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Effects of Aquatic Pole Walking on the Reduction of Spastic Hypertonia in a Patient with Hemiplegia: A Case Study

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Abstract

Here we report an acute effect of aquatic pole walking (PW) training intervention on a 64-year-old male patient with chronic hemiparesis and symptoms of spasticity in the right lower limb. A comparison of over ground walking before and after 20 minutes of aquatic PW training revealed a significant improvement in gait performance. As a main result, the average speed of walking after the intervention was 0.16 m/s after the intervention as compared to 0.04 m/s in the initial condition. The time taken for each stride cycle was drastically decreased, mainly due to shortening of the stance time. Underlying the improved gait performance was the emergence of functional muscle activity in the paralyzed and spastic leg muscles. The result observed in this patient should be further tested among a large population of patients presenting similar symptoms. Moreover, the basic mechanisms underlying aquatic PW intervention should be further elucidated.

Keywords: Stroke; Hemiplegic gait; Aquatic exercise therapy; Pole walking

Introduction

Stroke is a major cause of chronic impairment of motor functions and results in the limitation of daily activities, including locomotion. Stroke patients have difficulty controlling their movements due to the loss of muscle control, weak muscles, ataxia, dyspraxia, and an increase or decrease in muscle tone. At 6 months after the lesion, 50% of the patients exhibited some symptoms of hemiparesis, and 30% were unable to walk without assistance [1]. The development of effective neurorehabilitation strategies is therefore required for the restoration of functional walking.

Pole walking (PW), i.e., using a pair of poles (one in each hand) while walking, has been utilized among individuals with poor physical fitness and those with balance disability because the use of poles increases postural stability by increasing the base of support during the stance phase of walking. For stroke patients, moreover, enforced movements among four limbs are expected to correct asymmetrical load movements on their affected side during normal locomotion. Therefore, PW may have potential benefits for new interventions to effectively mitigate gait impairment and to modify the activation of brain and spinal locomotor circuits. However, stroke patients cannot receive the full benefit of PW on the ground because of their postural instability due to muscle weakness and spastic hypertonia.

An aquatic environment has clinical benefits for patients with motor dysfunction because of the known physical characteristics of water [2]. For instance, hydrostatic pressure enhances venous return and cardiac preload, consequentlyy reducing strain on the cardiopulmonary system [3]. Buoyancy alleviates stress on weight-bearing joints by providing body-weight support [4,5] and enables various body movements that cannot be performed on the ground. Based on these studies, aquatic exercises have recently attracted attention as a rehabilitation strategy after stroke. Particularly in post-stroke gait training, the effects of aquatic exercise have been demonstrated extensively by walking on an underwater treadmill [6,7]. This way of training, however, requires a special apparatus that is not readily accessible in the daily lives of patients.

Aquatic PW is a possible novel intervention for rehabilitation that is more easily accessible and can be performed safely in the daily lives of patients. To address its potential use for rehabilitation of walking, we report the acute effect of aquatic PW on a post-stroke patient in a chronic stage (12 years after lesion). Changes in gait performance were evaluated based on over ground walking speed both before and after training intervention. The electromyographic (EMG) activity of the lower-extremity muscles was measured to estimate neurological changes after the training. Possible mechanisms underlying these changes (if any) will be discussed from the perspective of the neural aspect of locomotion.

Methods

Participant

The participant was a 64 year-old male patient (height: 167.0 cm, weight: 58.2 kg) with chronic hemiparesis resulting from cerebral infarction 12 years prior to participation in the study. Computed tomography (CT) of the brain showed lesion locations with the defluxion of nerve tissues across the epithalamus, corona radiata, temporal lobe, and parietal cortex of the left hemisphere. Consequently, the participant exhibited paralysis on the right side of the body (Brunnstrom stage: right upper limb III, right lower limb III, right hand III), with Wernicke–Mann posture being associated with motor aphasia. In daily life, he walked independently by using a T-shaped handle cane held in the left hand. The joint passive range of motion (PROM) (for both the left and right side) are given in Table 1.

PROM (deg)			
		Right	Left
Shoulder	flexion	135	150
	extension	25	25
	abduction	90	145
	adduction	0	0
	external rotation	45	45
	internal rotation	45	45
Elbow	flexion	130	140
	extension	0	0
Wrist	flexion	90	90
	extension	90	85
Hip	flexion	80	90
	extension	0	0
	abduction	30	20
	adduction	10	20
	external rotation	35	25
	internal rotation	20	15
Knee	flexion	160	125
	extension	0	0
Ankle	plantarflexion	40	25
	dorsiflexion	0	5

Table 1: Joint Passive Range of Motion (PROM) of the participant.

The joint ROM showed significant differences between the left and right limb, with the differences dependent on the joints. The participant gave written informed consent for the purposes and procedures of the study. The experimental procedures were approved by the local ethics committee of the National Rehabilitation Center for Persons with Disabilities (Saitama, Japan) and were conducted in accordance with the Declaration of Helsinki.

Measurements

Before and after aquatic PW training in water that lasted for approximately 20 minutes, the participant underwent measurements where he performed normal walking both on land and in water. Both measurements were performed at the self-selected comfortable speed of the participant. For the measurements performed on land, the participant used his own T-shaped handle cane for safety. Gait behaviour was recorded using a video camera. Sufficient time intervals for rest were given between each recording and training session. Through both the training and recording sessions, one experimenter always stood near the participant for safety.

Aquatic PW training in water

The aquatic PW training was performed in a pool (15 m × 4 m) with the water depth approximately at the axillary level of the participant, corresponding approximately to a reduction of the body weight by 80% in comparison to that on land. The water temperature was maintained at 36°C. The duration of the training intervention with aquatic PW was approximately 20 minutes. Following a familiarization period that was performed immediately after water immersion, the participant underwent both assisted (upper and lower extremity movements manually assisted by an experimenter from behind) and unassisted (walking by his own effort) PW, each lasting for approximately 10 minutes.

For the aquatic PW, a pair of poles (Kizaki Corp., Nagano, Japan) with built-in 0.5 kg weights to resist buoyancy, and therefore dedicated to use in water, was used. The length of the poles was adjusted to a length at which the elbow joint angles were approximately 90°C when the subject stood upright with the poles and kept them naturally in front of him. Due to the participant's difficulty holding the pole in his right hand, the pole for the right hand was securely fixed at the palm using an elastic rubber band. To follow the possible changes in gait behaviour over the course of the aquatic PW, data recordings were performed during the training session as well.

Data recording

The electromyographic (EMG) activity of the muscles in the right (affected) side of the body was recorded from the following 8 muscles: soleus (SOL); medial head of gastrocnemius (MG); tibialis anterior (TA); rectus femoris (RF); biceps femoris (BF); biceps brachii (BB); triceps brachii (TB); trapezius (upper fibers) (TP). After skin preparation, pairs of conventional surface electrodes (Ag/AgCl, 0.8 cm in diameter) were placed along the muscle fibers. The inter-electrode distance was 2 cm. For EMG recordings in water, the electrodes were securely covered with water-resistant adhesive microfilms. The obtained EMG signals were amplified by using a bio-amplifier (AM601G, Nihon Koden, Tokyo, Japan). EMG data were digitized at a sampling frequency of 1 kHz (PowerLab/16SP, AD Instruments, Colorado Springs, CO, USA) and were stored in a computer for offline analysis. The obtained EMG signals were processed using a fourth-order Butterworth filter (bandpass: 20–300 Hz). EMG responses in the SOL, TA, and BF muscles were not appropriately recorded due to insufficient waterproofing.

For gait analysis, a sagittal view of the participant was recorded by using a video camera (HDR-CX180, Sony, Tokyo, Japan) placed approximately 5 m from the walking path. The sampling frequency was 30 Hz. In a later offline analysis using a motion analysis system (Frame-DIAS IV, DKH, Tokyo, Japan), the speed at which the subject walked along a 5 m walking path both before and after the aquatic PW training was detected on the basis of the lateral displacement of the tragion. To eliminate the acceleration and deceleration phases of walking, the time taken for walking the middle section of the path (1.8 m) was used to calculate walking speed. Moreover, on the basis of the moment of foot contact and toe-off both for the affected (right) and unaffected (left) side, gait parameters such as the stride time, stance time, and swing time were calculated for both limbs.

Results

Table 2 compares the gait performance of the participant before and after the 20 minute aquatic PW training. Most importantly, the average speed of over ground walking was greatly increased after the training intervention (0.16 m/s) compared with that before (0.04 m/s). This was reflected in the time taken for each stride cycle (stride time) both in the unaffected and affected limbs. In the stride cycles, moreover, it is obvious that most of the changes in stride time are due to changes in the stance time, in contrast to the swing time, which showed only minor changes. Consequently, the participant spent less time on the ground after the training (62.1% on the unaffected and 82.4% on the affected side after the training intervention, compared to 75.7% and 92.2%, respectively, before the intervention).

	Unaffected (left) side						**Affected (right) side**				
	Walking speed (m/s)	stride time (sec)	stance time (sec)	stance time (%stride)	swing time (sec)	swing time (%stride)	stride time (sec)	stance time (sec)	stance time (%stride)	swing time (sec)	swing time (%stride)
Pre	0.16	8.7 (8.8)	7.7 (8.7)	75.7 (15.5)	1.1 (0.3)	24.3 (15.5)	6.2 (8.4)	5.9 (8.4)	92.2 (5.7)	0.3 (0.1)	7.8 (5.7)
Post	0.04	2.2 (0.1)	1.3 (0.2)	62.1 (10.0)	0.8 (0.2)	37.9 (10.0)	2.2 (0.2)	1.8 (0.2)	82.4 (5.2)	0.4 (0.1)	17.6 (5.2)

Table 2: Comparisons of the gait performance (mean ± (SD)) before and after the training intervention in water.

There were substantial changes in the EMG activities of the MG and RF muscles, whereas other muscles showed only minor responses allowing pre- and post-training comparisons. The EMG activities of the MG and the RF muscles during the walking test are shown in Figure 1.

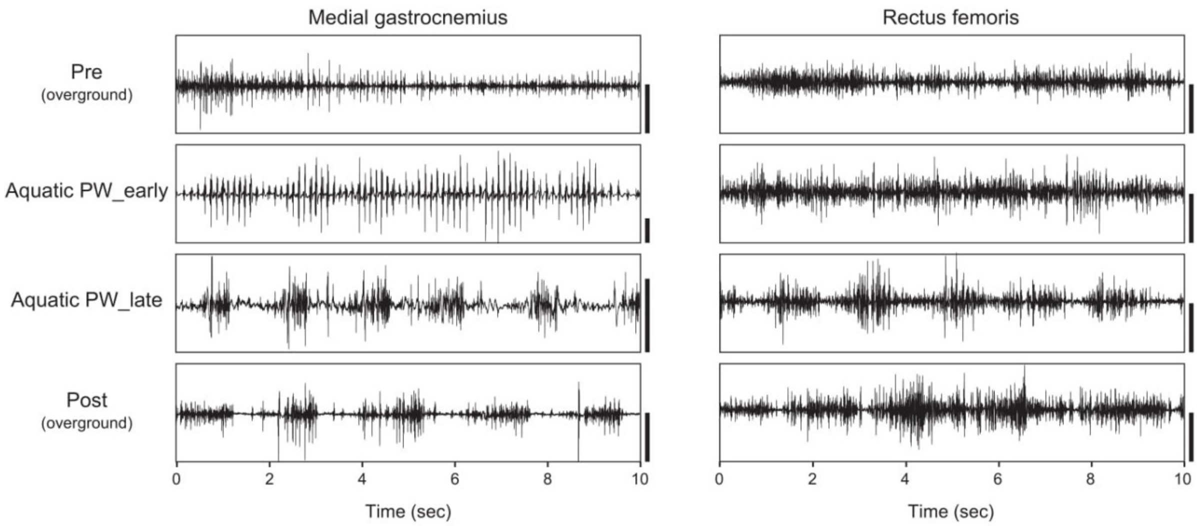

Figure 1: EMG activities of the medial gastrocnemius (MG) and the rectus femoris (RF) muscles over the course of the experiment (from upper to the lower panels). Pre- and post-training recordings were performed over ground. "Aquatic PW_early" and "Aquatic PW_late" show the EMG activities under different phases of aquatic PW (immediately after the beginning and at the final phase of the 20-minute training period). Calibration bars indicate 0.3 mV for the MG and 0.1 mV for the RF muscles.

In the "pre" condition, when the participant walked over ground, there was constant activity in both muscles, and amplitude modulation over the time course was rarely found. After water immersion, however, there was a small modulation in activity, with greater activity taking place at regular time intervals in both muscles (Aquatic PW_early). As training progressed, the modulation became more visible, and the activity was clearly enhanced in some phases but nearly absent in others (Aquatic PW_late). The EMG activities with clear modulation during the final phase of the aquatic PW training were carried over to the subsequent walking over ground. Although different in movement duration (as shown in the gait performance, previously), a clear distinction can be found between walking before (pre) and after (post) the 20-minute aquatic PW training.

Discussion

The development of effective rehabilitation strategies to restore gait function is imperative for stoke patients, since gait disorder is one of the major causes of reduced quality of life. In the present study, acute effects of new gait training with aquatic PW were reported for the first time. The result in a single stoke patient showed that, after this training, over ground gait performance was improved, with improvements in the emergence of functional muscle activity in the lower limb muscles, suggesting a potential benefit of this training. These changes would be brought about by the combined effects of both the physical characteristics of the aquatic environment and the walking accompanied by poles.

Abnormal EMG activities, such as constant activity with no modulation in the amplitude over the time course of walking, were changed to a more phasic pattern during the final phase of aquatic PW training. They were carried over to the subsequent over ground walking. These changes indicate that spastic EMG patterns were improved by aquatic PW. In the previous study, it was suggested that spastic movement is associated with impaired spinal reflex excitability as well as abnormal supraspinal drive and altered muscle properties [8]. Although we cannot specify the precise neural mechanism, we describe here several possible mechanisms responsible for the present results.

Water characteristics can directly affect the spasticity and muscle tonus in the lower leg muscles. The viscosity and drag force in water depress the rapid motion of each joint and are suggested to reduce the velocity-dependent spastic response [9]. Thermotherapy, including warm-water immersion, is known to reduce muscle tonus and muscle spasm [10]. Decreased excitability of alpha-motor neurons through a decrease in impulses from the muscle spindles has been suggested as a possible neural mechanism [11].

The buoyance of the water and the use of walking poles in both hands may indirectly reduce the spasticity. The present subject exhibited a hemiparetic gait on the ground and supported his weight on the unaffected side by using a T-cane. Asymmetric posture due to hemiplegia induces unsteady gait, leading to an increased fear of falling. Fear of falling is one of the factors of "postural threat," which has been reported to increase the excitability of the spinal stretch reflex [12]. Enhanced sympathetic and fusimotor drive during postural threat are thought to increase muscle spindle sensitivity [13]. Therefore, an unsteady gait on the ground may have led to spastic EMG activities through postural threat. On the other hand, in water, asymmetric posture can be improved by reducing the body weight through buoyancy. The use of walking poles would further enhance equal weight-bearing in the lower extremity. It would also increase the base of support during the stance phase of PW. All of these features indicate that aquatic PW acts to stabilize gait posture. There was the possibility that a reduced fear of falling improved spastic EMG activities.

Aquatic PW seems to have other benefits for stroke patients. This training may increase the motivation for walking. Stroke patients have difficulty moving independently on the ground. The buoyance of water and the use of the walking poles would help patients to control their locomotion in water. Therefore, aquatic PW may overcome patients' resistance to locomotion and increase their motivation for walking. In addition, this training could be widely applied for chronic stroke patients. Recently, the underwater treadmill has become known as a gait training tool for stroke patients. However, most facilities do not have the resources needed to do treadmill training in water. On the other hand, aquatic PW is easy to introduce in swimming pools because facilities have only to prepare the walking poles. This is another benefit of this new gait training.

Conclusion

In conclusion, we have demonstrated that aquatic PW improved gait performance in a single stroke patient with antispastic effects in the lower limb muscles. The most potential candidate for this effect is through decrease in muscle spindle sensitivity. Given the convenience, safety, and positive outcomes, we propose that this new gait training has many benefits for chronic stroke patients with spasticity. Further investigations among a large population of patients presenting similar symptoms will be helpful to support the result observed in this single patient.

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