Neurorehabilitation and Neural Repair

http://nnr.sagepub.com

Rhythmic Auditor y Stimulation Improves Gait More Than NDT/Bobath Training in Near-Ambulatory Patients Early Poststroke: A Single-Blind, Randomized Trial

M.H. Thaut, A.K. Leins, R.R. Rice, H. Argstatter, G.P. Kenyon, G.C. McIntosh, H.V. Bolay and M. Fetter

Neurorehabil Neural Repair 2007; 21; 455 originally published online Apr 10, 2007;

DOI: 10.1177/1545968307300523

Published by:
SAGE
http://www.sagepublications.com

On behalf of:

American Society of Neurorehabilitation

Rhythmic Auditory Stimulation Improves Gait More Than NDT/Bobath Training in Near-Ambulatory Patients Early Poststroke: A Single-Blind, Randomized Trial

M. H. Thaut, PhD, A. K. Leins, PhD, R. R. Rice, MS, H. Argstatter, MA, G. P. Kenyon, MS,
G. C. McIntosh, MD, H. V. Bolay, PhD, and M. Fetter, MD

Objectives. The effectiveness of 2 different types of gait training in stroke rehabilitation, rhythmic auditory stimulation (RAS) versus neurodevelopmental therapy (NDT)/Bobath–based training, was compared in 2 groups of hemiparetic stroke patients over a 3-week period of daily training (RAS group, n = 43; NDT/Bobath group =35). *Methods.* Mean entry date into the study was 21.3 days poststroke for the RAS group and 22.3 days for the control group. Patients entered the study as soon as they were able to complete 5 stride cycles with handheld assistance. Patients were closely equated by age, gender, and lesion site. Motor function in both groups was preassessed by the Barthel Index and the Fugl-Meyer Scales. *Results.* Pre- to posttest measures showed a significant improvement in the RAS group for velocity (P = .006), stride length (P = .0001), cadence (P = .0001) and symmetry (P = .0049) over the NDT/Bobath group. Effect sizes for RAS over NDT/Bobath training were 13.1 m/min for velocity, 0.18 m for stride length, and 19 steps/min for cadence. *Conclusions.* The data show that after 3 weeks of gait training, RAS is an effective therapeutic method to enhance gait training in hemiparetic stroke rehabilitation. Gains were significantly higher for RAS compared to NDT/Bobath training.

From Molecular, Cellular, and Integrative Neuroscience Programs, Colorado State University, Fort Collins (MHT); University of Applied Sciences Heidelberg, Heidelberg, Germany (AKL, HA, HVB); Poudre Valley Hospital, Fort Collins, CO (RRR, GCM); Colorado State University, Fort Collins (GPK); SRH-Hospitals Karlsbad-Langensteinbach, Karlsbad, Germany (MF).

Address correspondence to Michael H. Thaut, PhD, Molecular, Cellular, and Integrative Neuroscience Programs, Center for Biomedical Research in Music, 102 Music Building, Colorado State University, Fort Collins, CO 80523. E-mail: michael.thaut@colostate.edu.

Thaut MH, Nickel AK, Rice RR, Argstatter H, Kenyon GP, McIntosh GC, Bolay HV, Fetter M. Rhythmic auditory stimulation improves gait more than NDT/Bobath training in near-ambulatory patients early post stroke: a single-blind, randomized trial. *Neurorehabil Neural Repair* 2007;21:455–459.

DOI: 10.1177/1545968307300523

Key Words: *Gait rehabilitation—Stroke—Rhythmic auditory stimulation.*

Restoration of mobility is critical to successful rehabilitation after stroke, which makes recovery of functional gait a high priority. Each year, 750,000 individuals have a stroke in the United States, a prevalence of 200 to 300 per 100,000 inhabitants.[1,2] The vast majority of individuals in whom at least partial recovery is observed experience persistent problems especially in the area of neurological motor deficits. For example, epidemiological studies have shown that 20% of stroke survivors remain wheelchair bound and 60% show gait deficits of varying degrees.[3] However, intensive rehabilitation programs have shown to improve gait function[4] and continued research into the efficacy of various treatment approaches continues to hold great benefit.

A number of intervention techniques are in current use, based on different models of motor physiology and disease recovery. Traditional but still widely used techniques include neurodevelopmental therapy (NDT), in Europe known as Bobath-therapy, the Brunnstrom method, proprioceptive neuromuscular facilitation (PNF), and the Rood method.[4,5] However, the research evidence base for the effectiveness of one approach over another has not been demonstrated.

One recent form of gait therapy, rhythmic auditory stimulation (RAS), involves the use of rhythmic sensory cuing of the motor system. RAS is based on entrainment models in which rhythmic auditory cues synchronize motor responses into stable time relationships, similar to oscillator coupling models. Rhythm serves as an anticipatory and continuous time reference on which movements are mapped within a stable temporal template. The fast-acting physiological entrainment mechanisms between auditory rhythm and motor response serve as coupling mechanisms to stabilize and regulate gait patterns. In several clinical research studies, RAS significantly improved gait and other movement parameters (eg, upper extremity function) during rehabilitation for hemiparesis.[6-13] RAS can be used as a self-contained training protocol, but its principles of rhythmic cuing and temporal regulation can also be integrated into other interventions.

The purpose of this study was to examine the clinical efficacy of RAS, based on the experimental design of the study by Thaut et al,[7] by comparing 3 weeks of RAS against the NDT/Bobath method. which is one of the most widely used gait therapies.

Table 1. Subject Characteristics

	RAS	NDT/ Bobath
N	43	35
Age	69.2 ± 11	69.7 ± 11
Gender M/F	22/21	19/16
Side of hemiplegia (R:L)	20:23	16:19
Time between (days) stroke and admission to study	21.3 ± 11	22.2 ± 12
Location of stroke		
Middle cerebral artery	35	30
Internal capsule	4	4
Basal ganglia/thalamus	3	1
Subdural hematoma	1	

RAS = rhythmic auditory stimulation; NDT = neurodevelopmental therapy.

METHODS

Subject Selection

From an eligible catchment pool of 155 patients, 78 patients from 2 research centers in Germany and the United States were selected by a random number table. Patients were randomly assigned to either the experimental (RAS; n = 43; male = 22, female = 21) or control (neurodevelopmental technique/Bobath; n = 35; male = 19, female = 16) training group (see Table 1). Treatment allocation was accomplished by computerized random number generators in both centers. Random numbers for the allocation-to-treatment sequence were concealed from the recruiter and the therapists carrying out the training. Patients were informed of the 2 possible treatment allocations but blinded to the aims of an experimental versus control condition. Ethical review board clearance was obtained for all patients.

Subject Characteristics

Table 1 describes the patients. Mean age for the RAS group was 69.2 ± 11.5 and for the NDT/Bobath group 69.7 ± 11.2 years. Lesion site was closely matched in both groups. Mild to moderate sensory dysfunction was present in all middle cerebral artery distribution strokes. Both groups had lower limb spasticity, most pronounced in knee flexors/extensors, plantar flexion, and hip flexors/extensors, as typical for a stage 4 or early stage 3 on the Brunnstrom hemiplegia recovery scale.[14]

Subject Assessment and Training

Both groups were assessed by blinded physical therapists who performed the Barthel Index[15] and the Fugl-Meyer Scale.[16] The Fugl-Meyer score was 31.4 for the control group and 33.3 for the RAS group (balance and lower extremity function combined). The Barthel Index score was 45.5 for the control group and 47.5 for the RAS group. Patients entered the study within 4 weeks of onset, as soon as they could complete 5 stride cycles with handheld assistance by the therapist, that is, with no more than support of the forearm, wrist, and elbow at approximately 90 degrees of elbow flexion on the nonparetic side. Handheld assistance was available to all patients throughout training when needed.

Mean entry date poststroke was 21.3 ± 10.8 days for the RAS group and 22.3 ± 14.7 for the NDT/Bobath group. The study duration was 3 weeks, with gait training daily for 30 minutes, 5 times per week. Four gait therapists for each group conducted the training to ensure consistency in training protocols and procedures. Each center had its own independently trained pool of therapists. Therapists were not blinded to the treatment conditions of the study. However, because both conditions are considered full treatment conditions, no performance bias was expected. Total walking time was tracked in both groups to ensure consistent exercise duration. Pre-gait exercises were not included in the actual training period of the experimental trials and were carried out in similar fashion in both groups if therapeutically indicated.

RAS training followed established protocols[7,17] using a metronome and specifically prepared music tapes in digital MIDI format to ensure temporal precision and tempo stability as well as full capacity for frequency modulation of the stimulus based on patient needs. After an initial cadence assessment, cuing frequencies were matched to the gait cadence for the first quarter of the session. During the second quarter, cue frequencies were increased in 5% increments as

Table 2. Pretest and Posttest Means and Standard Deviations, Mean Differences Within and Between Groups, and 95% Confidence Intervals Around Mean Differences Between Groups

	Pretest Week 0		Posttest Week 3		Differences Within Groups Week 3 – Week 0		Differences Between Groups* Week 6 – Week 0
	Exp	Ctrl	Exp	Ctrl	Exp	Ctrl	
Velocity	14.1	13.0	34.5	20.3	20.4	7.3	13.1
(m/min)	(6.3)	(5.9)	(9.1)	(6.5)			(6.9, 19.3)
Stride length	0.53	0.50	0.88	0.67	0.35	0.17	0.18
(m)	(0.12)	(0.12)	(0.21)	(0.24)			(0.13, 0.23)
Cadence	53	50	82	60	29 10	19	
(steps/min)	(10.8)	(9.9)	(12.9)	(9.9)			(10.4, 27.6)
Symmetry	0.42	0.40	0.58	0.46	0.16	0.06	0.10
(swing ratios)	(0.12)	(0.12)	(0.05)	(0.07)			(–0.04, 0.24)

*CI boundaries in parentheses.

kinematically indicated without compromising postural and dynamic stability. During the third quarter, adaptive gait patterns, for example, ramp or step walking, were practiced. The last quarter was spent fading the cues intermittently to train for independent carryover. The control group trained the same amount of time and distance, following NDT and Bobath principles as well as using similar instructions about gait parameters to practice, but without rhythmic auditory cuing.

Testing

All patients were tested 1 day before the training sessions started and 1 day after the last training session. All available participant data after removing dropout participants were analyzed in an intention-to-treat analysis. Testing was carried out without RAS present. For testing, patients walked along a 10 m flat walkway. Two meters on either side were available for acceleration and deceleration without data recording. Gait parameters were recorded at a sampling rate of 500/sec with a computerized foot sensor system consisting of 4 foot contact sensors (heel, first metatarsal, fifth metatarsal, big toe) embedded into shoe inserts. Sensor data were stored online in a portable microprocessor and downloaded after the test walk into a PC with interface hardware and analysis software.

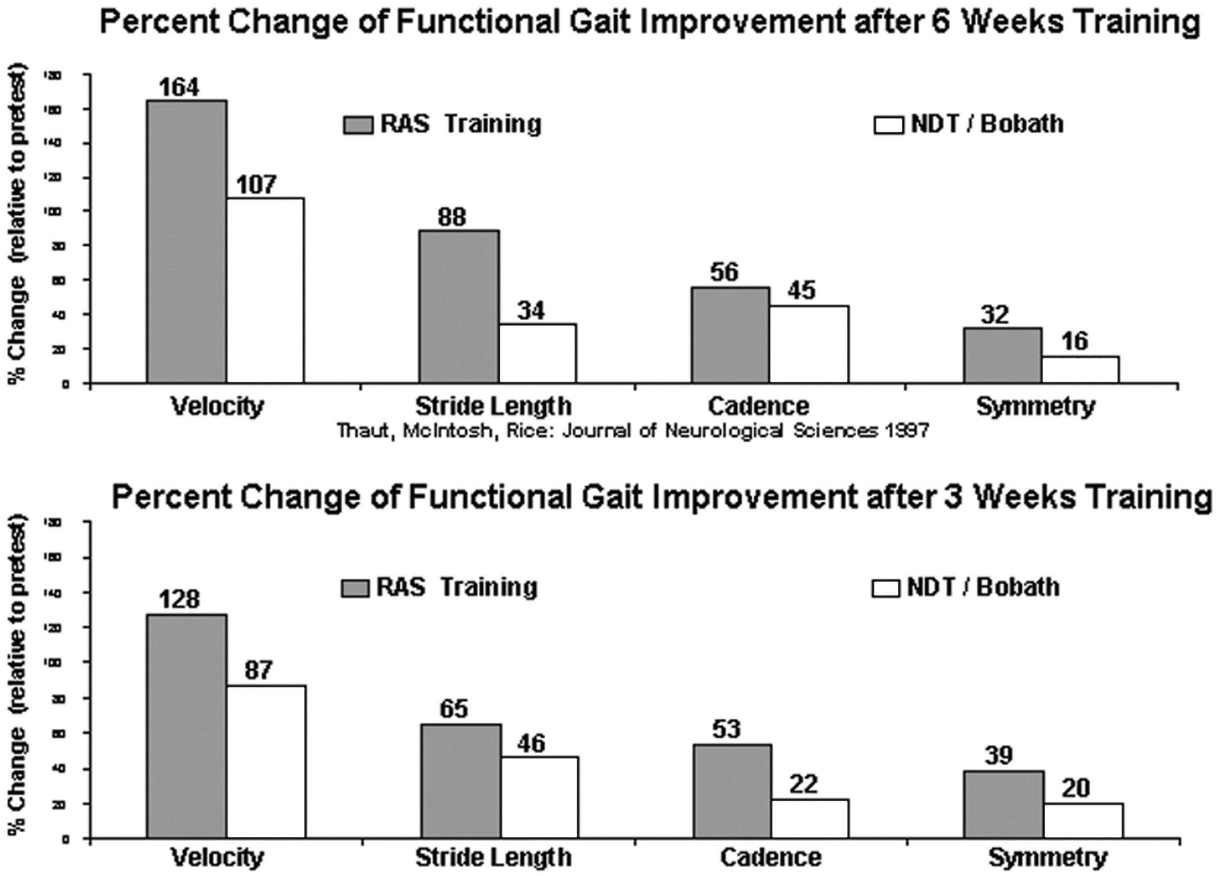
RESULTS

The dropout rate in one center was 23% of initially included patients. There was a 10% dropout rate in the other center. Dropout reasons were due to hospital transfer, early discharge, medical complication, or unspecified personal reasons.

Four major gait parameters critical for improved functional gait were measured and statistically analyzed: velocity, stride length, cadence, swing symmetry (calculated as the ratio between the swing times of 2 consecutive steps using the longer step—ie, paretic vs nonparetic leg—as the denominator). After statistical checks for equivalence of variance (Levene's *F* test) in each parameter, 2-tailed *t* test comparisons for independent samples were carried out for pretest differences between the RAS group and the NDT/Bobath group. Pre- and posttest means as well as effect size differences and confidence intervals are given in Table 2. At pretest, there were no significant differences between the 2 groups in each parameter: velocity ($df = 76$, $t = 1.01$, $P = .347$), stride length ($df = 76$, $t = 1.75$, $P = .111$), cadence ($df = 76$, $t = 1.49$, $P = .141$), and swing symmetry ($df = 76$, $t = 1.13$, $P = .285$).

After 3 weeks of gait training, *t* test comparisons for posttest differences between groups were carried out. Significant differences were found in favor of RAS training in all 4 gait parameters: velocity ($df = 76$, $t = 2.83$, $P = .006$), cadence ($df = 76$, $t = 5.13$, $P = .0001$), stride length ($df = 76$, $t = 4.6$, $P = .0001$), and symmetry ($df = 76$, $t = 2.13$, $P = .049$). Effect size analysis showed improvements for RAS over NDT/Bobath training of 13.1 m/min for velocity, 0.18 m in stride length, 19 steps/min in cadence, and 0.10 in gait symmetry (swing ratio) (Table 2).

Data of patient satisfaction showed a significant main effect in favor of the RAS group ($df = 1{,}24$, $F = 6.35$, $P = .019$). However, both groups showed continued increases in satisfaction ratings across therapy (RAS: 77%-84%-87%; NDT/Bobath: 64%-70%-75%).



Thaut, McIntosh, Rice: Journal of Neurological Sciences 1997

Figure 1. Comparison data for treatment duration.

DISCUSSION

Statistical analysis of 4 gait parameters after a 3-week gait training period in subacute hemiparetic stroke rehabilitation showed significantly greater improvements for training with rhythmic auditory stimulation relative to training within a standard NDT/Bobath protocol. Differences between pre- and posttest as expressed in percent change showed substantial differences between the 2 groups in favor of RAS: velocity 128.8% (RAS) versus 87.6% (NDT/Bobath); stride length 65.9% versus 46.1%; cadence 53.8% versus 22.2%; symmetry 39.1% versus 20.2% (Figure 1). Noteworthy is that RAS training produced mean effects substantially higher in improvement over NDT/Bobath training: 13.1 m/min for velocity, 0.18 m for stride length, 19 steps/min for cadence, and 0.10 in symmetry (swing ratio) over NDT/Bobath training (Table 2).

In the RAS group, significant increases in gait velocity were driven by somewhat larger increases in stride length than cadence. In the control group, a similar pattern of contribution was observed; however, with a much larger differential in magnitude for stride length relative to cadence, which only improved by 22% on average. Because changes in stride length and cadence are kinematically linked in healthy gait, increases in those parameters that are coupled more closely may suggest a more functional recovery of gait mechanics. Improvements in velocity that are mostly driven by stride length and a disproportionally smaller cadence change may indicate uncoupling of kinematic linkages due to compromised asymmetric step patterns.[4]

Although substantial increases in swing symmetry were seen for RAS relative to NDT/Bobath, the smaller improvement compared to the other parameters shows the higher resistance of this parameter to rehabilitation efforts.[1] However, the isochronous nature of the rhythmic timing cue still showed higher efficacy in symmetry restoration than NDT/Bobath alone. Similarly, moderate results in regard to swing symmetry were obtained by our group in a previous study,[7] but improvements in this parameter did not reach statistical significance.

Improvements in velocity, stride length, and cadence were statistically similar to previous data,[7] but with smaller percentage increase rates in this study compared to previous data. Velocity improved 128% versus 164%

in previous research (control group improvement 87.6% vs 107%). The main difference in treatment dosage between the 2 studies was the duration (3 vs 6 weeks). Therefore, the difference in percent improvement suggests that the additional 3 weeks of training had a substantial effect on speed of walking, which is a critical parameter in functional gait recovery. Although the current study was not designed to statistically compare different treatment durations, the similarity in treatment design and diagnostic patient selection criteria allows for a descriptive comparison between the current data and the previous study data,[7] showing the dosage benefit of 6 weeks of therapy over 3 weeks (Figure 1).

When referenced to percent of healthy normative data,[18] results showed substantial differences in favor of RAS. RAS-training patients reached 43.6% of healthy control velocity but only 26.3% in NDT/Bobath, in cadence 66.4% versus 48%, and in stride length 60.5 versus 51.8%.

Considering that predictive states in motor planning, as well as attentional and executive brain networks, reduce performance variability, the intrinsic time structure of rhythmic cues and their almost instantaneous synchronization effect on motor responses can play a critical role in performance regulation by enhancing temporal predictability via interval scaling. It has been shown in optimization models that a rhythmic cue as a predictive time constraint can result in the complete specification of the dynamics of the movement over the entire movement cycle, reducing variability, enhancing temporal precision, and facilitating the selection of optimal movement trajectories, velocity, and acceleration parameters. Thus, temporal-rhythmic motor cues do not only cue speed and timing of movement but also regulate comprehensive spatiotemporal and force parameters[19,20] in restoring motor function in brain rehabilitation.[5,21,22]

In summary, RAS significantly improved gait performance in subacute hemiparetic stroke rehabilitation over NDT/Bobath-based training. The 3-week training period showed smaller overall improvements when compared to a 6-week study with an identical therapy protocol, suggesting the functional importance of additional training for the patient's functional locomotor recovery. Future studies may follow 4 directions to further establish the role of RAS in gait rehabilitation: (a) test other treatment dosages for RAS, (b) compare RAS against other current gait-training methods besides NDT/Bobath, (c) investigate the potential to enhance RAS by adding other current gait therapy techniques, (d) study the effect of RAS in long-term outpatient or community-based settings.

REFERENCES

1. Hesse S, Werner C. Post-stroke motor dysfunction and spasticity: novel pharmacological and physical treatment strategies. *CNS Drugs.* 2003;17:1070-1093.
2. Williams GR, Jiang JG, Matchar DB, Samsa GP. Incidence and occurrence of total (first-ever and recurrent) stroke. *Stroke.* 1999;30:2523-2528.
3. Jorgensen HS, Nakayama H, Pedersen PM, Kammersgaard L, Raaschou HO, Olsen TS. Epidemiology of stroke-related disability. *Clin Geriatr Med.* 1999;15:785-799.
4. Mauritz KH. Gait training in hemiplegia. *Eur J Neurol.* 2002;9:23-29.
5. Hummelsheim H. Rationales for improving motor function. *Curr Opin Neurol.* 1999;12:697-701.
6. Thaut MH, McIntosh GC, Prassas SG, Rice RR. The effect of auditory rhythmic cuing on stride and EMG patterns in hemiparetic gait of stroke patients. *J Neurol Rehabil.* 1993;7:9-16.
7. Thaut MH, McIntosh GC, Rice RR. Rhythmic facilitation of gait training in hemiparetic stroke rehabilitation. *J Neurol Sci.* 1997;151:207-212.
8. Thaut MH, Kenyon GP, Hurt CP, McIntosh GC, Hoemberg V. Kinematic optimization of spatiotemporal patterns in paretic arm training with stroke patients. *Neuropsychol.* 2002;40:1073-1081.
9. Whitall J, McCombe Waller S, Silver KH, Macko RF. Repetitive bilateral arm training with rhythmic auditory cueing improves motor function in chronic hemiparetic stroke. *Stroke.* 2000;31:2390-2395.
10. Luft AR, McCombe Waller S, Whitall J, et al. Repetitive bilateral arm training and motor cortex activation in chronic stroke: a randomized controlled trial. *JAMA.* 2004;292:1853-1861.
11. Mandel AR, Nymark JR, Balmer SJ, Grinnell DM, O'Riain MD. Electromyographic feedback versus rhythmic positional biofeedback in computerized gait retraining with stroke patients. *Arch Phys Med Rehabil.* 1990;71:649-654.
12. McCombe WS, Whitall J. Hand dominance and side of stroke affect rehabilitation in chronic stroke. *Clin Rehabil.* 2005;19:544-551.
13. Schauer M, Mauritz KH. Musical motor feedback (MMF) in walking hemiparetic stroke patients: randomized trials of gait improvement. *Clin Rehabil.* 2003;17:713-722.
14. Brunnstrom S. *Movement Therapy in Hemiplegia: A Neurophysiological Approach.* Philadelphia, PA: Harper & Row; 1970.
15. Mahoney FI, Barthel DW. Rehabilitation of the hemiplegic patient: a clinical evaluation. *Arch Phys Med Rehabil.* 1954; 35:359-362.
16. Fugl-Meyer AR, Jääskö L, Leyman I, Olsson S, Steglind S. The post-stroke hemiplegic patient: a method for evaluation of physical performance. *Scand J Rehabil Med.* 1975;7:13-31.
17. Thaut MH. *Rhythm, Music, and the Brain: Scientific Foundations and Clinical Applications.* New York: Taylor & Francis; 2005.
18. Oeberg T, Karsznia A, Oeberg K. Basic gait parameters; reference data for normal subjects, 10-79 years of age. *J Rehabil Res Dev.* 1993;30:210-223.
19. Kenyon GP, Thaut MH. Rhythmic-driven optimization of motor control. *Recent Res Dev Biomech.* 2003;1:29-47.
20. Harris CM, Wolpert DM. Signal-dependent noise determines motor planning. *Nature.* 1998;194:780-784.
21. Hoemberg V. Evidence-based medicine in neurological rehabilitation—a critical review. *Acta Neurochir.* 2005;93: 3-14.
22. Molinari M, Leggio MG, De Martin M, Cerasa A, Thaut M. Neurobiology of rhythmic motor entrainment. *Ann N Y Acad Sci.* 2003;999:313-321.