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Influence of visual and auditory biofeedback on partial body weight support treadmill training of individuals with chronic hemiparesis: a randomized controlled clinical trial

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Background. **Stroke is an important causal factor of deficiency and functional dependence worldwide.**
Objective. **To determine the immediate effects of visual and auditory biofeedback, combined with partial body weight supported (PBWS) treadmill training on the gait of individuals with chronic hemiparesis.**
Design. **Randomized controlled trial.**
Setting. **Outpatient rehabilitation hospital.**
Populations. **Thirty subjects with chronic hemiparesis and ability to walk with some help.**
Methods. **Participants were randomized to a control group that underwent only PBWS treadmill training; or experimental I group with visual biofeedback from the display monitor, in the form of symbolic feet as the subject took a step; or experimental group II with auditory biofeedback associated display, using a metronome at 115% of the individual's preferred cadence. They trained for 20 minutes and were evaluated before and after training. Spatio-temporal and angular gait variables were obtained by kinematics from the Qualisys Motion Analysis system.**
Results. **Increases in speed and stride length were observed for all groups over time (speed: F=25.63; P<0.001; stride length: F=27.18; P<0.001), as well as changes in hip and ankle range of motion – ROM (hip ROM: F=14.43; P=0.001; ankle ROM: F=4.76; P=0.038), with no time*groups interaction. Other spatio-temporal and angular parameters remain unchanged.**
Conclusions. **Visual biofeedback and auditory biofeedback had no influence on PBWS treadmill training of individuals with chronic hemiparesis, in short term. Additional studies are needed to determine whether, in long term, the biofeedback will promote additional benefit to the PBWS treadmill training.**
Clinical rehabilitation impact. **The findings of this study indicate that visual and auditory biofeedback does not bring immediate benefits on PBWS treadmill training of individuals with chronic hemiparesis. This suggest that, for additional benefits are achieved with biofeedback, effects should be investigated after long-term training, which may determine if some kind of biofeedback is superior to another to improve the hemiparetic gait.**

KEY WORDS: Biofeedback, psychology - Paresis - Gait - Stroke - Randomized controlled trial.

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Stroke is an important causal factor of deficiency and functional dependence worldwide.[1] Hemiparesis is one of the most common clinical signs, often leading to compromised gait, which is slow and laborious in these patients, exhibiting a series of changes in spatiotemporal and angular variables, such as shorter stride length and decreased its speed and cadence.[2] Furthermore, there is a decrease in hip flexion associated with higher angles for knee flexion and ankle plantar flexion at initial contact of the paretic lower limb. In the stance phase the hip extension is limited and in the swing phase there is an excessive elevation of the foot and a reduction in knee flexion when the foot leaves the ground and at its peak flexion during the swing.[3]

Considerable research has been conducted on how to improve or optimize the functional capacity of individuals with impaired motor function after stroke. Several authors have proposed treadmill use with partial body weight support (PBWS) for gait training in these individuals.[4-7] This is based on indirect evidence, obtained in animal studies,[8-10] of the existence of specific neuronal circuits in the spinal cord able to generate rhythmic motor neural activity central pattern generators (CPG).[11] Treadmill training with PBWS may provide adequate afferent activity for these neuronal circuits and, therefore, influence gait pattern.[12]

Biofeedback is another therapeutic approach used within neurological rehabilitation. It provides individuals with information about their function or physiological response by widening and displaying this information, allowing modulation of motor response through the learning process.[13] A number of authors [14-18] have demonstrated its benefits on gait parameters in subjects with hemiparesis. Most of these studies used electromyographic biofeedback,[15-18] to the detriment of other forms, such as kinetics, kinematic and spatio-temporal biofeedback, and it remains unclear whether this method is effective for treating hemiparetic gait abnormalities.

In light of the importance of spatio-temporal biofeedback, due to its clinical applicability, new studies are needed to elucidate its use in the gait training of individuals with hemiparesis. Moreover, given that the literature has identified biofeedback as a powerful instrument for changing the motor strategies of individuals with neurological impairment, its use, in conjunction with gait training, can enhance the effects of altering the gait variables exhibited by these patients. Thus, this study aimed to determine the immediate effects of visual and auditory biofeedback, in conjunction with PBWS treadmill training, on the gait and motor function of hemiparetic individuals.

Materials and methods

Study design

This is a randomized and controlled clinical trial.

Participants

Participated in the study patients in the chronic stage of stroke, presenting hemiparesis resulting from non-recurrent unilateral cerebral lesion. The sample was composed of individuals with light to moderate spasticity, corresponding to level 1 and 2 of the Modified Ashworth Scale for lower limbs, evaluated in the hip, the knee and the ankle. The scale ranges from 0 to 5, where 0 represents no increase in muscle tonus and 5 indicates joint stiffness in flexion or extension.[19] Individuals were required to be able to walk functionally, with some help or with auxiliary devices, at gait levels 4 or 5 of the Functional Ambulatory Category protocol (FAC), which classifies walking ability into 6 levels, according to the amount of physical support needed to walk 10 meters.[20] Furthermore, individuals had to present with slow or moderate gait speed (less than 0.4 m/s or 0.4 to 0.8 m/s, respectively), in accordance with a speed-based classification system proposed by Bowden *et al*.[21] They had to be cognitive-impairment free, and obtain scores above 19/20 or 23/24 on the Mini Mental State Examination for unschooled and schooled patients, respectively.[22] Finally, individuals could not display other neurological or orthopedic pathologies that might cause functional sequelae, in addition to those resulting from stroke, nor visual and/or auditory deficiency that could compromise biofeedback training. Also excluded were individuals with hypertensive peaks during training and those who failed to understand training instructions.

A simple random sample was drawn and groups were numbered and coded such that the appraiser did not know which treatment the patient would receive and the patients did not know the goals of the training or the existence of other groups. Clinical, neurological and motor evaluation was performed by researcher 1; kinematic analysis by researcher 2 and gait training on the treadmill by researcher 3 who assisted patients during therapies. The results were analyzed by researcher 4 who was unaware of the randomization and trainings.

All the individuals signed an informed consent form, and the study was approved by the institutional Research Ethics Committee.

Sample calculation

Sample size was defined by the STATCALC Epi Info 6.04 program, considering a confidence level of 95% and study power of 80%. Gait velocity variable of individuals with stroke, obtained from the study conducted by Takami and Wakayama,[7] were used to make the calculations, resulting in a sample of 30 subjects for the three groups: control (N.=10), experimental I (N.=10) and experimental II (N.=10).

Measurement instruments

Neurological and motor assessment

National Institute of Health Stroke Scale [23] protocols were used for neurological evaluation and Stroke Rehabilitation Assessment of Movement [24] for motor function evaluation.

Assessment and gait training

Gait assessment was performed on a 10-m walkway. Kinematic, temporal and spatial data were obtained using the Qualisys Motion Capture System. Eight cameras were used in the study (Qualisys Oqus 300), with capture frequency of 120Hz.

Gait training was carried out on the Gait Trainer System 2 treadmill,[c] and a Biodex Unweighting System[c] was used.

Visual biofeedback

Visual biofeedback was obtained from the Gait Trainer[c] monitor, which provided real-time information about stride width and symmetry by displaying foot symbols on the screen as the individual took a step. Individuals were instructed to keep their feet within a 20cm rectangle, in order to follow visual cues and make the necessary corrections if the movement deviated from established patterns.

Auditory feedback

Auditory feedback was performed with a digital metronome at 115% of the individual's mean cadence.[25] To obtain this cadence, subjects were asked to walk for 10 meters and the number of steps was divided by time recorded. The individual was then instructed to keep pace with the metronome beep while walking.

Experimental protocols

Individuals were randomly allocated to three study groups: control, which performed only PBWS treadmill gait training; experimental I, which underwent PBWS treadmill gait training with visual biofeedback and experimental II, which used auditory biofeedback with PBWS treadmill gait training.

All individuals were submitted to clinical assessment to obtain personal information and data regarding the lesion, anthropometric measures and vital signs, followed by neurological and motor evaluation, using previously described protocols. Next, gait kinematics were analyzed, with participants wearing a pair of shorts provided by the observer and their usual footwear.

The Qualisys System was calibrated in the collection area and reference and tracking markers were fixed to the individual's skin. The segment model constructed contained the pelvis, thigh, leg and foot. Figure 1 shows the following anatomical references for marker placement: the highest point of the iliac crest, greater trochanter of the femur, lateral and medial condyle of the femur, lateral and medial malleolus, calcaneus and 1st and 5th metatarsals. Rigid rectangular-based clusters, each containing four tracking markers, were attached to the pelvis, thigh and leg. The pelvis cluster was fixed to the base of the sacrum between the posterior-superior iliac spines, while the thigh and leg clusters were positioned on the mid-third of the lateral surface of the segments. Three reference markers were also used as trackers on the ankle-foot complex: lateral malleolus, calcaneus and 5th metatarsal head.[26, 27]

After this procedure, a static collection was made to identify segments. Subjects were instructed to remain immobile in the orthostatic position for five seconds.

Reference markers were then removed, but tracking markers remained for dynamic collections, where individuals were asked to walk at a comfort-

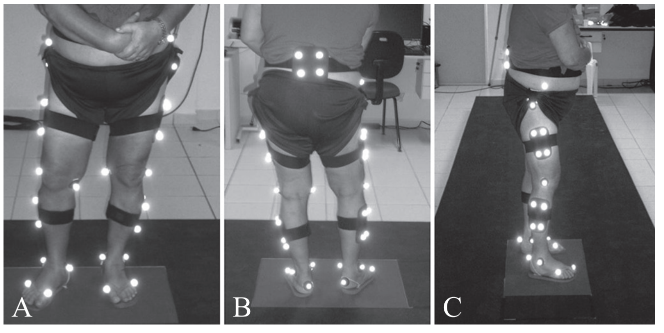

Figure 1.—Placement of reference and tracking markers – anterior (A), posterior (B) and lateral (C) view.

able speed along the walkway, during the 10 repetitions.

Following gait kinematics assessment, PBWS treadmill training was initiated, after patients were fitted with a support belt and given safety instructions. They were initially allowed a five-minute adaptation period to familiarize themselves with the equipment.

Body support weight used was 30%.[4, 6] Treadmill speed, on the other hand, was regulated according to the ability of each subject, who walked as fast as possible without muscle compensation or fatigue. The training period was 20 minutes and patients could rest for 2 minutes if their heart rate exceeded submaximal, that is, 75% HRmax (HRsubmax= 0.75 x (220 – age) or if they experienced muscle fatigue.

At the end of training, a reassessment was made using the Qualisys[b] 3D motion analysis system. The study design can be observed in Figure 2.

Data reduction

The data generated by Qualisys were exported to Visual 3D program. This system enables the construction of a biomechanics model and the assessment of the spatial-temporal variables of gait, as well as angular variation. A low-pass filter at a cutoff frequency of 6 HZ was applied to marker trajectories to eliminate noise caused by markers shifting their position.[28] To obtain joint angles, the software used the association between segments and the Cardan sequence.[29] The reference or orthostatic position was considered the neutral position.

The following spatial and temporal variables of

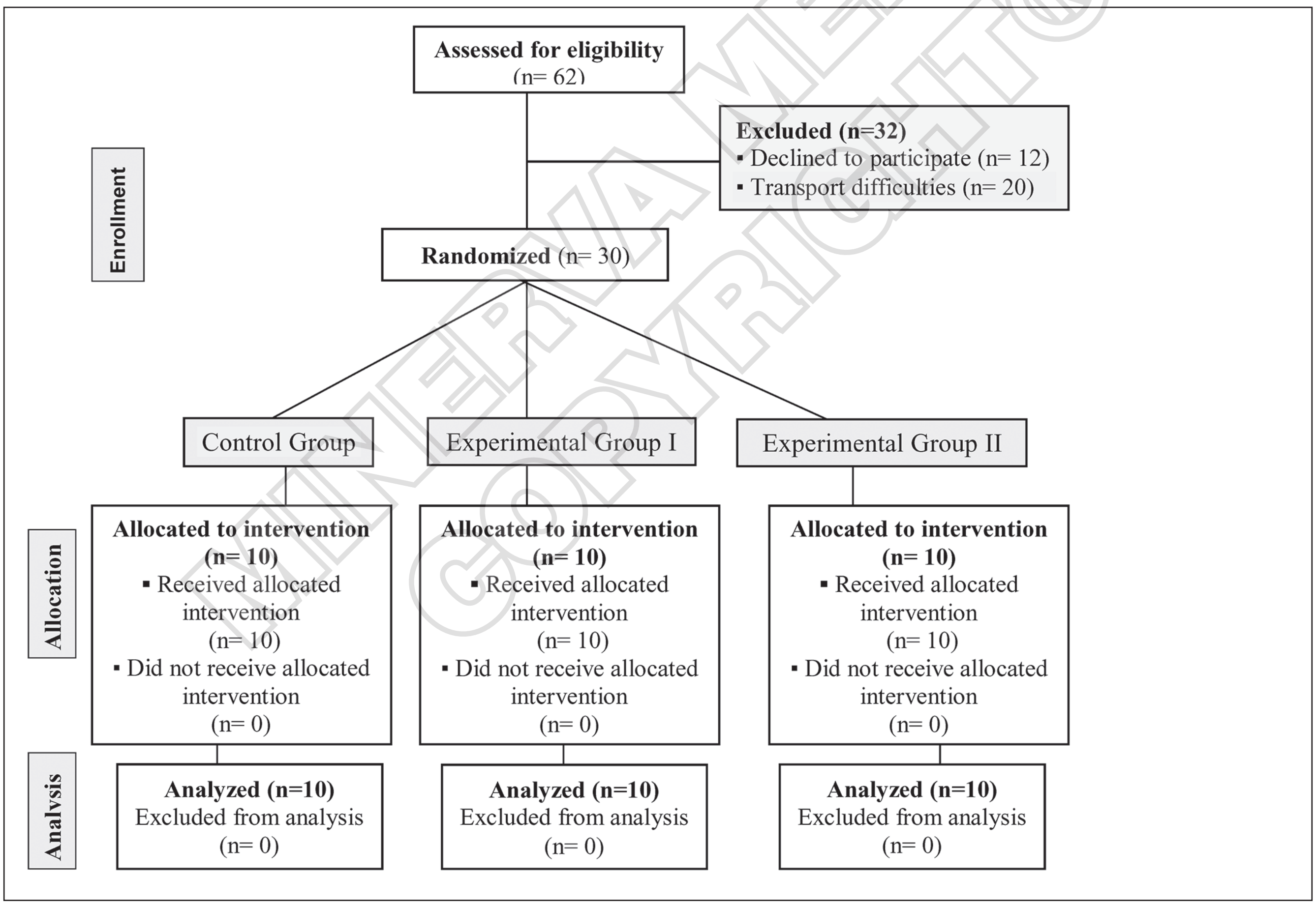

Figure 2.—CONSORT flowchart of study recruitment and completion.

gait were investigated: speed (m/s), stride length (m), cadence (steps/min), paretic stance time (s) – single stance time of paretic lower limb - and symmetry ratio of swing time (swing time of paretic lower limb/swing time of non-paretic lower limb). Angular variables investigated are related of the paretic lower limb displacements in the sagittal plane. Were evaluated the hip, knee and ankle motion (°), the maximum hip extension during stance (°), maximum hip flexion during swing (°), knee angle at Initial Contact (IC) - (°), maximum knee flexion during swing (°) and ankle angle at IC (°) and at Toe-Off (TO) - (°).

Gait speed was selected as the primary outcome measure, because it is a measure of the overall performance of the gait. The remaining variables were selected as secondary measures, being chosen because they represent important steps in hemiparetic gait rehabilitation that has been analyzed in other studies with this population.[30, 31]

To determine the start and end of each cycle two consecutive IC events of the paretic foot were needed. This was achieved by observing the markers placed on the calcaneus or head of the 5th metatarsus. Raising the foot was determined by the marker placed on the head of the 5th metatarsus. The events were defined based on the graphic representation of these markers on the y axis.[32] These definitions were also determined for the nonparetic foot to provide data for the analysis of gait-related variables.

Statistical analysis

Data were analyzed with Statistical Package for the Social Science (SPSS)17.0,[e] at a significance level of 5%. The Kolmogorov-Smirnov was applied to check data normality. Descriptive analysis of clinical and demographic variables was carried out using measures of central tendency and dispersion, and the Levene's test to verify inter-group homogeneity of variance.

Parametric repeated measures (3x2) ANOVA was applied to determine differences in spatio-temporal and angular gait variables between control, experimental I and experimental II groups, at baseline and post-training. The *post hoc* Bonferroni test was applied to detect which pairs of groups differ.

Results

Participants characteristics

Thirty subjects took part in the study (18 men and 12 women), aged 56.4±6.9 years, lesion time of 32.5±19.5 months, presenting with sequel from right (35%) or left hemiparesis (65%) resulting primarily from ischemic stroke (81%).

Groups were homogeneous in all clinical and demographic variables, and there were no statistically significant differences between them at baseline (Table I).

Outcome measures

Spatio-temporal variables

Spatiotemporal gait variables at baseline and post-training in the three study groups are illustrated in Table II, showing a increase in gait speed and stride

Table I.—*Clinical and demographic characteristics of the subjects in the Control (N.=10), Experimental I (N.=10) and Experimental II (N.=10) groups at baseline.*

Variables	Control	Experimental I	Experimental II	P
Age (years)	57.9±4.9	52.3±5.9	58.8±7.9	0.09
Height (cm)	160±5	166±8	160±6	0.60
Weigth (kg)	71.9±7.5	72.5±13.4	68.5±13.2	0.73
Months since stroke	27.4±17.4	37.8±21.5	34.1±20.2	0.41
ASHWORTH †	1.4±0.5	1.1±0.3	1.5±0.5	0.16
FAC	4.4±0.5	4.3±0.5	4.2±0.4	0.48
MMSE	25.1±10.1	26.5±6.5	24.1±14.8	0.26
NIHSS	2.1±1.5	2.5±1.3	3.6±1.8	0.28
STREAM	70.8±15.5	67.4±18.5	63.7±14.9	0.52

Values are mean±SD, *P<0.05.
†Ashworth Scale; FAC: Functional Ambulatory Category; MMSE: Mini Mental State Examination; NIHSS: National Institute of Health Stroke Scale; STREAM: Stroke Rehabilitation Assessment of Movement.

TABLE II.—*Spatiotemporal gait variables at baseline and post-training in the Control (N.=10), Experimental I (N.=10) and Experimental II (N.=10) groups.*

Variables	Control		Experimental I		Experimental II		95% Confidence Interval Lower Bound – Upper Bound
	Baseline	Post-training	Baseline	Post-training	Baseline	Post-training	
Speed (m/s)	0.45±0.15	0.53±0.18	0.51±0.17	0.57±0.21	0.41±0.13	0.50±0.18	0.43-0.56
Stride length (m)	0.72±0.17	0.79±0.18	0.82±0.25	0.86±0.28	0.60±0.19	0.70±0.23	0.67-0.83
Cadence (steps/min)	157.0±26.1	162.5±29.4	154.6±20.3	159.0±23.3	156.2±29.8	161.5±37.2	148.24-168.70
Paretic stance time (s) †	1.05±0.28	1.03±0.26	1.04±0.18	1.09±0.18	1.11±0.35	1.05±0.38	0.96-1.17
Symmetry ratio ‡	1.61±0.43	1.53±0.41	1.43±0.25	1.34±0.23	1.49±0.34	1.58±0.47	1.37-1.62

Values are mean±SD.
† Single stance time of paretic lower limb.
‡ Symmetry ratio = swing time of paretic lower limb/swing time of non-paretic lower limb.

length in all groups over time (speed: F=25.63; P<0.001; stride length: F=27.18; P<0.001) with no time*groups interaction (speed: F=0.25; P=0.776; stride length: F=1.00; P=0.380). Other spatio-temporal parameters remained unchanged.

Angular variables

Figure 3 depicts mean (and standard deviation) of the angular displacements in the sagittal plane of the three paretic lower limb joints (hip, knee and ankle).

Table III gives angular displacement values of the three joints in the control, experimental I and experimental II group, at baseline and post-training. Positive signs indicate flexion of the hip, knee and ankle dorsiflexion and negative signs indicate extension of the hip, knee, and ankle plantar flexion.

Changes in hip and ankle range of motion – ROM were observed (hip ROM: F=14.43; P=0.001; ankle ROM: F=4.76; P=0.038), with no time*groups interaction (hip ROM: F=2.043; P=0.149; ankle ROM: F=2.386; P=0.111). Other angular variables showed no change.

Discussion

Spatio-temporal variables

The gait of individuals with post-stroke hemiparesis is characterized by reduced speed, cadence, stride length, as well as temporal and spatial asymmetry.[2] In this study, gait speed and stride length increased in all the groups. Montoya [14] suggested a beneficial effect of visual and auditory biofeedback on the gait of hemiparetic patients, noting increased paretic step lengh and correction of step asymmetry. Although results showed changes in some spatio-

TABLE III.—*Angular gait variables at baseline and post-training in the Control (N.=10), Experimental I (N.=10) and Experimental II (N.=10) groups.*

Variables	Control		Experimental I		Experimental II		95% Confidence Interval Lower bound – Upper bound
	Baseline	Post-training	Baseline	Post-training	Baseline	Post-training	
Max hip extension during stance (°)	-5.2±8.4	-7.0±8.6	0.6±9.8	-0.4±13.4	0.4±12.0	-2.8±9.4	-5.84-1.00
Max hip flexion during swing (°)	19.7±8.8	18.8±8.0	27.5±7.9	28.5±10.6	22.9±11.3	23.5±9.1	20.49-26.46
Hip ROM (°)	24.9±6.4	25.8±6.8	26.9±7.2	29.0±9.9	22.5±7.1	26.3±7.1	23.16-28.65
Knee angle at IC (°)	13.0±8.8	13.5±6.2	11.1±9.3	8.2±8.6	12.8±16.1	13.3±15.5	7.87-16.11
Max knee flexion during swing (°)	38.0±15.8	38.4±12.3	45.5±10.2	45.3±11.1	36.5±21.3	39.6±19.9	34.81-46.27
Knee ROM (°)	35.1±15.6	34.6 ±12.8	39.4±11.7	41.8±11.2	33.7±9.9	36.7±10.3	32.62-41.15
Ankle angle at IC (°)	-5.6±7.0	-4.1±6.4	-7.4±5.4	-9.3±6.4	-7.8±7.0	-7.5±6.4	-9.26 - -4.61
Ankle angle at TO (°)	-5.1±8.3	-5.3±7.2	-9.5±9.8	-12.8±10.5	-9.5±9.1	-9.3±8.4	-11.84 - -5.31
Ankle ROM (°)	18.1±3.5	17.9±4.1	19.2±8.9	21.4±9.5	15.0±6.3	15.9±6.2	15.407-20.430

Values are mean±SD.
Max: maximum; ROM: range of motion; IC: initial contact; TO: toe-off.

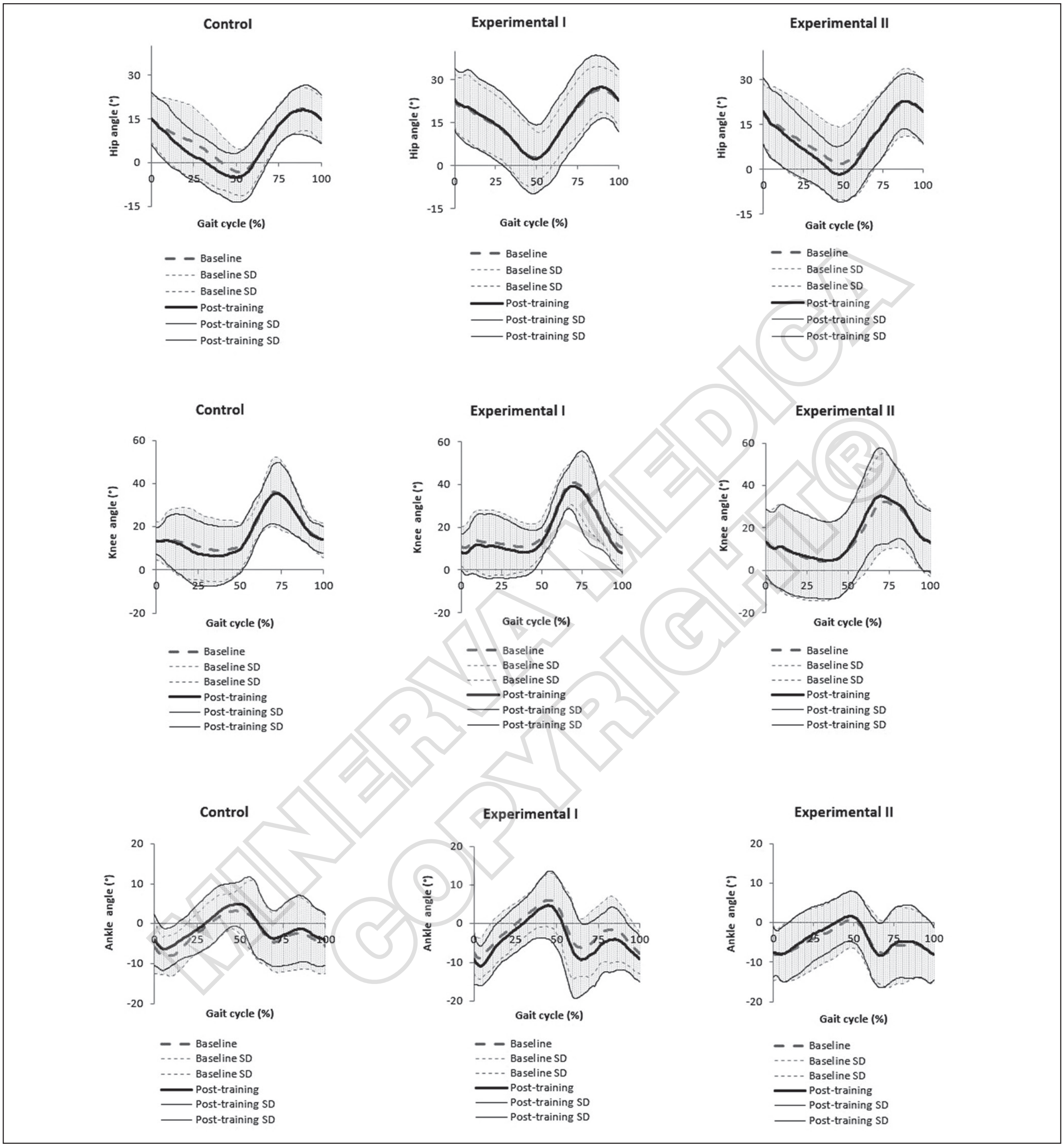

Figure 3.—Angular displacement of the hip (A), knee (B) and ankle (C) joints during the gait cycle for the control, experimental I and experimental II groups, at baseline and post-training. Positive values indicate flexion of the hip and knee and ankle dorsiflexion. Negative values indicate extension of the hip and knee and ankle plantarflexion.
SD: standard deviation.

temporal variables on the present study, this does not seem to be associated to visual or auditory stimuli, since they were also observed in the control group. This finding, therefore, may be attributed to PBWS treadmill training, which is known to promote a faster and more symmetrical gait in individuals with hemiparesis.[4,5,7,33]

PBWS treadmill training benefits are based on the existence of CPG, neuronal circuits in the spinal cord, already well documented in animal studies.[8,9,11] These generate rhythmic neural activity from afferent information originating in the visual, vestibular and proprioceptive systems.[11,12] These circuits, according to Kautz,[34] are responsible for the rhythmic alternating contraction of flexor and extensor muscles in the lower limb, and can therefore influence gait pattern.

Lewek et al.,[35] in a case series of chronic stroke patients also reported an improvement in gait speed, as well as in the spatiotemporal symmetry after treadmill training with visual and proprioceptive feedback during six weeks. However, none of these patients underwent only treadmill training (control group), remaining the question of whether the benefits were due to the additional stimulus (biofeedback) or simply to the action of the treadmill.

Stroke patients often increase the cadence rather than stride length in order to increase the gait speed and to get more functional walking.[36] In this study, participants were able to improve the speed by increasing stride length, since the cadence did not change after training. This is a positive factor, as it shows that these individuals have changed the motor strategy to achieve better gait patterns, although it also cannot be attributed to visual or auditory biofeedback provided.

Regarding the other spatiotemporal variables analyzed (single stance time of paretic lower limb and symmetry ratio of swing time), there was no statistically significant change after training. According Thaut et al.,[37] auditory biofeedback seems to encourage patients to walk in accordance with the training, adapting their gait to the rate of auditory cues. These authors performed gait training for six weeks with auditory cues in stroke patients, verifying improves in the symmetry of swing time of these pacientes.[37] In the present study, in contrast, the group that performed auditory biofeedback had no change in the temporal gait parameters, as well as the control group and the group that received visual biofeedback.

One factor that may be related to absence of temporal changes in the present study is that the temporal gait symmetry seems to be related to the weight bearing on the lower limbs and the balance, while the spatial symmetry seems to be related to the gait-patterning mechanism.[38,39] The treadmill training alone may have been able to interfere with the execution of the gait pattern, as discussed earlier, and have modified spatial symmetry; however, proper weight bearing on each lower limb and balance components were not directly trained in this study, nor in the group receiving auditory biofeedback or in other groups, which may have been partly responsible for the absence of changes in the temporal gait symmetry.

Angular variables

In addition to spatio-temporal variables, the gait of hemiparetic subjects exhibited a series of angular variable adaptations. According to Olney,[3] subjects with hemiparesis displayed impaired hip extension during the stance phase, which may impede backward movement of the thigh, diminishing forward motion and stride length. The three study groups exhibited greater hip ROM, possibly due to the tendency to increased extension angles after training. Although there were no alterations in lower paretic limb knee ROM in this study, ankle ROM also increased in the three study groups after training. The literature has shown that gains in ROM result in greater stride length and gait speed, making it an important aspect in the rehabilitation process.[3]

Tate and Milner[40] and Stanton et al.[41] performed systematic reviews of studies involving biofeedback for gait rehabilitation, suggesting moderate to large benefits from this training immediately after treatment. It is important to note, however, that most of the studies included in these revisions aimed to verify the effects of biofeedback in spatiotemporal gait parameters - considered the best describing the effects of biofeedback -[41] no studies reporting the effects on angular gait parameters of the hip, knee and ankle.

In fact, it is known that individuals with chronic stroke have characteristic gait patterns, molded by compensatory movements developed during the recovery. It is also known that chronic stroke patients are less responsive to treatment aimed at gait rehabilitation.[42] Thus, significant changes in joint angles may even occur - as a consequence of increased speed or stride length - but are expected after training of greater intensity and duration, able to overcome the inertia caused by the chronicity of these patients.

During gait training with biofeedback, patients received additional information regarding their physiological responses. Another question to consider is that these patients' capacity to use critical sensory feedback may be impaired and they might experience their internal feedback to help in the learning process and facilitate gait. On the other hand, patients may respond differently to the therapies, according to the cause of stroke.[43] The majority of individuals in our study (81%) had ischemic stroke, with this percentage evenly distributed between groups. This type of stroke tends to have worse neurological recovery and consequently worse functional prognosis, with less ability to respond to rehabilitation therapies, compared to hemorrhagic stroke.[43] In part, this may be able to explain the small responsiveness of patients in relation to the therapies applied, without significant differences between the experimental groups and the control group.

Stanton et al.,[41] in a recent systematic review, indicate that biofeedback training promotes short-and long-term improvements of gait of stroke patients, suggesting that motor learning actually occurs in these individuals. However, no studies included in this review found that the biofeedback provide additional gains to PBWS treadmill training, which is already known to improving gait in subjects with stroke.[33] In the present study, were found some short-term benefits, but independent of the training group. Long-term studies may show whether there is superiority of application of biofeedback in relation to PBWS treadmill training isolated, and furthermore, it may indicate if some kind of biofeedback (visual or auditory) will be more effective in improving the gait parameters in individuals with chronic stroke.

Study limitations

Our study investigated the immediate, but not the long-term effects of biofeedback. This may explain the absence of alterations in gait variables among training groups, since they might have had difficulty retaining information during the early phases of motor learning. In addition, we include patients with ischemic and hemorrhagic stroke, which could respond differently to the therapies.

It is suggested that new studies be conducted to determine the effect of a longer learning period, given the complexity of the task, in order to avoid masking possible differences between training methods and to verify reproducibility of results through follow-up investigations.

Conclusions

Visual biofeedback and auditory biofeedback had no influence on partial body weight support treadmill training of individuals with chronic hemiparesis, considering the immediate effects in the spatio-temporal and angular gait parameters. Additional studies are needed to determine whether the provision of biofeedback visual and/or auditory may be able to promote additional benefit to the treadmill training with partial body weight support, in the long term.

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