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Original Article

Effects of Balance Exercise Assist Robot (BEAR) in independently mobile patients by disease

Shinichiro Goto, OTR,[1] Kazuyo Oguchi, MD, DMSc,[1] Takashi Hoshino, RPT, MSc,[1] Takeshi Ikeuchi, RPT,[1] Takashi Asai, RPT,[1] Yuto Ota, OTR,[1] Taishi Ogawa, OTR,[1] Tatsuyuki Ito, RPT,[1] Eri Otaka, MD, PhD[1]

[1]Department of Rehabilitation, Kariya Toyota General Hospital, Kariya, Aichi, Japan

ABSTRACT

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Objective: To examine, by disease type, the effects before and after the use of the Balance Exercise Assist Robot (BEAR) training system.

Methods: Nineteen independently mobile patients who had used the BEAR system were evaluated for the outcome measures of the Mini-Balance Evaluation Systems Test (Mini-BESTest), comfortable walking speed, tandem gait speed, timed up-and-go test (TUG), functional reach test (FRT) and muscular strength test. The subjects were classified by disease, with five having spinal cord disease, nine with supratentorial stroke, and five with infratentorial stroke. The Wilcoxon signed rank test was used for comparison between before and after BEAR training sessions. Spearman's rank correlation coefficient was used to assess the relationship between the BEAR game level and the disease.

Results: TUG improved in spinal cord disease, in comparison between before and after BEAR training sessions. Comfortable walking speed, tandem gait speed and TUG improved in supratentorial stroke. Comfortable walking speed improved in infratentorial stroke. The Mini-BESTest improved in all the diseases. The attained game level was lower in infratentorial stroke than in spinal cord disease.

Discussion: We consider that BEAR training was highly effective in supratentorial stroke for improving the balance. On the other hand, the attained game level was low in infratentorial stroke, but we presume that the balance index would improve with repeated exercise at the appropriate level of difficulty.

Key words: Balance Exercise Assist Robot (BEAR), balance, disease, ataxia, robot

Introduction

About 80% of emergency ambulance transportation in Japan are caused by falls, and about 40% of the cases involving the elderly are diagnosed as requiring hospitalization. It has been reported that a decrease in lower limb muscle strength, unstable balance, and taking more than four oral medications results in a 100% likelihood of falling [1], and fall prevention is very important for maintaining ADL in rehabilitation patients with decreased physical function.

The Balance Exercise Assist Robot (BEAR), jointly developed by Toyota Motor Corporation and Fujita Health University, is a boarding-type robot, aimed at balance exercise support based on motor learning strategies. The BEAR system enables visualization of the patient's center of gravity. When the patient leans forward, backward, or sideways on the robot, the character on the monitor moves in the same direction. The exercises are designed as three different games: tennis as a forward and backward movement task, skiing as a side movement task, and rodeo as a disturbance coping task. In balance practice, it is desirable to set an appropriate degree of difficulty [2], but with the BEAR system, the degree of difficulty of each task is automatically adjusted according to the patient, and it is possible to practice at the appropriate difficulty level, wide center of gravity movement and disturbance handling. Also, motivation for practice is promoted by having gaming characteristics. The BEAR system is highly adaptable, and so far, the improvement effect on balance ability is reported in cerebrovascular disease [3], flail [4], and exercise instability [5].

Correspondence: Shinichiro Goto, OTR
Department of Rehabilitation, Kariya Toyota General Hospital, 5–15, Sumiyoshi-cho, Kariya, Aichi 448–8505, Japan.
E-mail: shinichiro.goto@toyota-kai.or.jp
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The Mini-Balance Evaluation Systems Test (Mini-BESTest) used in this study, based on the motion control system theory of the Balance Evaluation Systems Test (BESTest) [6], is a specialized dynamic balance function evaluation [7] that can be implemented in a short time. In Japan, Otaka et al. studied its validity for neuromuscular disease, cerebrovascular disorder, proximal femoral bone fracture surgery, and osteoporosis [8], and Miyata et al. reported its usefulness in cerebrovascular disease, lower limb fracture and vertebral fracture [9].

During BEAR training, patients admit to stagnation at the game level. There seems to be a difference in the progress of robot operation, but there are no reports on balance evaluation using the Mini-BESTest or a comparison of disease-specific balance improvement effects. Mini-BESTest examination of the BEAR system's disease-specific effects is directly related to the system setting and operation according to the disease and may contribute to the improvement of efficient balance ability.

Objective

The objective of our study was to examine the effect, by disease type, before and after the use of the Balance Exercise Assist Robot (BEAR).

Subjects and Methods

Of the 31 patients who participated in BEAR training sessions from March 2016 to November 2017, 19 independently mobile subjects took the Mini-BESTest. The subjects were 13 males and 6 females, average age of 55 (standard deviation ±16) years old, and median period after disease onset of 94 days (quartile range 56−554). The 19 subjects were classified by disease, with 5 having spinal cord disease, 9 with supratentorial stroke, and 5 with infratentorial stroke (Table 1).

The BEAR training sessions lasted 40 minutes and were conducted 5 times a week for hospitalized patients and 2 times a week for outpatients, a total of 16 times. Each tennis, skiing and rodeo game was played 4 times. The game levels ranged from a minimum of 1 through a maximum of 40, which were automatically determined during the test drive before starting the BEAR session and varied depending on the game results of each day. Values after the first and last executions were used to obtain the game levels.

The Mini-BESTest, comfortable walking speed, tandem gait speed, timed up-and-go test (TUG), and functional reach test (FRT) were measured before and after the exercise session as indicators of balance ability. Lower limb muscle strength of hemiplegic and non-hemiplegic sides for the iliopsoas, gluteus medius, quadriceps femoris, hamstrings, anterior tibialis, and gastrocnemius were measured by manual muscle testing (MMT). If both sides were impaired, we analyzed the severe side as hemiplegic and the mild side as non-hemiplegic for comparison with hemiplegic patients. The hemiplegic motor function assessment items of the Stroke Impairment Assessment Set (SIAS) were performed according to the stroke assessment method for spinal cord disease. We evaluated the proximal lower limb (hip flexion test), proximal lower limb (knee extension test), and distal lower limb (foot pat test) and used the total score (lower limb SIAS).

For statistical analysis, the Kruskal-Wallis test was used for comparison between disease groups, and the Wilcoxon signed rank test was used for comparison before and after the BEAR training sessions in each group. Spearman's rank correlation coefficient was used to assess the relationship between the game level and the balance index, muscle strength, and lower limb SIAS after using the BEAR. SPSS ver. 22.0 was used for statistical processing, and the significance level was set to 0.05. This research was performed with the approval of the Hospital Ethics Committee, and written informed consent was obtained from all participants after the study content was explained.

Results

1. Comparison between disease groups (Table 2)

Initially, there was a difference in lower limb SIAS. In spinal cord disease, paralysis was mild when compared to supratentorial stroke. There was no difference in game level in any of the diseases.

Upon completion, differences were found in comfortable walking speed, hemiplegia of hamstrings, and hemiplegia of gastrocnemius muscle. Higher game levels were attained for tennis, skiing and rodeo in spinal cord disease compared to infratentorial stroke.

2. Changes before and after BEAR use (Table 2)

The Mini-BESTest and game level improved in all diseases, but the improvement of walking speed, TUG, and muscle strength differed by disease.

Significant differences were found for the Mini-BESTest, TUG, tennis, skiing and rodeo in spinal cord disease.

Significant differences were found for the Mini-BESTest, comfortable walking speed, tandem gait speed, TUG, hemiplegic anterior tibialis muscle, tennis, skiing and rodeo in supratentorial stroke.

Significant differences were found for the Mini-BESTest, comfortable walking speed, hemiplegic iliopsoas muscle, skiing, tennis and rodeo in infratentorial stroke.

FRT did not show any significant difference in any of the diseases.

Table 1. Patient characteristics.

Subject	Classification (Cause disease)	Lesion site	Injured side	Age	Sex	TAO (days)	Assistance fo gait (ADL)	AFO (ADL)	Assistance fo gait (Evaluation)	AFO (Evaluation)	FIM (before evaluation)	Reached game level			Place
												Tennis	Skiing	Rodeo	
A	spinal cord disease	C5-6	both sides	56	male	1,290	T-cane(both)	None	None	None	123	40	32	31	Outpatient
B	spinal cord disease	Th2-3	both sides	66	male	907	T-cane(both)	RAPS-AFO	None	None	124	35	36	30	Outpatient
C	spinal cord disease	C1-2 Th2-6	left	31	male	200	None	None	None	None	119	32	40	40	Outpatient
D	spinal cord disease	C5-6	both sides	90	male	72	None	None	None	None	113	23	19	20	Outpatient
E	spinal cord disease	Th8	both sides	43	male	34	T-cane(both)	None	None	None	102	40	40	40	Hospitalization
F	supratentorial stroke	Frontal lobe	right	44	female	3,309	T-cane	RAPS-AFO	None	None	118	27	40	23	Outpatient
G	supratentorial stroke	Frontal lobe	right	44	female	3,119	T-cane	RAPS-AFO	None	None	118	28	36	19	Outpatient
H	supratentorial stroke	Frontal lobe	right	44	female	2,973	T-cane	RAPS-AFO	None	None	118	25	23	16	Outpatient
I	supratentorial stroke	cerebral white matter	right	69	male	113	T-cane	P-AFO	None	None	122	30	27	23	Outpatient
J	supratentorial stroke	subcortical	left	73	female	94	T-cane	None	None	None	103	19	18	16	Hospitalization
K	supratentorial stroke	putamen	right	53	male	62	T-cane	RAPS-AFO	None	None	103	31	30	40	Hospitalization
L	supratentorial stroke	putamen	right	75	male	61	T-cane	None	None	None	116	30	24	30	Hospitalization
M	supratentorial stroke	putamen	left	52	female	50	four-legged crutch	RAPS-AFO	None	RAPS-AFO	93	28	26	20	Hospitalization
N	supratentorial stroke	putamen	left	48	male	19	T-cane	P-AFO	None	None	101	35	40	40	Hospitalization
O	infratentorial stroke	cerebellum	both sides	54	male	196	None	None	None	None	122	19	14	16	Outpatient
P	infratentorial stroke	cerebellum	left	19	female	109	T-cane	None	None	None	103	26	33	20	Outpatient
Q	infratentorial stroke	pons	both sides	48	male	82	T-cane	RAPS-AFO	None	None	102	19	15	15	Hospitalization
R	infratentorial stroke	cerebellum	right	69	male	51	T-cane	None	None	None	111	20	14	19	Hospitalization
S	infratentorial stroke	cerebellum	both sides	70	male	37	None	None	None	None	109	23	22	21	Hospitalization

RAPS-AFO, Remodeled Adjustable Posterior Strut-ankle foot orthosis; P-AFO, Plastic-ankle foot orthosis.

Table 2. Changes before and after BEAR use and comparison between disease groups.

Evaluation	BEAR before and after training									Comparison between disease groups			
	Spinal cord disease			Supratentorial stroke			Infratentorial stroke			First	Last	Last multiple comparison	
	First	Last	*p*	First	Last	*p*	First	Last	*p*	*p*	*p*		
Total leg SIAS-M score	15	15	1.00	10	11	0.06	12	12	0.16	0.01 #	0.00 #	supratentorial-spinal cord	0.01
mini-BESTest	20	25	0.04 *	15	19	0.01 *	16	21	0.04 *	0.23	0.15		
Comfortable walking speed (km/h)	56.6	69	0.08	44.8	45.5	0.03 *	54.5	64.5	0.04 *	0.06	0.02 #	supratentorial-spinal cord	0.04
Tandem gait speed (m/min)	18	17	0.08	22	20.5	0.01 *	17	20	0.07	0.41	0.09		
TUG (s)	9.5	7.7	0.04 *	12.8	10.8	0.01 *	15	9.8	0.08	0.26	0.12		
FRT (cm)	29.5	30.5	0.08	32	31	0.38	33	30.5	0.89	0.79	0.77		
Iliopsoas													
unaffected side	5	5	0.32	5	5	1.00	4	5	0.16	0.32	0.73		
affected saide	4	5	0.16	3	4	0.18	4	4	0.05 *	0.44	0.11		
Gluteus													
unaffected side	4	5	0.08	5	5	0.32	4	5	0.16	0.16	0.94		
affected saide	4	4	0.32	3	4	0.13	4	4	0.32	0.39	0.60		
Quadriceps													
unaffected side	5	5	0.32	5	5	1.00	5	5	1.00	1.00	0.57		
affected saide	4	4	0.32	4	5	0.41	4	5	0.16	0.99	0.83		
Hamstrings													
unaffected side	4	4	0.41	5	5	0.10	4	5	0.16	0.30	0.13		
affected saide	3	4	0.10	3	3	0.08	4	4	0.16	0.14	0.02 #	—	—
Anterior tibialis													
unaffected side	5	5	0.32	5	5	0.32	5	5	1.00	0.57	0.61		
affected saide	4	4	0.41	3	4	0.05 *	4	5	0.08	0.08	0.09		
Gastrocnemius													
unaffected side	5	5	1.00	5	5	0.16	5	5	0.56	0.80	0.32		
affected saide	3	4	0.10	2	3	0.08	3	4	0.08	0.08	0.01 #	supratentorial-spinal cord	0.01
Tennis	1	35	0.04 *	7	28	0.01 *	1	20	0.04 *	0.13	0.01 #	infratentorial-spinal cord	0.01
Skiing	1	36	0.04 *	1	27	0.00 *	1	15	0.04 *	0.10	0.05 #	infratentorial-spinal cord	0.05
Rodeo	2	31	0.04 *	4	23	0.00 *	1	19	0.04 *	0.24	0.04 #	infratentorial-spinal cord	0.04

Wilcoxon signed rank test *$p<0.05$.
Kruskal-Wallis test #$p<0.05$.
※Values indicate the median value.
※In the case of both sides the side affected by the severe side was taken.

Table 3. Relationship between level attained for each game task and evaluation.

Evaluation	Spinal cord disease			Supratentorial stroke			Infratentorial stroke		
	Tennis	Skiing	Rodeo	Tennis	Skiing	Rodeo	Tennis	Skiing	Rodeo
Total leg SIAS-M score	0.09	−0.09	0.07	0.34	−0.38	0.24	0.15	0.15	0.00
mini-BESTest	0.31	0.41	0.44 *	0.56	0.78 *	0.64 *	−0.05	−0.05	−0.32
Comfortable walking speed (km/h)	0.14	0.13	0.31	0.38	0.25	0.46	−0.21	−0.05	0.10
Tandem gait speed (m/min)	0.31	0.34	0.31	0.26	0.64 *	0.28	−0.72	−0.87	−0.70
TUG (s)	−0.19	−0.12	−0.36	−0.31	−0.17	−0.36	0.41	0.87	0.10
FRT (cm)	0.32	0.46 *	0.31	0.49	0.71 *	0.49	−0.56	0.05	−0.70
Iliopsoas									
unaffected side	0.27	0.46 *	0.30	0.29	0.79 *	0.47	−0.30	0.15	−0.58
affected saide	0.16	0.21	0.25	0.65 *	0.65 *	0.57	0.15	0.15	0.00
Gluteus									
unaffected side	0.20	0.16	0.21	0.32	0.00	0.11	0.52	0.34	0.67
affected saide	0.08	0.08	0.24	0.63	0.64 *	0.60	0.54	0.00	0.71
Quadriceps									
unaffected side	0.20	0.28	0.07	0.22	0.61	0.22	−0.36	−0.36	−0.71
affected saide	0.05	0.01	−0.07	0.49	0.36	0.23	−0.30	0.15	−0.58
Hamstrings									
unaffected side	0.10	0.21	0.08	−0.23	0.29	−0.18	0.15	−0.30	0.00
affected saide	0.07	−0.04	0.14	0.55	0.26	0.38	0.00	−0.34	0.22
Anterior tibialis									
unaffected side	0.29	0.22	0.26	0.53	0.53	0.47	−	−	−
affected saide	−0.10	−0.21	0.03	0.65 *	−0.05	0.59	−0.30	0.15	−0.58
Gastrocnemius									
unaffected side	0.49 *	0.51 *	0.443 *	0.53	0.53	0.47	0.44	0.44	0.58
affected saide	0.23	0.23	0.31	0.50	0.19	0.42	0.65	0.65	0.58
Tennis	1.00	0.81 *	0.90 *	1.00	0.46	0.89 *	1.00	0.76	0.87
Skiing	0.81 *	1.00	0.75 *	0.46	1.00	0.58	0.76	1.00	0.56
Rodeo	0.90 *	0.75 *	1.00	0.89 *	0.58	1.00	0.87	0.56	1.00

Spearman's rank correlation coefficient *$p<0.05$.

※In the case of both sides the side affected by the severe side was taken.

3. Relationship between level attained for each game task and evaluation (Table 3)

In spinal cord disease, a positive correlation was found between tennis and non-hemiplegic gastrocnemius muscle, between skiing and FRT, non-hemiplegic iliopsoas and non-hemiplegic gastrocnemius muscle, and between rodeo and the Mini-BESTest and non-hemiplegic gastrocnemius muscle.

In supratentorial stroke, a positive correlation was found between tennis and hemiplegic iliopsoas muscle, between skiing and the Mini-BESTest, tandem gait speed, FRT, non-hemiplegic iliopsoas, hemiplegic iliopsoas and hemiplegic gluteus medius muscles, and between rodeo and the Mini-BESTest.

No correlation was found between any of the items and infratentorial stroke.

Discussion

The effect of BEAR training on independently mobile patients differed in improvement items by disease. This difference was related to the difficulty of the evaluation item. After BEAR training, the numerical value of the Mini-BESTest, which is regarded as a balance index, improved with all diseases. Although the period after onset differed between patients, it is considered that improvement of multiple evaluation values related to balance ability irrespective of acute or chronic period indicates that BEAR training is effective for improving balance ability. Appropriate difficulty level and motor learning ability by repetitive exercise was one factor for the improvement effect. In motor learning, there are internal models [10] such as a forward model that predicts the motor result from the input of the motor command and the output of the motor trajectory [11], and the inverse model that predicts the input of the target trajectory, error signal and the output of the motor command from the desired motor result [12]. BEAR exercise (front and rear, left and right repetitive movements) at an appropriate degree of difficulty is involved in the correction of error information by feedback and feedforward of the internal model, and the movement itself was considered to enhance the balance ability.

Tsunoda et al. [13] reported that balance exercise using the BEAR system contributed to the improvement of dynamic attitude control ability in patients with chronic cerebrovascular disease, and the attained game level of each task reflected the balance ability of the patient after execution. In this research, similar results were also considered in supratentorial stroke. However, in infratentorial stroke, improvement of the Mini-BESTest was similar to that in spinal cord disease and supratentorial stroke, even though the game level was half as difficult. In infratentorial stroke, performing feedforward control that calculates the motor trajectory of fast movements was difficult [14–16] (Figure 1), and learning was delayed [17]. Therefore, improvement in game level that accompanies balance improvement was considered slow compared with that in spinal cord disease (Figure 2). However, improvement in game level did not appear to be directly related to balance ability enhancement since the Mini-BESTest had improved. This can also be inferred from the fact that there was no correlation between the attained game level of each task and individual evaluation items during the final evaluation in infratentorial stroke. Namely, balance exercise based on motor learning at the appropriate

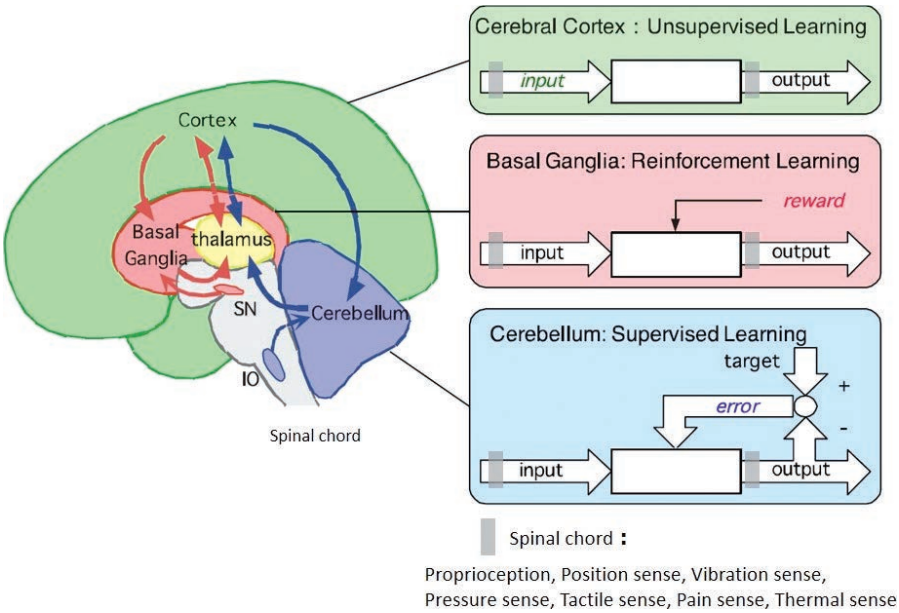

Figure 1. Learning algorithms of cerebellum, basal ganglia, and cerebral cortex (Doya [15, 16]). Partial modification.

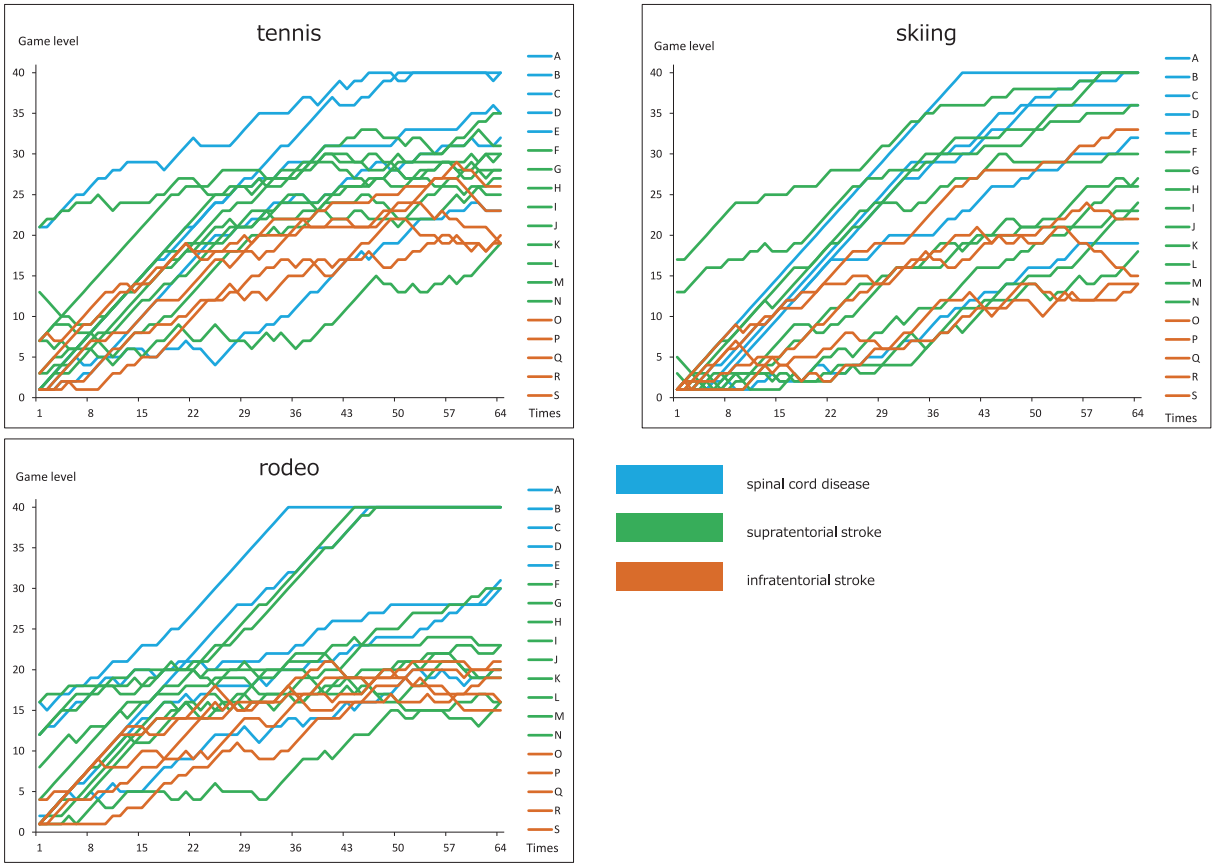

Figure 2. Game level transition of each disease by game.

difficulty level setting was considered important for improving balance ability.

Overcompensation of the upper limbs during robot operation in an attempt to advance the game level during the BEAR training session is a common clinical feature. To increase the balance improvement effect of the BEAR system, it is necessary to avoid overcompensation without regard for the game level and to encourage movement of the center of gravity of the lower limbs. Furthermore, the patient's decline in motivation due to the inability to advance the game level may be gradually overcome after the patient has reached an appropriate level (range where BEAR operation is possible with lower limbs).

There are certain limitations to the results and interpretation of this study due to the small number of cases for each disease and lack of comparison with a control group.

Conclusion

The effect of BEAR training in independently mobile patients differed in improvement items by disease.

1. Effective improvement of TUG was found in spinal cord disease.
2. The BEAR training effect was highest for improving comfortable walking speed, tandem gait speed and TUG in supratentorial stroke.
3. Effective improvement of comfortable walking speed was found in infratentorial stroke. Although the attained level of difficulty of the BEAR exercise games was half that in the other diseases, balance ability was improved by the same degree.

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