The Journal of Physical Therapy Science

S P T S

Original Article

Effect of upper extremity load on pelvic movements during wheeled upright walker use

Hiroki Aoyama, RPT, MS[1)*], Kazuo Yonenobu, PhD[2)], Katsushi Ogawa, PhD[3)], Seonghee Jeong, PhD[3)]

[1)] *Department of Physical Therapy, Aino University: 4-5-4 Higashioda, Ibaraki, Osaka 567-0012, Japan*
[2)] *Osaka Yukioka College of Health Science, Japan*
[3)] *Department of Electro-Mechanical Engineering, Osaka Electro-Communication of University, Japan*

Abstract. [Purpose] This study aimed to elucidate the effects of upper extremity loading on pelvic movements during wheeled upright walker use. [Participants and Methods] Thirteen healthy male adults participated in this intervention study. Participants walked under five conditions with targeted loads on their upper extremities of 0%, 10%, 20%, 30%, and 40% of their body weights using a wheeled upright walker with armrests. Measured items included gait velocity and stride length; the angle of the maximum trunk anterior tilt; the range of motion of the trunk and pelvis in the movements of obliquity, tilt, and rotation; and the amplitude of the center of mass in the vertical and lateral directions captured and calculated using a three-dimensional motion analysis system. [Results] Increasing the load on the upper extremities did not shorten the stride or restrict pelvic movement during gait using upright walker use. The range of pelvic rotation with walker use increased versus that of the standard gait. [Conclusion] The pelvis showed quantitative movements during gait using the wheeled upright walker with armrests. These results could be helpful in the development of robotic assistive devices.
Key words: Wheeled upright walker, Trunk and pelvic movement, Robotic gait assistive device

INTRODUCTION

Improvement of gait ability is the most critical issue in clinical rehabilitation. Recently, gait retraining using a treadmill or assistive robots has increasingly been used with patients who have central nervous system or neuromuscular diseases[1–3]. These commercialized devices are recognized to be efficient rehabilitative tools to help patients maintain proper posture and decrease body weight load during repeated gait exercise[4, 5]. However, these devices are too large for many patients in rehabilitation clinics to manage. We therefore instead propose the use of a walker-type assistive robot for these patients to use in their daily lives.

Walkers, which are easy for patients to handle, are common assistive devices found in hospitals and other healthcare facilities. Individuals who have weakened lower extremities can use a walker to help them walk safely and stably.

Few researchers have attempted to assess gait functionality while using a walker, from the perspective of biomechanics[6, 7]. Fast et al.[8] evaluated the pattern and magnitude of forces transmitted through the frames of walkers during ambulation. Viegas et al.[9] proposed a measurement system to characterize an individual's gait when using a walker assistive device by using load cells to measure the force applied on the legs of the walker. These studies primarily investigated the force on a pick-up walker and did not explore the kinematics of pelvic movement.

Although the use of gait rehabilitation robots initially focused on controlling leg movement, recent studies of such devices have considered the importance of pelvic motion in normal locomotion[4, 10, 11]. Mun et al.[12] evaluated lower-limb dynamics, including descriptive gait parameters, by restricting pelvic lateral displacement and rotation, and they found that pelvic restriction considerably altered normal gait dynamics. As Saunders et al.[13] pointed out, the pelvis plays a critical role in normal gait, by efficiently controlling the center of mass movement. It is therefore essential to consider pelvic motion when developing rehabilitative gait devices. However, no previous studies have investigated how the pelvis moves when a person walks using a wheeled upright walker with armrests.

The use of a wheeled upright walker with armrests could limit the movement of the trunk due to the arms being fixed. However, we hypothesized that pelvic movement could occur to some extent. If our hypothesis were proper, it would be meaningful to assist the pelvis during gait exercises using a robotic, wheeled upright walker.

This study aimed to elucidate the effects of a load on the upper extremities on the movement of the pelvis while using a wheeled upright walker. We sought to understand the implications for gait assistive control, which adapts the movement of the pelvis during gait when using a wheeled upright walker.

PARTICIPANTS AND METHODS

The participants were 13 healthy young men (mean age: 22.1 ± 1.0 years, mean weight: 69.7 ± 9.2 kg, mean height: 174.4 ± 4.9 cm) who lived in the Kansai area in Japan. Exclusion criteria were neurologic or orthopedic problems that could disturb walking. We obtained written informed consent from each of the participants before enrolling them in the study. This study was reviewed and approved by the Aino University Ethics Committee (Aino2019-03, Osaka, Japan).

Using a wheeled upright walker with an armrest, participants walked on the walkway three times at their preferred speed. We remodeled the commercially available wheeled upright walker (Paramount Bed, KA-391, Tokyo, Japan) to embed the four load sensors between the armrest and the frame, set in the walker's right front, left front, right rear, and left rear. We had made the measurement system so that the participants could see their load on the armrest on the real-time graphical display in front of them while walking. The armrest was set at the same height as a participant's elbow joint to contact the armrest widely in the upright standing position. We dictated that they walk with five targeted load conditions of their upper extremities, 0%, 10%, 20%, 30%, and 40% of their body weight (BW). We also explained that the participants should imitate the person with weak stability of the lower extremities to increase the load on the upper extremities without changing the position of their forearms. In the 0% BW condition, they were instructed to push the walker forward not to lean on it. The target value, rUB [%], is defined according to the upper limb load (ULL) ratio to BW, as follows:

$$rUB = ULL / BW \times 100$$

There were 29 markers attached to each participant (MAC3D system, Motion Analysis Corporation, Rohnert Park, CA, USA). The markers were placed at the top, front, and rear of the head, both sides of the shoulders, elbows, wrists, right scapula, both sides of the anterior superior iliac spine, the center of the posterior superior iliac spine, both sides of thighs, the lower legs, lateral and medial knees and ankles, and heels and toes. We calculated the angles between each body segment, the gait velocity, stride, and the center of mass (COM), using Cortex-64 software (Motion Analysis Corporation).

We recorded data once the participants had declared that they were familiar with the sensation of their target load by engaging in some pre-trials. The walkway in the experimental room was approximately 4 meters long. There were eight far-infrared cameras, which were used by the three-dimensional motion capture system to capture the markers on the participants. Participants were instructed to walk on the first one of three force plates (BP400600-2000, AMTI, Watertown, MA, USA) with their right foot and not place the walker wheels on the force plate.

For data analysis, we selected the gait cycle from the first initial contact of the right foot on the first force plate to the second initial contact of the right foot. Items measured were the maximum vertical ground reaction force per body weight (GRF/BW); gait velocity and stride length; the angle of the maximum trunk anterior tilt; the range of motion of the trunk and pelvis in the movement of obliquity, tilt, and rotation; and the amplitude of the center of mass (COM) in the vertical and lateral directions. We defined the angle of the maximum trunk anterior tilt as the angle formed by trunk segment calculated by the three-dimensional motion analysis system and the absolute horizontal axis of the room calculated before the measurement. We use the word obliquity to refer to the movement in the frontal plane, tilt as the movement in the sagittal plane, and rotation as the movement in the horizontal plane (Fig. 1). Representative values were calculated using the average from three trials in each condition.

We performed a one-way analysis of variance for each measurement item, followed by post hoc multiple comparisons using SPSS v. 20.0 (IBM, Chicago, IL, USA); values of $p < 0.05$ were considered to be significant.

RESULTS

Significant differences were observed among all conditions ($p < 0.01$) in the angle of the maximum trunk anterior tilt increasing with rUB. The mean value was $6.7 \pm 7.1°$ with 0%, $13.6 \pm 5.8°$ with 10%, $21.7 \pm 4.9°$ with 20%, $26.1 \pm 5.8°$ with

J. Phys. Ther. Sci. Vol. 34, No. 4, 2022

270

30%, and 28.9 ± 5.7° with 40% rUB (Table 1A).

With 40% rUB (0.68 ± 0.11 m/s) and 30% rUB (0.71 ± 0.11 m/s), the velocity was significantly lower (p=0.025 and 0.014, respectively) than that with 0% (0.74 ± 0.09 m/s) (Table 1B). The stride was significantly larger (p=0.037) with 30% rUB (1.11 ± 0.09 m) than that seen with 0% (1.06 ± 0.06 m) (Table 1C).

With 0% rUB (5.4 ± 1.6°), the range of motion of the trunk tilt was significantly larger than that with 10% (4.1 ± 0.9°), 30% (4.0 ± 1.1°), and 40% (3.9 ± 1.0°) (p=0.036, 0.014, and 0.023, respectively). Approximately 4° of trunk tilt motion was observed with 10%, 20%, 30%, and 40% rUB.

Regarding the range of motion of the trunk obliquity, the mean value with 10% rUB (3.5 ± 0.9°) was significantly larger than that with 30 (2.9 ± 0.7°) and 40% rUB (2.9 ± 0.5°) (p=0.004 and 0.047, respectively). Furthermore, the mean value with 20% rUB (3.3 ± 0.8°) was significantly greater than that with 30% (p=0.033).

With 10% rUB (3.8 ± 1.1°), the range of motion of the trunk rotation was significantly lower than that with 0% (4.9 ± 1.5°) and 40% rUB (4.6 ± 1.3°) (p=0.023 and 0.049, respectively) (Table 2).
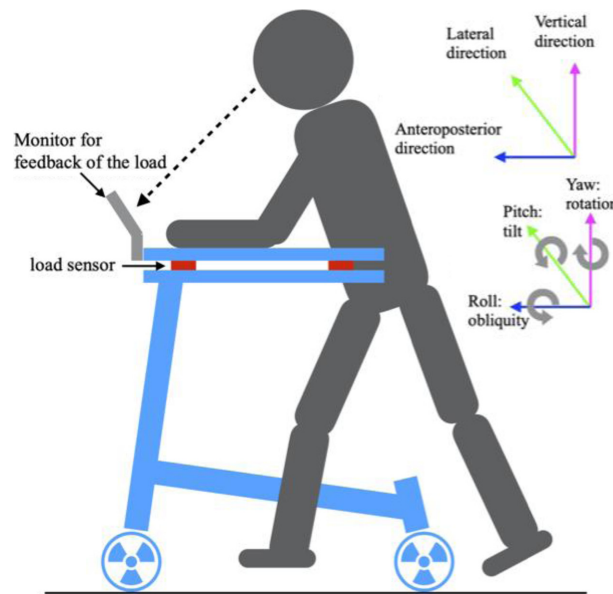

Fig. 1. Definitions of directions.

Table 1. (A) The angle of the maximum trunk anterior tilt, (B) velocity, and (C) stride

rUB	0% a	10% b	20% c	30% d	40% e	Post hoc
(A) (degrees)	6.7 ± 7.1	13.6 ± 5.8	21.7 ± 4.9	26.1 ± 5.8	28.9 ± 5.7	a>b, c, d, e** b>c, d, e** c>d, e** d>e**
(B) (m/s)	0.74 ± 0.09	0.72 ± 0.08	0.71 ± 0.08	0.71 ± 0.11	0.68 ± 0.11	a<e*; d<e*
(C) (m)	1.06 ± 0.06	1.07 ± 0.09	1.09 ± 0.08	1.11 ± 0.09	1.12 ± 0.11	a<d*

*p<0.05, **p<0.01.

Table 2. Range of motion of trunk movement

Movement	rUB					Post hoc
	0% a	10% b	20% c	30% d	40% e	
Tilt (degrees)	5.4 ± 1.6	4.1 ± 0.9	4.4 ± 1.0	4.0 ± 1.1	3.9 ± 1.0	a>b, d, e*
Obliquity (degrees)	3.2 ± 0.6	3.5 ± 0.9	3.3 ± 0.8	2.9 ± 0.7	2.9 ± 0.5	b>d, e** c>d*
Rotation (degrees)	4.9 ± 1.5	3.8 ± 1.1	4.0 ± 1.3	4.3 ± 1.8	4.6 ± 1.3	a>b* b<e*

*p<0.05, **p<0.01.

No significant differences were observed among rUB with any directions of the range of motion in the pelvic movement. The mean degrees of motion in the pelvic tilt, obliquity, and rotation were 3.9°, 6.8°, and 14.2°, respectively (Table 3).

With 0% rUB (17.4 ± 3.4 mm), the vertical amplitude of COM was significantly greater than that with any other condition (p<0.01). The value with 10% rUB (13.5 ± 2.6 mm) was also significantly higher than that with 20% (12.1 ± 2.2 mm), 30% (11.7 ± 2.9 mm), and 40% rUB (10.4 ± 3.2 mm) (p<0.05).

For the lateral amplitude of COM, 0% rUB (52.4 ± 18.1 mm) showed a significantly greater value than that with any other condition, and 10% rUB (41.8 ± 13.2 mm) showed a significantly greater value than that with 30% (33.1 ± 11.3 mm) and 40% rUB (29.8 ± 13.7 mm) (Table 4).

DISCUSSION

This study examined changes in the gait of healthy young people assisted by a wheeled upright walker, elicited by different loads on the upper extremities. This information will be helpful in identifying which elements of movement during a walker's gait are restricted or augmented by the load on the upper extremities when developing a robotic gait assistive device.

This study showed that gait with a wheeled upright walker restricted most aspects of an individual's movement except for pelvic movement and stride. Some studies previously reported that the trunk tilt range of motion varied from 2.0° to 12.6° during normal gait with no limitation of the arm swing[14]. In our results, compared with 0% rUB, the range of motion of the trunk tilt decreased with 10%, 30%, and 40% rUB. However, approximately 4° of movement was observed in every condition despite the increased maximum anterior tilt of the trunk anterior. These observations indicate that the trunk moves back and forth in the walker to some degree during the gait cycle. With 10% rUB, the trunk tilt and rotation range decreased, but obliquity increased. Participants could have retained some lateral trunk movement when the load on the upper extremities was slight, such as with 10% rUB. As the rUB increased and the lateral trunk movement was restricted, rotation of the trunk might be needed as an alternative. Krebs et al.[14] reported that during an average level gait the mean range of trunk obliquity was 5.4° and rotation was 9.0°. However, the values we obtained were lower than these results. Notably, trunk rotation showed a V-shaped curve. Participants should make their trunk rigid to transfer the load to the upper extremities; however, as rUB increases, participants might also need to rotate their pelvis and trunk further to maintain their stride. Though our results showed statistical significance in the range of the trunk movement in conditions, the difference was slight. We emphasize that immobilization of the upper extremities during wheeled upright walker-assisted gait restricts trunk movement, especially in obliquity and rotation.

During standard, level gait, the vertical displacement of COM is approximately 45 mm[15]. Our results showed that the vertical amplitude of COM was less than this, at 17.4 mm, even with 0% rUB. With rUB of 20% or over, a significant decrease in the vertical amplitude of COM occurred. We suspect that the restricted range of motion in trunk obliquity and rotation was a factor that constrained the vertical amplitude of COM. The mean value of the lateral amplitude of COM with 0% rUB in this study was 52.4 mm, which is similar to the reported value for normal gait. However, the lateral amplitude of COM seemed to be limited with 20% or over rUB. As the load on the lower extremities decreases, the vertical and lateral amplitudes of the COM might have resulted in being lower.

The wheeled upright walker's gait restricted the vertical and lateral amplitudes of COM with 20% or over rUB.

The angle of the maximum trunk anterior tilt significantly increased with increasing rUB. When using the upright walker, the load on an individual's lower extremities can be relieved by placing their forearms on the armrest of the walker. Okada

Table 3. Range of motion of pelvic movement

Movement	rUB					
	0%	10%	20%	30%	40%	Mean
Tilt (degrees)	4.2 ± 2.6	4.1 ± 1.3	3.9 ± 1.0	3.5 ± 0.9	3.9 ± 1.9	3.9 ± 0.3
Obliquity (degrees)	6.9 ± 2.0	6.4 ± 3.1	6.6 ± 2.0	6.6 ± 2.1	7.4 ± 1.8	6.8 ± 0.4
Rotation (degrees)	14.8 ± 4.5	13.6 ± 3.3	14.0 ± 2.3	14.3 ± 3.5	14.2 ± 3.6	14.2 ± 0.4

Table 4. The amplitude of center of mass (COM)

Direction	rUB					
	0% a	10% b	20% c	30% d	40% e	Post hoc
Vertical (mm)	17.4 ± 3.4	13.5 ± 2.6	12.1 ± 2.2	11.7 ± 2.9	10.4 ± 3.2	a>b, c, d, e** b>c, d, e**
Lateral (mm)	52.4 ± 18.1	41.8 ± 13.2	35.3 ± 12.4	33.1 ± 11.3	29.8 ± 13.7	a>b, c, d, e** b>d, e**

*p<0.05, **p<0.01.

J. Phys. Ther. Sci. Vol. 34, No. 4, 2022

272

et al.[16] reported that the degree of the anterior trunk tilt and the armrest load were almost directly proportional when using a wheeled upright walker with armrests. In our study, the trunk was tilted anteriorly at 13.6° with 10% rUB and 28.9° with 40% rUB, which could be challenging to describe as a proportional relationship. Our results seemed to differ from those of Okada and colleagues because they measured the trunk tilt angle without provisions of the arm position. In contrast, in our experiment the participants were forced to bear the load on their forearms in the same place during gait, thus keeping the load fixed. However, we should carefully consider that the anterior trunk tilt could suggest the quantity of the load on the armrest during gait while using a wheeled upright walker.

With 30% rUB, the gait velocity was significantly lower compared with 0% rUB, while the stride was significantly increased. During gait using a wheeled upright walker, the force from the load on the upper extremities can be divided into two vectors: anterior elements that assist the tires of the walker to move forward and downward factors that increase the friction between the tires and floor. The increased trunk anterior tilt is thought to have enhanced the downward force. The stride must in turn be longer to maintain the same velocity.

The rotation of the pelvis plays an important role in lengthening the stride. A previous study on human walking stated that the total range of motion of the pelvic tilt in the sagittal plane is usually reported to be 4°, obliquity in the frontal plane to be 4°, and rotation in the transverse plane to be 10°[15]. In our study, the mean range of motion of the pelvis under all conditions was approximately 3.9° and 6.8° in the sagittal and frontal planes, respectively, which is similar to normal walking. Meanwhile, the mean value for pelvic rotation was 14.2°, which was far higher than the reported normal range of 8°.

Several authors have emphasized the importance of pelvic movements in human gait[4, 12, 15]. One of the essential functions of the pelvis is to produce a forward rotation on the swinging leg and an opposite rotation in the terminal stance phase. The increase of the pelvic rotation seen in this study might be an alternative strategy to maintain forward propulsion. Our results revealed that pelvic movement was not reduced even when using the walker; on the contrary, the range of pelvis rotational motion was surprisingly higher than that seen during the standard gait. These results can be used as indicators for the development of a robotic-assistive device system, which controls pelvic motion during walking while using a wheeled walker.

To inspect the movement of the pelvis during gait while using a wheeled upright walker, we asked our healthy participants to imitate patients who need an assistive device while walking. One of the limitations of this study was that the simulated gait did not represent exactly the gait of actual patients. However, we could reveal that our hypothesis was correct, i.e., that pelvic movement would occur to some extent even when using a wheeled upright walker. In future studies, we should examine the human force and torque used to control the pelvis during gait with a wheeled upright walker, because the pelvis was clearly able to move in the walker. The recruitment of more participants, including elderly persons, would be helpful to clarify the characteristics of gait while using a wheeled walker. This study represents a first step in developing a robotic-assistive walker in the future.

Conference presentation

Okada J, Jeong S, Aoyama H, et al.: Clinical significance of upper limb dependence measurement in walking training. LIFE2018, 2018 (Sep. 6 −8), Tokyo, Japan.

Aoyama H, Hori H, Yonenobu K, et al.: The movement of trunk and pelvis in the rolling stand-up walker: Primary research for the exploitation of rehabilitation walker. 19th International Conference on Control, Automation and Systems (ICCAS 2019), 2019 (Oct. 15–18), Jeju, Korea.

Conflicts of interest

The authors have no conflict of interest.

REFERENCES

1) Colombo G, Joerg M, Schreier R, et al.: Treadmill training of paraplegic patients using a robotic orthosis. J Rehabil Res Dev, 2000, 37: 693–700. [Medline]

2) Ichinose WE, Reinkensmeyer DJ, Aoyagi D, et al.: A robotic device for measuring and controlling pelvic motion during locomotor rehabilitation. Proceedings of the 25th Annual International Conference of the IEEE Engineering in Medicine and Biology Society, 2003, 2: 1690–1693.

3) Weber LM, Stein J: The use of robots in stroke rehabilitation: a narrative review. NeuroRehabilitation, 2018, 43: 99–110. [Medline] [CrossRef]

4) Veneman JF, Menger J, van Asseldonk EH, et al.: Fixating the pelvis in the horizontal plane affects gait characteristics. Gait Posture, 2008, 28: 157–163. [Medline] [CrossRef]

5) Schück A, Labruyère R, Vallery H, et al.: Feasibility and effects of patient-cooperative robot-aided gait training applied in a 4-week pilot trial. J Neuroeng Rehabil, 2012, 9: 31. [Medline] [CrossRef]

6) Alkjaer T, Larsen PK, Pedersen G, et al.: Biomechanical analysis of rollator walking. Biomed Eng Online, 2006, 5: 2. [Medline] [CrossRef]

7) Shin E, Jeon B, Song B, et al.: Analysis of walker-aided walking by the healthy elderly with a walker pocket of different weights attached at different locations. J Phys Ther Sci, 2015, 27: 3369–3371. [Medline] [CrossRef]

8) Fast A, Wang FS, Adrezin RS, et al.: The instrumented walker: usage patterns and forces. Arch Phys Med Rehabil, 1995, 76: 484–491. [Medline] [CrossRef]

9) Viegas V, Pereira JD, Postolache O, et al.: Spy walker: a convenient way to assess gait in walker assistive devices. IEEE International Instrumentation and Measurement Technology Conference (I2MTC), 2018, pp. 1–6.

10) Aoyagi D, Ichinose WE, Harkema SJ, et al.: A robot and control algorithm that can synchronously assist in naturalistic motion during body-weight-supported

gait training following neurologic injury. IEEE Trans Neural Syst Rehabil Eng, 2007, 15: 387–400. [Medline] [CrossRef]

11) Koceska N, Koceski S: Review: robot devices for gait rehabilitation. Int J Comput Appl, 2013, 62: 1–8.

12) Mun KR, Guo Z, Yu H: Restriction of pelvic lateral and rotational motions alters lower limb kinematics and muscle activation pattern during over-ground walking. Med Biol Eng Comput, 2016, 54: 1621–1629. [Medline] [CrossRef]

13) Saunders JB, Inman VT, Eberhart HD: The major determinants in normal and pathological gait. J Bone Joint Surg Am, 1953, 35-A: 543–558. [Medline] [Cross-Ref]

14) Krebs DE, Wong D, Jevsevar D, et al.: Trunk kinematics during locomotor activities. Phys Ther, 1992, 72: 505–514. [Medline] [CrossRef]

15) Perry J: Gait analysis: normal and pathological function. West Deptford: SLACK Incorporated, 1992, pp 131–140.

16) Okada J, Jeong S, Aoyama H, et al.: Clinical significance of upper limb dependence measurement in walking training. LIFE2018, 2018, 1: 1–2.

J. Phys. Ther. Sci. Vol. 34, No. 4, 2022

274