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ORIGINAL ARTICLE

Effects of Rhythmic Auditory Stimulation During Hemiplegic Arm Reaching in Individuals with Stroke: An Exploratory Study

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Summary *Objective/Background:* This study investigated the effects of rhythmic auditory stimulation (RAS) on muscle activity and elbow motion during arm reaching with hemiplegic arm in participants with stroke.
Methods: Sixteen adults with stroke who resided in a community were recruited in this study. The RAS consisted of sound emitted from a digital metronome. While sitting upright in a chair, participants reached their arms towards a target (a switch on a table) both with and without RAS. The three-dimensional motion analysis system and surface electromyography system were used for measurements during the reaching tasks.
Results: We found that RAS elicited better performance in reaching movements than those movements performed without RAS. RAS shortened the movement time ($p = .002$), reduced the change in acceleration ($p = .001$), increased the elbow extension range of motion ($p = .001$), increased muscle activation of the triceps brachii ($p = .024$), and reduced the co-contraction ratio ($p = .015$) of the affected arm.

Conflicts of interest: All contributing authors declare that they have no conflicts of interest.
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Conclusion: RAS might be a useful technique to facilitate improvements in motor function of the affected arm in patients with stroke.

Introduction

Aspects of lifestyle that are most affected by a physical handicap within 1 year of a stroke include physical independence (66% of stroke survivors) and occupation (75% of stroke survivors; Sturm et al., 2002). Movement deficits associated with stroke are most evident in the extremity contralateral to the side of the brain in which the stroke occurred, and are characterized by weakness of specific muscles (Bourbonnais & Vanden Noven, 1989). In addition, abnormal muscle tone, abnormal postural adjustment, abnormal movement synergy, incorrect timing of components within a movement pattern, and loss of interjoint coordination characteristically appear on the affected side (Cirstea & Levin, 2000). Deficits in upper extremity function are the main functional limitation experienced by stroke patients. Despite intensive rehabilitation, only approximately 5% of stroke patients recover full function of the affected side, and approximately 55–75% remain permanently disabled, severely limiting their participation in activities of daily living (Feys et al., 1998; Jørgensen et al., 1999). For these reasons, the recovery of upper extremity motor function is an essential goal in the rehabilitation of stroke patients.

Reaching, which is a fundamental component of daily movement, involves kinematic parameters and muscle activation that often show abnormal patterns in stroke patients (Cirstea, Mitnitski, Feldman, & Levin, 2003). The functional problems that accompany a hemiparetic arm are decreased agonistic muscle activity and decreased coordination between agonist and antagonist muscles in the affected arm (Barker, Brauer, & Carson, 2009). Poststroke weakness in muscles of the arm and reduction in the degree of co-contraction significantly correlate with motor impairment and physical disability in patients with hemiparesis of the arm (Chae, Yang, Park, & Labatia, 2002). Co-contraction indicates impairment of the coordination between agonist and antagonist muscles, and is largely due to impaired agonist muscle activation rather than due to excessive antagonist muscle activation. As a result, upper extremity rehabilitation in stroke patients focuses on facilitating agonist muscle activation and decreasing abnormal co-contraction instead of inhibiting antagonist muscle activation (Gowland, deBruin, Basmajian, Plews, & Burcea, 1992; McCrea, Eng, & Hodgson, 2005). Therefore, an approach to improve activity of the agonist muscle and coordination between antagonist and agonist muscles is needed for optimal motor function recovery of the hemiparetic arm.

Recently, rhythmic auditory stimulation (RAS) has been reported as an effective intervention for improving movement in the affected extremities of stroke patients (Thaut, Kenyon, Schauer, & McIntosh, 1999). RAS is a neurological technique that uses the physiological effects of auditory rhythm on the motor system to improve the control of movement in rehabilitation and therapy (Thaut & Abiru, 2010). Rhythm is an essential element of music. Music with rhythmic structure evokes positive emotional responses, and activates movements through the limbic system (Thaut et al., 1999). The auditory rhythm, which acts as an internal timekeeper in the body, affects muscle activation as well as brain mechanisms that control muscle contraction and coordination, and can be repeated on a regular basis for effective functional training (Thaut, 2009). Movements tend to synchronize with the rhythm suggesting that the movement is generated by RAS. RAS stimulates the cerebral cortex, basal ganglia, and cerebellum, and is transmitted to the autonomic nervous system through the brainstem and spinal cord (Thaut et al., 1997). Neurophysiologic research has shown that effects of auditory rhythm are observed at the level of the brainstem due to the audiomotor pathways that communicate by reticulospinal connections, and in the motor system (Thaut, 2009; Thaut & Abiru, 2010). Humans tend to move to biological rhythms, and when the rhythmically structured external auditory stimulation is provided, movement is controlled according to that rhythm. In addition, sensual rhythm and movement have been reported to be instinctively connected (Thaut et al., 1999).

Based on these physiological connections, a large number of clinical studies have examined the effectiveness of rhythm and music in producing functional changes in gait in patients with stroke, Parkinson's disease, traumatic brain injury, and other conditions (Thaut & Abiru, 2010). RAS can be used in this context in two ways (Thaut, 2009). First, RAS can be implemented as an immediate entrainment stimulus providing rhythmic cues during movements. For example, individuals may listen to a metronome or rhythmic music tape while walking to enhance their walking tempo, balance, and control of muscles in their extremities. In addition, RAS can be used as a facilitating stimulus for training (Humphrey, 2009).

RAS is primarily used in gait training to aid in the recovery of functional, stable, and adaptive gait patterns in patients with significant gait deficits due to stroke, Parkinson's disease, traumatic brain injury, or other causes (Kwak, 2007; Thaut, 2009). Results have suggested that RAS significantly improves gait pattern, gait velocity, and stride length, and reduces variability in activation of the gastrocnemius muscle (Fernandez del Olmo & Cudeiro, 2003; Kwak, 2007; Thaut et al., 2007; Thaut, McIntosh, & Rice, 1997). It has also been shown that when the legs move in time with a rhythm, the movement pattern becomes smooth and natural due to functional facilitation of the muscle activity pattern by internal timing effects (Paltsev & Elner, 1967). Based on these studies, standard protocols for RAS as a gait-training technique have been developed (Thaut & Abiru, 2010).

Studies on the effects of motor training with concomitant RAS have also been extended to upper extremity rehabilitation in stroke patients. Recent research has examined the ability of rhythmic auditory-motor entrainment to improve hemiparetic arm function. Whitall, McCombe Waller, Silver, and Macko (2000) developed the bilateral arm training with rhythmic auditory cueing (BATRAC) therapy based on the concepts of bilaterality and rhythmicity. BATRAC improved functional motor performance of the paretic arm and increased isometric strength and range of motion (ROM), and that these benefits were largely sustained 8 weeks after completion of the training. BATRAC is thought to improve movement in cases of hemiparesis through rhythmic repetition of an action by auditory cueing. Another study demonstrated that BATRAC induces reorganization in the contralesional motor networks by comparing arm movements and brain activation between a BARAC therapy group and a standardized dose-matched therapeutic exercises (DMTEs) group. They found that the BATRAC group, but not the DMTE group, showed increased hemispheric activation of sensorimotor areas in the contralesional brain hemisphere (precentral gyrus and postcentral gyrus) and in the ipsilesional cerebellum during movement of the affected arm. These results suggest that rhythmic auditory cueing of arm movements is an effective adjunct to rehabilitation programmes aimed at improving hemiparetic arm movements (Luft et al., 2004).

Several studies have demonstrated that use of RAS in stroke patients affects kinematic variables such as movement time, velocity, smoothness, variability, and compensatory movement. Thaut, Kenyon, Hurt, McIntosh, & Hoemberg (2002) demonstrated that RAS during reaching decreased movement variability, increased movement speed, and produced a smoother trajectory in hemiparetic stroke patients. One study of five stroke patients attending a 2-week RAS training programme showed a significant decrease in compensatory trunk movement, increased shoulder flexion, increased elbow extension, and significant improvements in movement time and velocity (Malcolm, Massie, & Thaut, 2009).

Although these studies have demonstrated the effects of RAS on arm function and kinematic variables in stroke patients, they did not evaluate changes in muscle activation and co-contraction, which are significant components of arm movement. In addition, most research has used RAS as a facilitating stimulus for training, which has resulted in improvement in motor function. Thus, additional research is needed to demonstrate the positive effect of RAS on motion and muscle activation during task performance in stroke patients, and this information may help to increase the effectiveness in rehabilitation of stroke patients.

The purpose of this study was to investigate the effects of RAS on the motion and muscle activation of the affected elbow joint during arm reaching with hemiplegic arm in stroke.

Methods

Participants

Sixteen participants with stroke (9 men, 7 women) living in Wonju City, South Korea, were recruited in this study by convenience sampling. The mean age of participants was 49.2 years, and the mean time since stroke onset was 23.8 months. Eleven participants were diagnosed with right-sided hemiparetic stroke, and five were diagnosed with left-sided hemiparetic stroke. The participants had a mean score of 27.3 on the Korean Mini-Mental State Examination, and a mean score of 55.0 on the Fugl-Meyer Assessment Upper Extremity Scale. The general characteristics of the participants are presented in Table 1.

Inclusion criteria for all participants were as follows: (a) history of ischemic or hemorrhagic stroke, (b) hemiparesis (Brunnstrom arm recovery stage < 5), (c) hearing within normal limits, (d) no contractures or excessive spasticity (Modified Ashworth Scale ≥ 3), (e) having no visual neglect or visual field deficits, (f) no balance problems that may compromise safety while sitting, and (g) the ability to understand and follow the instructions given by the researcher. Eligibility was determined by review of medical records and clinical assessments.

Before beginning the study, the experimental procedure was explained and written voluntary consent was obtained from all participants.

Instruments

Three-dimensional motion analysis system

A three-dimensional motion analysis system (Compact measuring system 10; Zebris Medical GmbH, Isny im Allgäu, Germany) was used to measure the speed, range, and smoothness of movement at the elbow joint (Fig. 1). The equipment consisted of a computer, a body surface marker (diameter 1 cm) to capture ultrasonic signals, a cable adapter to carry information from the markers, a measuring sensor to recognize ultrasonic signals, and a holding device for the measuring sensor. The coordinates were defined by the *x* (front—back), *y* (right—left), and *z* (up—down) axes, and the sampling rate was 50 Hz. Information from each surface marker was converted to three-dimensional coordinates using *WinArm* software (Zebris Medical GmbH).

The three markers were located on each participant's affected arm at the ulnar styloid process, the lateral epicondyle of the humerus, and the side of the humerus achieving a straight line to the lateral epicondyle. *3DAwin* 1.02 software (Zebris Medical GmbH) was used to analyse movement time, elbow joint ROM, and movement units.

Electromyography system

Electromyography (EMG) was recorded from the triceps and biceps brachii according to published guidelines (Barker et al., 2009; Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). EMG data were collected through a Biomonitor ME6000 EMG system (Mega Electronics Ltd, Kuopio, Finland; Fig. 2) during the reaching task. Skin was first prepped with an alcohol wipe, and the standard Ag/AgCl bipolar surface electrodes (St. Paul, Minnesota) were attached to the biceps brachii and the lateral head of the triceps brachii on the hemiparetic arm. Interelectrode distance was fixed at 2 cm, and electrodes were attached parallel to the muscle fibres.

All EMG signals were amplified, digitized at a sampling rate of 1,000 Hz, and band-pass (20—450 Hz) filtered.

Table 1 Characteristics of Participants.

Participants	Sex	Age (y)	Stroke duration (mo)	Affected arm	MMSE-K	FMA-U	Recovery stage [a]	MAS-elbow	Proprioception
1	M	61	2	Lt	30	63	5	0	+
2	M	65	1	Rt	25	52	5	0	+
3	M	20	3	Rt	17	52	5	0	+
4	M	50	3	Lt	28	52	5	0	+
5	M	41	1	Rt	20	64	5	1	+
6	F	59	1	Rt	27	64	5	0	+
7	M	56	40	Rt	26	30	3	1+	+
8	F	44	36	Rt	29	58	5	1	+
9	M	52	62	Lt	28	64	5	1	+
10	F	52	60	Rt	26	55	4	1+	+
11	F	60	65	Rt	27	55	5	1	+
12	M	21	41	Rt	30	57	4	1+	+
13	F	25	36	Rt	29	43	5	0	+
14	F	76	2	Lt	23	63	5	0	+
15	F	59	72	Rt	27	60	4	1+	+
16	M	19	2	Lt	26	63	5	0	+
Mean		49.2	23.83		27.33	55.0			

Note. FMA-U = Fugl-Meyer Assessment Upper Extremity Scale; MAS = Modified Ashworth Scale; MMSE-K = Korean Mini-Mental State Examination.

[a] Brunnstrom arm function recovery stage.

Normalization to maximal voluntary isometric contractions (MVICs) and the root mean square (RMS) calculation were performed using *MegaWin 3.1* software (Mega Electronics Ltd).

Procedure

Participants performed a repetitive forward reaching task at 1-minute intervals using the affected arm, and completed each trial either with or without RAS. To control for order effects on performance with and without RAS, the trial order with or without RAS was randomly assigned by tossing coin.

Participants began in a starting position in which they were seated with 90° knee flexion in the height-adjustable straight-backed chair, with their trunk strapped to the back of the chair to prevent trunk movement, and their elbow positioned at 90° flexion. The affected hand was placed on a start-point box, which was located on the adjustable table. The target object was a switch with a diameter of 7 cm and a height of 5 cm, which was placed on the table at a distance that could be reached by full extension of the elbow joint without compensatory movement of the trunk. RAS was provided by a digital metronome placed in the corner of the table. In the RAS condition, participants touched the target and start points according to the sound produced by the metronome (Fig. 3).

To practice the task and determine the preferred auditory stimulation frequency, each participant performed a repetitive forward reaching task for 1 minute using the affected arm. After 5 minutes of rest, additional

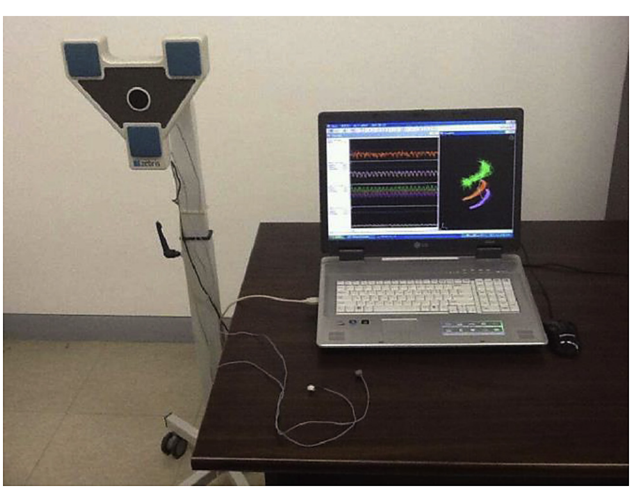
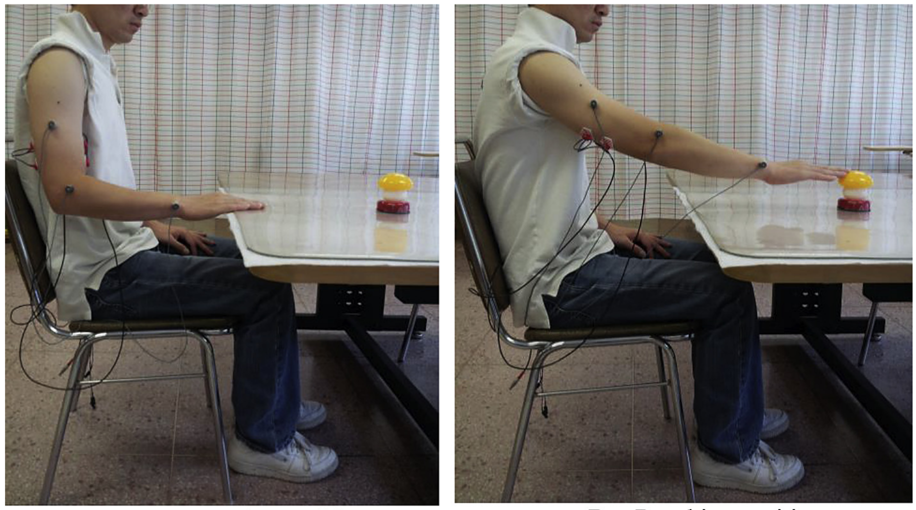


Figure 1 Three-dimensional motion analysis system (Compact Measuring System 10).

Figure 2 ME6000 electromyography system.



A. Starting position B. Reaching position

Figure 3 Position of the participant and the target. The (A) starting and (B) reaching positions relative to a participant with right hemiparesis is shown. The target was positioned on the surface of the table and arranged in a straight line.

EMG data were recorded during MVIC of each muscle (triceps and biceps brachii) using a standard manual muscle testing technique (Kendall & McCreary, 1983) to normalize EMG amplitude according to individual differences. The MVIC trials consisted of three exertion periods of 5 seconds, with a 1-minute rest period between periods. The MVIC value was determined by calculating the mean peak amplitude of each MVIC trial (Wagner, Dromerick, Sahrmann, & Lang, 2007). The trial was started after a 5-minute resting period. First, three markers were attached to the affected arm: one on the ulnar styloid process, one on the lateral epicondyle of the humerus, and one on the side of the humerus on a straight line to the lateral epicondyle (Fig. 3). The affected hand was placed at the start point on the table, and the opposite hand was comfortably placed on the knee. In the non-RAS trials, participants alternately touched the target and start points using the affected arm at a comfortable pace. In the RAS trials, participants performed the same movement sequence in time with the metronome beat. The frequency of the RAS was matched to the participant's preferred movement speed, which was assessed prior to the start of the trial, and participants typically started moving after they had heard the metronome beat two to three times. Participants were given sufficient practice trials to ensure full understanding before the actual recording of data, and were given 3-minute breaks between trials. The three-dimensional motion analysis system and surface EMG system were used for measurements during the reaching tasks.

Data collection

Because adaptation time is necessary to perform tasks in rhythm, we used only the last five reaching trials (1 minute each) for statistical analysis. Using a three-dimensional motion analysis system, the reaching segment was defined as the points along which angular velocity started at 0, increased, and then decreased to approximately 0 again. In the surface EMG system, the reaching segment was defined as the increase in amplitude of the agonist muscle (triceps brachii) from minimum to maximum activity. All data are shown as the mean of the values from the last five reach trials.

Variables

Movement speed, range, and smoothness were assessed by motion analysis in this study. Movement speed was defined as the time lapse from the start of the movement to the end of the reach (target), movement range was the maximum elbow extension ROM when reaching towards the target, and smoothness was the number of movement units divided by the change in angular acceleration while reaching towards the target. A movement unit was counted when the angular acceleration passed "0" and then returned to "0" (Rice, Alaimo, & Cook, 1999). Shorter movement time indicates higher efficiency in the execution of movement, greater elbow extension reflects greater ROM, and fewer movement units indicate smoother reach (Lin, Wu, Lin, & Chang, 2008).

Muscle activity and the co-contraction ratios of the triceps and biceps brachii were measured using a surface EMG system. The %MVIC represents the relative level of muscle activation during the reaching task, and indicates how much overall muscle capacity is being used (Wagner et al., 2007). The EMG data collected during the reaching task over 1-minute intervals were expressed as the %MVIC to depict changes in muscle activity. The %MVIC represents the effort required to perform the reaching task, and indicates how much of the overall muscle capacity is required to perform the task. This statistic normalizes muscle activity based on the maximum muscle capacity of each individual. The co-contraction ratio of two muscles was defined as the ratio of RMS of the antagonist muscle (biceps brachii) to the RMS of the agonist muscle (triceps brachii) during reaching. This was assessed using RMS during the co-contraction period while performing the reaching task. A

Table 2 Changes in Motion Variables ($N = 16$).

Motion variables	Conditions		Change	*t*	*p*
	Without RAS	With RAS			
Movement time (ms)	977.50 (473.75)	869.25 (410.32)	−108.25 (112.51) **	−3.85	.002
Movement unit	20.15 (9.69)	17.19 (7.87)	−2.96 (2.78) **	−4.26	.001
Elbow extension ROM (degrees)	153.01 (9.19)	157.94 (6.89)	4.93 (5.00) **	3.95	.001

Note. RAS = rhythmic auditory stimulation; ROM = range of motion. Data are presented as mean (standard deviation).
** $p < 0.01$.

smaller co-contraction ratio reflects better coordination of agonist and antagonist muscles (Chae et al., 2002).

Statistical analysis

Paired *t* tests were used to test for differences in movement time, elbow extension ROM, movement units, %MVIC, and co-contraction ratios with and without RAS. All analyses were conducted using SPSS 18.0 (SPSS Inc., Chicago, IL, USA). The level of significance was set at $p = .05$.

Results

Movement time ($p = .002$) and the number of movement units ($p = .001$) decreased significantly, whereas elbow extension ROM ($p = .001$) improved significantly during reaching with RAS (Table 2).

During reaching with RAS, the muscle activation increased significantly in the triceps brachii (11.77 ± 8.21 % MVIC compared with 13.91 ± 9.05 %MVIC; $p = .024$). In addition, there was no significant difference in %MVIC of the biceps brachii ($p = .911$; Table 3). The co-contraction ratio, defined as the muscle activation of the antagonist muscle (biceps brachii) divided by the muscle activation of the agonist muscle (triceps brachii), was significantly decreased during reaching with RAS ($p = .015$; Table 4).

Discussion

This study examined the effects of RAS in the elbow motion as well as the muscle activation of elbow while reaching with the affected arm in hemiparetic stroke patients. RAS produced by a digital metronome had a positive influence on motion and muscle activity during repeated reaching with the affected arm. RAS significantly decreased movement time and the number of movement units, and significantly increased elbow extension ROM relative to reaching without RAS. RAS also produced a noticeable increase in muscle activation of the triceps brachii, which is the agonist muscle for reaching, and in the co-contraction ratio between the triceps and biceps brachii compared with reaching without RAS.

Our results confirm previous findings that rhythmic cueing improves quality of movement and motor control in stroke patients. In one study, significant decreases in time to perform the reach cycle, decreases in compensatory trunk movement, increases in shoulder flexion, increases in elbow extension, and significant improvements in movement time and velocity were observed after extensive training (both on-site and home-based training) on a reaching task with RAS (Malcolm et al., 2009). Another study demonstrated that RAS during reaching decreased movement variability, increased speed of movement, and smoothed notion trajectory in hemiparetic stroke patients (Thaut et al., 2002). In general, rhythmic programmed movement has been shown to be more efficient in terms of movement execution (less movement time) and smoothness during reaching (fewer movement units; Lin et al., 2008). RAS allowed for preprogrammed movements that were more efficient and smooth, and had wider ROM. These results are likely the result of auditory rhythms transmitted to the motor system, which provided constant feedback on timing during planning and performing of exercises to improve kinematic stability.

In addition, we measured muscle activity of the triceps and biceps brachii in relation to elbow motion, and identified differences. In this study, EMG data collected during the reaching task over 1-minute intervals were expressed as the %MVIC to depict changes in muscle activity. The %MVIC represents the effort required to perform the reaching task, and indicates how much of the overall muscle capacity is required to perform the task (McCrea et al., 2005; Wagner et al., 2007). This effectively normalizes the muscle activity based on the maximum muscle capacity of each individual. While pathological synergistic muscle activity is

Table 3 Changes in Muscle Activation of the Triceps and Biceps Brachii ($N = 16$).

Muscle activation (%MVIC)	Conditions		Change	*t*	*p*
	Without RAS	With RAS			
Triceps brachii	11.77 (8.21)	13.91 (9.05)	2.14 (3.41) *	2.51	.024
Biceps brachii	14.37 (7.38)	14.42 (7.38)	0.05 (1.76)	0.11	.911

Note. MVIC = maximal voluntary isometric contraction; RAS = rhythmic auditory stimulation. Data are presented as mean (standard deviation).
* $p < .05$.

Table 4 Changes in Co-contraction Ratio ($N = 16$).

Conditions		Change	t	p
Without RAS	With RAS			
1.96 (1.60)	1.76 (1.45)	−0.20 (0.28) *	2.75	.015

Note. RAS = rhythmic auditory stimulation. Data are presented as mean (standard deviation).
* $p < .05$.

one recognized limitation of MVIC testing in participants with hemiparesis, we used the maximal EMG values recorded during MVIC testing (Wagner et al.). Use of RAS also produced a noticeable improvement in %MVIC of the triceps, but no difference in %MVIC of the biceps, and significantly decreased the co-contraction ratio due to increases in %MVIC of the triceps in the simultaneous contraction range.

Stroke patients often have difficulty with muscle activity while attempting to move the affected upper extremity. Massie, Malcolm, Greene, and Browning (2012) suggested that impairments in the ability to generate sufficient muscle activation may contribute to the difficulty in generating continuous reaching motions. Reduced specificity of muscle activation and high levels of agonist—antagonist co-contraction may contribute to difficulties with movement (Musampa, Mathieu, & Levin, 2007). Therefore, interventions that target these specific motor impairments are necessary. RAS is a technique that exploits the physiological effects of auditory rhythm on the motor system to improve the control of movement in rehabilitation and therapy (Thaut & Abiru, 2010). The auditory rhythm acts as an internal timekeeper, affecting muscle activation as well as brain mechanisms that control the timing of muscle contraction. RAS can be repeated on a regular basis for use in functional training (Thaut, 2009). These motion and muscle activation outcomes suggest that RAS may be beneficial for its ability to facilitate continuous reaching movements of the upper extremity in stroke patients.

In summary, our results suggest that RAS improved motion and muscle activation in the affected arm during reaching in stroke patients. The use of RAS does not require expensive treatment equipment, and can be combined with a variety of rhythmic activities during long-term rehabilitation of stroke patients. In particular, use of RAS during occupational therapy that consists of therapeutic activities that require repetitive movement patterns of the arm can augment the positive effects of the intervention. Thus, applying RAS to appropriate training and therapeutic activities for stroke patients will likely improve both quality of motion and muscle activation.

This study had several limitations. First, this was a pilot study with a small sample size. Participants were not homogenous in terms of age and duration to stroke onset. It was also difficult to recruit patients with a similar kind of arm impairments. Second, the study only considered one movement pattern to reach one target position. Movements might involve arm joints and muscles, which have not been investigated. An experiment with a larger scale involving similar demographics may be carried out in future.

Conclusion

This study examined the effects of RAS on motion and muscle activation of the elbow during reaching in recovering stroke patients. Use of RAS was associated with improvements in motion quality and muscle coordination of the elbow during reaching. Based on these results, RAS might be a useful technique to improve motor function of the affected arm in patients with stroke.

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