLS–LS than during TLS for the middle and last periods. The soleus muscle activity was greater during OLS–FS than during TLS for all time periods.

Table 3 shows the basic statistics for body sway variables in each test and the results of the two-way ANOVA. A significant interaction was observed for the X axis path length, and the post hoc analysis showed that the mean path length was greater during OLS–FS than during OLS–LS and TLS in all time periods. No significant differences were observed between OLS–LS and TLS. Moreover, the mean path length was greater in the first period than in the middle and last periods during OLS–FS. Total path length showed a significant main effect with regard to both factors (test methods and time periods), and the mean was greater during OLS–FS than during TLS. However, no significant difference was observed between time periods. Y axis path lengths showed a significant main effect with regard to the test method factor only, and the post hoc analysis showed that the mean path length was greater during OLS–FS and OLS–LS than during TLS in the first period and larger during OLS–FS than during TLS in the middle and last periods.

3.1 Discussion

Elderly people who cannot perform OLS entirely or those who can perform it only for 1 min may need hand help during OLS training. The hand help method enables them to perform OLS for 1 min; however, it is important to consider that a reduction in the burden imposed on the leg caused by hand help may reduce training benefits. In this study, we compared leg muscle activity and body sway during TLS, OLS–FS, and OLS–LS. All body sway variables showed greater path length values during OLS–FS than during TLS. On the other hand, only the Y axis path length was greater during OLS–LS than during TLS in the initial period. In addition, the X axis path length was greater during OLS–FS than during OLS–LS.

A base of support during OLS is smaller in the coronal plane because of the elongated shape of the human foot. Therefore, people show poor stability in the left–right direction when performing OLS [11]. Posture during OLS using hand help stabilizes the body because haptic cues are available, and the supporting base increases in the direction of where the hand is placed. In particular, when a subject places a hand in the direction of the small supporting base, posture notably stabilizes [8]. During OLS–FS, the subject places a hand in front of the body, but the base of support in the front–back is relatively large during OLS. Hence, we conclude that hand help during OLS–FS contributes to a small extension of the supporting base in the front–back direction, but does very little to stabilize body sway in the left–right direction. In contrast, because OLS–LS was assisted by hand help in the left–right direction, we believe that this extended to a supporting base in the left–right direction and notably enhanced postural stability.

Table 1. Basic statistics of mean %RMS of each muscle in each time period and each test and the result of two-way ANOVA

											n = 11
Tibialis anterior muscle	**Time unit**							**F value**	**P value**		**Post hoc Tukey's HSD**
	0–20 s		**20–40 s**		**40–60 s**						
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**					
TLS	5.0%	2.3%	5.3%	3.1%	4.6%	2.3%	F1	16.790	0.00	*	All time units: OLS–FH > TLS
OLS–FH	22.3%	11.4%	24.7%	11.8%	23.2%	12.9%	F2	1.849	0.18		OLS–LH: 0-20 s > 40–60 s
OLS–LH	15.0%	9.3%	12.3%	10.7%	10.6%	7.8%	F3	2.917	0.03	*	
Gastrocnemial muscle	**Time unit**							**F value**	**P value**		Post hoc Tukey's HSD
	0–20 s		**20–40 s**		**40–60 s**						
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**					
TLS	8.9%	3.6%	9.0%	3.7%	8.9%	3.7%	F1	21.527	0.00	*	0–20 s: OLS–FH > TLS
OLS–FH	26.2%	9.9%	25.3%	10.1%	25.6%	9.0%	F2	0.343	0.71		20–40 s, 40–60 s:
OLS–LH	20.1%	7.9%	21.2%	9.6%	22.2%	10.0%	F3	1.348	0.27		OLS–FH, OLS–LH > TLS
Soleus muscle	**Time unit**							**F value**	**P value**		Post hoc Tukey's HSD
	0–20 s		**20–40 s**		**40–60 s**						
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**					
TLS	11.0%	5.3%	11.0%	5.1%	11.1%	5.1%	F1	33.308	0.00	*	All time units:
OLS–FH	30.8%	9.4%	29.6%	6.9%	29.2%	7.3%	F2	0.399	0.68		OLS–FH, OLS–LH > TLS
OLS–LH	23.3%	5.2%	23.4%	5.2%	23.2%	4.6%	F3	0.645	0.63		

*Note. *: $p < 0.05$; F1: standing posture; F2: time unit; F3: interaction; TLS: two legs stance; OLS–FH: one leg stance with front support; OLS–LH: one leg stance with lateral support*

Table 2. Basic statistics of maximum %RMS of each muscle in each time period and each test and the result of two-way ANOVA

											n = 11
Tibialis anterior muscle	**Time unit**							**F value**	**P value**		Post hoc Tukey's HSD
	0–20 s		**20–40 s**		**40–60 s**						
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**					
TLS	6.7%	3.0%	7.0%	3.9%	7.2%	6.0%	F1	29.358	0.00	*	0–20 s: OLS–FH > TLS
OLS–FH	37.3%	16.5%	44.0%	17.2%	40.8%	21.7%	F2	0.223	0.80		20–40 s, 40–60 s:
OLS–LH	25.2%	14.2%	20.7%	14.8%	20.2%	13.0%	F3	1.621	0.19		OLS–FH > OLS–LH, TLS
Gastrocnemial muscle	**Time unit**							**F value**	**P value**		Post hoc Tukey's HSD
	0–20 s		**20–40 s**		**40–60 s**						
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**					
TLS	12.5%	5.8%	11.6%	4.3%	11.9%	6.2%	F1	20.860	0.00	*	0–20 s: OLS–FH > TLS
OLS–FH	35.7%	14.3%	34.5%	12.9%	34.5%	13.5%	F2	0.043	0.96		20–40 s, 40–60 s:
OLS–LH	28.6%	12.2%	30.0%	11.8%	29.9%	13.6%	F3	0.868	0.49		OLS–FH, OLS–LH > TLS
Soleus muscle	**Time unit**							**F value**	**P value**		Post hoc Tukey's HSD
	0–20 s		**20–40 s**		**40–60 s**						
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**					
TLS	12.3%	5.4%	12.2%	5.5%	14.8%	10.8%	F1	26.122	0.00	*	All time units: OLS–FH > TLS
OLS–FH	45.1%	16.5%	50.2%	22.1%	43.3%	14.1%	F2	0.714	0.50		
OLS–LH	30.5%	8.1%	30.5%	9.0%	33.5%	12.7%	F3	2.079	0.10		

*Note. *: $p < 0.05$; F1: standing posture; F2: time unit; F3: interaction; TLS: two legs stance; OLS–FH: one leg stance with front support; OLS–LH: one leg stance with lateral support*

Table 3. Basic statistics of COP path length in each time period and each test and the result of two-way ANOVA

											n = 11
Total path length (cm)	**Time unit**							**F value**	**P value**		**Post hoc Tukey's HSD**
	0–20 s		**20–40 s**		**40–60s**						
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**					
TLS	20.1	5.8	20.7	5.6	19.8	5.6	F1	21.085	0.00	*	All time units: OLS–FH > TLS
OLS–FH	74.2	42.8	63.3	23.0	62.4	29.3	F2	3.884	0.04	*	
OLS–LH	48.1	28.5	41.0	21.0	38.7	16.0	F3	2.102	0.10		
X axis path length (cm)	**Time unit**							**F value**	**P value**		Post hoc Tukey's HSD
	0–20 s		**20–40 s**		**40–60 s**						
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**					
TLS	10.0	2.2	11.1	3.5	10.7	4.1	F1	37.250	0.00	*	All time units:
OLS–FH	47.4	25.0	39.8	12.9	37.1	13.1	F2	4.383	0.03	*	OLS–FH > OLS–LH, TLS
OLS–LH	17.8	13.5	14.6	8.8	12.8	6.1	F3	3.564	0.01	*	OLS–FH: 0–20 s > 20–40 s, 40–60 s
Y axis path length (cm)	**Time unit**							**F value**	**P value**		Post hoc Tukey's HSD
	0–20 s		**20–40 s**		**40–60 s**						
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**					
TLS	15.2	5.5	15.2	4.5	14.2	3.7	F1	14.106	0.00	*	0–20 s: OLS–FH, OLS–LH > TLS
OLS–FH	48.7	32.1	42.0	18.6	43.2	25.0	F2	3.020	0.07		20–40 s, 40–60 s: OLS–FH > TLS
OLS–LH	41.1	23.3	35.6	18.2	34.3	14.2	F3	1.215	0.32		

*Note. *: $p < 0.05$; F1: standing posture; F2: time unit; F3: interaction; TLS: two legs stance; OLS–FH: one leg stance with front support; OLS–LH: one leg stance with lateral support*

The muscle activity (mean and maximum %RMS) of all muscles (gastrocnemius medialis, soleus, and tibialis anterior muscles) was greater during OLS–FS than during TLS. In addition, the mean and maximum %RMS of the gastrocnemius medialis muscle in the middle and last periods and maximum %RMS of the soleus muscle were greater during OLS–LS than during TLS in all time periods. Because an individual must support their entire body weight with only one leg and adjust their center of gravity sway during OLS, exertion of large leg strength is required. Ankle strategy greatly contributes to the maintenance of stable posture [12]. Plantarflexion muscles (gastrocnemius medialis and soleus muscles) primarily adjust the center of gravity because the center of gravity in the standing position is in front of the heel [13]. Therefore, we conclude that the activity of the plantarflexion muscles was greater during OLS–FS and OLS–LS than during TLS.

In addition, the muscle activity of the tibialis anterior muscles was greater during OLS–FS than during TLS. It can be inferred that elderly people with inferior balance [14] control body sway by contracting the plantarflexion and dorsalflexion muscles together and increasing ankle stiffness. This may occur even in healthy adults when they are placed in a state of unstable posture [15]. Hence, it can be concluded that subjects stabilize posture by contracting the tibialis anterior, gastrocnemius medialis, and soleus muscles together during OLS–FS because their posture is unstable.

This study had several limitations. One was the small sample size. Eleven elderly adults who could not perform OLS for 1 min participated in this study. Many findings resulted from this study, but we may have missed small differences (for example, difference like a Cohen's d < 0.2) because of the small sample size. Although we believe that the main results will not change if the sample size is increased, the details of the difference between OLS–FH and OLS–LH may have been clearer. The other limitation was the maximum isometric contraction method used. In this study, during plantar flexion, the tester held the subject's upper sole instep with his/her hands. In general, plantarflexion muscles are very strong and are measured using a technical device. However, subjects of this study were elderly people who could not perform OLS for 1 min, and their leg strength was very poor. Therefore, we were able to measure it by hand and are confident that the data obtained is reliable. If we measured subjects with better physical fitness, a technical device could have been used to obtain more accurate data.

4. CONCLUSION

Regardless of hand support position, gastrocnemius medialis and soleus muscle activity is greater during OLS than during TLS. However, the tibialis anterior muscle activity is smaller during OLS–LS than during OLS–FS and decreases with time. In addition, total body sway in the left–right direction is greater during OLS–FS than during TLS, but it is greater during OLS–LS than during TLS only for body sway in the front–back direction. Body sway in the left–right direction during LS–FS is greater than that during OLS–LS and stabilizes with time. From the above, OLS–FH may be useful to train the elderly because of the greater leg muscle activity and body sway compared with TLS. On the other hand, OLS–FH may not be useful to train the elderly because the left–right body sway during OLS–LH is almost the same as TLS.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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