Chapter 12

Application of Robotics for Therapeutic Exercise of Neural Disorder

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Abstract

Background: The application of robots for rehabilitation has been developing over the past decade. In neuro-rehabilitation, motor learning has become an important topic. To maximize the effect of motor learning, we need to clarify the key muscle and adequate intensity.

Objective: Examination of a new method of robotic rehabilitation that employs a motion capture system and ground reaction force platforms to calculate kinematic and kinetic parameters.

Design: A cross-sectional study of healthy subjects and individual cerebral palsy and stroke patients as case studies.

Methods: We employed a motion capture system and ground reaction force platforms to calculate kinematic and kinetic parameters of healthy volunteers, a cerebral palsy patient, and a stroke patient in both gait and active movement assessments. This method allows the comparison of motor performances before and after exercise. A hybrid assistive limb (HAL) was employed for the exercise. HAL is a humanoid exoskeletal robot that uses bioelectrical signals as triggers.

Results: Immediate and after effects on gait velocity, step length, and hip extensional moments were observed in healthy subjects and the stroke patient. The cerebral palsy patient showed improvement in range of movement in a practised movement.

Keywords: robotics, neuro-rehabilitation, motor learning, stroke, cerebral palsy

1. Introduction

The application of robotics and mechatronics for medical rehabilitation has been developed over the past decade. In particular, the power assistive apparatus may affect neuro-rehabilitation based on the brain cell plasticity. In 1992, prior to the beginning of the applications of the robotic, Wernig advocated the weight support treadmill (WST) for gait exercise in paraplegic patients [1]. He reported that some patients showed recovery of EMG of the lower extremities, or actual gait function remarkably after 5–20 months. For the WST, two physical therapists are required to guide the movement of the lower extremities manually. In 1999, Hocoma Corporation (Volketswil, Switzerland) developed Lokomat, which is a WST that does not require physical therapists assistance [2]. In the last 15 years, 600 Lokomats have been used in the world. There are two uses of robots in medical rehabilitation. One is the use as a supportive device in daily living such as orthoses. The other is the use in therapeutic exercise. For functional recovery of the patients with neural disorder, motor learning is necessary. For appropriate motor learning, appropriate repetitions and appropriate difficulty of the task are necessary. For the appropriate difficulty of the task, feedback is the key. However, we have no good tool that can control the feedback gain easily. We suggest that hybrid assistive limb (HAL): Cyberdyne Inc., Japan) may be a solution HAL, which is controlled by surface EMG of flexor and extensor of the hip and knee. However, the effects of therapeutic exercise using HAL for patients with neural disorder are unclear. In this study, we clarify the effects of therapeutic exercise using HAL.

2. Method

2.1. Hybrid assistive limb

HAL was employed for the therapeutic exercise [3]. HAL is a powered exoskeleton bionic device that is controlled by surface EMG of the hip flexor, hip extensor, knee flexor, and knee extensor muscle of the subject. HAL consists of a CPU, interface units, surface EMG, plantar pressure sensors, four motor units, a lithium polymer battery, and exoskeletal of lower body (**Figure 1**).

2.2. Motor learning and its effect on development of gait function

We focused on the activation of the gluteus maximus muscle. Subjects demonstrated good feedback from surface EMG. The tasks were squatting and walking. The numbers of the exercises were 500 repetitions and 500 steps (**Figure 2**).

We had conducted the exercise programs once a week for three times for patients (2.3.2, 1.3.3). Furthermore, we conducted the exercise programs once a week for three times for healthy subjects to investigate the after-effect (1.3.1).

2.3. Assessments of gait and motor performance

Before and after exercise, gait or throwing motion was captured. Infrared reflectors attached on the bilateral acromion, lateral epicondyle of humerus, styloid process of the radius, the

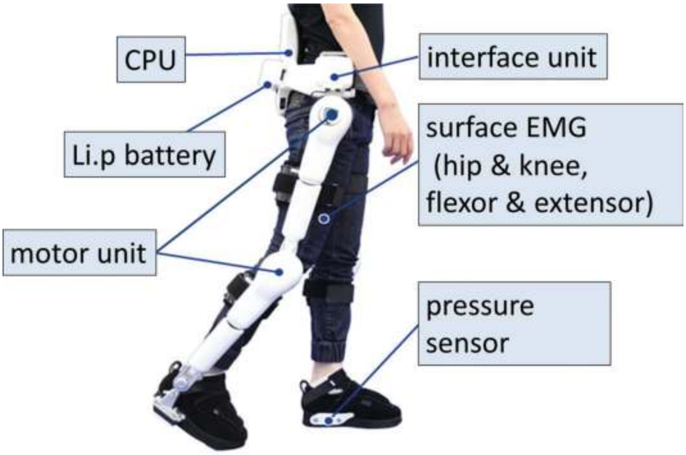

Figure 1. The structure of HAL.

head of the third metacarpal bone, greater trochanter, lateral edge of the femoral bone, lateral malleolus, and the head of the fifth metatarsal bone. A three-dimensional motion capture system (VICON 612: Vicon Motion Systems Ltd., UK) was employed to measure the spatial coordinates of the body joints, which were substituted into the numerical model with human dynamic constants. Joint angles, angular velocities, linear velocities, trunk inclinational angle, and deviation of the center of gravity were calculated. Simultaneously, five ground reaction force platforms (OR6-6: AMTI Inc., USA) were employed to measure the ground reaction force and the displacement of center of pressure during walking. Inverse dynamics was applied to calculate the joint moment of the hip.

Figure 2. The setting of exercise with HAL (left, squatting; right, walking).

2.4. Subjects

2.4.1. Experiment of healthy subjects

Ten healthy volunteers (five male, five female, age, 20–22 years old, height, 1.61–1.71 m, body weight, 51.2–62 kg) participated in the experiment. The university ethic committee approved the experimental protocol (2014-177). All of the subjects signed the consent form before experiment.

2.4.2. Experiment of electric wheelchair user with cerebral palsy

One boccia player with cerebral palsy (male; age, 22 years; height, 1.51 m; body weight, 52 kg; type, spastic diplegia; locomotion level, electric wheelchair; Boccia level, BC2) participated in the study.

2.4.3. Experiment of wheelchair user with stroke

One volunteer with stroke (female; age, 67 years old; height, 1.61 m; body weight, 48 kg; type, cerebral infarction; affected side, right, post stroke, 17 years; Brunnstrom recovery stage, upper extremity 2 and lower extremity 3; locomotion level, wheelchair; complications and higher brain dysfunctions, negative) participated in the study. Until the beginning of the exercise program, the stroke volunteer could not hold a standing posture by herself. She could not walk at all without an ankle foot orthosis, a T-cane, and support of a care giver. At initial contact, rapid hip flexion, trunk anterior bending, and posterior withdraw of the pelvis were observed. During the single limb support phase, extensional thrust of the knee was observed. During terminal stance, heel-off was not observed. We accessed her main issue as insufficiency of gluteus maximus activation.

2.5. Statistical analysis

For healthy subjects, Kruskal-Wallis test was used to assess the effect of exercise. When appropriate, Tukey-Kramer test was conducted (Statview 5.01). p-Values <0.05 were considered statistically significant.

3. Results

3.1. Healthy subjects

Gait velocity and step length were increased immediately after exercise and after 1 h compare to before exercise (**Table 1**).

Maximal hip extensional moment in loading response was greater immediately after exercise compare to before exercise in every trial. Maximal hip extensional moment in loading response after one hour was greater than that before exercise in three subjects. The difference in the hip joint angle in terminal stance before and after exercise was not significant.

	Day 1			Day 2			Day 3		
	Before	**After**	**1 h**	**Before**	**After**	**1 h**	**Before**	**After**	**1 h**
Step length (m)	1.16 ± 0.15	1.37 ± 0.21*	1.29 ± 0.18*	1.17 ± 0.18	1.24 ± 0.18*	1.21 ± 0.1*	1.16 ± 0.12	1.25 ± 0.14*	1.24 ± 0.1*
Velocity (m/s)	1.20 ± 0.14	1.34 ± 0.16*	1.25 ± 0.14*	1.16 ± 0.16	1.21 ± 0.18*	1.23 ± 0.09*	1.18 ± 0.1	1.22 ± 0.31*	1.23 ± 0.11*
Hip moment (Nm/kg)	0.45 ± 0.08	0.61 ± 0.14*	0.57 ± 0.11	0.42 ± 0.12	0.55 ± 0.15*	0.52 ± 0.11	0.50 ± 0.12	0.66 ± 0.1*	0.61 ± 0.15

*p < 0.05.

Table 1. Comparison of gait parameter before and after exercise.

3.2. Electric wheelchair user with cerebral palsy

Boccia ball velocity at release after exercise was greater than that before exercise (**Figure 3**).

The range of motion of the shoulder during throwing after exercise was greater than that before exercise (**Figure 4**).

In contrast, range of motion of the anterior inclination of the trunk during throwing after exercise was less than that before exercise (**Figure 5**).

3.3. Wheelchair user with stroke

Gait velocity and step length after exercise were greater than that before exercise (**Figure 6**).

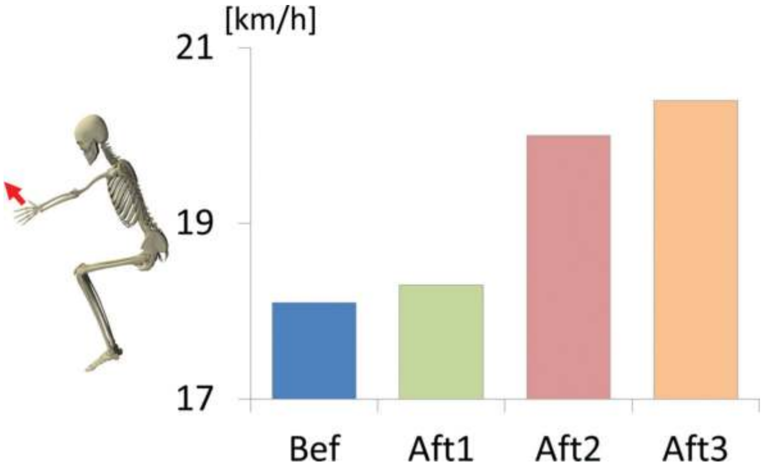

Figure 3. Ball velocity at release second before and after exercise. Bef, before exercise; Aft, after exercise.

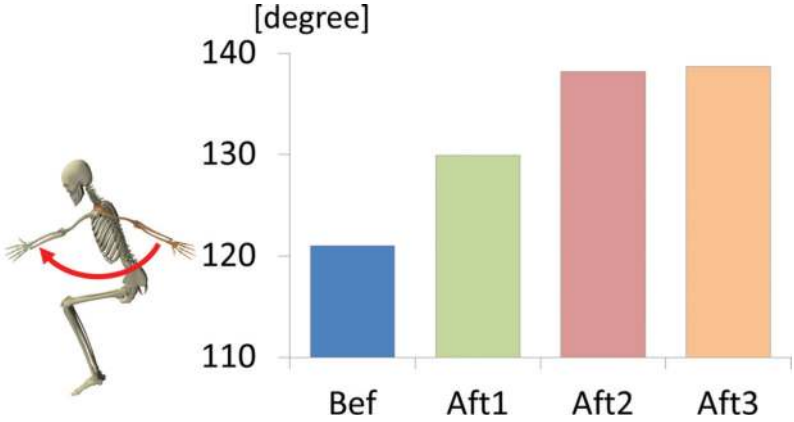

Figure 4. The range of motion of the shoulder during throwing before and after exercise. Bef, before exercise; Aft, after exercise.

The hip joint angle and the anterior inclination of the trunk at initial contact after exercise were less than that before exercise (**Figure 7**).

Maximal hip extensional moment in loading response after exercise was greater than that before exercise (**Figure 8**).

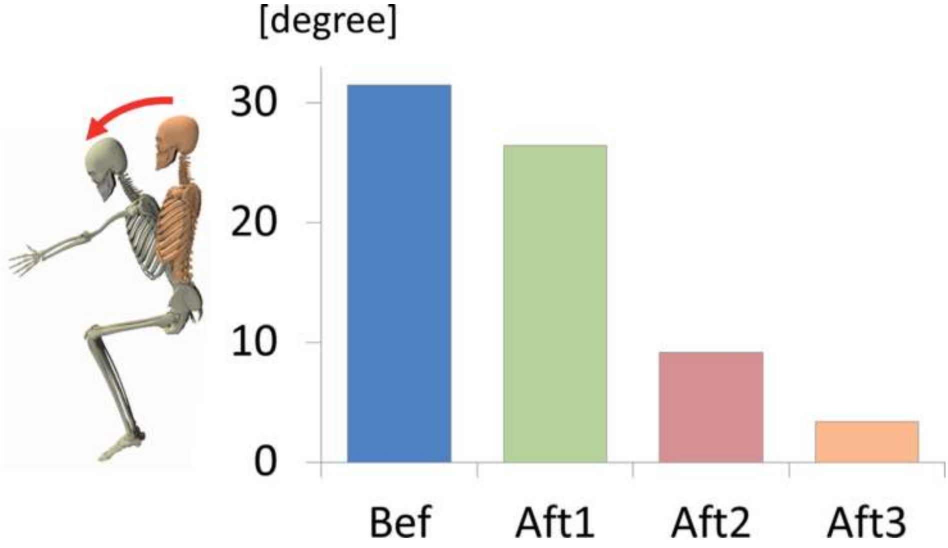

Figure 5. Range of motion of the anterior inclination of the trunk during throwing before and after exercise. Bef, before exercise; Aft, after exercise.

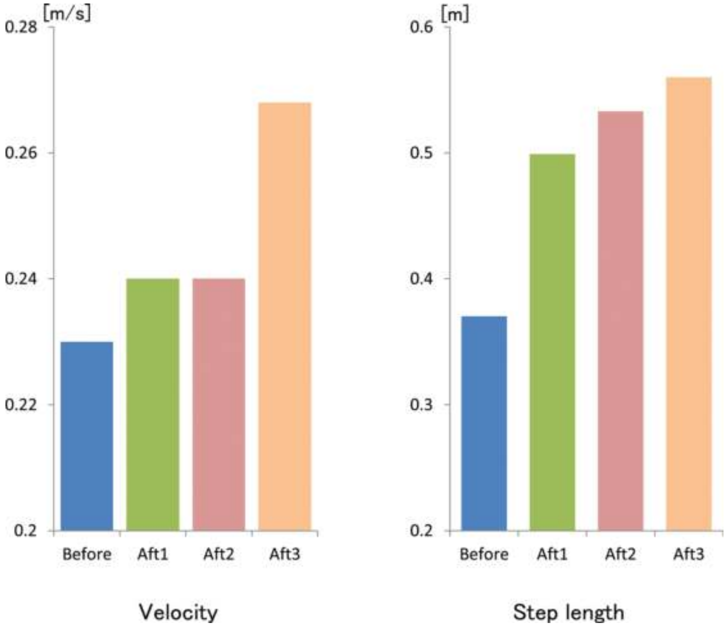

Figure 6. Gait velocity and step length of before and after exercise. Bef, before exercise; Aft, after exercise.

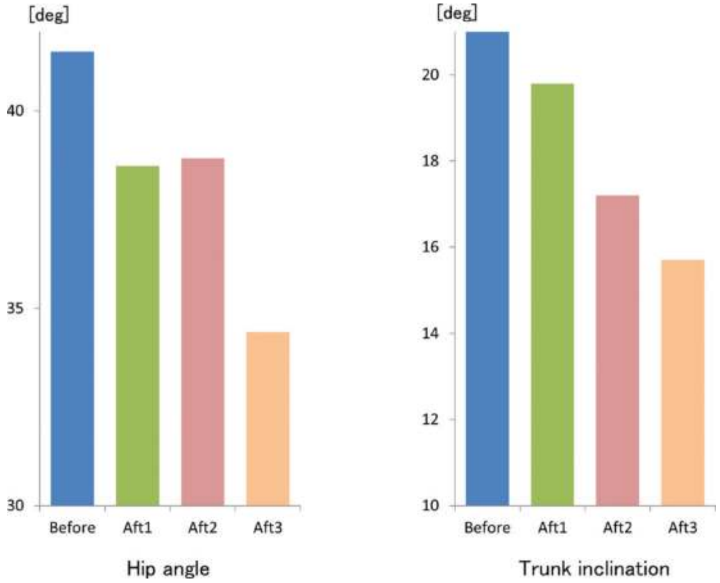

Figure 7. The hip joint angle and the anterior inclination of the trunk at initial contact of before and after exercise. Bef, before exercise; Aft, after exercise.

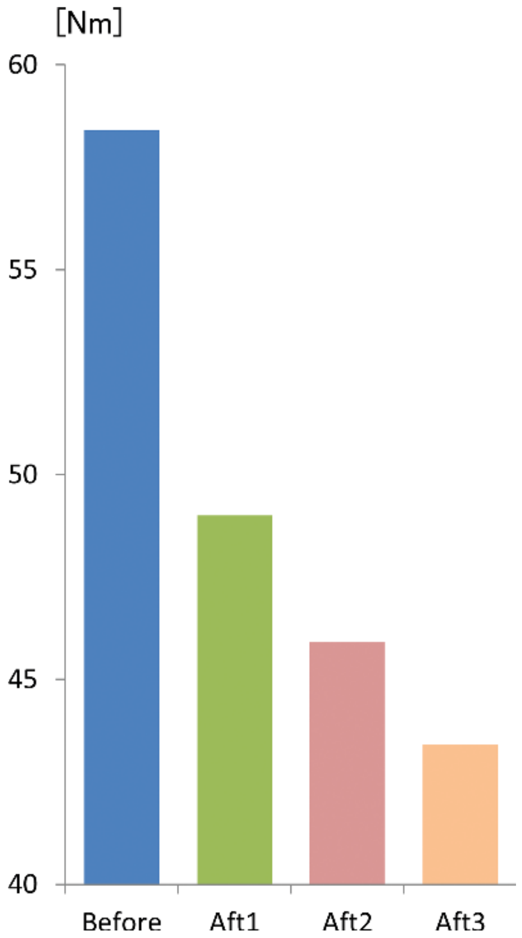

Figure 8. Maximal hip extensional moment in loading response of before and after exercise. Bef, before exercise; Aft, after exercise.

4. Discussions

Motor learning is defined as the process of improving motor skills through practice, with long-lasting changes in the capability for responding [4]. After-effect is a process of motor adaptation [5]. We considered that these kinematic changes were after-effects resulting from the robotic exercise. There are two important points in motor learning, one is the effect with repetition, and the other is the difficulty of the task. Prism adaptation requires 500 repetitions for motor reference. An appropriate difficulty of the task, not too hard and not too easy, is also necessary for motor reference. Thus, the load in motor learning, especially in early phase, should be quite different from that in muscle training. Because body weight may be excessive for weak muscles, wheelchair users may have little chance to activate their hip muscles. For the normal subjects, the difficulty of the task is easy so that there is no difference in hip moment between before and after exercise. However, it is too difficult for wheelchair users to walk 500 steps without support. The exoskeletal structure of HAL stabilized the lower body of the subjects, and the power assist in the hip in loading response allows the upper body to be upright and advances the contralateral leg forward. Furthermore, triggering of EMG increases the visual and the somatosensory feedback (normal sensation of "muscle activation-joint motion"). As a result, the difficulty of the task can be reduced to appropriate level. With only three times of exercise, wheelchair users showed a tremendous effect of our proposed exercise. This result suggests that wheelchair users learned how to activate the gluteus maximus during walking or throwing.

5. Conclusions

Our results suggest that the application of the HAL for motor learning may improve motor function in subjects with neural disorders.

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