Case Report

A Patient with Concomitant Myelopathy-associated Balance Impairment and Cognitively-impaired- not-demented Status for Whom Robot-based Rehabilitation was Effective

Yasuo Mikami *[1], Yuji Arai[2], Suzuyo Ohashi[1], Koshiro Sawada[1]
Norihide Itoh[3], Kazuya Ikoma[4] and Toshikazu Kubo[1-4]

[1]*Department of Rehabilitation Medicine,*
Kyoto Prefectural University of Medicine Graduate School of Medical Science
[2]*Department of Sports and Para-Sports Medicine,*
Kyoto Prefectural University of Medicine Graduate School of Medical Science
[3]*Department of Advanced Rehabilitation Medicine,*
Kyoto Prefectural University of Medicine
[4]*Department of Orthopaedics,*
Kyoto Prefectural University of Medicine Graduate School of Medical Science

Abstract: Robot rehabilitation using a Balance Exercise Assist Robot (BEAR) was performed in a patient with concomitant myelopathy-associated balance impairment and cognitive impairment. Balance improved, showing the efficacy of BEAR for this patient. Verbal instructions by a therapist was required to play a tennis game among the programs performed, but skiing and rodeo games were intuitively easy for the patient to understand. This suggests that these games are useful exercise tasks for patients with cognitive impairment.

Key Words: Robot rehabilitation, Cognitive impairment, Balance, Myelopathy.

Introduction

As Japan has become a super-aging society, there has been an increase in the number of patients with motor system diseases, such as joint, vertebral and spinal cord diseases[1)2)]. Cognitive impairment has also increased, and patients with both diseases have become common[3)]. In these patients, there are greater risks of fall, fracture, and a bedridden status due to marked decline of balance[4-6)], and it is important to maintain activities of daily living (ADL) by training for maintenance and improvement of balance. Such rehabilitation treatment includes stretching and muscle strengthening exercises, sensory input training, balance control training, task-oriented training, vestibular sensory training, patient education, and injury prevention guidance[7)]. Balance control training can improve sway of the center of gravity[8)], but conventional methods

Received: April 4, 2018. Accepted: June 8, 2018
* Correspondence to Yasuo Mikami 465 Kajii-cho, Kawaramachi-Hirokoji, Kamigyo-ku, Kyoto, 602-8566, Japan
mikami@koto.kpu-m.ac.jp

have difficulties with adjustment of the level for individual patients, small movements, and the boring nature of the training. Moreover, the core symptoms of cognitive impairment and behavioral and psychological symptoms are problematic in rehabilitation treatment[9]. Originality is needed for effective balance control training in these patients.

Ozaki et al. developed a Balance Exercise Assist Robot (BEAR) for balance control training that can be adjusted in difficulty level in steps[10]. Patients operate the standing-ride type self-propelled robot and move a character presented on a monitor screen under the guidance of a therapist, so that they can continue training while having fun. Ozaki et al. performed rehabilitation using BEAR in 8 patients (mean age: 50 years old) with impaired walking function due to central nervous system (CNS) disease and showed improvement of balance evaluation items, such as tandem gait speed, Functional Reach Test, functional base of support, and lower extremity muscle strength[10]. In another study, the same items were shown to have significantly improved in frail elderly subjects (mean age: 73 years old) treated with BEAR, compared to similar subjects who received conventional rehabilitation[11]. Furthermore, Itoh et al. found that postural perturbation coping exercise using BEAR decreased robot movement and range of motion of the hip joint in 9 healthy volunteers (mean age: 23 years old)[12], clarifying that BEAR can control posture through an ankle strategy[12].

We encountered a patient with concomitant myelopathy-induced balance impairment and cognitive impairment for whom balance control training using BEAR was possible and led to improvement of balance function.

Patient

The patient was a 69-year-old woman with a chief complaint of gait disturbance. She started having difficulty with walking at about 50 years old and became aware of muscle weakness and hypesthesia of the bilateral lower limbs at 56 years old. Sensory disturbance of the bilateral lower limbs aggravated to ataxic gait at 60 years old, and she visited our hospital. The patient was diagnosed with ossification of the cervical and thoracic posterior longitudinal ligament and treated with laminoplasty (T1-5) and posterior fusion (C5-T5). After surgery, spasticity of the lower limbs and numbness of the feet remained, but muscular strength and hypesthesia improved, and the patient became able to walk for a short distance using canes. However, at 68 years old, 12 years after surgery, disturbance of the spinal pyramidal tract occurred, although without progression of the compression for the spinal cord, and persisted due to aging and reduced activity. This manifested as disturbance of balance and marked reduction of walking function. The patient was admitted for robot-based rehabilitation at 69 years old. Her medical history included surgeries for breast cancer, ovarian cancer, and lung cancer at 50, 60, and 68 years old, respectively. She had no experience of skiing, horse riding, or tennis, which were included in the robot rehabilitation program.

Findings on admission

Height was 161 cm and body weight was 58 kg. Muscle strength evaluation using MMT right/left) was bilateral hip flexion, 4/4; extension, 4/4; abduction, 4/4; adduction, 5/5; knee flexion, 4/4; extension, 5/5; ankle dorsiflexion, 5/5; plantar flexion, 5/5. A sensory evaluation showed normal superficial and deep sensations, but numbness in the bilateral toes. Patella tendon and Achilles tendon reflexes were enhanced, and a Romberg test was positive. The patient could walk indoors while holding on to something and could move while pushing a walker outdoors, but her walking distance was short. Standing on one leg was not possible on either side.

Communication was favorable, but the patient appeared to be absent-minded. Her Mini Mental State Examination (MMSE) score was 27/30, which is within the normal range, but her Frontal Assessment Battery (FAB) score was 12/18, showing a decline of executive function, and her Behavioral Assessment of Attentional Disturbance (BAAD) score was 6/18, indicating attention disorder. No hemorrhage, infarction, space-occupying lesion, or hippocampal atrophy was noted on head MRI. In an analysis using a voxel-based specific regional analysis system for Alzheimer's Disease, the volume of interest was 0.79 and there was no atrophy of the parahippocampal gyrus. Therefore, the patient was diagnosed with cognitively-impaired-not-demented status.

BEAR

BEAR is a robot based on a 'Winglet' standing-ride type personal mobility vehicle made by Toyota Motor Corporation[10). Inverted pendulum control by two in-wheel motors on the left and right controls the robot so as to retain the rider's posture in an upright position, using a sensor to detect the posture (Fig. 1). Accordingly, the robot moves in the anteroposterior direction when the rider moves their center of the gravity in the anteroposterior direction, and rotates when the center of gravity moves in the lateral direction. Since a shift of the center of gravity is reflected in movement of the robot, this shift can be visualized, which is useful for feedback to the user. In addition, parameters of the robot and games are adjustable so that balance practice can be performed at the optimum difficulty level for each patient.

Protocol of robot rehabilitation

Practice of balance using BEAR was performed 4 days a week for 2 weeks (8 days in total). The training time per day was 3 periods of 40 min each (120 min in total). Within a 40-minute training session, a game, warm up, preparation of the practice environment, vital sign measurement, stretching, and rest were performed under the guidance of a physical therapist. Three games (tennis, skiing, and rodeo) were played (Fig. 2). A video of each game was presented on the monitor screen, and the patient performed balance training through moving the standing-ride type robot. Each game program included 4 games with a dura-

Fig. 1. Balance Exercise Assist Robot (BEAR)
Since a shift of the center of gravity is reflected in movement of the robot, this shift can be visualized on the monitor screen.

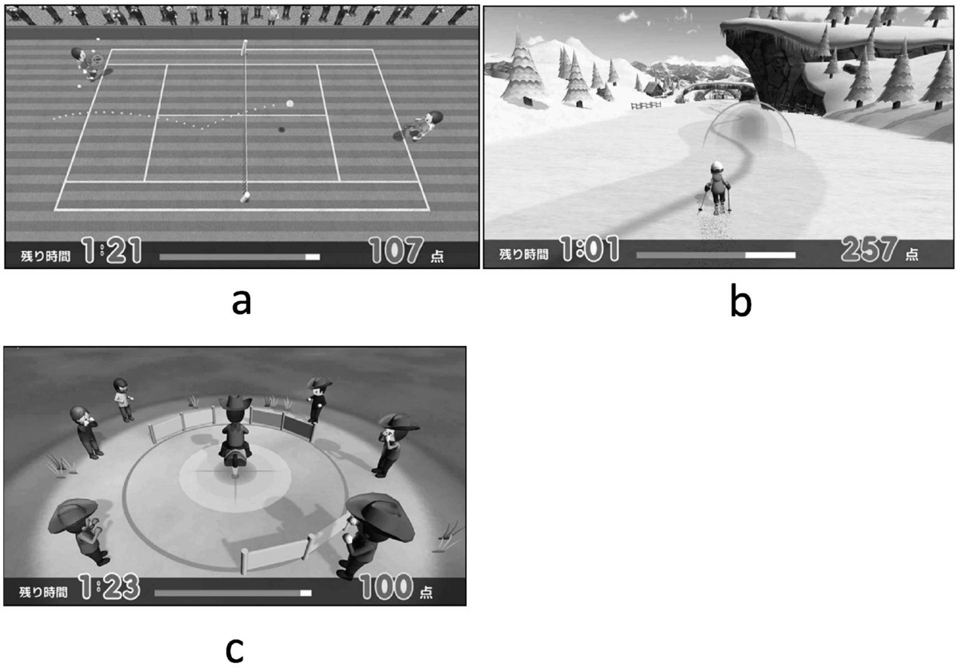

Fig. 2. Monitor screen of BEAR
a) tennis game, b) skiing game, c) rodeo game

tion of 90 s per game, and 12 games were performed each day (a total of 96 sessions in 8 days). Each program started at level 1, and the difficulty level rose or fell in the following session if the game task success rate was ≥70% or ≤40%, respectively, during the balance practice.

Method for each game and adjustment of difficulty level

In the tennis game, the target moves in the anteroposterior direction to reach the ball in time and hit it back to the opponent. The difficulty level was adjusted by changing the speed of the ball and the width of the racket. The speed of the ball gradually increases and the racket width becomes smaller as the difficulty level rises. The skiing game requires passing through the center of gates on a course by rotation in the lateral direction on the screen by scrolling forward. The difficulty level was adjusted based on the number and position of the gates. In the rodeo game, erratic motion randomly occurs 16 times within a 90-second period and the user tries to retain a fixed position. The difficulty level was adjusted based on the foot plate inclination angle and period of inclination during motion. Erratic motion occurs in the anteroposterior direction only up to level 15 and also in the lateral direction at higher levels.

Evaluation items

The level of each game was recorded and time-course changes until the 96th (final) game were evaluated. The Berg Balance Scale, lower limb muscle strength, Functional Reach Test, Timed Up and Go Test, gait steps were evaluated before and after training.

Results

Changes in game level

The patient was able to perform all 96 games (Fig. 3). No aggravation of neurologic manifestation or complications such as fall occurred during training. Each game level did not improve for 2 days (24 games in total) after initiation of robot rehabilitation, but then the skiing game level continuously increased until 8 days. The rodeo game level continuously increased until 5 days after initiation up to level 15, with erratic motion in the anteroposterior direction only, but only slightly improved thereafter after inclusion of motion in the lateral direction. The tennis game level did not improve for 5 days after initiation. The patient continued to practice this game with verbal guidance of the physical therapist, and the level then continuously increased until 8 days after initiation of treatment.

Changes in balance function

The score on the Berg Balance Scale improved from 35 before training to 39 after training, with improvements in retention of standing position, functional reach, stepping up and down on a footstool, and one-leg standing, but no change in lower limb muscle strength (Table 1). The distances on the Functional Reach Test improved from 22 cm on the left and 22.5 cm on the right before training to 27 cm and 30.5 cm, respectively, after training. Time on the Timed Up and Go Test was reduced from 92.57 s before training to 86.08 s after training. The patient could not perform accurate tandem gait after training, even with use of canes. At one month after completion of training, the Berg Balance Scale was 37, functional reach was 24 cm on the left and 25 cm on the right, and the time on the Timed Up and Go Test was 102.39 s, showing that the improvement in balance function had decreased.

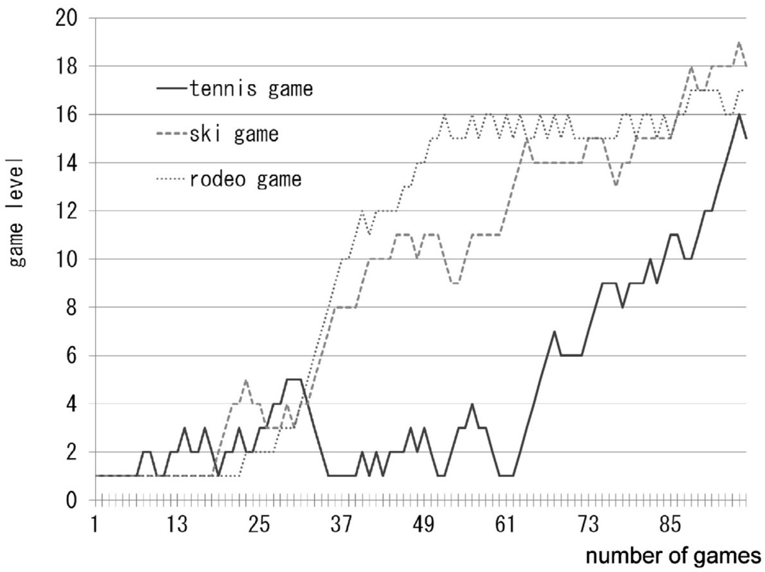

Fig. 3. Changes in game level
Each game was evaluated until the 96^{th} session.

Table 1. Changes in balance function
Berg Balance Scale, Functional Reach Test and Timed Up and Go Test

	before robot rehabilitation	after robot rehabilitation
Berg Balance Scale	35	39
Sitting unsupported	4	4
Change of position: sit to stand	4	4
Change of position stand to sit	4	4
Transfers	4	4
Standing unsupported	2	3
Standing with eyes closed	4	4
Standing with feet together	3	3
Tandem standing	0	0
Standing on one leg	0	1
Turning trunk (feet fixed)	2	2
Retrieving objects from floor	4	4
Turning 360 degrees	1	1
Stool stepping	0	1
Reaching forward while standing	3	4
Functional Reach Test（cm） left side	22	27
right side	22.5	30.5
Timed up and Go Test（sec）	92.6	86.1

Discussion

Balance is defined as control of body mass within the base of support, and is exerted through interactions among many elements, including the musculoskeletal system, sensory function (visual, somatic, and vestibular sensations), sensory integration, and cognitive function. Impairment of these elements causes a decline in balance function and increases the risk of fall[4-6]. Since our patient had cognitively-impaired-not-demented status, as well as spasticity of the lower limbs and decreased lower limb muscle strength due to myelopathy and sensory disturbance in the plantar region, her balance was further decreased and she had a markedly increased risk of fall. Rehabilitation was necessary, but this was likely to be difficult if the patient was unable to understand the objective of each program or perform the treatment. This difficulty is common in patients with cognitive impairment due to core symptoms such as memory impairment, attention disorder, visual perception impairment, speech impediment, executive function disorder, apraxia, and decline of judgment capacity; and behavioral psychological symptoms such as depression, insomnia, anxiety, loss of motivation, misidentification, irritation, restlessness, loitering, violence, abusive words, hallucination, and delusion[9]. In our patient, the FAB score was 12/18, showing a decline of executive function, and the BAAD score was 6/18, showing attention disorder. However, exercise therapy may reduce the decline in physical functions (strength, balance, mobility, endurance) in patients with mild cognitive impairment[13][14] . Therefore, we considered that exercise therapy that takes cognitive function into consideration may improve balance function.

There has been recent progress in development of robot-supported rehabilitation treatment[15-17]. Robots can assist training performed by therapists through accurate repetitive assistance with motion and automatic adjustment of assistance for lack of muscle strength. In the present case, training was performed using BEAR for robot-supported balance control training. BEAR shifts the center of gravity in the anteroposterior and lateral directions by adjusting various muscle activities around the ankles, knees, and hip joints to overcome impaired balance[10]. Game properties are incorporated to make the training more enjoyable, and the difficulty level of games is automatically adjusted based on the results of the previous game, which facilitates effective motor learning. Our patient performed training by playing tennis, skiing, and rodeo games. She played these games 96 times over 8 days, and each game level improved, along with improvements in the Functional Reach Test and Timed Up and Go Test. Despite her cognitively-impaired-not-demented status, the patient was able to play the games on the screen as exercise tasks requiring meeting of a challenge, attentiveness, ability to concentrate, and memory. The Berg Balance Scale, Functional Reach Test, and Timed Up and Go Test were used for evaluation of balance function. In case reports, when changes in these items after treatment exceed the minimal detectable change 95 (MDC95), the treatment is judged to be effective. In patients with brain diseases (Parkinson's disease, cerebrovascular disorder, and dementia) and the elderly, the MDC95 for the Berg Balance Scale is 2-16.66, that for the Functional Reach Test is 4-12.64 cm, and that for the Timed Up and Go Test is 1.75-5 s[18-21], with the MDC95 markedly depending on age, activity, and disease. The MDC95 for these tests in patients with spinal disorder are unclear, which made it difficult to evaluate the significance of changes in our patient, but the Berg Balance Scale improved from 35 before training to 39 after training; the distances for the left and right upper limbs increased from 22 to 22.5 cm and from 27 to 30.5 cm, respectively, on the Functional Reach Test; and the time decreased from 92.57 to 86.08 s on the Timed Up and Go Test. Although the changes were small, these results show improvement in all 3 items and suggest that BEAR improves myelopathy-associated decline of balance function.

Regarding the mechanism underlying this effect, since muscular strength did not change after BEAR in this patient, BEAR may have improved sensory input. Balance control requires visual, vestibular, and somatic sensory inputs, and these are integrated in the CNS to produce balance function. The sensory inputs are not homogenous, and changes correspond to diseases inducing abnormalities in sensation, environment, and physical activity[22]. The effect of BEAR was acquired within a short time (2 weeks), suggesting changes mainly in visual and vestibular sensory inputs, and not through somatic sensory input from the lower limbs, which had been impaired by myelopathy for a long time. Visual sensory input provides the relative positional relationship with surrounding objects, and thus serves as an information source concerning the head position and movement. The ratio of visual sensory input increases with performance of gymnastics and bicycle road racing[23][24], suggesting that visual sensory input may have increased based on information on the monitor in BEAR, with a subsequent influence on balance function. Vestibular sensory input serves as an information source related to acceleration loaded on the head. An increase in this input due to acceleration produced by a shift of the center of gravity on BEAR may have also influenced balance function. Furthermore, since aggravation of neurologic manifestations or fall did not occur in BEAR, this method is safe for patients with a CIND status.

All game levels improved, but changes varied among the games: the skiing game level gradually improved from day 3 to 8 after initiation; the rodeo game level improved from day 3 to 5, but only slightly thereafter; and the tennis game level did not change until day 5, but improved under verbal instructions by the therapist until day 8. The game methods and adjustment of the difficulty level may have been influenced by the reduced cognitive function of the patient. In the skiing game, the subject skis by operating the robot in the lateral direction to move a character on the screen in the lateral direction. In the rodeo game, vertical movement of a character on the screen is stopped by the subject operating the robot in the anteroposterior direction up to level 15. The patient easily understood these games intuitively and performed the exercise tasks despite her cognitive impairment because movement of the robot in these games was consistent with actual movements in skiing and rodeo, which made the operation directions simple. Therefore, these games were effective for this patient. In contrast, in the tennis game, the subject moves a character on the left side in the monitor screen by operating the robot in the anteroposterior direction and hits back a ball coming from the right side. In actual tennis, players move in the lateral direction and hit the ball back, but in this game the subject has to control the robot in the anteroposterior direction. When cognitive function is impaired, it may be difficult to develop a strategy from the visual information and execute this strategy in the tennis game. Therefore, the patient needed to practice movement of the direction of the robot under verbal instructions by a therapist.

A limitation of the study is the investigation of only the short-term treatment effect. Observations of the persistence of the effect and the fall prevention outcome are necessary. Moreover, the effect of a single training session with BEAR did not persist for a long time. There is a need to investigate persistence of the effect by repeating robot rehabilitation or using this approach for a prolonged period.

Conclusions

Robot rehabilitation using BEAR resulted in improvement of balance in a patient with concomitant myelopathy-induced balance impairment and cognitively-impaired-not-demented status. Verbal instruction by a therapist was required for the tennis game, but the skiing and rodeo games were intuitively understandable for the patient, despite her cognitive impairment. These results suggest that these games are useful exercise tasks and that BEAR has efficacy for treatment of patients with cognitively-impaired-not-demented status.

The authors declare there are no conflicts of interest regarding the publication of this article.

References

1) Yoshimura N, Muraki S, Oka H, Mabuchi A, En-yo Y, Yoshida M, Saika A, Suzuki T, Yoshida H, Kawaguchi H, Nakamura K, Akune T. Prevalence of knee osteoarthritis, lumbar spondylosis and osteoporosis in Japanese men and women: the research on osteoarthritis/osteoporosis against disability study. J Bone Miner Metab 2009; 27: 620-628.

2) Yoshimura N, Muraki S, Nakamura K, Tanaka S. Epidemiology of the locomotive syndrome: The research on osteoarthritis/osteoporosis against disability study 2005-2015. Mod Rheumatol 2017; 27: 1-7.

3) Alzheimer's Disease International. World Alzheimer Report 2015, The Global Impact of dementia : An Analysis of Prevalence, Incidence, Cost and Trends 2015.

4) Nakamura K, Ogata T. Locomotive Syndrome: Definition and Management. Clin Rev Bone Miner Metab 2016; 14: 56-67.

5) Baker NL, Cook MN, Arrighi HM, Bullock R. Hip fracture risk and subsequent mortality among Alzheimer's disease patients in the United Kingdom, 1988-2007. Age Ageing 2011; 40: 49-54.

6) Eriksson S, Gustafson Y, Lundin-Olsson L. Risk factors for falls in people with and without a diagnose of cognitive dementia living in residential care facilities: a prospective study. Arch Gerontol Geriatr 2008; 46: 293-

306.
7) Tyner T, Allen DD. Balance and fall risk. In: Cameron MH, Monroe LG, editors. Physical rehabilitation: evidence-based examination, evaluation, and intervention. St Louis: Saunders 2007; 321-328.
8) Shumway-Cook A, Woolacott M. Assesment and treatment of patients with postural disorder. In: Motor control: theory and practical applications. Baltimore: Willians & Wilkins: 1995; 207-35.
9) Lövheim H, Sandman PO, Karlsson S, Gustafson Y. Behavioral and psychological symptoms of cognitive dementia in relation to level of cognitive impairment. Int Psychogeriatr 2008; 20: 777-789.
10) Ozaki K, Kagaya H, Hirano S, Kondo I, Tanabe S, Itoh N, Saitoh E, Fuwa T, Murakami R. 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.
11) Itoh N, Tanabe S, Hirano S3, Saitoh E, Kawabata J, Imoto D, Mikami Y, Kubo T. Changes in postural strategy during exercise against perturbation using the balance exercise assist robot: a pilot study. J Phys Ther Sci 2017; 29: 16-19.
12) Ozaki K, Kondo I, Hirano S, Kagaya H, Saitoh E, Osawa A, Fujinori Y. Training with a balance exercise assist robot is more effective than conventional training for frail older adults. Geriatr Gerontol Int 2017; 17: 1982-1990.
13) Lam FM, Huang MZ, Liao LR, Chung RC, Kwok TC, Pang MY. Physical exercise improves strength, balance, mobility, and endurance in people with cognitive impairment and dementia : a systematic review. J Physiother 2018; 64: 4-15.
14) Karssemeijer EGA, Aaronson JA, Bossers WJ, Smits T, Olde Rikkert MGM, Kessels RPC. Positive effects of combined cognitive and physical exercise training oncognitive function in older adults with mild cognitive impairment or dementia : A meta-analysis E.G.A. Ageing Res Rev 2017; 40: 75-83.
15) Colombo G, Wirz M, Dietz V: Driven gait orthosis for improvement of locomotor training in paraplegic patients. Spinal Cord 2001; 39: 252-255.
16) 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.
17) Aach M, Cruciger O, Sczesny-Kaiser M, Höffken O, Meindl RCh, Tegenthoff M, Schwenkreis P, Sankai Y, Schildhauer TA. Voluntary driven exoskeleton as a new tool for rehabilitation in chronic spinal cord injury: a pilot study. Spine J 2014; 14: 2847-2853.
18) Steffen T1, Seney M. Test-retest reliability and minimal detectable change on balance and ambulation tests, the 36-item short-form health survey, and the unified Parkinson disease rating scale in people with parkinsonism. Phys Ther 2008; 88: 733-746.
19) Donoghue D1; Physiotherapy Research and Older People (PROP) group, Stokes EK. How much change is true change? The minimum detectable change of the Berg Balance Scale in elderly people. J Rehabil Med 2009; 41: 343-346.
20) Muir-Hunter SW, Graham L, Montero Odasso M. Reliability of the Berg Balance Scale as a clinical measure of balance in community-dwelling older adults with mild to moderate Alzheimer disease: a pilot study. Physiother Can 2015; 67: 255-262.
21) Lee HS, Park SW, Chung HK. The Korean version of relative and absolute reliability of gait and balance assessment tools for patients with dementia in day care center and nursing home. J Phys Ther Sci 2017; 29: 1934-1939.
22) Hwang S, Agada P, Kiemel T, Jeka JJ. Dynamic reweighting of three modalities for sensor fusion. PLoS ONE 2014; 9: e88132.
23) Asseman FB, Caron O, Rémieux J. Are there specific conditions for which expertise in gymnastics could have an effect on postural control and performance? Gait Posture 2008; 27: 76-81.
24) Lion, A Gauchard GC, Deviterne D, Perrin PP. Differentiated influence of off-road and on-road cycling practice on balance control and the related-neurosensory organization, J Electromyograph Kinesiol 2009; 19: 623-630.

〈和文抄録〉

ロボットリハビリテーションが有効であった軽度認知機能障害を持つ脊髄症由来バランス障害の1例

三上 靖夫*[1]，新井 祐志[2]，大橋 鈴世[1]，沢田光思郎[1]
伊藤 慎英[3]，生駒 和也[3]，久保 俊一[1,4]

[1]京都府立医科大学大学院医学研究科リハビリテーション医学
[2]京都府立医科大学大学院医学研究科スポーツ・障がい者スポーツ医学
[3]京都府立医科大学リハビリテーション先進医療開発講座
[4]京都府立医科大学大学院医学研究科運動器機能再生外科学

脊髄症によって生じたバランス障害に，軽度の認知機能障害を持つ症例に対し，Balance Exercise Assist Robot（BEAR）を用いたロボットリハビリテーション治療を施行した．バランス障害は改善し，BEARを用いたリハビリテーション治療は有効であった．BEARには3つのゲームプログラムがあり，テニスゲームは，理学療法士による口頭指示を要したが，スキーゲームとロデオゲームは患者の理解を得て行うことができた．BEARは軽度の認知機能障害を持つ患者に対しても有用なリハビリテーション機器と考えた．

キーワード：ロボットリハビリテーション，認知機能障害，バランス，脊髄症．