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Original Article (short paper)

Aerobic training in aquatic environment improves the position sense of stroke patients: A randomized clinical trial.

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Abstract — Aims: (Stroke patients often present sensory-motor alterations and less aerobic capacity. Joint position sense, which is crucial for balance and gait control, is also affected in stroke patients). To compare the effect of two exercise training protocols (walking in deep water and on a treadmill) on the knee position sense of stroke patients. **Methods:** This study was designed as a randomized controlled clinical trial. Twelve adults, who suffered a stroke at least one year prior to the start of the study, were randomly assigned to one of two groups: 1) pool group submitted to aerobic deep water walking training; and 2) the treadmill group which was submitted to aerobic walk on a treadmill. Measurements: The position sense, absolute error and variable error, of the knee joint was evaluated prior to and after nine weeks of aerobic training. **Results:** The pool group presented smaller absolute (13.9º versus 6.1º; $p < 0.05$) and variable (9.2º versus 3.9º; $p < 0.05$) errors after nine-weeks gait training than the treadmill group. **Conclusions:** Nine-week aerobic exercise intervention in aquatic environment improved precision in the position sense of the knee joint of stroke patients, suggesting a possible application in a rehabilitation program.

Keywords: position sense, aerobic exercise, stroke, proprioception

Introduction

The joint position sense refers to the static positioning of a body segment in space[1]. Joint position sense is important for the maintenance of posture, for the coordination between trunk and limbs and to improve the performance during daily life activities[2,3]. Individuals with anterior cruciate ligament injury[3] or patients with arthroplasties[4] have significant joint position sense problems. On the other hand, although central neurological diseases affect the performance of motor actions, it is not clear whether or not part of the loss in performance is related to the decrease in the joint position sense.

Stroke causes deficits to the consciousness, language, cognition, perception and sensation, and movement. Motor deficits are characterized by paralysis (partial or total) of the body occurring contra-laterally to brain injury. Stroke also alters muscle tonus (spasticity), impairs reflex regulation, affects motor coordination and postural control[5]. After a stroke, motor action performance is also affected by sensory alterations because it changes the postural frame of reference and how the muscle and joints are grouped into synergies[6]. Disorders in knee control are common and disabling in stroke patients.

Individuals who have suffered a stroke show less aerobic capacity compared with healthy people at similar age because the paretic muscle changes by disuse and weakness linked to neural alterations[6]. This leads to low resistance, fatigue and takes the person to a sedentary life style with low physical fitness[6,7]. To overcome such a problem, physical exercises, especially those that stimulate increased aerobic capacity, should protect against disuse and immobility. Aerobic capacity increases the ability to do daily life activities and improves life quality and functional skills[8,9]. The major problem is to maintain the adherence to aerobic exercise after a stroke.

Aquatic training and therapy are often included in rehabilitation programs[10,11], though it has the disadvantage of being more costive than therapy in ground environment. Comparing exercising in water with exercising on land, it can be postulated that exercising in water provides unusual sensory stimuli because patients experience a different environment, water buoyancy facilitates the patient's movement reducing the external forces applied on the body, and the postural instability in water requires a high postural input for the performance of motor tasks[12,13,14]. This condition is unclear for stroke survivors. Therefore, what is the effect of water walking aerobic training in stroke survivors condition? The study's objective was to compare the effect of two modalities of aerobic training (walking in deep water versus treadmill walking on land) on knee joint position sense of participants with chronic sequelae of ischemic stroke. Our hypothesis is that the aerobic training in aquatic environment will improve the precision and accuracy of the position sense in stroke patients to a greater extent than the treadmill training.

Due to the differences in the sensory input between these two modalities, it might be that joint position sense is differently affected according to the environment where the aerobic exercise is performed. If so, it could be an important and desirable secondary gain in favor of aquatic rehabilitation performed by stroke patients.

Method

Design

This study is a randomized controlled clinical trial with a blinded examiner. This research project was approved by the local ethics committee (Approval number: No 1.220.023). All participants signed an informed consent document as per University policy and procedures of this study followed the guidelines as developed by the national health council.

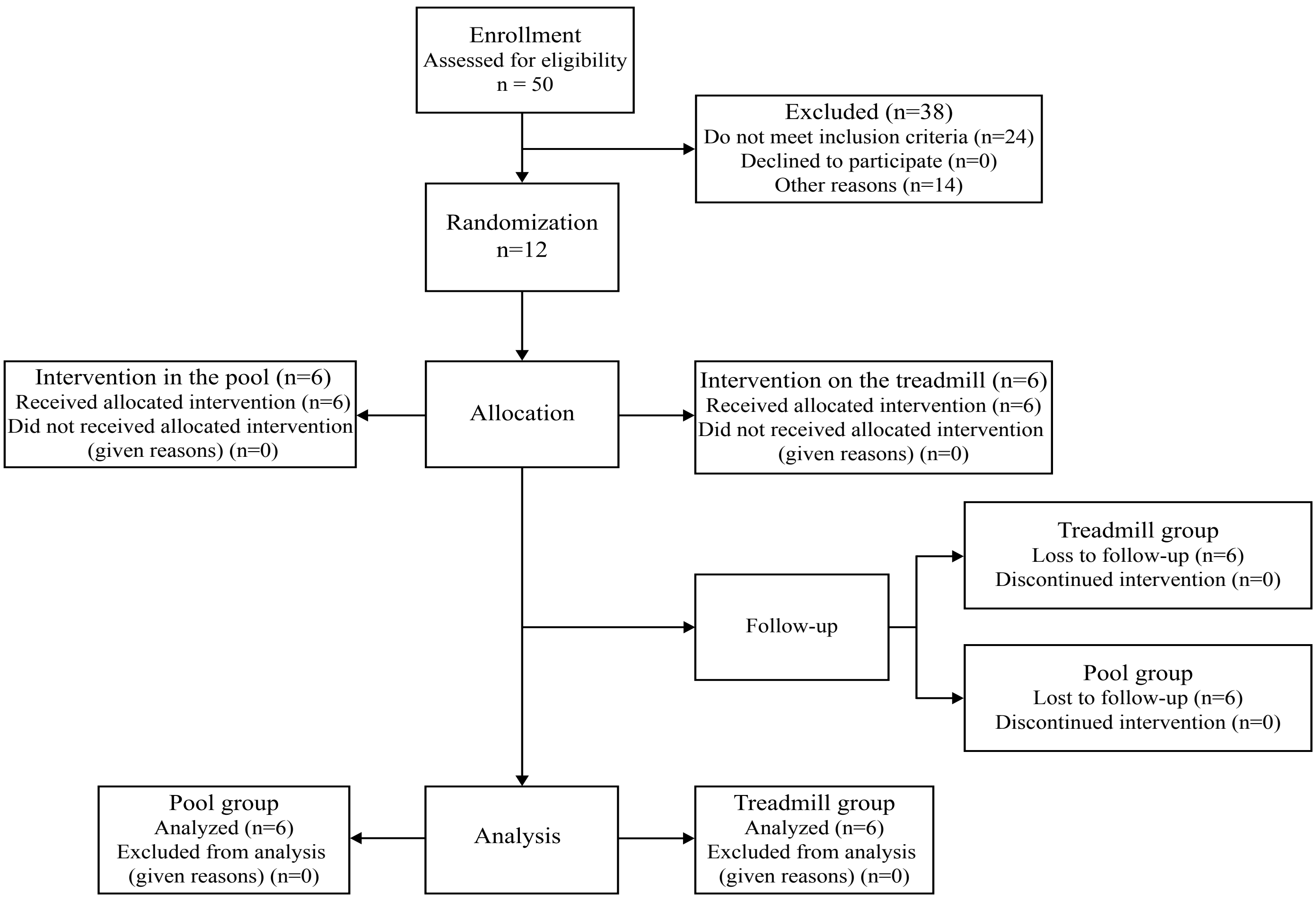
Participants

Fifty adults who had a stroke at least one year prior to this study were recruited for evaluation. Those persons have not had any other treatment for their chronic stroke condition; in fact, all of them were at a waiting list for physical therapy treatment. Each participant had a neurological evaluation assessment screening and those who met the inclusion criteria were selected for the study. As inclusion criteria, participants had to be independent walkers or dependent on a single cane support to walk. We excluded participants with arrhythmias or recent heart surgery; those who had a smoking or drinking habit; those with hypertension or uncontrolled diabetes mellitus; those who had recently suffered an orthopedic injury (joint instability, dislocation, recent fractures, severe contractions in muscles in the lower limbs, and others); or those who had suffered aphasia or inability to follow two commands simultaneously. Although the volunteer would be excluded from participation if, during the training sessions he suffered nausea, dizziness, malaise, fainting, tachycardia, excessive sweating, or any sign of autonomic changes, no dropout was recorded. From the fifty assessed for eligibility, twenty four did not meet inclusion criteria and fourteen did not participate due to personal reasons. The sample (n =12) contained men and women from 40 to 65 years old with spastic hemiparesis. For the pool group (PG), participants attended to stationary water walking aerobic training; while for treadmill group (TG), participants attended to treadmill walking aerobic training.

Randomization and Intervention protocols

Figure 1 shows the flowchart for participant selection and allocation process. Participants were randomly allocated within PG or TG. Twelve opaque sealed envelopes were used: six had a double folded sheet with the number 1 and six had such a folded sheet with the number 2 (1 for PG and 2 for TG). Each participant has chosen an envelope, opened it and give the folded sheet to the responsible for the allocation group. This independent researcher read the number, recorded it, refolded and returned the sheet to the envelope. Participants were blinded for group allocation, as well as that independent researcher did not know the meaning of numbers 1 and 2.

Figure 1. Flowchart containing the number of participants in each group and the experimental phase.



Position Sense test

Participants knew that the aim of gait training was to improve their general health condition; but, they were not aware about outcomes of this research project. The examiner that evaluated the position sense was blinded to the participant's group. The position sense test is applied to check if someone is able to move passively or actively one joint to pre-defined joint angle. To evaluate the knee joint position sense, we used an isokinetic dynamometer (Biodex, System 3, USA). Participants remained seated with the belts fastened to reduce body movement. The axis of the dynamometer was aligned with the lateral epicondyle of the knee and the distal support of the isokinetic arm was located 3cm above the lateral malleolus.

Prior to position sense test, each participant had enough time to get used to the isokinetic machine. After this adaptation, the position test started. First, the participant should be aware about the target: the knee was passively extended at 10^o/s from 90^o (the initial position) to the target (75^o), it has remained at the target for 10 s, and was flexed to the initial position. For the last part of this test, the participant should press the locking bottom twice: one to release the isokinetic arm movement and again to stop it, when the target was reached. This task was repeated three times with 20 s between trials to avoid fatigue. The same evaluation was performed before and after the application of the nine-week program of aerobic training.

The final angular position of the dynamometer and the target position were recorded. From these measures, the absolute error (AE) and variable error (VE) were calculated[3,15]. AE is the absolute difference between actual performance and the goal[15], giving information about the committed error and it is the precision of the performance:

$$AE = \frac{\sum_{i=1}^{n} |X_i - T|}{n}$$

where x_i is measured value, T is the target value and n is the number of trials. VE is the variability of the error over a series of trials and represents the accuracy of the performance:

$$VE = \sqrt{\frac{\sum_{i=1}^{n} (X_i - \bar{X})^2}{n}}$$

where $\bar{X}$ is the x mean over the number of trials and n is the number of trials.

Gait Training

To reduce the risk that an aerobic exercise may cause to stroke survivors, the hemodynamic evaluation of the individual was conducted by a licensed physical therapist.

Participants were encouraged to keep a constant gait pattern for the paretic and non-paretic sides. If necessary, participants could use walking aids. TG participants used a body weight suspension system to protect them against falling and the PG participants wore an aquatic float around the trunk. Heart rate and blood pressure were monitored to ensure that participants would complete the task at an appropriate submaximal intensity. The gait training protocol was repeated three times/week for nine weeks (Table 1).

Both groups received individual treatment. No adverse events or side effects were reported.

Table 1– Training protocols for the treadmill (TG) and pool (PG) groups.

		1st week	**2nd to 9th week**
Warm up	Time (minutes)	5	5
	Activity performed	walk	walk
	% of heart rate during training session	40	40
Training session	Time (minutes)	30	40
	Activity performed	Stationary gait	Stationary gait
	% of heart rate during training session	50	60
Cool down	Time (minutes)	5	5
	Activity performed	walk	walk
	% of heart rate during training session	30	40

Statistical Analysis

Analysis of variance (ANOVA) was performed on the descriptive measures and groups to determine if there was a bias in the initial differences between groups. The dependent variables AE and VE were compared using two way ANOVA with the factors Group (PG and TG) and Condition (pre-intervention and post-intervention). The alpha level was set at 0.05. The *post hoc* Tukey test was used for multiple comparisons when appropriate. Cohen's *d* effect size was calculated[16], where an effect size of d=0.2 indicated a small effect, d=0.5 a moderate effect and d=0.8 a large effect. All analyses were performed in SPSS statistical software, version 17.0 (SPSS Inc., Chicago).

Results

Descriptive characteristics of each training group are presented in Table 2. There were no differences between groups for those variables (p > 0.05).

Table 2. Mean (standard deviation) of descriptive measures of the treadmill (TG) and pool (PG) groups. FAC (functional ambulation classification). MMSE (mini mental state examination). *P* values obtained comparing TG with PG are also shown.

Variable	**TG (n=6)**	**PG (n=6)**	***P value***
Age (years old)	54.8 (7.7)	61.7 (10)	0.2
Sex	5 F e 1 M	5 F e 1 M	
Affected side	4 R e 2 L	2R e 4L	
Score FAC	4 (0.63)	4.2 (0.75)	0.7
Lesion time (months)	56.6 (33)	67.6 (51)	0.7
Score MMSE	24.2 (4.2)	24.5 (4.3)	0.9

For the AE (Figure 2), there was Condition *versus* Group interaction ($F_{1,80}$=6.0 p=0.01 ES=0.5, power=0.96). The PG presented the highest pre training AE (p<0.01) and their AE decreased post training (p<0.01). However, there was no difference between pre and post training for TG. Both Condition ($F_{1,8}$=10.3, p=0.01, ES=0.5, power=0.96) and Group ($F_{1,80}$=10.3 p<0.01, ES=0.50, power=0.96) affected AE as main factors. Post hoc analysis showed that AE decreased post training (p<0.01) and it was the highest for PG (p<0.01).

For VE (Figure 3), the statistical analysis indicated the interaction between Condition and Group ($F_{1,80}$= 5.7 p=0.02, EF=0.55, power=0.99). Variable error was greater in PG than for the treadmill group. For PG, VE decreased after training (p<0.05). The statistical analysis revealed that, for the pre training, VE was the highest for the pool group (p<0.01). For TG, VE for pre and post-training were similar (p>0.05). Both Condition ($F_{1,8}$=10.3, p<0.01, ES=0.6, power=0.99) and Group ($F_{1,80}$=8.3 p=0.01, ES=0.55, power=0.98) affected AE as main factors. Post hoc analysis showed that VE decreased post training (p<0.01) and it was the highest for PG (p<0.01).

Figure 2. Mean (+*SD*) of the absolute error (AE) for the interaction between the factors condition (pre and post training) and group (pool group-PG, and treadmill group-TG). *significantly lower than pre training, p < 0.05. #Significantly higher than pre training in the treadmill group, p < 0.05.

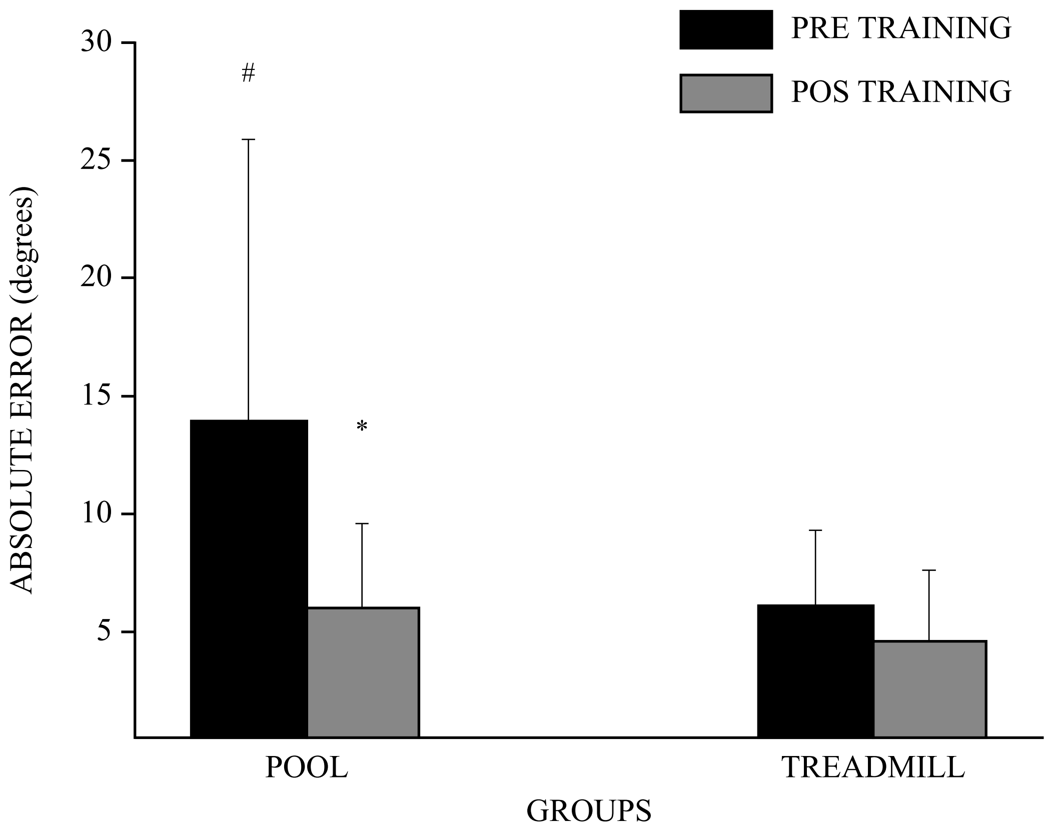
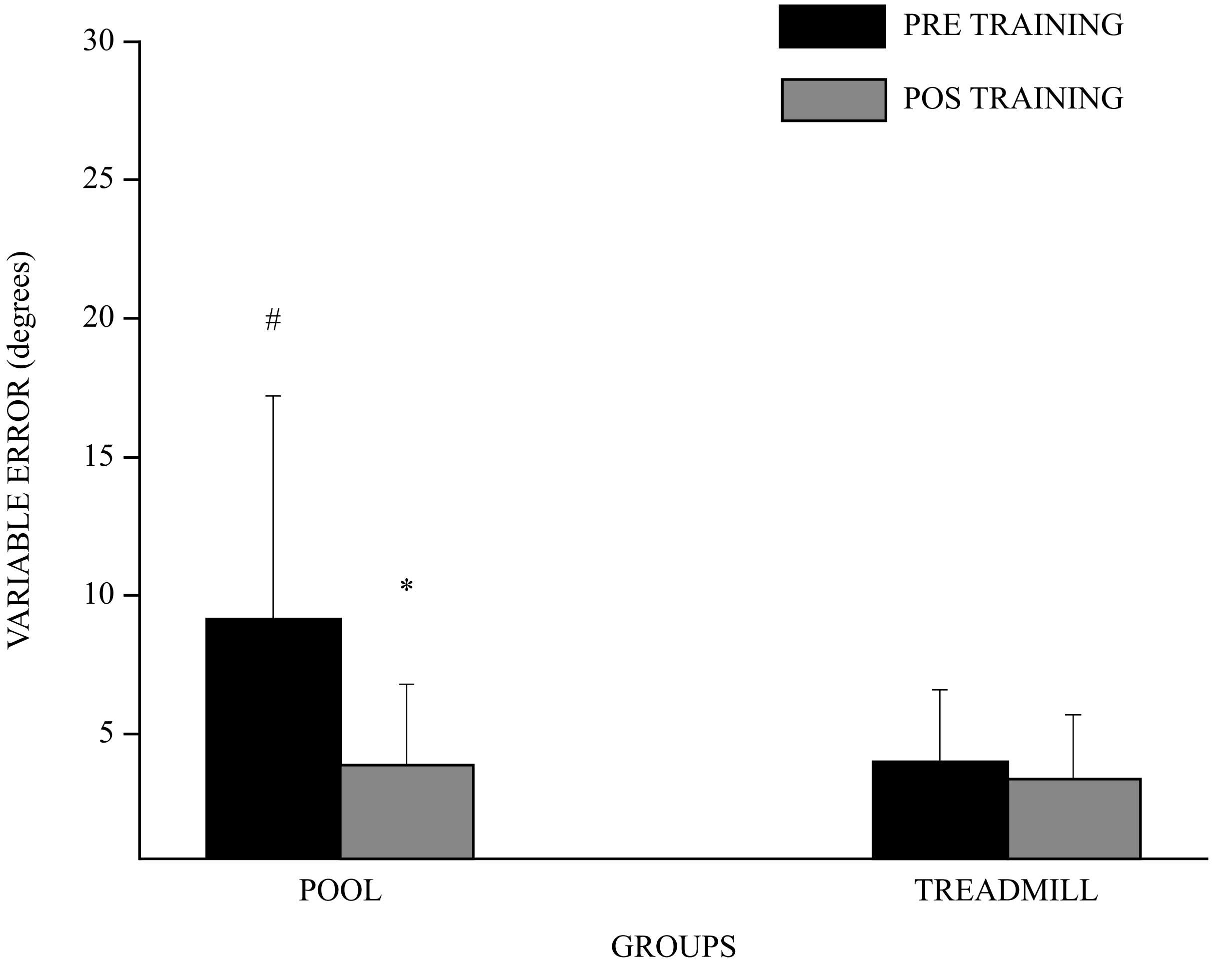


Figure 3. Mean (+SD) of the variable error (VE) for the interaction between the factors condition (pre and post training), and group (Pool group, PG; and treadmill group, TG). *significantly lower than pre training, $p < 0.05$. #Significantly higher than pre training in the treadmill group, $p < 0.05$.



Discussion

The purpose of this study was to evaluate the effect of two types of aerobic training on the knee joint position sense of stroke patients. Position sense was quantified by the absolute and variable errors, which show, respectively, the precision and accuracy of the performance of a motor skill[16,17]. Precision and accuracy of knee joint position sense, which is a method to isolate the proprioception sensory component[3], increased after the aerobic training in the pool, but not for the aerobic treadmill training. The same trend was true for the variable error.

For stroke patients, spasticity and directional hypometry might increase the precision in position sense for the paretic limb. The limitation in the range of motion of the paretic limb enhances the approach to the targets which are close to the joint positions achieved in daily life activities performed by stroke people[18,19]. Usually, post stroke patients have muscle tone alteration, changes in the muscle activation pattern and body segment kinematics[20,21,22] that may cause falls. Jensen, Fischer and Kjaer[23] evaluated the position sense of groups of patients with anterior cruciate ligament injury and also showed that, after an exercise program, more reliable positioning sense in the injured side was observed.

While walking in deep water improves the cardiovascular and motor control systems, stroke participants presented higher knee joint sense accuracy after the pool gait training protocol. The acute benefits of aerobic exercises to proprioception are potentially related to neurophysiological alterations such as higher discharge of neurotransmitters and higher motor unit recruitment. These neurophysiological alterations optimize sensory-motor integration possibly allowing a more efficient error correction in the joint positioning sense with consequently greater functionality of these individuals[24]. Thus, the sensory-motor system of these patients was optimized by the aerobic training allowing increased proprioception.

Aerobic exercises can produce little or no gain in strength in healthy and active populations because it requires no specific load to allow muscle hypertrophy to take place. However, peripheral adaptations may differ fundamentally in stroke patients, making it possible that training through aerobic exercise can improve lower limb strength thus enhancing balance, functional mobility, gait and fall prevention[17].

Both precision and accuracy improved after the gait training in the pool. Kisner and Colby[25] emphasized the benefits of exercise to facilitate movement and proprioception. Swanik et al[26] reported that the improvement in the position sense during exercise arises from stimulating the muscles and joints. The improvement in the position sense performance of stroke patients after an exercise program indicates an adaptation of the central nervous system to the peripheral signals coming from muscle spindles and joint receptors.

Gait training in the water improved precision and accuracy of joint position sense. This result supported our hypothesis that aerobic training in aquatic environment would improve the precision and accuracy of the position sense in stroke patients more than treadmill training. Water exercise has been suggested to enhance sensory input[13]. Water exercise appears to challenge the sensory motor and the postural system in an unusual way compared with the same activities performed on land[12]. Exercises performed in aquatic environment improve balance, strength and muscular endurance in the elderly[13,14] or in post stroke patients[13,15]. The current study shows that the improvement in the knee joint position suggests an adaptation of the central nervous system. However, the clinical and functional improvements should be investigated to confirm this.

Although the groups had similar for their clinical and functional characteristics, the treadmill gait training group presented the lowest precision and accuracy when compared with gait training in the water group in the pre-intervention session. Thus, the groups presented motor sensory differences which can alter the performance of the motor skills during some functional tasks that demand higher specificity of this system[17].

In conclusion, a nine-week aerobic gait training exercise in water improved the precision and accuracy of the knee joint position sense in stroke patients, whilst gait training on a treadmill did not. Therefore, gait training in water may be a better way to develop postural stability in stroke patients and suggested a possible alternative to rehabilitation training.

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