J. Phys. Ther. Sci. 29: 16–19, 2017

The Journal of Physical Therapy Science

Original Article

Changes in postural strategy during exercise against perturbation using the balance exercise assist robot: a pilot study

Norihide Itoh, RPT, DMSc[1–3)*], Shigeo Tanabe, RPT, PhD[3)], Satoshi Hirano, MD, DMSc[4)], Eiichi Saitoh, MD, DMSc[4)], Jumpei Kawabata, RPT[5)], Daisuke Imoto, RPT[2)], Yasuo Mikami, MD, PhD[2)], Toshikazu Kubo, MD, PhD[1, 2, 6)]

1) Department of Advanced Rehabilitation Medicine, Graduate School of Medical Science, Kyoto Prefectural University of Medicine: 465 Kajii-cho, Kawaramachi-Hirokoji, Kamigyo-ku, Kyoto 602-8566, Japan
2) Department of Rehabilitation Medicine, Graduate School of Medical Science, Kyoto Prefectural University of Medicine, Japan
3) Faculty of Rehabilitation, School of Health Sciences, Fujita Health University, Japan
4) Department of Rehabilitation Medicine I, School of Medicine, Fujita Health University, Japan
5) Department of Rehabilitation, Fujita Health University Hospital, Japan
6) Department of Orthopaedics, Graduate School of Medical Science, Kyoto Prefectural University of Medicine, Japan

Abstract. [Purpose] To clarify the changes in postural strategy by evaluating leg joint motion and muscle activity before and after continuous exercise against perturbation using the Balance Exercise Assist Robot (BEAR). [Subjects and Methods] Nine healthy subjects (male 7, female 2; mean age 23 ± 1 years) performed a postural perturbation coping exercise only. In the task, the robot leaned and moved automatically. Participants were instructed to maintain their default upright position and they performed the exercise five times in a row (1 minute/trial). Changes in total movement distance, range of motion of each joint (hip, knee, ankle), and mean activity of each muscle for the first and fifth trials were compared. [Results] The total movement distance of BEAR and range of motion in the hip decreased significantly from the first trial to the last trial. No change in muscle activity was observed in the rectus femoris, biceps femoris, tibialis anterior or gastrocnemius. [Conclusion] The results for exercise against perturbation using BEAR in this study suggest that BEAR may be a promising method to improve the ankle strategy for maintaining a standing posture.

Key words: Robot, Rehabilitation, Postural balance

(This article was submitted Aug. 9, 2016, and was accepted Sep. 14, 2016)

INTRODUCTION

Recently, a variety of gait and balance training equipment that employs robotic technology has been introduced[1–4)]. Robotic rehabilitation, compared with conventional practice tools, is highly useful in clinical practice as it can supply real-time data that permits immediate user feedback. We developed the Balance Exercise Assist Robot (BEAR) (Toyota Motor Corp., Toyota City, Japan) based on the personal transport assistance robot device ridden in the standing position (Fig. 1)[1)]. Ozaki et al. performed three types of balance training therapy using the BEAR in eight patients with central nervous system disorders and found that dynamic balance and leg strength improved after the tasks compared with baseline[1)]. However, the physical

*Corresponding author. Norihide Itoh (E-mail: nitoh@koto.kpu-m.ac.jp)

effects of BEAR have not been described. Therefore, this pilot study was designed to clarify the changes in postural strategy during exercise against perturbation using BEAR by evaluating leg joint motion and muscle activity.

SUBJECTS AND METHODS

Nine healthy subjects (male 7, female 2; mean age 23 ± 1 years; height 171.8 ± 7.1 cm; weight 60.0 ± 7.4 kg) participated in this study. No subject had a history of neurological or orthopedic disease, or experience of exercise using the BEAR. All subjects provided written informed consent for the experimental procedure, which was approved by the human ethics committee of Fujita Health University (No. 15-148). This study was performed in accordance with the Declaration of Helsinki.

Participants performed a postural perturbation coping exercise only. In the task, the robot leaned and moved automatically (sinusoidal wave with a frequency of 0.5 Hz and amplitude of 4°). Participants were instructed to maintain their default upright position and they performed the exercise five times in a row (1 minute/trial). In the first and fifth trials, the total movement distance of the BEAR was calculated. In addition, joint angles (hip flexion/extension, knee flexion/extension, and ankle dorsiflexion/plantar flexion) and muscle activity of the lower extremities were measured during both trials.

The total movement distance of the robot was calculated from the coordinate information on the computer. All data for joint angles and electromyography (EMG) were measured on the right leg. Measurement time was fixed at 60 sec. Motion data of the lower extremity was collected with the KinemaTracer motion analysis system (KISSEI COMTEC Co., Ltd., Matsumoto, Japan) with four 60 Hz cameras. Each participant had five markers placed on their right leg to define the joint center and axes of motion: (1) on the acromia; (2) one-third distance from the great trochanter on a line joining the anterior superior iliac spine and great trochanter; (3) midpoint of the anteroposterior diameter of the lateral femoral epicondyle; (4) lateral malleolus; and (5) fifth metatarsal head. Each angle of hip, knee and ankle joint was calculated as the motion of the distal segment relative to the proximal segment. To obtain an accurate estimate of the individual ensemble average, 29 cycles were averaged and a normalized perturbation cycle was set at 200 points. For time-normalized data, the individual joint motions of the lower limb were averaged for each subject to obtain an ensemble average for every subject at each joint of motion.

Surface EMG data were collected simultaneously from the rectus femoris, biceps femoris long head, anterior tibialis and gastrocnemius. The myoelectric signals were amplified 1,000-fold, filtered with a 0.03 Hz low-cut analog filter, and telemetered via a multichannel biotelemetry system (WEB-5000, Nihon Kohden Corp., Tokyo, Japan). Data acquisition was performed using a DAQ measurement system (USB-6229, National Instruments Japan Corp., Tokyo, Japan). The EMG data were recorded at a sampling frequency of 1.8 kHz and were band pass filtered between 10 and 500 Hz to remove low frequency motion artifact and high frequency noise via a third-order Butterworth filter using LabVIEW 8.5 custom-made software (National Instruments Japan Corp., Tokyo, Japan). Subsequently, the data were processed for rectification and integrated per 20 msec and quantified for electromyogram intensity as percent of maximum voluntary contraction (%MVC).

Changes in total movement distance, range of motion of each joint (hip, knee, ankle), and mean activity of each muscle (rectus femoris, biceps femoris, tibialis anterior, gastrocnemius) for the first and fifth trials were compared using the Wilcoxon signed rank test. The significance level was set at $p<0.01$. SPSS version 21 (IBM Corp., NY, USA) was used for statistical analyses.

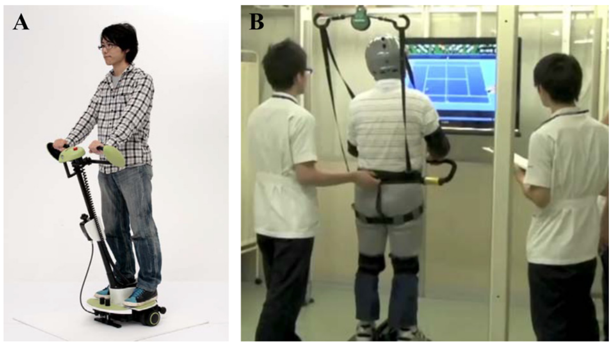

Fig. 1. BEAR system
A) Personal transport assistance robot used in the system
B) Whole apparatus (the robot, LCD screen, and harness)

RESULTS

Table 1 shows all the results. The total movement distance of BEAR decreased significantly from the first trial to the last trial (p=0.008), and the range of motion in each joint also decreased between the first and last trials. However, the change in range of motion was only statistically significant for the hip joint. For all of the muscles tested, the %MVCs in the fifth exercise trial were slightly lower than in the first trial, although none of these differences were statistically significant.

DISCUSSION

In this study, changes in postural strategy during a perturbation coping exercise were examined using BEAR. A comparison of the first and fifth exercise trial showed that the total movement distance of BEAR decreased; this suggests that users improved their performance of maintaining standstill over the repeated trials of the exercise. This robot, which adopts the inverted pendulum control, follows the center of gravity of the movement of the user. If the user can compensate for the postural perturbation caused by BEAR, the total movement distance of the robot decreases.

Although the range of motion of all measured joints of the lower limbs tended to decrease, a significant difference was seen only for the hip joint. Ankle and hip movements are considered to play an important role in adjusting standing balance. These methods of control are called the ankle strategy and hip strategy, respectively[5)]. The two strategies are not independent, but rather function by adjusting in relation to one another based on the extent of postural sway. The hip strategy is employed in accordance with the necessary ankle torque concomitant with the ankle strategy[6)].

Between the first and fifth trials, change in range of motion of the ankle joint was minimal and less than that observed at the hip. After repeated exposure to the perturbation trial, subjects tended to achieve an optimal standing posture; although the postural strategy was mixed (hip and ankle) at the beginning of the experiment, with repeated trials, hip motion was reduced and movement converged mostly to the ankle joint. Woollacott et al.[7)] reported that as exposure to a horizontally displaced platform was repeated, the postural sway of subjects became less, that is, the amplitude of the postural response became smaller. Corna et al.[8)] have reported that, with continuing severe perturbation on a moving platform, shaking of the body is gradually reduced, so that it becomes easier for the subject to resist. This result for lower limb motion is similar to those of the posture change in our study.

There was a trend toward reduced muscle activity in the four recorded muscles, but none of the changes were statistically significant. This may be because the muscle activity values were less than 10% of the MVC and it is possible that the influence of ‘noise’ masked detection of changes.

Once proficient in the exercise against perturbation using BEAR, the subject does not require a large torque to counter the perturbation and is able to control their center of gravity in the upright position. In addition, after mastering the perturbation task, subjects achieved standing posture control primarily via the ankle joint. The exercise against perturbation using BEAR was expected to reveal an effect on the ankle strategy for standing posture control.

A number of limitations of this study warrant mention. Firstly, it is possible that holding the BEAR handle might influence the process by which subjects reacquire their balance ability. Therefore, it will be necessary to examine the motion not only of the lower limbs but also the upper limbs, trunk and head. Secondly, the minimal joint movement and muscle activity measured in the study may have been because subjects anticipated the degree of perturbation by BEAR because the same intensity was used for practice and the trial. Therefore, our results may not reflect the full magnitude of change in posture control. Finally, the main targets of balance training in the clinical setting are the elderly and patients with balance disorders. However, our

Table 1. Results for total movement distance of BEAR, range of motion and percent of maximum voluntary contraction (%MVC)

Variable	First trial	Last trial	p value
Total movement distance (m)	11.53 ± 2.78	7.27 ± 2.16	0.008
Range of motion (degrees)			
Hip joint	12.1 ± 4.5	8.1 ± 2.6	0.008
Knee joint	3.7 ± 2.9	2.2 ± 0.8	0.028
Ankle joint	11.3 ± 2.7	9.6 ± 1.4	0.011
%MVC (percent)			
Rectus femoris	2.36 ± 1.62	1.79 ± 1.06	0.075
Biceps femoris	2.82 ± 1.46	1.99 ± 1.13	0.075
Tibialis anterior	3.69 ± 2.85	2.78 ± 2.18	0.038
Gastrocnemius	8.45 ± 3.94	7.23 ± 4.03	0.066

Values are mean ± SD.

study subjects were healthy young people who may have different posture control abilities to a patient population[9, 10].

In conclusion, the results of our study indicate that exercise against postural perturbation using BEAR may be a suitable method to enhance the ankle strategy for maintaining an upright posture.

ACKNOWLEDGEMENTS

We would like to offer our special thanks to the members of Toyota Motor Corporation, who provided a Balance Exercise Assist Robot for this research. The study was supported in part by JSPS KAKENHI Grant Number 25350637, as well as by a research grant from Toyota Motor Corporation.

REFERENCES

1) Ozaki K, Kagaya H, Hirano S, et al.: Preliminary trial of postural strategy training using a personal transport assistance robot for patients with central nervous system disorder. Arch Phys Med Rehabil, 2013, 94: 59–66. [Medline] [CrossRef]
2) Colombo G, Wirz M, Dietz V: Driven gait orthosis for improvement of locomotor training in paraplegic patients. Spinal Cord, 2001, 39: 252–255. [Medline] [CrossRef]
3) Wong CK, Bishop L, Stein J: A wearable robotic knee orthosis for gait training: a case-series of hemiparetic stroke survivors. Prosthet Orthot Int, 2012, 36: 113–120. [Medline] [CrossRef]
4) Aach M, Cruciger O, Sczesny-Kaiser M, et al.: Voluntary driven exoskeleton as a new tool for rehabilitation in chronic spinal cord injury: a pilot study. Spine J, 2014, 14: 2847–2853. [Medline] [CrossRef]
5) Horak FB, Nashner LM: Central programming of postural movements: adaptation to altered support-surface configurations. J Neurophysiol, 1986, 55: 1369–1381. [Medline]
6) Runge CF, Shupert CL, Horak FB, et al.: Ankle and hip postural strategies defined by joint torques. Gait Posture, 1999, 10: 161–170. [Medline] [CrossRef]
7) Woollacott MH, von Hosten C, Rösblad B: Relation between muscle response onset and body segmental movements during postural perturbations in humans. Exp Brain Res, 1988, 72: 593–604. [Medline] [CrossRef]
8) Corna S, Tarantola J, Nardone A, et al.: Standing on a continuously moving platform: is body inertia counteracted or exploited? Exp Brain Res, 1999, 124: 331–341. [Medline] [CrossRef]
9) Woollacott MH, Shumway-Cook A: Changes in posture control across the life span—a systems approach. Phys Ther, 1990, 70: 799–807. [Medline]
10) Horak FB, Henry SM, Shumway-Cook A: Postural perturbations: new insights for treatment of balance disorders. Phys Ther, 1997, 77: 517–533. [Medline]