J. Phys. Ther. Sci.
24: 287–290, 2012

Effects of Forward Tilt of the Seat Surface on Trunk and Lower Limb Muscle Activity during One-leg Wheelchair Propulsion

Tetsu Suzuki, PT, PhD[1)], Jun Fukuda, PT[2)], Daisuke Fujita, PT, MS[3)]

[1)] *Department of Physical Therapy, Shimane Rehabilitation College: 1625-1 Minari, Okuizumo, Nita, Shimane, 699-1511 Japan. TEL: +81 854-54-0001, E-mail: su2uki0824@hi2.enjoy.ne.jp*
[2)] *Department of Physical Therapy, Shimane Rehabilitation College*
[3)] *Department of Rehabilitation, Faculty of Health Science and Technology, Kawasaki University of Medical Welfare*

Abstract. [Purpose] To investigate the effects of forward tilt of the seat surface on the efficiency of wheelchair one-leg propulsion. [Subjects] Subjects were 10 healthy adults (4 men, 6 women; mean age, 27.7 ± 6.1 years; height, 166.8 ± 6.5 cm; weight, 57.9 ± 12.2 kg). [Method] This study investigated the effects of forward tilt of the seat surface (0° or 10°) on the efficiency of one-leg propulsion, based on muscle activity of the rectus abdominis, internal oblique, lumbar erector spinae, lumbar multifidus, hamstring and external oblique muscles when propelling a wheelchair at 1 m/s, and the time taken to travel 10 m using one-leg propulsion at maximum effort. [Result] Time taken to travel 10 m at maximum effort was significantly shorter with forward tilt than without. Muscle activity of all the muscles except the external oblique was significantly lower with forward tilt than without. [Conclusion] Tilting the wheelchair seat forward may be useful during one-leg wheelchair propulsion for individuals with decreased ability to tilt the pelvis forward.

Key words: Wheelchair, Forward tilting seat, Muscle activity

(This article was submitted Oct. 18, 2011, and was accepted Nov. 11, 2011)

INTRODUCTION

Wheelchairs are an important auxiliary means of movement for hemiplegic patients with decreased walking function. The method by which a wheelchair is propelled varies depending on the function of the trunk and lower limbs of the patient, but in many cases involves one-arm, one-leg propulsion, using the upper and lower limbs on the unaffected side, or one-leg propulsion using only the lower limb on the unaffected side[1–3)].

In one-leg propulsion, the lower limb plays important roles mainly as the propulsive force and in steering. The angle of the trunk is also important for the efficiency of one-leg propulsion. Adopting a slightly forward tilting position of the trunk during propulsion is generally recommended[1–3)]. In studies with healthy individuals as subjects, higher propulsion speed, increased floor reaction force in the vertical component, and decreased lower limb muscle activity were reported during one-leg propulsion with the trunk and pelvis in a forward tilt position compared to the neutral or backward tilt positions[2, 3)]. This appears to be because load on the lower limbs increases with forward tilt of the pelvis, so the propulsive force of the lower limbs can be harnessed more efficiently. Load on the lower limbs when sitting is ≥25% with forward tilt of the pelvis, about 25% in a neutral position, and ≤25% in a backward tilt[4, 5)]. Forward tilt of the pelvis when sitting requires appropriate activity of the erector spinae, internal oblique, hip flexor, and other muscles[6, 7)]. Hemiplegic patients, however, have difficulty tilting the pelvis forward because of decreased trunk function[8)]. As a result, the pelvis is tilted backward during one-leg propulsion, and tilted and rotated toward the unaffected side, while the upper trunk is retroflexed and tends to rotate laterally to the unaffected side, often resulting in inefficient propulsion[9)]. Moreover, the seat surface angle of wheelchairs that are used in hospitals and similar places is set at a backward tilt of 0–5° for comfort and stability[10)]. However, backward tilt of the seat surface tends to result in backward tilt of pelvis. A propulsion style that uses the lower limbs as the propulsive force is therefore likely to be inefficient. By tilting the seat surface of a chair forward, the strength needed for forward tilt of the pelvis can be complemented and the pelvis backward tilt moment caused by stretch of the muscle group of the posterior thigh that includes the hamstrings can also be reduced, thereby enabling a sitting position with the pelvis in a forward tilt position and little trunk muscle activity compared with a seat surface angle of 0°[11)]. Thus, one-leg propulsion may be able to be performed more efficiently by tilting the seat surface angle of a wheelchair forward.

Many studies of wheelchair propulsion have involved upper-limb propulsion, but few have investigated of one-arm, one-leg propulsion or one-leg propulsion[1–3)]. In addition, we have found no studies which have investigated how forward tilt of the seat surface of a wheelchair affects wheelchair propulsion efficiency using electromyography of the trunk and lower limbs. The lower limb is used for both one-arm, one-leg propulsion and for one-leg propulsion. The present study investigated the effects of forward tilt of the seat surface on the efficiency of one-leg wheelchair propulsion. To evaluate this we measured the muscle activity of the trunk and lower limbs during propulsion of a wheelchair at a speed of 1 m/s, and the time taken to travel a distance of 10 m with one-leg propulsion at maximum effort.

SUBJECTS AND METHODS

Subjects were 10 healthy adults (4 men, 6 women; mean age, 27.7 ± 6.1 years; height, 166.8 ± 6.5 cm; weight, 57.9 ± 12.2 kg). None of the subjects had any history of orthopedic disorder of the trunk or lower limbs within the previous year, limited range of motion of the trunk or lower limbs, or neurological signs. The study purposes, methods, and risks were explained to all the subjects before participation, and their written consent was obtained. If pain or discomfort was felt in the lumbar area or lower limbs during measurements, measurements were stopped.

The wheelchair used in the study had a lifting seat with a seat surface angle of 0° (Lowver; Seastar, Japan). For ease of propulsion with one leg, the footrest on the side that would be used to propel the wheelchair was removed. To create forward tilt of the seat surface, a forward tilt mat made of cushion material with a 10° angle was used (length, 40 cm; width, 40 cm; Funaki-gishi, Japan). Subjects were positioned so that the ischial bone reached a line 3/4 of the total depth of the seat from the front. The height of the wheelchair was then adjusted for each subjects using the forward-tilt mat, so that the entire sole of the foot could touch the floor, with the hip and knee joints at 90° and the ankle at 0°. This height was set as the reference value. When using the forward-tilt mat, the height of the chair was readjusted so that the line 3/4 from the front of the forward-tilt mat that the ischial bone was in contact with the same height as this reference value. One-leg propulsion was performed using the right lower limb as the propelling leg. With reference to previous studies[2], subjects were instructed to use a rearward kicking motion from heel contact through toe off for propulsion, with the trunk tilted slightly forward. They were instructed to place both upper limbs lightly on the thighs and leave them relaxed. For line of sight, subjects looked at an eye level target 15 m in front of them. Before the measurements, each subject practiced this propulsion method until the actions could be performed smoothly.

Muscle activity of the trunk and lower limbs during one-leg propulsion at 1 m/s, and the time taken to travel a distance of 10 m when moving with one-leg propulsion at maximum effort were then measured under the two conditions of with and without the forward-tilt mat. A distance of 10 m is covered in 10 ± 0.5 s at a speed of 1 m/s with one-leg propulsion, and the same number of leg propulsion movements was set for each subject in conditions both with and without the forward-tilt mat. During one-leg propulsion at maximum effort, the number of propulsions was left to the individual. For both tasks, the starting foot position was with the right heel on the propulsion side not touching the floor when the subject was seated in the wheelchair. No run-up distance was used ahead of the start line, but subjects were asked to continue for 3 m beyond the finish line so that they would not slow down before the finish line. Both tasks were measured three times for each condition. To avoid accumulation of fatigue, a rest of 3 min was enforced between each task.

With reference to the study of Suzuki et al.[11], muscle activity of the trunk and lower limbs was measured using surface electromyography (Vital Recorder 2; Kissei Comtec, Japan). The bandpass filter was set at 10–500 Hz, and the sampling frequency at 1,000 Hz. Bimutas II software (Kissei Comtec) was used for analysis of the electromyograms. Target muscles and the electrode attachment sites were the rectus abdominis (~2-3 cm lateral to the navel), external oblique (lateral inferior margin of the 8th rib), internal oblique (2–3 cm medially and 2–3 cm inferiorly to the anterior superior iliac spine), lumbar erector spinae (2–3 cm lateral to the spinous process at the L3 level), lumbar multifidus (immediately lateral to the spinous process at the L5/S1 level), and hamstring (muscle belly 2/3 distal to the line connecting the posterior knee joint and greater trochanter). All were on the right side. Electrodes (Ag-AgCl disposable body surface electrodes, Blue Sensor N-00S; Medicotest A/S, Denmark) were attached after adequately preparing the skin at an inter-electrode distance of 25 mm parallel to the direction of muscle fibers in the target muscle. The ground electrode was attached to the right acromion. A foot switch was also attached to the right heel. Afterwards, to measure the muscle activity of each target muscle at maximum voluntary contraction (MVC), subjects maintained the final foot position in normal grade exercise in a manual muscle test[12] for the muscle being measured, and muscle activity was measured for 5 s. The mean integrated value of the middle 3 s was then calculated, and a value 10/3 times that value was used as the MVC. The integrated value of the trunk and lower limb muscle activities during one-leg propulsion at a speed of 1 m/s was calculated for the propulsion from the start to the finish line for each of the two conditions of with and without the forward-tilt mat. The start point of propulsion was confirmed with the waveform of the foot switch, and the end point was determined with the stop watch that simultaneously measured muscle activity. The muscle activities were normalized to their respective MVC values, then the mean values were calculated for the two conditions of with and without the forward-tilt mat.

The time taken to travel a distance of 10 m when moving with one-leg propulsion at maximum effort was measured using a stop watch. The mean values of the times taken to travel a distance of 10 m when moving with one-leg propulsion at maximum effort under the two conditions of with and without the forward-tilt mat were calculated.

SPSS version 16 software was used for the statistical analyses. The time taken to travel a distance of 10 m when moving with one-leg propulsion at maximum effort and the integral values of trunk and lower limb muscle activities during one-leg propulsion at a speed of 1 m/s were compared between with and without the forward-tilt mats using the

Table 1. Comparison of the times taken to travel 10 m during one-leg propulsion at maximum effort with and without the forward-tilt mat

	With the forward-tilt mat	Without the forward-tilt mat
Times taken to travel 10 m (sec)	6.5 ± 0.8	7.4 ± 1.1*

Values are mean (SD). *: Significant difference between two conditions ($p < 0.05$)

Table 2. Comparison of the trunk and lower limb muscle activities during one-leg propulsion at a speed of 1 m/s with and without the forward-tilt mat

	With the forward-tilt mat	Without the forward-tilt mat
(%MVC)		
RA	14.0 ± 7.7	16.9 ± 9.2*
EO	12.2 ± 7.4	13.1 ± 9.0
IO	29.0 ± 17.5	37.8 ± 20.7*
LES	28.7 ± 9.3	35.6 ± 9.7*
MF	26.1 ± 8.3	35.9 ± 8.8*
HAM	40.8 ± 18.2	46.6 ± 24.3*

Values are mean (SD), %MVC : % Maximum voluntary contraction, RA: rectus abdominis, EO: external oblique, IO: internal oblique, LES: lumbar erector spinae, MF: lumbar multifidus, HAM: hamstring. *: Significant difference between two conditions ($p < 0.05$)

Wilcoxon rank-sum test. The level of statistical significance was chosen as <5% in all the analyses.

RESULTS

No subjects dropped out, and all measurements were completed on the same day. No deficits in measurement data were present. Times taken to travel a distance of 10 m when moving with one-leg propulsion at maximum effort were significantly shorter with the forward-tilt mat than without those (Table 1). Muscle activities of the rectus abdominis, internal oblique, lumbar erector spinae, lumbar multifidus, and external hamstring muscles were significantly lower with the forward-tilt mat than without those during one-leg propulsion at a speed of 1 m/s. No significant difference was seen in the muscle activity of the external oblique between the two conditions (Table 2).

DISCUSSION

Forward tilt of the pelvis and increasing the load on the lower limbs is important during one-leg propulsion of wheelchairs[1–3]. By tilting the seat angle of the wheelchair forward, the strength needed to tilt the pelvis forward can be complemented[11 ,13], and more efficient one-leg propulsion is possible compared with normal wheelchair use. In the present study, to investigate whether one-leg propulsion can be made more efficient use by tilting the seat surface of the wheelchair forward, we compared the time taken to travel a distance of 10 m when moving with one-leg propulsion at maximum effort and the trunk and lower limb muscle activities during one-leg propulsion at a speed of 1 m/s under the two conditions with and without a forward-tilt mat.

We found that muscle activities of the rectus abdominis, internal oblique, lumbar erector spinae, lumbar multifidus, and external hamstring muscles were significantly lower with the forward tilt mat than without it at 1 m/s and the same number of leg propulsion movements. This suggests that tilting the wheelchair seat surface forward enables more efficient one-leg propulsion of a wheelchair with lower activity of the trunk and lower limb muscles. Forward tilt of the pelvis when sitting requires appropriate activity of the lumbar erector spinae, lumbar multifidus, internal oblique, hip flexor, and other muscles[6, 7]. By tilting the seat surface forward, the forward tilt moment acts on the pelvis and pelvis backward tilt moment is decreased by the muscle group of the posterior thigh, including the hamstrings. Activities of these muscles have been reported to decrease in a sitting position with forward tilt on a forward tilting seat surface compared to a normal seat surface[11]. In addition, during one-leg propulsion of a wheelchair, the lateral hamstring acts as the forward propulsive force through the flexion of the knee and as a force exerting pressure on the foot with extension of the hip[2]. This study did not measure movement of the trunk during wheelchair propulsion. We presumed that because of the forward inclination of the pelvis during use of the forward-tilt mat, the trunk would have been inclined further forward than when the mat was not in use. Forward inclination of the pelvis and forward inclination of the trunk would increases the load on the legs, so we think the action of pressing the foot using hip extension with the hamstrings would have been reduced. As a result, we think that more efficient one-leg propulsions with lower muscle activities of the trunk and lower limbs is possible by tilting the wheelchair seat surface forward.

In addition, the time to travel a distance of 10 m when moving with one-leg propulsion at maximum effort was significantly shorter with the forward-tilt mat than without it. This indicates that the maximum propulsion speed is increased by tilting the wheelchair seat surface forward. Previous studies[2, 3] have also reported that propulsion speed is increased by tilting the seat surface forward and imposing a forward tilt of the trunk, as in this study. The reason for this increased propulsion speed is thought to be that the propulsive force of the lower limb can be effectively harnessed by encouraging forward tilt of the pelvis and increasing load on the leg by tilting the seat surface forward.

Seat surfaces of hospital wheelchairs are generally set at a backward angle of 0–5°[10]. This angle is superior in terms of comfort and stability when sitting, but is unsuitable for one-leg propulsion since the pelvis tends to tilt backward. In addition, hemiplegic patients show poor ability to tilt the pelvis forward because of decreased trunk function[8], and wheelchairs with seat surfaces tilted backward are even more inefficient for one-arm, one-leg propulsion and for one-leg propulsion. Tilting the seat surface of a wheelchair forward may be useful during one-leg propulsion of a wheelchair for individuals with decreased ability to tilt the pelvis forward.

This was a basic study conducted with healthy individuals as subjects. Several limitations must be considered in interpreting the results, and it is not yet clear whether the results can be generalized to patients with hemiplegia and other conditions. Investigations of the risk of falling or sliding down the seat when the wheelchair seat surface is tilted forward, and the level of trunk and lower limb function required to safely use a wheelchair with a forward-tilted seat surface will also be needed. In terms of actual clinical application, consideration of a safety bar or an ischial bone rest in the seat surface will also be necessary[13]. In addition, forward and backward movements of the trunk, which is a factor affecting trunk muscle movement while propelling a wheelchair, were not measured. Moreover, no investigation was conducted during the wheelchair propulsion with a seat having a backward tilt of 0–5°, which is generally used in wheelchairs. This was because of difficulties encountered in making a suitable mat with an angle of less than 5°. We would like to investigate these issues in the future studies.

REFERENCES

1) Harigai T, Kimura S, Kakurai S: Kinematic and kinetic analysis of one-hand foot wheelchair driving. Jpn J Rehabil Med, 1995, 32: 225–231 (in Japanese). [CrossRef]
2) Kaeatsu A, Hosaka Y, Kinjo M: Kinetic analysis of one hand and leg wheelchair propulsion according to trunk inclination. Akitadaigaku-daigakuinigakukeikenkyukahokengakusenkoukiyou, 2009, 17: 20–28 (in Japanese).
3) Saito Y, Matsumoto M, Yoshinaga T: Relation of posture and independent mobility in wheelchair foot propulsion. Kawasaki Med Welf J, 2006, 15: 521–528 (in Japanese).
4) Samuelsson K, Björk M, Erdugan AM, et al.: The effect of shaped wheelchair cushion and lumbar supports on under-seat pressure, comfort, and pelvic rotation. Disabil Rehabil Assist Technol, 2009, 4: 329–336. [Medline] [CrossRef]
5) Harrison DD, Harrison SO, Croft AC, et al.: Sitting Biomechanics Part I: Review of the literature. J Manipulative Physiol Ther, 1999, 22: 594–609. [Medline] [CrossRef]
6) O'Sullivan PB, Dankaerts W, Burnett AF, et al.: Effect of different upright sitting postures on spinal pelvic curvature and trunk muscle activation in a pain-free population. Spine, 2006, 31: E707–E712. [Medline] [CrossRef]
7) Miyamoto Y: Activity of the hip flexor in an upright sitting posture. Shijounomiyagakuendaigakurihabiriteshongakubukiou, 2006, 2: 1–7 (in Japanese).
8) Tomita Y, Sato F, Uno J, et al.: Trunk Movement: Trunk movement in hemiplegia. Rigakuryoho J, 1991, 25: 88–94 (in Japanese).
9) Kawada K, Yamamoto S: Motion analysis of driving wheelchairs with lower legs of hemiplegic patients. Rigakuryoho Kagaku, 2008, 23: 789–793. [CrossRef]
10) Rory A.: Cooper: Wheelchair selection and configuration. New York: Demos Medical Pub, 1998, pp1-42.
11) Suzuki T, Hirata J, Ohtsuki K, et al.: Comparison of trunk muscle activities and spinal curvature when sitting on a kneeling chair and sitting on a conventional chair —Investigation of two sitting postures—. Rigakuryoho Kagaku, 2011, 26: 263–267 (In Japanese). [CrossRef]
12) Hislop HJ, Montgomery J: Daniels and Worthingham' muscle testing. Philadelphia: W.B. Saunders Company, 1995.
13) Genda E: Wheelchair for hemiplegia. Bulletin of the Japanese Society of Prosthetic and Orthotic Education. Res Dev, 2010, 26: 157–163 (In Japanese).