Age-related changes in postural control for wearing shoes using different process of leg-raising processes in the sitting position: a pilot study

RYOSUKE MIYADERA, PhD, OTR1, 2)*, TSUNETO FURUTA, OTR2)

1) Department of Occupational Therapy, Faculty of Health Science Technology, Bunkyo Gakuin University: 1196 Kamekubo, Fujimino, Saitama 356-8533, Japan
2) Division of Occupational Therapy, Faculty of Rehabilitation, Gunma University of Health and Welfare, Japan

Abstract. [Purpose] Wearing shoes can be difficult for people who experience movement difficulties. This study aimed to compare young adults and senior adults while wearing shoes in order to quantify kinematic, physiological, and ergonomic points of variance. [Participants and Methods] Nine young adults (mean age, 21 years) and nine senior adults (mean age, 70 years) were included in the study. We investigated four postural combination of using hand and crossing legs used while wearing shoes: 1) time required to wear shoes, 2) the center of pressure point, 3) muscle activation within the right sartorius, the left rectus femoris, the gluteus maximus, and the internal oblique, and 4) the perceived ease of task performance via a numerical rating scale. [Results] The activities of the internal oblique and the gluteus maximus were significantly higher in senior adults than in young adults. Wearing shoes without using hands was associated with the highest value for the ease of performance among the four patterns for both groups. [Conclusion] Our results suggested that the muscles analyzed in this study were important for safety and postural maintenance while performing activities of daily living tasks in leg-raising processes in the sitting position, with lower level of muscle activity.

Key words: Wearing shoes, Postural control, Level of muscle activity

INTRODUCTION

In patients with hemiplegia, the loss of muscle strength and diminished sensation affects the ability to exercise postural control. Therefore, performing activities of daily living (ADL) tasks such as wearing shoes can be very difficult1, 2). Some rehabilitation settings teach patients with hemiplegia to cross the paralyzed leg over the unaffected leg and then wear shoes. However, leg-raising processes in the sitting position may be difficult for people with poor postural control, reduced leg muscle strength or activation, and poor manual dexterity. Limited range of motion (ROM) in the hips and thoracic spine exerts a greater influence on how shoes are worn than that of lumbar joint restrictions3, 4). Horak et al.5) analyzed postural control from a biodynamic and cognitive viewpoint and clarified the postural and movement changes attributed to age and environment. In particular, ADL tasks involving minimal support, such as standing, or tasks that require a large shift of angle, such as reaching, require high postural stability. In the present study, we examined postures used to wear shoes in a cohort of young adults and senior adults in order to quantify the kinematic, physiological, and ergonomic factors that affect the process of wearing shoes. Our results may provide insight into the relative utility of wearing shoes while maintaining leg-raising processes in the sitting position.

*Corresponding author. Ryosuke Miyadera (E-mail: miyadera@shoken-gakuen.ac.jp)

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PARTICIPANTS AND METHODS

Our convenience sample comprised a “young adult” group recruited from Bunkyo Gakuin University (Saitama, Japan) and a “senior adult” group recruited from the Silver Human Resources Center of Fujimino City (Saitama, Japan). All participants were male and right lower limb dominant. This study was approved by the research ethics committee of Bunkyo Gakuin University, and written informed consent was obtained from all participants before the study.

All participants wore rehabilitation shoes of the same model (Fig. 1). These shoes were developed for adults with difficulty in tying shoelaces and are widely available at rehabilitation sites throughout Japan. The shoes are made of cloth with a back-and forth fastener and Velcro fastener. We selected the shoe size for each participant according to recommendations set forth by the Japanese Industrial Standards Committee: length=foot length ± 2 mm, lap diameter=width −2 mm +3 mm. All participants wore socks during testing.

Postural control was monitored with the use of a three-dimensional motion analysis system VICON MX (VICON Inc., Oxford, UK) and two force plates (AMTI Inc., MA, USA). The data from VICON was acquired in the X-, Y-, and Z-coordinates. Positive X, Y, and Z values were defined as the right side, the front side, and the top side, respectively, of the participants. The measurement frequency was 100 Hz. The electromyographic (EMG) activity, which was monitored using the multi-telemeter system WEB-5000 (NIHON KODEN Inc., Tokyo, Japan) and bipolar steel surface electrodes spaced 10 mm apart with a ground electrode, was recorded using PowerLab 16/30 and analyzed using LabChart 6 (ADInstruments Inc., Lexington, Australia). Hip joint ROM was measured using a goniometer (OG Giken Inc., Okayama, Japan).

We measured the starting sitting posture while participants sat in a chair with the hip and knee at 90° flexion and 1/3 of the length of the femur in contact with the seat. Both feet were placed on one of the force plates, and all legs of the chair were placed on the other plate. The meters were reset prior to each trial, and participants were instructed to sit comfortably in the chair, with both hands on the thighs. The participants then wore their shoes using the following four patterns in sequence9.

Pattern A: With the shoes on the floor, each participant wears his shoes without using hands; pattern B: Performed as pattern A, but the right lower limb dominant was lifted with the left hand; pattern C: Each participant’s right lower limb dominant crossed over and onto the left lower limb without using hands; pattern D: Performed as pattern C, but the right lower limb dominant was lifted with the left hand (Fig. 2). Each participant received instructions on the four patterns by the author and practiced the patterns prior to the start of testing. The order of the four patterns was randomized, and all measurements were repeated.

We recorded the total time taken to wear shoes for each of the four patterns. The total time was divided into five phases: reaching for the floor, undoing the shoes fastener, flexion of the hip joint or crossing legs, inserting the foot into the shoes, and redoing the shoes fastener (Fig. 3). These phases were compared as a percentage of the total time. The starting and ending time for each phase was confirmed by placing three markers, one each, on the top of the head, the third head of the metacarpal bone of the left hand, and the lateral malleolus.

Postural control was also calculated from the amount of movement of the center of pressure (COP) point and the total trace length of the COP (L-COP) on the X-axis and Y-axis from all of the force plates7,8. The ratio of muscle activity for maximum voluntary contraction (%MVC) during the leg-raising processes in the sitting position was calculated by attaching electrodes to the right side of the sartorius, the left rectus femoris, the glutaeus maximus, and the internal oblique9. The electrodes were placed as per the guidelines of the Surface EMG for Non-Invasive Assess-

Fig. 1. Shoes used in this study; rehabilitation care shoes with a fastener, hook, and loop fastener: “New Partner Shoes” No.3 (Ueyama Inc., Hyogo, Japan).

Fig. 2. Postural patterns used while wearing shoes.
Pattern A: With the shoes on the floor, each participant wears his shoes without using hands.
Pattern B: Performed as pattern A, but the right lower limb dominant was lifted with the left hand.
Pattern C: Each participant’s right lower limb dominant crossed over and onto the left lower limb without using hands.
Pattern D: Performed as pattern C, but the right lower limb dominant was lifted with the left hand.

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ingredient of Muscles project, with emphasis on adequate skin preparation including shaving, light abrasion, and sterilization\textsuperscript{10}. %MVC indicated the mean value of the activity for each 0.5 s before and after the maximum activity of all muscles.

The ease of wearing the shoes was evaluated according to a Numerical Rating Scale (NRS) where “0” indicated greatest imaginable difficulty in wearing shoes and “10” indicated least difficulty in wearing shoes according to the participant’s response. In order to confirm hip joint flexibility, we measured passive range of flexion, abduction, and extension of the right hip joint.

The time taken to wear shoes, postural control, and muscle activity were recorded twice, and the second value was used for analysis. The NRS and ROM were recorded once. All these variable factors were compared with pattern D as the control, and the four patterns were classified according to the ease of performance as indicated by the NRS scale. $P<0.05$ was considered statistically significant. These analyses were performed using the Statistical Package for Social Science (SPSS, ver.18, IBM Inc., Japan) software. A one-way analysis of variance was used to test for between-group differences; Bonferroni’s correction was used for multiple comparisons. Data were presented as mean ± standard deviation (SD), unless otherwise stated.

**RESULTS**

The study cohort comprised nine young adults aged 21.4 ± 2.2 years (mean ± SD) and nine senior adults aged 70.3 ± 3.1 years (Table 1).

The time taken to wear shoes is shown in Table 2. When performing pattern A, the groups took the shortest amount of time (A<C<B<D). Comparison of the time of the phases of wearing with pattern D as the control (except for the phase of reaching for the floor common to all four patterns) showed that, when performing pattern A, the senior adult group took a significantly shorter amount of time.

The COP and %MVC during the leg-raising processes in the sitting position are shown in Table 3. The amount of the L-COP was the largest for pattern D among all four patterns (A<B<C<D). The senior adult group took significantly longer than the young adult group for patterns C (senior adult group: 1,557.5 ± 361.2 mm; young adult group: 1,155.4 ± 159.9 mm) and D (senior adult group: 2,722.6 ± 954.7 mm; young adult group: 1,878.3 ± 331.0 mm). The amount of movement of COP for pattern C was significantly larger in the positive direction of the X-axis (i.e., right movement) in the young adult group than in the senior adult group (senior adult group: 38.7 ± 16.6 mm; young adult group: 62.1 ± 14.5 mm) and significantly larger in the negative direction of the X-axis (i.e., left movement) in the senior adult group than in the young adult group (senior adult group: −27.7 ± 13.6 mm; young adult group: −6.5 ± 5.0 mm). For %MVC, muscle activity of the gluteus maximus and the internal oblique during posture maintenance was higher in the senior adult group than in the young adult group for all four patterns. This trend was particularly noticeable in the internal oblique for pattern A (senior adult group: 65.8 ± 17.6%; young adult group: 26.9 ± 11.3%). Additionally, for pattern A, the muscle activities of the sartorius and gluteus maximus were significantly higher in the senior adult group than in the young adult group (senior adult group: 45.1 ± 22.0%; young adult group: 24.5 ± 7.9%) and (senior adult group: 55.3 ± 29.6%; young adult group: 32.0 ± 10.3%), respectively (Table 4).

On the NRS, pattern A showed the highest score (A>C>B>D) (Table 5). Compared with pattern D (senior adult group: 3.3 ± 1.6; young adult group: 2.9 ± 0.9), the senior adult group scored significantly higher for pattern A (8.0 ± 1.9) and the young adult group for patterns A (7.6 ± 0.9) and C (6.6 ± 1.8). No significant difference in hip joint ROM was observed between the young adult and senior adult groups.
DISCUSSION

In this study, we analyzed postures using various patterns while wearing shoes based on the time taken, COP movement, and muscle activation of the right sartorius, the left rectus femoris, the gluteus maximus, and the internal oblique in young adults and senior adults. The time taken to complete the task, which shows the relative efficiency of different ways of wearing shoes, was shortest for pattern A (A<C<B<D), demonstrating that hand intervention delays raising of the leg. Moreover,
when each phase of the operation was compared with the total elapsed time, a large portion was taken up by undoing and redoing the shoes fastener, which is a complex operation.

From results of muscle activity, the gluteus maximus and the internal oblique exhibited more activation in the senior adult group than in the young adult group during the leg-raising processes in the sitting position. Therefore, the COP shift in the senior adult group for patterns C and D was significantly longer, as indicated by the results of the L-COP (Table 3). These muscles are important for postural control during single-leg sitting. Additionally, for pattern C, the senior adult group took significantly longer than the adult group when moving in the direction of the X-axis. As shown in Table 5, when a member of the senior adult group simultaneously moved his leg and inclined his pelvis, the inclination of the upper part of the body was balanced by the backward adjustment of the pelvic muscles on the side of one leg in order to support tilting, with the pelvis acting as fulcrum. With the pelvis acting as the body’s fulcrum, the COP moved to the other side; thus, the muscle activity of the gluteus maximus could not increase but was compensated for by increased activity of the internal oblique.

To determine the ease of wearing shoes, we evaluated the NRS after the posture measures. The NRS showed the same pattern of results as the time taken to wear shoes. Increases in time reflect the complexity of the operation, which may have led participants to think that the shoes were harder to wear, although we cannot confirm this hypothesis at this time. This study showed that if the time cannot be measured, evaluating the NRS can closely predict the efficiency of wearing shoes.

When the upper limbs are not utilized, wearing shoes may be the easiest task by raising the leg only slightly for a short time (as in pattern A). To facilitate this pattern, rehabilitation shoes should be designed as easy-to-wear, including a wide top and a stable and broad base, and should be easy to wear using only one hand.

Raising the leg and then crossing it over the non-affected leg to achieve leg-raising processes in the sitting position without hand support (as in pattern C) required a great deal of activation within the muscles that were analyzed in this study. This task may be difficult for patients with hemiplegia. This difficulty can be overcome by utilizing the hand to lift the leg (as in pattern D).

Conflicts of interest
None.

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Table 4. Comparison of %MVC in the young adult and senior groups during the raising a leg with sitting position for pattern A

| Muscle          | Young Adults (n=9) | Senior Adults (n=9) |
|-----------------|------------------|-------------------|
| Sartorius       | 24.5             | 45.1              |
| Internal oblique| 26.9             | 65.8              |
| Rectus femoris  | 29.5             | 39.1              |
| Gluteus maximus | 32.0             | 55.3              |

*: Significantly different from the young adult group (p<0.05).

Table 5. NRS for ease of wearing shoes for the four patterns

| Pattern | Young Adults (n=9) | Senior Adults (n=9) |
|---------|-------------------|-------------------|
| A       | 7.7               | 8.0               |
| B       | 3.3               | 4.6               |
| C       | 6.6               | 5.7               |
| D       | 2.9               | *#                |

Higher score means easier.
*: Significantly different from pattern A (p<0.05).
#: Significantly different from pattern C (p<0.05).