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Rhythmic facilitation of gait training in hemiparetic stroke rehabilitation

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Abstract

Experimental and control groups of 10 hemiparetic stroke patients each underwent a 6 week, twice daily gait training program. The control group participated in a conventional physical therapy gait program. The experimental group trained in the same basic program with the addition of rhythmic auditory stimulation (RAS). Patients entered the study as soon as they could complete 5 strides with hand-held assistance. The training program had to be completed within 3 months of the patients' stroke. In the experimental group RAS was used as a timekeeper to synchronize step patterns and gradually entrain higher stride frequencies. Study groups were equated by gender, lesion site, and age. Motor function was assessed at pretest using Barthel, Fugl-Meyer, and Berg Scales. Walking patterns were assessed during pre- and post-test without RAS present. Pre- vs post-test measures revealed a statistically significant ($P<0.05$) increase in velocity (164% vs 107%), stride length (88% vs 34%), and reduction in EMG amplitude variability of the gastrocnemius muscle (69% vs 33%) for the RAS-training group compared to the control group. The difference in stride symmetry improvement (32% in the RAS-group vs 16% in the control group) was statistically not significant. The data offer evidence that RAS is an efficient tool to enhance efforts in gait rehabilitation with acute stroke patients. © 1997 Elsevier Science B.V.

Keywords: Stroke; Gait; Rehabilitation; Auditory rhythm

1. Introduction

Motor dysfunction is one of the most frequently encountered and therapeutically persistent problems after stroke. Therefore, recovery of motor function is a major emphasis in almost all rehabilitation efforts for stroke patients. Motor deficit characterized by hemiparesis is a common manifestation of cerebral hemispheric stroke in the middle cerebral artery vascular distribution. One of the most desired outcomes of rehabilitation is the improvement of ambulatory function since it determines to a large degree the status of the patient in respect to activities of daily living and associated quality of life (Richards et al., 1993). Current programs in stroke rehabilitation have met with varying success. A recent assessment of the efficacy of stroke rehabilitation shows mixed results (Jeffery and Good, 1995). For example, a study by Hesse et al. (1994) with mildly affected stroke patients who were mostly past the acute recovery stage of 3 months showed significant improvement in gait velocity and aspects of stride symmetry, yet endurance, symmetry of ground-reaction forces and functional performance did not improve after daily training for 4 weeks. Therefore, the further refinement of efficient rehabilitation techniques remains an important challenge.

Gait of hemispheric stroke patients is characterized by several abnormal features. Among those features are varied degrees of asymmetry in stride times and stride length, slowed velocity, poor joint and posture control, muscle weakness, abnormal muscle tone, and abnormal muscle activation patterns, mostly affecting the paretic side. What is important to note is that the resulting deficits in gait

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performance are not only due to muscle weakness but to complex abnormalities in motor control (Good, 1994). Therefore, rehabilitation strategies for gait recovery need to address the facilitation of appropriate motor control strategies.

The recent emergence of new data regarding the physiologic mechanisms underlying recovery, specifically in respect to the facilitation of cortical reorganization and the application of learning and training paradigms, may provide new avenues to develop strategies to enhance motor recovery. For instance, several authors have noted evidence for the possible stimulation or 'unmasking' of intact alternate motor control centers (Fries et al., 1993; Chollet et al., 1991; Brion et al., 1989; Freund and Hummelsheim, 1985), and the modulation of cortical motor output through motor training (Pascual-Leone et al., 1993; Aizawa et al., 1991; Bach-y-Rita, 1992). Research data are yet equivocal as to what extent the utilization of sensorimotor facilitation can strengthen training paradigms and/or shift motor control strategies in motor rehabilitation (Good, 1994). However, recent data suggest rehabilitative procedures that involve highly repetitive, rhythmically patterned movement training to be particularly effective (Buetefisch et al., 1995), possibly by facilitating long-term potentiation in the sensorimotor cortex as a mechanism for motor learning (Asanuma and Keller, 1991a,b).

Therefore, to further clarify the role of sensory stimuli in motor recovery we sought to determine the usefulness of auditory rhythm as an external timekeeper to enhance efforts in gait rehabilitation with stroke patients within 3 months post cardiovascular accident (CVA). Our study was based on previous work in which we had used auditory rhythm in an entrainment design to study the immediate effect on gait patterns in stroke patients without training effect (Thaut et al., 1993). Our data showed a significant improvement in motor unit recruitment patterns, weight bearing stance time on the paretic leg, and stride symmetry in 10 hemispheric stroke patients, ranging from 4 weeks to 2 years post stroke. These results were repeated in 3 consecutive trials, each 2 weeks apart from each other. In the current study we investigated the rhythmic entrainment effect as a therapeutic technique in gait training of acute stroke patients within 3 weeks post CVA.

2. Methodology

2.1. Subjects

Twenty subjects, 10 male and 10 female, were randomly assigned to either an experimental group, using rhythmic auditory stimulation (RAS) with conventional physical therapy (PT), or a control group, using only conventional PT for gait training. Conventional PT was based on the Neurodevelopmental Treatment (NDT) approach. Each group was matched by gender (5 male and 5 female patients), and lesion site (5 right- and 5 left hemispheric strokes; localized by MRI scan). The mean age was 73±7 for the RAS-group, and 72±8 for the control group. The 2 groups were further assessed at the outset of the experiment by a physical therapist blind to the experiment on the Barthel Index (Mahoney and Barthel, 1954), the Fugl-Meyer Scale (Fugl-Meyer et al., 1975) and the Berg Scale (Berg et al., 1989). The Barthel Index was also readministered at the post-test. The Barthel Index for the RAS-group was 53 at pre-test and 86 at post-test, and 50 and 82 respectively for the control group. The Fugl-Meyer score was 9 for balance and 25 for lower extremity function in both groups. The Berg score was 45 for the RAS-group and 50 for the control group.

In the RAS-group, 5 subjects had right-hemispheric middle cerebral artery (MCA) strokes, 3 had left internal capsule (IC) and 2 had left MCA strokes. Three subjects had suffered a second strokes. Six strokes were ischemic and 4 hemorrhagic.

In the control group, 4 subjects had right MCA strokes, 1 had a right IC stroke, 2 had left MCA and 3 left IC strokes. Two subjects had suffered a second stroke. Five strokes were hemorrhagic and 5 ischemic.

Mild to moderate distal sensory dysfunction was manifested in all MCA distribution strokes and not displayed in the patients with IC strokes. Both groups had lower limb spasticity, mostly seen in knee flexors/extensors, plantar flexor, and hip flexion/extension patterns, as typical for stage 4 of the hemiplegia recovery scale described by Brunnstrom (1970).

2.2. Training

Patients entered the study as soon as they could complete 5 strides with hand-held assistance by the therapist, i.e. supporting the forearm, wrist and elbow at approximately 90 degree elbow flexion on the nonparetic side, within 3 weeks post CVA. Hand-held assistance was also given to the patient throughout experimental trials and gait training time when needed. The average entry post CVA for the study was 16.1±4 days for the RAS-group and 15.7±4 days for the control group. The entire training duration for the study was 6 weeks. In both groups patients trained twice daily, 30 min each in the morning and the afternoon 5 days a week. A pool of 4 physical therapists, 2 for each group, was specifically trained to handle patients in both groups in order to warrant a maximum degree of consistency in training style. Patients who were in separate treatment groups were also assigned separate rooms in the hospital for the duration of the study. In both groups the total walking time and distance was tracked to ensure that both groups exercised approximately the same amount. Pre-gait exercises were not included in the 60 min training time in this study, and were carried out in similar fashion in both groups if therapeutically indicated.

In the RAS-group, patients trained their walking by using a metronome or specifically prepared music tapes. After an initial cadence assessment during a 1 to 2 min warm-up walk, the rhythm frequency was matched to the gait cadence for the first quarter of the session.

During the second and third quarter the rhythm frequency was incrementally increased by 5 to 10%, depending on the patient's ability. The last quarter was spent with RAS intermittently faded to train for independent carry-over of improved gait patterns. The control group trained the same amount of time and distance with equivalent instructions regarding speed improvement, however, without RAS facilitation.

2.3. Testing

All patients were pre- and post-tested the day before commencing and the day after concluding the training. Pre- and post-tests were carried out without RAS. For testing patients walked along an 10 meter flat walkway with data recorded only along the middle 6 meters. Stride timing was recorded at a sampling rate of 500 per s with a computerized foot sensor system consisting of 4 foot contact sensors (heel, 1st and 5th metatarsal, big toe) embedded into shoe inserts, a portable microprocessor to record data, and computer interface and data analysis hard and software. Electromyographic activity (EMG) of the medial gastrocnemius (MG) was recorded with surface electrodes; bipolar silver/silver chloride, 8 mm diameter with 2 cm spacing embedded in a plastic enclosure. On-site preamplification of 35 (v/v) was followed by an amplification of 10,000 to 50,000 with highpass filtering at 20 Hz before recording at 500 samples per s with a 12 bit analog to digital converter. Electrode placement, longitudinally along the major belly portion of the muscle, was performed by a physical therapist experienced in electromyography.

2.4. Data analysis

Stride parameters of 5 stride cycles were used to assess improvement in gait ability with regard to velocity, stride length, and swing symmetry. Symmetry was calculated as the time ratio between the swing times of 2 successive steps using the longer step as the denominator. Percentage change scores for all stride data were computed for each subject and averaged across groups for statistical analysis. Percentage change scores were chosen to offset individual performance differences at the outset of the study. Mann-Whitney rank-order tests were used for statistical analysis of differences between groups. Nonparametric statistics were selected to offset possible violations of normalcy in percentage score distributions in relatively small samples.

Variability of EMG shape patterns was computed on the full-wave RMS-rectified signal of the paretic leg by calculating integrated amplitude values (in μV) and amplitude ratios (in μV/ms) and their respective standard deviations. Five strides were used to compute an ensemble average of the shape of the EMG curve (12).

2.5. RAS

The rhythmic stimulus in the training sessions consisted of music tapes played over headsets that were prerecorded on a synthesizer/sequencer module. The module was used to record the same music digitally at various frequencies suitable for the patients' gait cadence. The sequencer was used as a variable frequency driver for the music. Instrumental music in 4 different styles was prepared (classic, folk, country, jazz). The music was recorded in 2/4 meter to match the rhythm of the step patterns in gait. A metronome beat was overlaid on the strong beat of the music to enhance the rhythmic perception for the patient. Rhythmic and melodic patterns in-between the metronome beats subdivided the basic meter in ratios of 1:2 and 1:4.

3. Results

3.1. Stride parameters

During pre-test both groups showed highly abnormal stride data compared to normal age-matched data (Oeberg et al., 1993) which are reported in the literature as 73 m/min for velocity, 1.27 m for stride length, and 113 steps/min for cadence. The mean velocity for the RAS-group was 19.7±11 m/min and 17.3±7 m/min for the control group. Stride length was shortened to 0.64±0.31 m for the RAS-group and 0.55±0.11 m for the control group. Strong lower-limb hemiparesis was evidenced by a mean swing symmetry ratio of 0.64±0.16 for the RAS-group and 0.61±0.25 for the control group. Mean cadence values were 63±10 steps/min for the RAS group, and 62±20 steps/min for the control group.

Post-test data show that both groups improved their stride parameters over the 6-week therapy period. However, there were significant differences in the recovery rate between experimental and control conditions. The mean velocity had increased in the RAS-group to 48±18 m/min, and to 32±10 m/min in the control group. RAS-trained subjects lengthened their stride on the average to 1.00±0.30 m, and control subjects had increased their stride length to 0.69±0.19 m. Mean symmetry ratios improved considerably for the RAS-group (0.82), and to a

Table 1
Results

	Velocity (m/m)	Stride length (m)	Symmetry	Cadence
RAS	19.7±11	0.64±0.31	0.64±0.16	63±10
group	48.0±18	1.00±0.30	0.82±0.14	98±17
Control	17.3±7	0.55±0.11	0.61±0.25	62±20
group	32.0±10	0.69±0.19	0.68±0.23	90±16

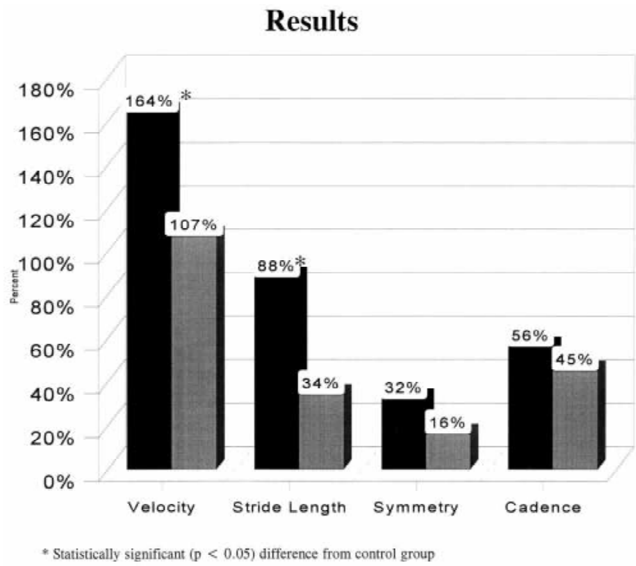

Fig. 1. Percentage change scores from pre- and post-test between RAS and control group for velocity, stride length, symmetry, and step cadence.

lesser degree for the control group (0.68). Mean cadence improved to 98±17 steps/min in the RAS-group, and to 90±16 steps/min in the control group (Table 1).

Percentage change scores for all stride data are summarized in Fig. 1. The mean percentage increase in velocity was 164% for the RAS-group, and 107% for the control group. The difference between groups was statistically significant (MW [MW=Mann Whitney]$_{calc}=132$, $P<0.05$). Stride length had improved by 88% in the RAS-group compared to 34% for the controls. Group differences for stride length were also statistically significant ($MW_{calc}=136$, $P<0.02$). Although RAS-training had improved symmetry by 32% compared to 16% for conventional PT, the differences in improvement rate between the 2 groups were statistically not significant ($MW_{calc}=129$, $P=0.09$). Likewise, differences in step cadence improvement between the 2 groups (56% for RAS, 45% for PT) were nonsignificant, indicating that the velocity improvement in the RAS-group was mostly caused by increased stride length.

3.2. EMG analysis

A variability analysis was computed on the ensemble average of the shape of the EMG-curve of the gastrocnemius muscle on the paretic limb, using the standard deviations of the integrated amplitude values. Coefficients of variation (Standard Deviation/Mean x 100) were computed to normalize variability ratios. In the RAS-group, coefficients of variations were 69±11% lower at post-test than at pretest. In the control group coefficients of variations had decreased from pre- to post-test by 33±31%. Group differences for EMG variability were statistically significant ($MW_{calc}=138$; $P<0.02$). Sample traces from pre- and post-test recordings from a RAS-group subject are given in Fig. 2.

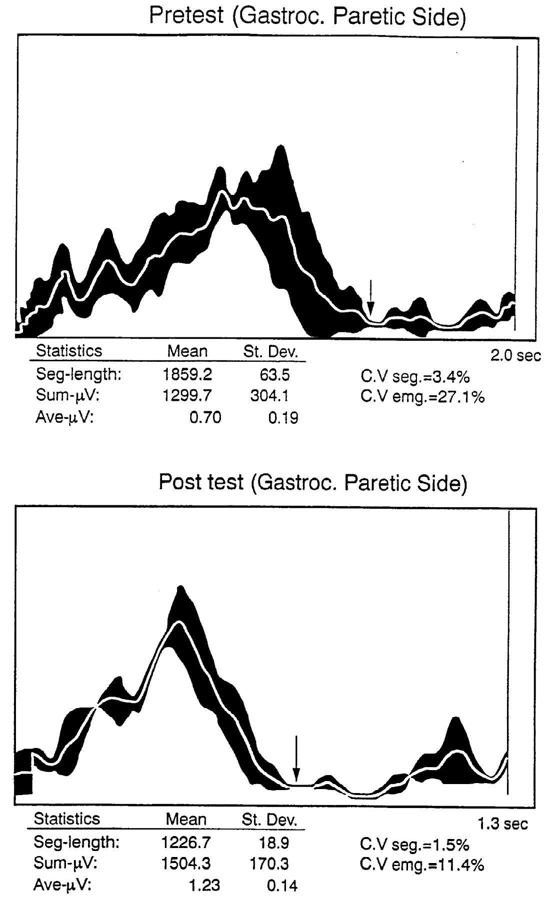

Fig. 2. Averaged RMS full-wave rectified EMG traces (5 step cycles) from a RAS subject. Muscle shown is the gastrocnemius on the paretic side (right). Shaded area around the EMG curve is 1 standard deviation band around the mean. Arrow denotes toe-off. Graph begins and ends on heelstrike. Statistics under the graph show segment length (in ms), sum and averaged amplitude (in μV), and the coefficients of variation of averaged segment length and EMG amplitude. Clearly visible is the reduction in amplitude variability from pre- to post-test.

4. Discussion

Pre- to post-test comparisons between 2 closely matched groups of stroke patients showed that rhythmic facilitation of gait training significantly improved gait velocity and stride length relative to gait training without rhythmic facilitation. Rhythmic facilitation also produced a noticeable improvement in stride symmetry compared to the control group. However, the difference between the 2 groups was not significantly different. Whereas velocity increases in the RAS-group were mainly driven by lengthening of strides (88%) and to a smaller degree by faster step rates (56%), those contributions were reversed in the control group, where increases in step frequency were higher (45%) than changes in stride length (34%).

Obviously, velocity increases which are proportionally driven by more step lengthening than higher step frequencies result in a more efficient gait pattern. The reason that the velocity increase of the control patients relied more on higher step rates may have been due to the fact that improvements in stride length were compromised in the control group by the persistence of high asymmetry in the step patterns.

An important finding for gait recovery is the large degree of restoration of swing symmetry after the RAS-training. Asymmetry is a persistent feature in gait patterns of stroke patients, and is very resistant to rehabilitation efforts. Improved symmetry allows for more normal gait patterns, higher velocity, and more evenly distributed exercise of both lower limbs. The timing symmetry inherent in the rhythmic signal may have served as an efficient cue for the patient to achieve a higher degree of temporal stride symmetry accompanied by lengthened stride. Similar to Hesse et al. (1994), NDT provided a more limited restoration of gait symmetry in our study. Gait facilitation through other sensorimotor systems using, e.g. visual cuing of stride length, to improve gait symmetry has been successfully demonstrated by Montoya et al. (1994). However, whereas visual cuing may preferentially access spatial control parameters of movement, Richards et al. (1992) have proposed that RAS may act on more central facilitation mechanisms since the symmetry of stride times as well as stride length have been shown to improve with RAS (Prassas et al., 1997). However, the lack of statistical significance of a relatively large group difference in our study sample due to inconsistency in improvement patterns across patients underlines the problems in finding effective methods to restore gait symmetry in hemiparetic stroke patients.

An interesting finding which has been noticed in previous research (Thaut et al., 1993; Miller et al., 1996; Rossignol and Melvill Jones, 1976; Safranek et al., 1982) is the effect of auditory rhythm on EMG activity, especially the reduction of amplitude variability as a result of rhythmic training. Our data suggest that auditory rhythmic timekeepers may enhance more regular motor unit recruitment patterns. The functional significance of this effect for motor control is not entirely clear. However, it underscores the existence of physiological mechanisms between the auditory and the motor systems. The ability of auditory rhythm to effectively entrain motor patterns and also influence nontemporal parameters such as stride length, may help to assign rhythmic auditory stimuli a larger role in motor control than previously assumed. Considering (a) the particular effectiveness of the auditory system to process timing information with a high degree of speed and accuracy, and (b) the fundamental importance of timing for all parameters of complex movement, a model of rhythmic auditory-motor entrainment provides an intriguing context for further study. Hemispheric stroke patients may particularly benefit from RAS since auditory rhythm is processed bilaterally and no difference in performance was observed in this study as in our previous work (Thaut et al., 1993) between left- and right-hemispheric patients.

To control for motivational–emotional factors in the music to enhance gait performance, the same music was used for a patient's training period. Repetitive use of music of relatively low complexity has been shown to provide redundancy in music perception which strongly reduces affective arousal related to motivational states (Berlyne, 1971).

Substantial increases in walking speed are an important functional goal in gait rehabilitation if safe gait patterns, e.g., avoiding an increased risk of falling, are maintained. In our study sample, increased velocity was accompanied by substantial increases in stride symmetry which may be considered one indicator that postural stability was not compromised. Functional benefits of higher walking speed include reduced travel time which may help to increase the ambulatory range for the patient as well as reduce physical fatigue. In the current state of gait rehabilitation, techniques that complement and enhance therapeutic efforts are greatly needed. This study provided the first evidence that rhythmic entrainment mechanisms, utilized as a training device for stroke patients, can improve important gait parameters within a rehabilitative context.

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