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Patterned ground reaction forces and electromyographic activities in the lateral sitting transfers – The influence of trunk forward tilting –

Hiroaki Hirose[1], Toshiaki Suzuki[2] and Tomoaki Shimada[3]

This study investigated patterned ground reaction forces and electromyographic activities of lower-limb and trunk muscles during lateral sitting transfer using the lower-extremities with various forward angles of the trunk.
Thirty healthy volunteers were requested to perform the movement under three predefined experimental conditions; 10-degree, 35-degree and 60-degree forward trunk angles.
Peak vertical force (Fz) under 10-degree was lower than those under 35-degree and 60-degree. Minimum anteroposterior force (Fy) under 10-degree was lower than those under 35-degree and 60-degree. For the tibialis anterior (TA), vastus medialis muscle (VM) and vastus lateralis muscle (VL), the root-mean-square values under 10-degree were larger than those under 35-degree and 60-degree.
It was concluded that slight forward tilting of the trunk was disadvantageous with respect to stability of the movement and load on the muscles during lateral sitting transfer.

Key words
Lateral sitting transfer,
Ground reaction forces (GRFs),
Electromyographic activity

1. Introduction

A transfer is a pattern of movement by which the patient moves from one place to another. For individuals with paraplegia, lateral sitting transfer using the upper extremities is commonly performed several times in daily living[1).

They lift the buttocks off the bed and move from the bed to the wheelchair[1). This activity, however, places an increased demand on the upper extremities compared with a standing transfer and is often identified as a potential source of shoulder pathology[2-4). Perry et al[5) reported the intensity of shoulder muscle load during the lateral sitting transfer using the upper extremities. It is necessary to reduce the load on the upper extremities.

Also it is noted that lateral sitting transfer is useful for elderly subjects who cannot stand up. It is necessary to bear the weight on the lower extremities as much as possible to reduce the load on the upper extremities. Although there is presumably a relationship between the forward angle of the trunk and the muscular effort on the lower extremities, the muscle activity involved in lateral sitting transfer has not yet been reported.

The present study documented the patterned ground reaction forces (GRFs) and electromy-

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ographic (EMG) activities during the lateral sitting transfer using the lower extremities with various forward angles of the trunk in a group of healthy subjects. In addition, Borg assessment of the level of perceived difficulty during lateral sitting transfer was conducted.

2. Methods

2.1. Participants

Thirty male volunteers between the ages of 21 and 35 years (mean 28.3; SD 4.7) with no known musculoskeletal or neurological dysfunction participated in this study. The mean weight of the subjects was 58.9 kg (SD 5.2), and mean height was 1.70 m (SD 0.06). All subjects gave written informed consent for the study.

2.2. Procedures

The subjects were requested to perform the following movements according to three predefined experimental conditions: 10-degree, 35- degree and 60-degree forward angle of the trunk (Fig. 1.). The subjects started the motion with a light signal.

Each subject performed a lateral sitting transfer using an ejector seat, with their arms folded over their chest. The ejector seat heights were adjusted to their lower limbs. Each subject was verbally instructed to perform lateral sitting transfer at a natural motion speed. The subjects were required to keep their right foot on the force platform in front of the seat throughout the lateral sitting transfer (Fig. 2.). Three successful trials were recorded for each condition with adequate rest provided between trials to prevent fatigue.

After completing each trial, subjects estimated the rate the level of perceived difficulty using the Borg (6-20) scale for perceived exertion[6]. After becoming familiarised with the lateral sitting transfer task, the GRFs and the EMG activities during the lateral sitting transfer were collected by computer. All data were time synchronized.

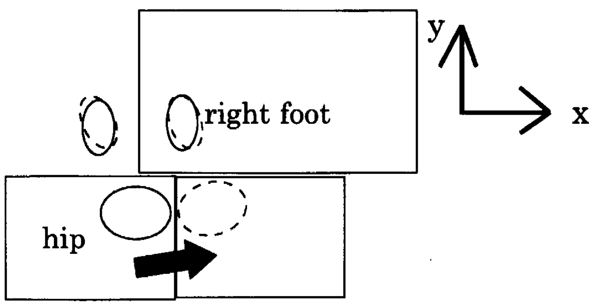

Fig. 2. Schematic representation of the force platform conditions in this study.
The vertical (Fz), anteroposterior (Fy) and mediolateral (Fx) ground reaction forces (GRFs) on the right limb during the sitting transfer were recorded using a calibrated force platform.

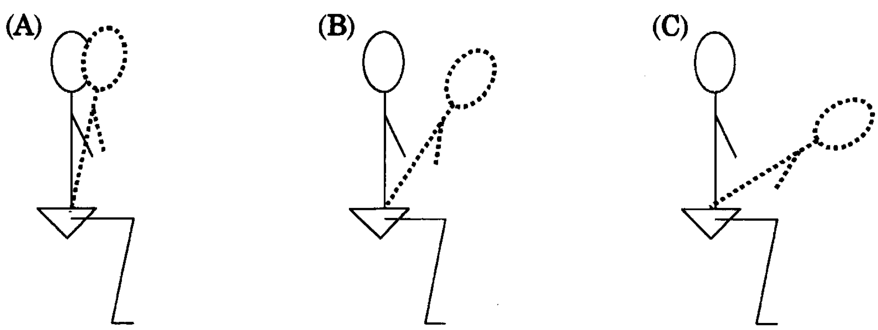

Fig. 1. Schematic representation of the three experimental conditions in this study.
(A) 10-degree condition; (B) 35-degree condition; (C) 60-degree condition.

2.3. Equipment

Movements with a lateral sitting transfer from a seated position were recorded by three digital video cameras with a shutter speed of 1/100 s.

The vertical (Fz), anteroposterior (Fy) and mediolateral (Fx) GRFs on the right limb during lateral sitting transfer were recorded using a calibrated force platform MG2080 (Anima, Inc., Tokyo, Japan). The force platform signals were sampled by computer at a rate of 60 Hz for 3 seconds. The ejector seat was not in contact with the force platform and therefore did not contribute to the applied force.

The force platform, calibrated to the subject's body weight, was positioned under the right foot and measured the GRFs. The following GRF parameters were evaluated: peak Fz (vertical; % body weight), minimum Fz (vertical; % body weight), peak Fy (anterior; % body weight), minimum Fy (posterior; % body weight), peak Fx (lateral; % body weight) and minimum Fx (medial; % body weight).

EMG activities were recorded with an 8-channel MyoSystem1200 EM-112 EMG system (Noraxon USA, Inc., Arizona, USA), using pairs of surface silver/silver chloride electrodes attached 2.0 cm apart from center to center over representative muscles of the right limb and trunk: tibialis anterior (TA), lateral gastro-cnemius (LG), vastus medialis (VM), vastus lateralis (VL), semitendinosus (ST), gluteus maximus (GM) and lumbar paraspinal (LPS) at the level of L3. Active electrodes were placed over each muscle while subjects were seated.

The skin was cleaned and abraded to achieve a skin impedance of < 5kΩ. The EMG signals were digitized online with a sampling frequency of 1080 Hz using a USB Analog Digital Converter (Noraxon USA, Inc., Arizona, USA).

The EMG signals were band-pass filtered (10 - 500 Hz) and the root mean square (RMS) values of EMG were calculated over the entire duration of motion for each transfer trial. The RMS value was calculated using the formula of Basmajian and De Luca[7] as a measure of muscular activity.

All these data collection devices (e.g. videography, force platform, EMG) were calibrated and synchronized to begin recording upon an external trigger.

2.4. Data analysis

Means and standard deviations for the quantitative components of GRFs and RMS values were calculated for this study. A one-way repeated measures analysis of variance (ANOVA) was used for data analyses. Significance was defined as $p<0.05$, and Tukey post-hoc tests were used for pair-wise comparisons. All statistical analyses were performed using the SPSS software version 11.0J (SPSS Inc.). Steel Dwass's test was used for Borg scale data analyses, assuming significance at $p<0.05$.

3. Results

3.1. Total times during the lateral sitting transfer

The total time required performing lateral sitting transfer ranged from 0.9 to 3.2 s (Table 1.). The total time under the 10-degree condition (mean = 1.5 s) was shorter than those under the 35-degree condition (mean = 1.8 s; $p<0.05$) and 60-degree condition (mean = 2.1 s; $p<0.05$).

3.2. Ground reaction forces during the lateral sitting transfer

Peak Fz (% body weight) under the 10-degree condition (mean = 52.6 %) was lower than those under the 35-degree condition (mean = 59.1 %; $p<0.05$) and 60-degree condition (mean = 61.4 %; $p<0.05$). Minimum Fy under the 10-degree condition (mean = -13.6 %) was lower than minimum Fy under the 35-

degree condition (mean = -9.6 %; $p<0.05$) and 60-degree condition (mean = -7.9 %; $p<0.05$). Thus, the posterior reaction force under the 10-degree condition was higher than those under the 35-degree or 60-degree condition. There were no significant differences in minimum Fz, peak Fx, minimum Fx and peak Fy (Table 2.).

3.3. EMG activity during the lateral sitting transfer

The RMS for TA under the 10-degree condition (mean = 94.1 μV) was higher than that under the 35-degree condition (mean = 49.3 μV; $p<0.05$) and 60- degree condition (mean = 35.7 μV; $p<0.05$). The RMS for VM and VL under the 10-degree condition (mean = 123.7 μV, 147.8 μV) was higher than that under the 35-degree condition (mean = 60.5 μV, 76.2 μV; $p<0.05$) and 60- degree condition

Table 1. Means and standard deviations of total times required to perform lateral sitting transfer (n=30)

Condition	Mean time (s)	Range (s)
(A)	1.5 (0.4)	0.9 - 2.3
(B)	1.8 (0.5)	1.2 - 3.0
(C)	2.1 (0.5)	1.2 - 3.2

(* A vs B; * A vs C)

(A) 10-degree condition; (B) 35-degree condition; (C) 60-degree condition.
Note: Standard deviations are in parentheses. *$p<0.05$

Table 2. Means and standard deviations of GRFs (% body weight) during lateral sitting transfer (n=30)

Condition	Peak GRFs (%)		
	Fz (%)	Fx (%)	Fy (%)
(A)	52.6 (11.2)	4.2 (2.4)	0.9 (0.8)
(B)	59.1 (10.5)	4.4 (2.4)	0.9 (0.6)
(C)	61.4 (9.8)	4.0 (2.4)	1.2 (0.7)
Condition	**Minimum GRFs (%)**		
	Fz (%)	Fx (%)	Fy (%)
(A)	4.8 (5.2)	-2.0 (2.3)	-13.6 (3.8)
(B)	5.9 (5.2)	-1.1 (1.0)	-9.6 (1.9)
(C)	6.9 (5.2)	-1.0 (0.8)	-7.9 (1.7)

(Peak Fz: * A vs B; * A vs C. Minimum Fy: * A vs B; * A vs C)

(A) 10-degree condition; (B) 35-degree condition; (C) 60-degree condition.
Note: Standard deviations are in parentheses. *$p<0.05$

(mean = 53.3 μV, 61.5 μV; p<0.05). There were no significant differences among conditions for other muscles (Table 3., Fig.3.).

3.4. Borg scale for perceived exertion

The mean Borg scale under the 10-degree condition (mean = 12.1) was higher than those under the 35-degree condition (mean = 9.4; p<0.05) and 60-degree condition (mean = 9.2; p<0.05) (Table 4.).

4. Discussion

In this study, we analyzed the ground reaction forces and electromyographic activities of muscles in the leg, thigh and trunk in healthy subjects performing the lateral sitting transfer maneuver. The subjects were requested to perform the movement under three predefined experimental conditions; 10-degree, 35-degree and 60-degree forward angle of the trunk.

4.1. Total times during the lateral sitting transfer

The total time under the 10-degree condition was shorter than those under the 35-degree and 60-degree conditions. Goulart et al[8] reported that the total time for the standing-up movement was shorter and the seat-off (thighs leave seat) occurred earlier when the forward tilting of the trunk was more limited. In this study, also, it is considered that the total time has been shortened when the angle of forward tilt was limited to 10-degrees, because the seat-off under the 10-degree condition may be shorter than that under the 35-degree or 60-degree condition.

Table 3. Means and standard deviations of RMS during lateral sitting transfer (n=30)

Condition	RMS of EMG (μV)		
	(A)	(B)	(C)
TA	94.1 (38.2)	49.3 (19.4) *	35.7 (20.0) *
LG	35.7 (42.2)	36.9 (56.8)	35.5 (53.2)
VM	123.7 (81.7)	60.5 (44.8) *	53.3 (50.9) *
VL	147.8 (47.4)	76.2 (45.1) *	61.5 (52.5) *
ST	35.4 (39.9)	21.4 (19.3)	30.2 (39.8)
GM	23.9 (27.7)	20.6 (26.5)	20.7 (26.8)
LPS	41.6 (26.3)	33.5 (20.3)	30.1 (21.8)

(A) 10-degree condition; (B) 35-degree condition; (C) 60-degree condition.
Tibialis anterior (TA), lateral gastrocnemius (LG), vastus medialis (VM), vastus lateralis (VL), semitendinosus (ST), gluteus maximus (GM) and lumbar paraspinal (LPS) at the level of the L3.
Note: Standard deviations are in parentheses. *p<0.05

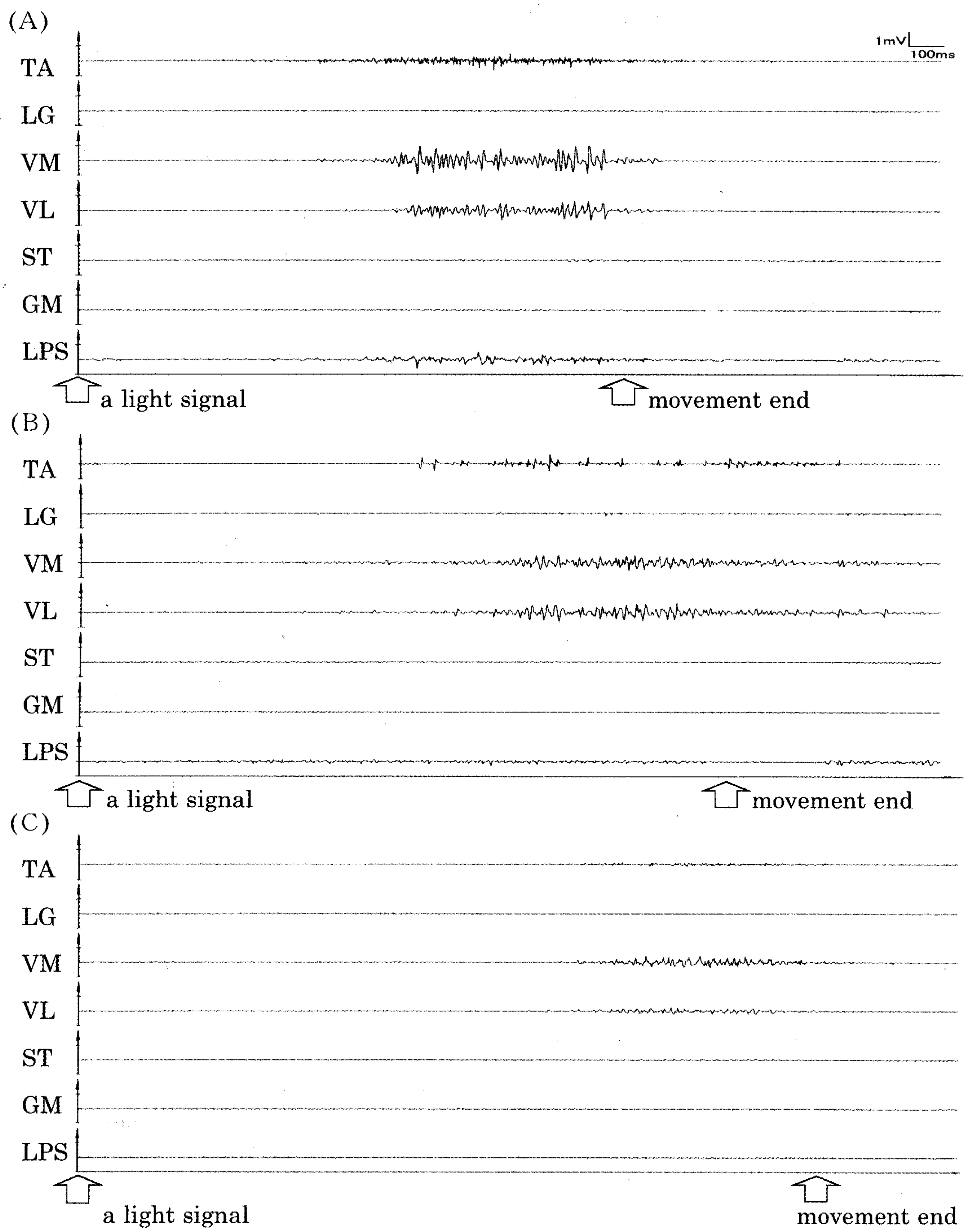

Fig. 3. Representative trial from one of the subjects illustrating the EMG activity.
(A) 10-degree condition; (B) 35-degree condition; (C) 60-degree condition. Tibialis anterior (TA), lateral gastrocnemius (LG), vastus medialis (VM), vastus lateralis (VL), semitendinosus (ST), gluteus maximus (GM) and lumbar paraspinal (LPS) at the level of the L3.

Table 4. Means and standard deviations of Borg scale for perceived exertion during the lateral sitting transfer (n=30)

Condition	Mean time (s)	Range (s)
(A)	12.1 (2.1)	8 - 17
(B)	9.4 (2.1)	7 - 14
(C)	9.2 (1.9)	7 - 12

(A) vs (B): *; (A) vs (C): *

(A) 10-degree condition; (B) 35-degree condition; (C) 60-degree condition.
Note: Standard deviations are in parentheses. *$p<0.05$

4.2. Ground reaction forces during the lateral sitting transfer

Under the 10-degree condition, peak Fz (vertical) is lower than that under the 35-degree or 60-degree condition, because the anterior shift of the body weight associated with the forward tilt of the trunk was smaller.

Minimum Fy (posterior) under the 10-degree condition was lower than those under the 35-degree and 60-degree conditions. The posterior reaction force is increased when lifting the buttocks with a small anterior shift of the body weight. At 10-degrees, the posterior reaction force was larger than that under the 35-degree or 60-degree condition, suggesting unstable movement and the risk of the feet slipping on the floor.

4.3. EMG activity during the lateral sitting transfer

The RMS of EMG for TA, VM, and VL under the 10-degree condition was higher than those under the 35-degree and 60-degree conditions. Goulart et al[8] reported that TA was activated only scarcely with 'flexion of the trunk during sit-to-stand movement', while TA activation was enhanced with 'trunk straight during sit-to-stand movement' . And in the condition of 'flexion of the trunk' , the strategy that trunk flexion compensated the action of TA decreased the need for preparatoy postural adjustment[8].

When the trunk is tilted forward at 10 degrees rather than at 35-degree or 60-degree, it is considered that anterior shift of the body weight is reduced and maximal knee extension moment is increased. And strong extensor muscle contraction was necessary to stand up without increased forward tilt of the trunk.

The loads on VM and VL were shown to be greater at 10-degree than at 35-degree or 60-degree condition.

4.4. Borg scale for perceived exertion

The mean Borg scale under the 10-degree condition was higher than that under the 35-degree and 60-degree conditions. Goulart et al[8] reported that in the condition of 'flexion of the trunk', the strategy decreased the need for preparatory postural adjustment. The level of perceived difficulty is higher at 10 degrees than at 35 degrees or 60 degrees because of the difficulty and instability in controlling body balance during lateral sitting transfer with the trunk forward tilting at 10 degrees.

4.5. Clinical implications

From the findings in this study, it was suggested that limited forward tilting of the trunk was disadvantageous with respect to stability of the movement, load on the muscles and the perceived difficulty during lateral sitting transfer using the lower extremities.

4.6. Limitations

Conclusions based on this study should be considered in context of the limitations. The standardized foot position intended to reduce inter-subject variation may have altered the natural pattern of movement. Hanke et al[9] reported that foot position might offer a more valid and arguably more reliable method of analyzing of movement.

5. Conclusion

The results of this study suggest that, in lateral sitting transfer using the lower extremities, the posterior reaction force was larger, making the movement unstable, when the trunk was tilted forward 10 degrees compared to that at 35 degrees or 60 degrees. Furthermore, the loads on VM and VL were larger under the 10-degree condition. Therefore, reduced forward tilting of the trunk was suggested to be disadvantageous during lateral sitting transfer using the lower extremities with respect to the stability of the movement and load on the muscles.

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