Effect of Sensory Stimuli on Muscle Activation on the Bimanual Arm Trainer for Upper Limb Rehabilitation Post-Stroke

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Abstract

Background: Few cost-effective, beneficial ways to rehabilitate hemiparetic individuals with a limited active range of motion currently exist. The Bimanual Arm Trainer (BAT) is a non-powered device with movement troughs that train shoulder external rotation through harnessing the movement in the unaffected arm and coupling it with the affected arm. The BAT was found to be safe and feasible to facilitate motor recovery in individuals with severe hemiparesis. Thus, the purpose of this study was to evaluate the efficacy of the video game, Canoe Adventure, and the various stimulatory cues the game provides with the BAT.

Methods: Twenty-two participants with severe hemiparesis that restricts range of motion (suggested by Ashworth score > 3 at any joint) trained with the device for twelve sessions under each of the four stimulatory conditions. The device marked the cue where the patient had the most active range of movement. Improvements in active range of motion and Fugl-Meyer scores were assessed six weeks before the start of intervention, pre-intervention, and post-intervention.

Results: Patients tolerated training under these four conditions and showed an overall improvement in their motor impairment. Patients improved significantly by an average of 1.43 in their upper extremity on the Fugl-Meyer scale score. Improvement in the lower trapezius and pectoralis major were the most significant in the visual cue. Trends of the latissimus dorsi, lower trapezius, pectoralis major, and the infraspinatus muscles were approaching significance in the visual and audiovisual cues.

Conclusion:

The BAT was suitable with unimanual and bimanual training under the Canoe Adventure game and the sensory stimuli. The device improved the upper extremity for patients, and improvements in muscle activation under the visual condition had the most significance.

Introduction

Stroke affects one in six individuals worldwide (Thrift et al., 2014) and is the leading cause of hospitalization and mortality; 85% of stroke victims are affected by hemiparesis along the major sequelae (Saposnik, Teasell & Mandani, 2010). Hemiparesis results in the difficulty to perform activities of daily living and to walk and balance. Upper-arm rehabilitation is vital in order to increase the quality of life of a patient post-stroke, but only 30% of the stroke patients who need rehabilitation are able to get it (Go et al., 2013). Thus, finding a cost-effective, beneficial way to rehabilitate hemiparetic individuals is vital.

Constraint-induced movement therapy is the most widely used, even considered to be the most successful treatment for the upper limb (Wolf et al., 2006). This is a form of therapy that constrains the non-affected arm and forces the affected arm to move on its own, limiting the ability of the brain to only learn from the affected side. However, its use raises questions about patient safety and satisfaction (You et al., 2005). Schallert et al. (1996) found that the "forced overuse" that CIMT requires caused a delay in the improvement of motor skills and even caused the lesion volume to increase. Thus, there has been a push to find rehabilitation methods that are safer, motivational, and able to use at an early post-stroke stage. Previous studies focus on finding cost-effective, motivational ways to help stroke victims regain function in their arm. Long-term recovery is aided by a patient's connection with their body, participation in daily life, and sense of self (Arntzen, Borg & Harmran, 2015). Having a type of therapy that keeps a patient motivated and interested in continuing therapy is vital for improvement, and various forms of rehabilitation have been utilized to sustain patient motivation. Some methods of post-stroke rehabilitation include task-oriented training, mirror therapy, rhythmic music therapy, robotic-assisted movement therapy, bilateral training, virtual reality therapy, and other game therapies (Meng et al., 2018).

Particularly, bimanual arm training is a type of rehabilitation that utilizes both arms in rehabilitating upper-limb movement. Bimanual training allows for a heightened interlimb coordination between the paretic and the non-paretic arm, as the non-paretic arm guides the paretic arm on how to move (Sleimen-Malkoun, Temprado, Thefenne & Berton, 2011). Essentially, information from the affected side transfers to the unaffected side. It exists in two forms: active bimanual training and active-passive bimanual training. In active bimanual training, the arms move independently and simultaneously. The paretic arm is required to have some movement on its own in order to carry out this type of bimanual training. In active-passive bimanual training, the movement of the non-paretic arm drives and mirrors the movement of the paretic arm, so that individuals with severe hemiparesis are still able to complete this approach. Both forms of bimanual training have been found to be effective. Luft et al. (2004) found that active bimanual arm training was effective with rhythmic auditory stimulation and led to significant gains in arm function. Stinear & Byblow (2004) found that active-passive bimanual training without any auditory stimulation increased the performance of the paretic arm.

Facilitating shoulder external rotation is vital. Shoulder internal rotation is the earliest motor movement that occurs in hemiparetic individuals (Fugl-Meyer, Jääskö, Leyman, Olsson & Steglind, 1975), yet this impairment is the result of an abnormally increased activation of the pectoralis major (Roh, Rymer, Perreault, Yoo & Beer, 2013). This muscle internally rotates and adducts the shoulder, and its abnormal activation makes it more difficult for patients to train out of shoulder internal rotation, a position that is more natural for post-stroke patients. Facilitating shoulder external rotation is vital to regain activities of daily living, decrease patient disability and obtain a neutral position with the hand and forearm.

Therefore, Raghavan et al. (2017) utilized bimanual active-passive arm training to create the Bimanual Arm Trainer (BAT). It focuses on training shoulder external rotation, creating a movement track to train shoulder external rotation for individuals in order to prevent from facilitating a wrong course of movement, and was found to decrease upper-limb motor impairment (Raghavan et al., 2017). However, this study was a pilot study, and patients completed on the BAT without any stimuli. Auditory or visual stimuli has been used in the past to enhance rehabilitation, so we plan to evaluate methods to enhance BAT training. The BAT was both feasible and effective, so therefore we aim to evaluate the extent to which motor learning can be enhanced during BAT training with auditory and visual stimuli on a customized video game, and examine if we can predict the type of stimuli that optimizes learning based on a patient's level of arm impairment. We hypothesized that an auditory stimuli would prove to be the most beneficial, due to how rhythm increases the amount of dopamine in the cerebellum and pallidus and pre-supplementary motor areas of the brain, thus enhancing the brain's ability to re-learn motor functions (Schaefer et al., 2014). Furthermore, because the bimanual arm trainer trains shoulder external rotation, I expected to find changes in the Inf, PM, PD, LD, and PM, which are muscles that are involved in shoulder external rotation (Kurokawa et al., 2014).

Methods

Participants

Twenty-two participants (ten males and twelve females, mean age ± SE = 55.1 ± 3.3 yrs) from New York University Medical center participated in this study. Informed consent was given through the Declaration of Helsinki and approved by the local institutional review board. All patients had severe chronic post-stroke hemiparesis (time since stroke: 38.3 ± 27.8 months.

The inclusion criteria were: 1) abie to read and write in English and give informed consent; 2) 18-90 years old; 3) able to follow instructions and complete all required visits; 4) able to comply with the therapy protocol; and 4) have a unilateral stroke.

The exclusion criteria were: 1) severe upper extremity spasticity that restricts the full passive range of motion (suggested by Ashworth score of > 3 at any joint); 2) evidence of alcohol, drug abuse, or relevant neuropsychiatric condition such as psychotic illness or severe depression; 3) history of surgery or other significant injury to the upper extremity that could cause mechanical limitations that preclude task performance; 4) previous neurologic illnesses such as head trauma, prior stroke, epilepsy, or demyleniating disease; 5) complicating medical problems like uncontrolled hypertension, diabetes with signs of polyneuropathy, several renal, cardiac, or pulmonary disease, or evidence of other concurrent neurologic or orthopedic conditions precluding the subject from complying with the study protocol; and 6) any other condition or situation that could put the subject at risk, confound the study results, or interfere significantly with the subject's participation in the study

Data Collection / Assessments

Assessments of active range of motion and the Fugl-Meyer scale of the upper extremity was utilized at recruitment (PRE1), 6 weeks post recruitment at pre-training(PRE2), and post-training (POST). Active range of motion was evaluated using the Motion Monitor 3D electromagnetic motion sensor system. Participants started in a neutral position (elbow at 90 degrees) and were asked to complete shoulder internal and external rotation, shoulder abduction, shoulder flexion and extension, forearm pronation and supination, elbow flexion and extension, and wrist flexion and extension actively. This allowed for the measurement of the muscle activation of the biceps (BIC), infraspinatus (Inf), latissimus dorsi (LD), posterior deltoid (PD), pectoralis major (PM), tricep (TRI), upper and lower trapezius (UT and LT). FMS scale scores were calculated at the upper extremity and the hand and wrist.
The time from PRE1 to PRE2 provided a six week control period conducted before training in order to establish the patient's initial level of functionality and assess the patient's spontaneous improvement levels before the start of the training sessions.

Description of the Bimanual Arm Trainer (BAT)

The BAT provides a movement track to train external and internal shoulder rotation. Using connectable movable troughs, it links the movements of the affected and unaffected arm and provides resistance. The paretic arm does not need movement ability, as the movements of the non-paretic arm drives the movements of the paretic arm, causing both arms to simultaneously move together, from a closed position, (internal shoulder position with a flexed elbow) to an open position (external shoulder position with an extended elbow). The BAT is a non-powered device, designed to restore balance between the muscles in the front chest and upper back. In this study, the device was combined with a customized video game, which was paired with auditory and visual stimuli to enhance movement.

Training

Patients underwent a total of twelve sessions, which occurred twice to three times a week for around six weeks. Each session started with a baseline warm-up session, followed by grip training, then a presentation of all four conditions, and another baseline warm-up session. Each session ended with the game, which consisted of two rounds of ten minutes of the canoe under the patient's favored condition followed by one minute of grip training. Patients alternated from performing thirty seconds of shoulder movement bimanually to unimanually with the affected arm alone. In grip training, patients turned their wrist to catch fruit in a basket, followed by a release and opening of their hand to catch water in a cup. In the warm-up sessions, patients would train for five minutes under the condition at which the patient performed best. The favorable condition was selected in the presentation of all four conditions. Patients completed two rounds of thirty second bursts of each condition, with a five second break in between. The device marked a patient's maximum active range of motion for each condition, and the cue where the patient achieved the most movement was selected as the most favorable.

Each set was paired with a different sensory condition provided by the game. The game, Canoe Adventure, required patients to row their arms and collect buoys. A row required the patient to complete shoulder external rotation to bring the oars outward, and return the arms back to shoulder internal rotation to bring the oars inward. The cues in the game were presented in a random order and aimed to enhance movement. Visual stimuli was the presentation of ghostlike, shadow arms that the patient was instructed to follow while moving their arms to row a canoe that the game showed. Rhythmic auditory stimuli was the presentation of the sound of waves that the patient was instructed to row in sync to in the game. Another condition combined auditory and visual stimuli, and the final condition contained no additional stimuli.

Data Analysis

Patient safety was ensured with a qualitative analysis during training. Differences in changes of EMG activation based on condition and time was analyzed with two-way ANOVA tests. The statistical significance value was set at 0.05, but any values that were between 0.05 and 0.10 were considered to be approaching significance.

For both Fugl-Meyer and EMG, change was measured over two time periods, the control period (Pre1 to Pre2) and the intervention period (Pre2 to Post). We utilized t tests to measure the significance of change within each of these periods. Improvements in Fugl-Meyer scores indicated an improvement in motor recovery. Comparisons of the change in the pre-intervention stage was conducted with changes in the post-intervention stage, in order to ensure that any improvement in motor recovery was due to the

BAT. Furthermore, improvements in certain muscle groups were evaluated through improvements in EMG values. This value was considered to be the "change score," which for the control period, was Pre2 - Pre1 and for the intervention period, Post - Pre2. Preferences for certain conditions was evaluated through the condition that produced the greatest EMG activation across all muscle groups.

Results

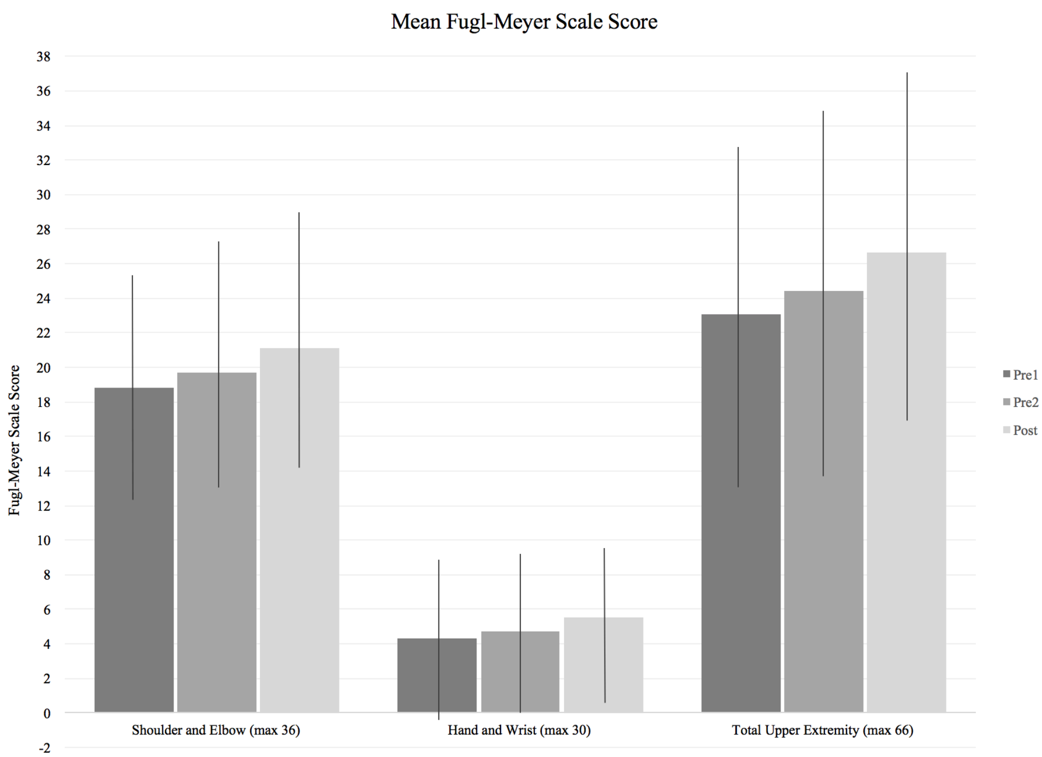
Outcomes		Pre 1	Pre 2	Pre2 vs Pre1 (p)	Post	Post vs Pre2 (p)	Change Pre-Intervention Pre2 - Pre1	Change Post-Intervention Post – Pre2	Change Pre- vs Post-Intervention (p)
FMA Mean (SD)	Upper	18.79 (6.77)	19.70 (7.08)	0.0497	21.125 (6.93)	0.000272	0.913 (2.11)	1.43 (1.59)	0.2830
	Hand/Wrist	4.29 (4.68)	4.74 (4.83)	0.4045	5.5 (4.32)	0.083846	0.304 (1.72)	0.8261 (2.19)	0.4390
	Total	23.08 (9.84)	24.43 (10.68)	0.0509	26.625 (10.40)	0.001178	1.217 (2.83)	2.261 (2.911)	0.2050
Audio Condition Mean (SD)	BIC EMG	0.522 (0.14)	0.529 (0.20)	0.7524	0.515 (0.20)	0.9861	-0.0146 (0.20)	-0.00108 (0.28)	0.7740
	INF EMG	0.556 (0.22)	0.486 (0.18)	0.1978	0.498 (0.20)	0.7359	-0.0800 (0.28)	0.0123 (0.17)	0.3246
	LD EMG	0.489 (0.17)	0.503 (0.16)	0.4802	0.558 (0.18)	0.3226	0.0250 (0.16)	0.05587 (0.26)	0.8069
	LT EMG	0.536 (0.14)	0.527 (0.17)	0.9352	0.549 (0.19)	0.6891	-0.0033 (0.18)	0.0224 (0.26)	0.7980
	PD EMG	0.490 (0.20)	0.464 (0.20)	0.3987	0.462 (0.17)	0.9794	-0.0455 (0.24)	-0.00128 (0.23)	0.5279
	PM EMG	0.534 (0.19)	0.464 (0.21)	0.1888	0.526 (0.17)	0.2290	-0.0715 (0.24)	0.0612 (0.23)	0.1603
	TRI EMG	0.622 (0.20)	0.590 (0.20)	0.4649	0.650 (0.15)	0.2095	-0.0441 (0.27)	0.0603 (0.22)	0.2523
	UT EMG	0.623 (0.15)	0.573 (0.15)	0.1822	0.580 (0.19)	0.8819	-0.0523 (0.17)	0.00718 (0.22)	0.4433
Visual Condition Mean (SD)	BIC EMG	0.554 (0.17)	0.535 (0.22)	0.7234	0.534 (0.24)	0.7229	-0.0192 (0.25)	-0.0241 (0.31)	0.8304
	INF EMG	0.622 (0.19)	0.510 (0.19)	0.0320	0.530 (0.20)	0.6708	-0.1119 (0.23)	0.01895 (0.21)	0.1170
	LD EMG	0.585 (0.18)	0.502 (0.16)	0.0330	0.540 (0.20)	0.4328	-0.0829 (0.17)	0.0387 (0.23)	0.1090
	LT EMG	0.590 (0.19)	0.483 (0.15)	0.0541	0.575 (0.21)	0.0353	-0.1065 (0.24)	0.09206 (0.19)	0.01988
	PD EMG	0.529 (0.21)	0.529 (0.18)	0.9996	0.481 (0.21)	0.2953	2.68E-05 (0.23)	-0.0477 (0.21)	0.5218
	PM EMG	0.530 (0.22)	0.457 (0.21)	0.3095	0.551 (0.17)	0.0249	-0.0738 (0.33)	0.0939 (0.18)	0.0903
	TRI EMG	0.671 (0.19)	0.618 (0.21)	0.3160	0.643 (0.18)	0.6220	-0.0529 (0.24)	0.02490 (0.23)	0.3661
	UT EMG	0.643 (0.16)	0.586 (0.15)	0.1816	0.583 (0.18)	0.9348	-0.0567 (0.19)	-0.00328 (0.19)	0.38699
Audiovisual Condition Mean (SD)	BIC EMG	0.546 (0.18)	0.567 (0.20)	0.6608	0.525 (0.22)	0.4590	0.0215 (0.23)	-0.04219 (0.26)	0.5017
	INF EMG	0.602 (0.22)	0.500 (0.20)	0.0354	0.491 (0.24)	0.8103	-0.1018 (0.21)	-0.00917 (0.18)	0.1030
	LD EMG	0.577 (0.18)	0.494 (0.17)	0.0427	0.566 (0.19)	0.1926	-0.0828 (0.18)	0.0718 (0.25)	0.0714
	LT EMG	0.565 (0.18)	0.501 (0.16)	0.2444	0.588 (0.20)	0.0680	-0.0641 (0.25)	0.08667 (0.21)	0.0924
	PD EMG	0.531 (0.19)	0.501 (0.19)	0.4553	0.453 (0.21)	0.3080	-0.0302 (0.19)	-0.04765 (0.21)	0.8038
	PM EMG	0.571 (0.21)	0.484 (0.21)	0.0999	0.535 (0.19)	0.3101	-0.0867 (0.24)	0.0509 (0.23)	0.0877
	TRI EMG	0.647 (0.22)	0.627 (0.22)	0.7325	0.623 (0.26)	0.9466	-0.0205 (0.28)	-0.0035 (0.24)	0.85299
	UT EMG	0.639 (0.16)	0.593 (0.17)	0.1833	0.595 (0.19)	0.9688	-0.0459 (0.16)	0.00199 (0.24)	0.4675
Neutral Condition Mean (SD)	BIC EMG	0.507 (0.17)	0.561 (0.20)	0.3304	0.559 (0.18)	0.9719	0.0539 (0.25)	-0.00214 (0.28)	0.6039
	INF EMG	0.586 (0.21)	0.471 (0.19)	0.0488	0.490 (0.21)	0.6172	-0.1149 (0.26)	0.01908 (0.18)	0.06459
	LD EMG	0.555 (0.18)	0.517 (0.15)	0.1488	0.543 (0.19)	0.6005	-0.0386 (0.12)	0.0268 (0.24)	0.3164
	LT EMG	0.569 (0.15)	0.512 (0.20)	0.2438	0.524 (0.18)	0.8290	-0.0572 (0.22)	0.0123 (0.26)	0.4567
	PD EMG	0.534 (0.17)	0.473 (0.19)	0.2533	0.445 (0.18)	0.5176	-0.0616 (0.25)	-0.0272 (0.19)	0.6647
	PM EMG	0.560 (0.19)	0.468 (0.22)	0.1222	0.549 (0.21)	0.2251	-0.0911 (0.27)	0.0801 (0.30)	0.1056
	TRI EMG	0.653 (0.16)	0.601 (0.23)	0.3785	0.624 (0.16)	0.6242	-0.0519 (0.27)	0.02301 (0.22)	0.4242
	UT EMG	0.635 (0.14)	0.606 (0.16)	0.4290	0.587 (0.19)	0.7297	-0.0292 (0.17)	-0.0189 (0.25)	0.8905

Fugl-Meyer Action Scores

Significant differences in the mean FMA scores ± SD of the upper extremity during the control period ($p = 0.0497$) and the intervention period ($p = 0.00027$) were found. The mean FMA for Pre1 was 18.79 ± 6.77, for Pre2 it was 19.70 ± 7.08, and for Post it was 21.125 ± 6.93, which shows a general upward trend in the upper extremity. However, the improvement of FMA upper extremity, demonstrated by the significance in between the scores ~~change score~~ from pre- to post-intervention, was not considered to be significant ($p = 0.283$), but does show a large positive increase, from 0.913 ± 2.11 in control to 1.43 ± 1.59 in intervention.

For the hand and wrist FMA, differences were not significant in either set of time periods. However, the mean difference from Pre2 to Post was approaching significance ($p = 0.083$), but likewise, it also showed a small improvement, from a change score of 0.304 ± 1.72 in control to 0.8261 ± 2.19 in intervention.

Nevertheless, significant differences were found in the mean total FMA scores, even though the change from pre-to-post intervention was not considered to be significant ($p = 0.205$). The difference in the mean FMA values of the control period significant as well (p = 0.051) with mean values of 23.08 ± 9.84 in Pre1 and 24.43 ± 10.68 in Pre2. From Pre2 to Post, which had a mean value of 26.63 ± 10.40, the difference approached significance (p = 0.0012). Because of the very small p value, this is a highly significant p value, which indicates the overall efficacy of the device, regardless of the stimuli that was used. The significance of this p value indicates that this device is highly suitable for training the upper extremity.

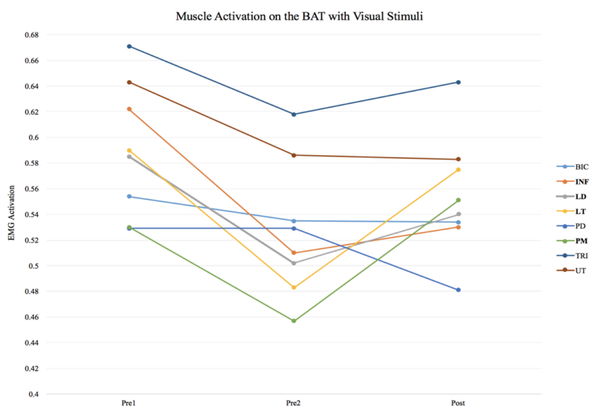


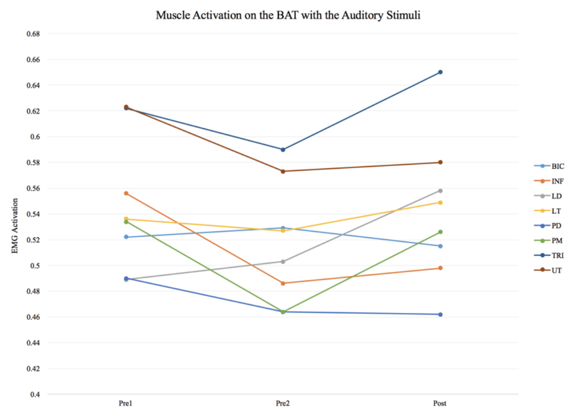
EMG

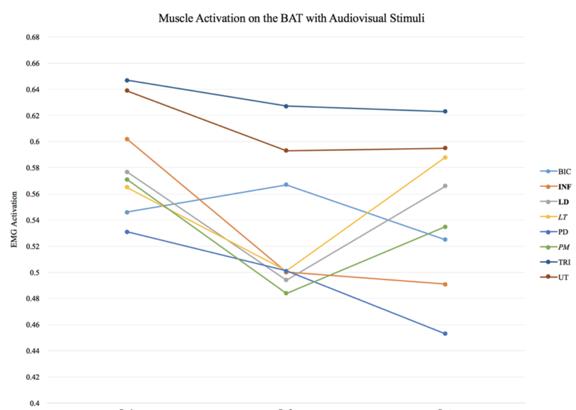
From Pre1 to Pre2, there was generally a decrease in muscle activation across all conditions and muscles, which was shown by the negative change score.These differences were generally insignificant, with only a few change scores during the control period being considered significant. These were the EMG of the Inf muscle for visual (-0.1119 ± 0.23), audiovisual (-0.1018 ± 0.21), and neutral (-0.1149 ± 0.26) and the LD muscle for visual (-0.0867 ± 0.24) and audiovisual (-0.0828 ± 0.18). The LT muscle for visual (-0.1065 ± 0.24) and the PM muscle (-0.0867 ± 0.24) for audiovisual were approaching significance.

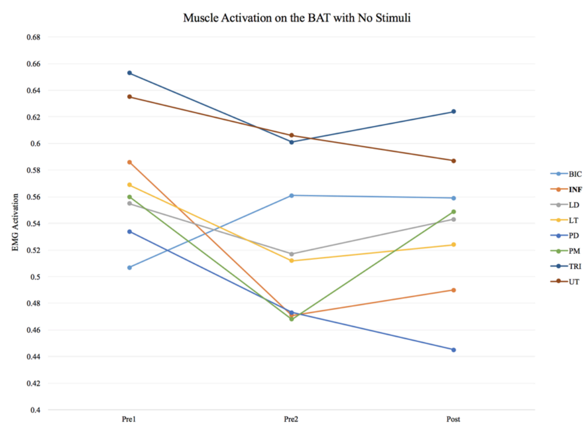
However, from Pre2 to Post, there was generally an increase in muscle activation across all conditions and muscles, which was shown by the positive change score. Likewise, these differences were generally insignificant, with only a few differences being considered significant or approaching significance. These were the EMG of the LT muscle in the visual (0.09206 ± 0.19, p = 0.035) and audiovisual cues (0.08667 ± 0.21, p = 0.068), as well as the PM muscle in the visual cue (0.0939 ± 0.18, p = 0.025). Thus, these were the muscles that were activated the most by the training.

These scores indicate significance between time periods. Particularly, the increase in the LT activation during the training period was significantly more than in the control period under the visual condition, and approached significance in the audiovisual condition. Other scores that approached significance was that of the PM in the visual and audiovisual conditions, LD in the audiovisual, and the Inf in neutral.









Discussion

The purpose of this study was to evaluate the added benefit of using four different sensory conditions on the Canoe Adventure game paired with the BAT, a mechanical device that facilitates shoulder external rotation by providing coupled bimanual arm training. Patients tolerated training under these four conditions and showed an overall improvement in their motor impairment, as demonstrated by the Fugl-Meyer scores. Furthermore, the six-week training period showed an increase in the muscle activation at some muscles.

Ability for BAT to Boost Motor Performance

BAT training allowed for patients affected by severe poststroke hemiparesis to improve their upper extremity. The bimanual approach to training increases motor activity in both hemispheres of the brain, which contrasts against CIMT, which only trains one hemisphere of the brain (Stinear & Byblow, 2002). Thus, the bimanual-to-unimanual approach used on the BAT allows patients with limited function on their paretic arm to reduce their impairment without constraining the other arm to force the paretic arm to move. BAT training boosted individuals' motor learning, as demonstrated by the trends towards improvements that were found in the Fugl-Meyer scores from the control period to the intervention period. Improvement from Pre2 to Post helps show that the BAT is an effective rehabilitation device that could be used on chronic stroke patients. Even though we did not find any significant difference between changes in FMA score during the invention period as compared to the control period , the trend for the greater improvement in FMA during the intervention period suggests that there is a possibility that a greater sample size and/or a longer intervention period could produce significant effects.

Furthermore, the bimanual arm trainer aims to train individuals out of internal shoulder rotation by training external rotation. This is critical because chronic post-stroke patients with hemiparesis are often affected by the flexor synergy pattern due to their inability to activate their muscles effectively and accurately (Brunnstrom, 1956). Training shoulder external rotation allows them to train out of shoulder internal rotation. The muscles that are stuck in the flexor synergy pattern are the biceps (BIC), posterior deltoid (PD), pectoralis major (PM), and upper trapezius (UT). On the other hand, the lower trapezius (LT), latissimus dorsi (LD), infraspinatus (Inf), and triceps (TRI) are antigravity muscles that aid scapular stabilization, which allow the patients to regain control of their arm.

I expected to find changes in the Inf, PM, PD, LD, and PM, which are muscles that are involved in shoulder external rotation. However, EMG activation from the visual cue in the PM and LT muscles were the most significant, and therefore were activated the most by the intervention. Furthermore, we found that the difference between the visual and audiovisual group, LD, LT, PM, and Inf muscles were approaching significance. The LT is a muscle that helps position the shoulder blade during shoulder external rotation, which is what was trained primarily with the BAT. Likewise, the inf is a muscle that works primarily in shoulder external rotation; the LT and inf are coupled muscles in shoulder external movement (Joshi, Thigpen, Bunn, Karas & Padua, 2011). Finally, the PM and LD work together to restore shoulder external rotation. In a 2004 study, patients with a massive rotator cuff deficiency were treated at the PM and LD tendons and were found to have an increased shoulder external rotation because their muscle strength improved after the surgery (Aldridge, Atkinson, & Mallon, 2004).

Effect of the Visual Cue

Many muscle groups in the visual and audiovisual cues significantly improved over both time points, but we did not find a significant difference on how much they were improving. The trend for improvement in muscle groups from Pre2 to Post2 suggests that likewise, a greater sample size and/or greater training dosage could confirm that a specific sensory condition is more beneficial to a specific muscle group than another.

The visual condition showed the most muscle improvement from the control period to the end of the intervention period. In the past, studies that investigated the impact of auditory and visual cues looked at their effects on Parkinson's disease patients. In these studies, visual cues were the most effective, allowing patients to have a smoother gait with increased velocity and stride lengths (Lee et al., 2012; Ying & Norman, 2006). A study by Ying & Norman (2006) added that the auditory cues did not have any added benefit to Parkinson's patients.

Our results showed the like for stroke patients. The visual cue showed the most significant muscle activation of all the other cues. This may be because visual cues tend to provide patients with a sense of realism, giving them a sense of spatial awareness through a guide that allows them to visualize the geometry of their body while moving (Palacios-Navarro et al., 2016). It also allows the patient to prepare their body for their next movement by visualizing it (Azulay et al., 2006) With these visual cues, a patient could see the path of their next movement paths. In the case of this study, it is the ghost arms that serve as a movement track for the patient to follow.

Meanwhile, auditory cues only provide patients with a sense of presence with a movement track that can only be heard, causing patients to respond to the cues in their own manner and rhythm (Hendrix & Barfield, 2006). To train effectively under an auditory cue, patients would need a strong sense of rhythm perception. Thus, for individuals with severe hemiparesis, visual cues offset a patient's possible lack of rhythm integration. Another possible explanation of these results is that the rowing sounds that we utilized as the auditory cue were not precise enough, timing wise, to support rhythmic entrainment. This is because studies involving training with an auditory cue tend to use a metronome, which entrains each movement to a specific beat that matches the pacing of the individual. The metronome is a lot more consistent than these waves might have been.

Visual cues have been used mostly with training the lower extremity for stroke patients, and this is the first study in my knowledge that utilizes both auditory and visual cues and compares its efficacy to train the upper extremity for stroke patients.

Limitations

This study, with twenty-two subjects, had a small sample size and therefore small statistical power, as many results were not considered to be significant. Furthermore, even though muscular learning at EMG was shown, the results were not considered significant. A higher training dosage and larger sample size may be needed for significance to be realized at the level of FMA. However, the trends of these results are still noteworthy, as most subjects showed improvement in FMA and muscle activation over the small dosage of training from the control period over the six week intervention period.

Conclusion

This study showed the suitability of the BAT for motor learning, incorporating stimuli into the unimanual and bimanual movements. The improvement of muscle activation under certain conditions as well as the most favorable condition, was indicated. Trends of the efficacy of the visual condition were found for four muscle groups. Thus, the benefits of additional sensory stimuli could be implemented into future post-stroke rehabilitation systems, in order to drive improvements in muscle activation and motor learning.

Future studies include using a larger sample size and a larger training dosage to confirm the trends of our data, as well as evaluating the circumstances that make a certain condition more favorable, as we work to tailor rehabilitation to a stroke patient's needs. We could also reevaluate the rhythmic auditory condition of the waves to perfect the timing of it similar to a metronome and retest its efficacy.

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