



# Differences in muscle activity and fatigue of the upper limb between Task-Specific training and robot assisted training among individuals post stroke

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## ABSTRACT

**Objective:** To compare the activity and fatigue of upper extremity muscles, pain levels, subject satisfaction levels, perceived exertion, and number of repetitions in Task-Specific Training (TST) compared with Robot-Assisted Training (RAT) in individuals post-stroke.

**Methods:** Twenty sub-acute post stroke subjects (16 men; median (interquartile range) age 64.0 (71.5–57.0) years) received two 30-min treatment sessions, one TST and one RAT. Before each session, the Visual Analogue Scale (VAS) was administered. Activity levels and fatigue of six muscles were monitored using surface electromyography and the number of repetitions was counted. After each session, the subjective assessment questionnaire of treatment, the Borg scale and VAS were administered.

**Results:** During TST, the Anterior Deltoid, Upper Trapezius and Biceps were more active, while during the RAT, the Triceps was more active. The Triceps activity increased during TST towards the end of the session. The pain levels increased after TST and the number of repetitions was higher compared to RAT. There were no significant differences in muscle fatigue, perceived physical exertion and subject satisfaction levels between both treatment sessions.

**Conclusion:** This is the first study to explore the biomechanics of both treatment methods and might therefore shed light on the mechanisms behind their positive outcomes. Due to the differences in the biomechanics of the treatments, a combination of both treatments may be beneficial to the activation of different muscle groups, thereby contributing to the rehabilitation program post stroke.

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## 1. Introduction

Motor training of the paretic Upper Extremity (UE) is an essential part of post stroke rehabilitation. High-intensity, repetitive task-oriented treatment has been found to be one of the most effective treatment methods for motor rehabilitation after stroke (Song, 2015). Several treatment methods, e.g. Robot Assisted Training (RAT) and Task-Specific Training (TST), elicit such treatment of the affected UE (Timmermans et al., 2014; Winstein et al., 2016).

The TST is a repetitive exercise, during which the patient practices goal-directed motor tasks (Pinter and Brainin, 2012). The difficulty levels of the chosen tasks are progressively adapted to the abilities of the patient (Arya et al., 2012), and personal preferences

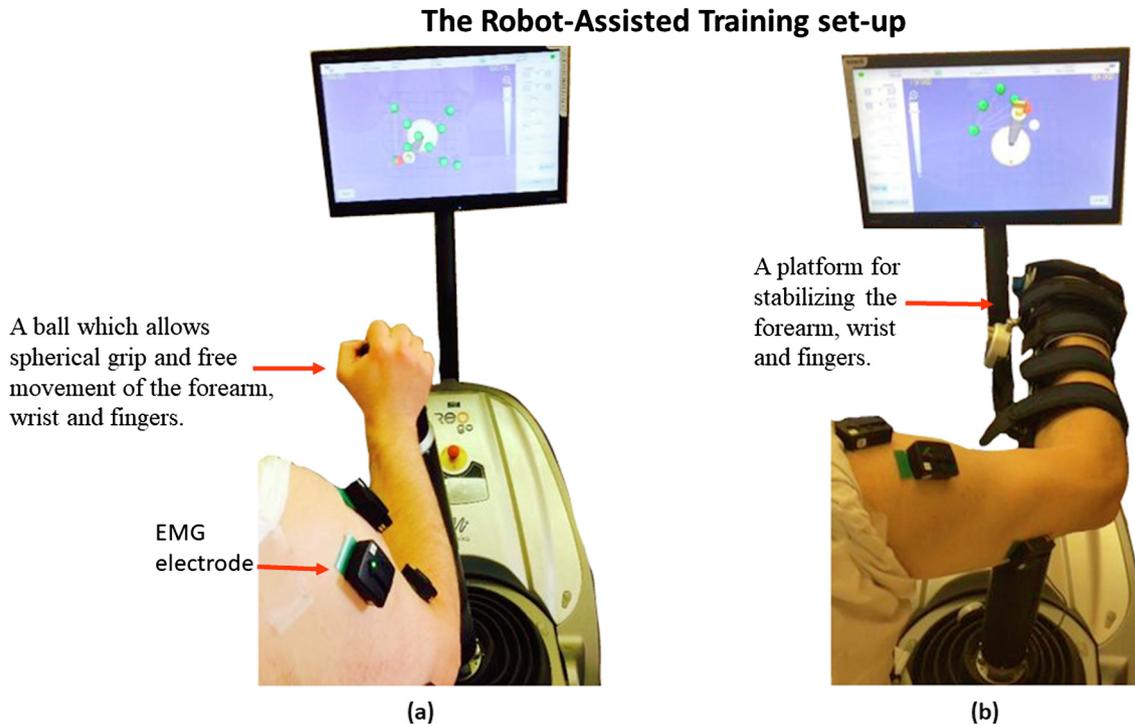
of the patient are considered. Hence, TST is a well-practiced treatment in rehabilitation clinics. However, current advancements in technology used in rehabilitation have shown promising results in elevating the satisfaction levels of the patient following the treatment and reducing the rehabilitation period (Rand et al., 2008).

Over the last decade, electromechanical devices have been designed to augment the capabilities of motor rehabilitation. Most of the robotic devices have been designed to provide proximal exercise (Veerbeek et al., 2017). In a recent intervention study that explored the effects of RAT applied in addition to the conventional therapy in subacute stroke patients, the authors noted an improvement in the motor muscle test and quality of life physical subset (Zengin-Metli et al., 2018). A recent review concluded that robot-assisted therapy had positive effects on the recovery of upper extremity motor function in patients with early-stage stroke (Kim et al., 2017).

An example for an end-effector robot is the REO-GO system (Motorika Medical Ltd, Israel; Fig. 1). This stationary robot includes

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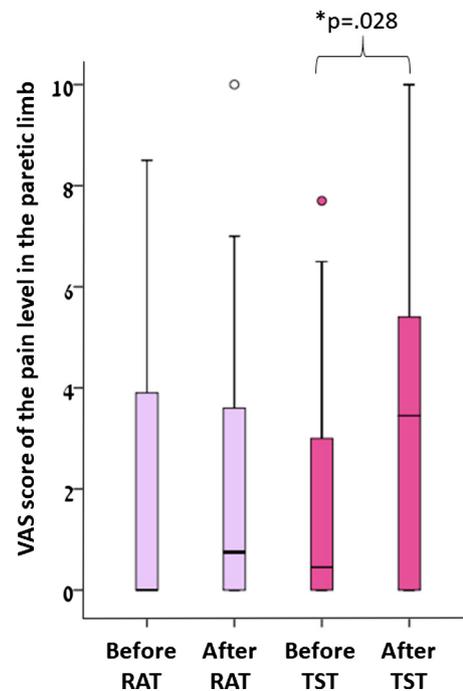
E-mail address: [portnoys@post.tau.ac.il](mailto:portnoys@post.tau.ac.il) (S. Portnoy).



**Fig. 1.** The end-effector robot used in this study (REO-GO, Motorika Medical Ltd, Israel). This stationary robot includes a telescopic arm and screen, and provides different exercise therapy modalities according to the motor ability and motivation of the patient. Two types of handles can be utilized: (a) ball which allows spherical grip and free movement of the forearm, wrist and fingers, or (b) a platform for stabilizing the forearm of the subject. Electromyography (EMG) electrodes were placed on the upper limb of the subject to record muscle activity.

a telescopic arm and screen, and provides different exercise therapy modalities according to the motor ability and motivation of the patient. The robot provides proximal upper limb training in a three-dimensional (3D) environment. The REO-Go was found to significantly improve the Fugl-Meyer Assessment (FMA) scores compared with self-guided therapy (Takahashi et al., 2016). Since this mode of RAT may involve high-intensity, repetitive exercise, and holds certain benefits compared with TST, e.g. distal end support that can assist weaker patients, the clinician may consider combining it with the conventional TST or even replacing the TST with RAT. A comparison of the actual biomechanics between the two exercises is therefore warranted, since if findings show differences between TST and RAT, a preference to one of the methods may hamper the rehabilitation process of the patient. Since the main purpose of TST and RAT of the upper limb is to exercise the muscles, a comparison of factors such as muscle fatigue during a full treatment session between the two treatments may point to the benefits of choosing either treatment for an individual patient. To date, a comprehensive evaluation of the differences between TST and RAT has not been performed. Knowledge of the differences in motor strategy and fatigue during each treatment may indicate which type of exercise would most benefit the patient in different stage of the rehabilitation. In other words, the clinicians could utilize this knowledge to optimize the patient-specific rehabilitation program (see Fig. 2).

Our study objectives were therefore to compare the activity levels and fatigue of the UE muscles of the paretic limb, as well as the number of repetitions during each session, level of satisfaction, perceived physical exertion and pain, between a RAT and TST single session. We hypothesized that muscle activation and the change in muscle activation would be greater in TST than in RAT but that the muscle fatigue would be greater in RAT. Additionally, we hypothesized that the number of repetitions and pain levels would be greater in TST, however we expected the satisfactory



**Fig. 2.** The pain levels reported by the subjects before and after Task-Specific Training (TST) and Robot-Assisted Training (RAT).

levels to be higher in TST as well, due to the task-oriented approach of this rehabilitation method. This is the first study to explore the biomechanics of both treatment methods and might therefore shed light on the mechanisms behind their outcomes.

## 2. Methods

### 2.1. Study design

A cross-sectional intra-subject study design.

### 2.2. Participants

The inclusion criteria were: (a) 18 to 85 year old individuals in the sub-acute phase (up to three months) following stroke, who were hospitalized at Hadassah Mount Scopus Hospital; (b) National Institutes of Health Stroke Scale (NIHSS) score between 3 and 15; (c) intact cognitive function (score > 21 points on the Mini Mental State Examination); (d) mild to moderate weakness of the affected UE (score > 20 points on the FMA); (e) normal or corrected eyesight. The exclusion criteria were: (a) neurological, cardio-vascular or orthopedic impairment, unrelated to the stroke, which restricts upper limb function; (b) a pace-maker. The study was approved by the Helsinki committee of the hospital (approval #0295-15-HMO).

### 2.3. Research tools and protocol

Each subject signed an informed consent pretrial. Each subject received two 30-min. treatment sessions, administered one to seven days apart: one session of TST and one session of RAT (in a cross-over design, so that ten subjects began with the TST and then received the RAT and the other ten subjects received the RAT and then the TST).

The RAT (ReoGo; Motorika Medical, Caesarea, Israel) consists of a computer screen, adjustable chair and motorized arm with two types of handles: (a) ball which allows spherical grip and free movement of the forearm, wrist and fingers (Fig. 1a), (b) a platform for stabilizing the forearm of the subject (Fig. 1b). The device has five work modes: guided passive motion, initiated motion, step initiated motion, follow-assisted, and free motion (un-assisted). Each subject was instructed to move the motorized arm from one virtual point to another (seen in both frames in Fig. 1), performing reaching tasks in 3D (where the handle is also lifted or pushed down). The distance and directions of the virtual points were adjusted according to the arm functionality of the subject. In this study, we used two modalities of the RAT: “follow assisted” (the handle moves at a slow speed towards the target. Once the user applies force to the handle in the specified direction the speed is increased. An orange arrow indicating the direction of the force applied by the user is displayed onscreen), and “free” (the user actively leads the movement). The TST protocol included the conventional, repetitive, task-oriented training of the affected arm. The tasks were selected by the subject from a detailed chart, and the difficulty of the tasks was modified according to the abilities of the subject. The chart contained the following tasks: reaching to a paper cup and bringing it to the face, lifting a cup, transferring rice from one container to another with a spoon, bringing a spoon of rice to the face and then emptying it in a glass on the table, sticking a fork in a fruit and bringing it to the mouth, lifting an apple from the table and bringing it to the mouth, folding a towel, stacking folded towels one on top of the other, putting on a hat, putting on eyeglasses, bringing a cell phone to the ear, spreading lotion on the opposite limb, spreading lotion on the face, drawing vertical and horizontal lines on a vertical surface, taking five coins out of a wallet, moving five coins from the table to a container, cleaning the table, cleaning a vertical surface. Each subject selected at least five tasks, which were meaningful to him or her, according to the treatment protocol, practiced daily in our rehabilitation center. The subjects performed 20 repetitions of each of the selected tasks. The

difficulty levels of the tasks were modified by controlling the weight of the manipulated objects and the between-repetition rest duration.

Before each session, the Visual Analogue Scale (VAS) was administered as the subjects marked the pain level in their paretic UE. During each session, the activity levels of six UE muscles were monitored using surface Electromyography (sEMG). Telemetric sEMG electrodes (Trigno™ Wireless EMG, Delsys, Boston, MA, USA) were placed on the paretic limb of each subject. The electrodes were placed according to the recommendations of Surface Electromyography for the Non-Invasive Assessment of Muscles (SENIAM; (Hermens et al., 2000)). The skin was shaved and cleaned with alcohol pads. The electrodes were attached, parallel to the direction of the fibers of the following muscles: anterior and middle deltoid, upper trapezius, triceps, biceps and serratus anterior. Dynamic EMG data were recorded at a frequency of 1500 Hz for the entire duration of each session. During each session, the number of repetitions was counted. After each session the Subjective Assessment Questionnaire of Treatment, the Borg Scale and the VAS were administered.

### 2.4. Post analysis

A self-designed LabView code (v.15, National Instruments, Austin, TX, USA) was used to read the EMG raw data, and perform baseline correction, filtering (6th order Butterworth filter with cut-off frequencies of 20–500 Hz), and full signal rectification. Then, sEMG data were Root Mean Squared (RMS) for consecutive segments of 50 ms. Hanning sliding window was used for the frequency analysis using short-time Fourier transform. Three parameters were calculated for each muscle, for each of the two treatment sessions: (a) mean RMS during the first five minutes; (b) the ratio (in percent) between the mean RMS in the last five minutes and the mean RMS in the first five minutes, as a measure of change in muscle activity during the session; The following formula was used:

$$(1) \text{ Muscle activity}[\%] = \frac{\text{MeanRMS}_{\text{last 5minutes}}}{\text{MeanRMS}_{\text{first 5minutes}}} \cdot 100$$

and (c) muscle fatigue. The quantification of muscle fatigue was performed according to the findings of Brody et al (Brody et al., 1991), who showed that the decrease of pH is related to the decrease in the conduction velocity of a muscle fibre, which in turn, causes a decrease in the median frequency. Although there is no clear threshold for a reduction in the median frequency signifying the onset of fatigue, it is well established that fatigue is correlated with a reduction in EMG spectral measures. We calculated muscle fatigue as the difference in the median frequency of the first five minutes and the median frequency of the last five minutes. A positive number indicates muscular fatigue.

Additionally, we compared the number of repetitions, level of satisfaction, perceived physical exertion and pain between the two treatment sessions.

Statistical analyses were performed in SPSS (version 25). Grubb's test was used to remove outliers. The Shapiro-Wilk normality test was used. Since the distribution of the variables was not normal for most variables, non-parametric tests were used. Descriptive statistics of the demographic data were calculated and presented using median and Interquartile Range (IQR). The Mann-Whitney test was used to compare the outcome measures between the group that began with RAT and the group that began with TST, in order to confirm that there was no learning effect between sessions. The Friedman test was used to assess differences between the variables of the study. If statistical significance was found, post hoc Wilcoxon tests were performed. The effect size

was calculated separately for each outcome measure according to effect size calculation for a-parametric tests (Fritz et al., 2012).  $p < .05$  was considered significant difference.

### 3. Results

Twenty one participants enrolled in the study. One subject dropped out of the study before completing the TST session due to early discharge. See personal characteristics in Table 1. No differences were found in the study outcome measures between the group that began with RAT and the group that began with TST, so that there was no learning effect between the two treatment sessions. During RAT, four subjects used the forearm support handle (Fig. 1b). Fourteen subjects practiced free movement and six subjects also engaged in active-assisted exercises using the “follow assisted” modality. The exercise protocols for both RAT and TST were fitted to each subject according to his or her physical abilities by one trained occupational therapist (NS) that provided the treatment sessions for the entire study population. The therapist personalized each treatment session according to the accepted principals practiced in the occupational therapy department so

that all the sessions were similar to those provided to post stroke patients that did not participate in the study.

The muscle activity in the first five minutes was significantly higher in the anterior deltoid, upper trapezius and biceps muscles in the TST compared to RAT, and significantly higher in the triceps during RAT compared to TST (Table 2). The change in the level of the activity of the triceps during the entire session was significantly higher during TST compared to RAT. Additionally, we found significant differences in the changes in the activity levels during a specific exercise. Specifically, during RAT, the anterior and middle deltoid, triceps and biceps muscles decreased their activity. During TST, the biceps and serratus anterior muscles decreased their activity. There were no significant differences in muscle fatigue between the two treatment sessions. However, during TST there was significant muscle fatigue in the upper trapezius, triceps and serratus anterior muscles, while in the RAT, there was significant fatigue in the triceps muscle.

The number of repetitions was higher during the TST (151.0 (113.3–205.5)) compared with the RAT (93.0 (78.5–120.0)), with significance level of ( $Z = -2.9, p = .004$ ). There was no significant difference between the two sessions in the pain levels reported before each session ( $Z = -0.3, p = .754$ ), however after the TST, the pain levels significantly increased ( $Z = -2.2, p = .028$ ). There were no differences in the perceived physical exertion levels between the two sessions ( $Z = -0.3, p = .977$ ), nor in the subjective satisfaction levels ( $Z = 0.0, p = 1.000$ ) or level of enjoyment ( $Z = -0.2, p = .854$ ).

The power calculated for the findings of the significant difference in activity levels of the anterior deltoid and upper trapezius was 99.8% and 89.0%, respectively. We further calculated a power of 80.7% for the finding regarding significant change in level activity of the triceps muscle.

### 4. Discussion

In this study, we compared the muscle activity and fatigue of the affected UE post stroke, pain levels, perceived physical exertion and the satisfaction of the subject, between TST and RAT. We chose

**Table 1**

Personal characteristics of the participants. Numeric values are presented as median (Md) and interquartile range (IQR) in parentheses.

	Md (IQR)
Age, years	(57.0–71.5) 64.0
NIHSS (3–15)	(4.0–8.5) 6.0
MMSE (0–30)	(25.2–28.0) 27.0
FMA (0–66)	(32.0–61.5) 52.5
	N (%)
Gender (male/female)	(80) 16/(20) 4
Dominant hand (right/left)	(80) 16/(20) 4
Paretic UE (right/left)	(70) 14/(30) 6
Paretic Dominant UE	14 (70)

NIHSS = National Institutes of Health Stroke Scale; MMSE = Mini Mental State Examination; FMA = Fugl-Meyer Motor Assessment; UE = Upper Extremity.

**Table 2**

Median (25th – 75th percentiles) of the recorded muscle activity. Muscle activity in the first five minutes was calculated as the mean of the Root Mean Square (RMS). The changes in the level of activity were calculated as the ratio between the mean RMS in the last 5 min and the mean RMS in the first 5 min. Data are presented as median (Md) and interquartile range (IQR) in parentheses.

Muscles	Variables	Md (IQR)		Wilcoxon	
		TST	RAT	Z,p	$\Gamma^{\vee}$
<b>Anterior Deltoid</b>	<b>Muscle activity in the first 5 m (mV)</b>	<b>(3.6–9.0) 6.3</b>	<b>(2.1–4.9) 2.7</b>	<b>–3.8, 0.001</b>	<b>–0.851</b>
	Changes in the level of activity (%)	(64.5–127.9) 101.8	(62.3–112.4) 83.7*	–1.1, 0.248	–0.272
	Fatigue (Hz)	(2.4–8.6–) 3.3	(7.4–12.2–) 2.5	–0.4, 0.717	–0.083
<b>Middle Deltoid</b>	<b>Muscle activity in the first 5 m (mV)</b>	<b>(1.9–8.9) 3.8</b>	<b>(2.1–5.6) 2.7</b>	<b>–0.9, 0.370</b>	<b>–0.200</b>
	Changes in the level of activity (%)	(63.3–128.3) 92.2	(36.0–107.1) 70.5*	1.8, 0.068	–0.442
	Fatigue (Hz)	(7.0–8.2–) 0.1	(7.8–8.4–) 1–	–0.7, 0.502	–0.150
<b>Upper Trapezius</b>	<b>Muscle activity in the first 5 m (mV)</b>	<b>(6.8–12.9) 10.4</b>	<b>(2.2–4.9) 3.4</b>	<b>–3.1, 0.002</b>	<b>–0.684</b>
	Changes in the level of activity (%)	(63.3–114.0) 81.1	(69.2–150.2) 119.2	–1.3, 0.199	–0.303
	Fatigue (Hz)	(1.7–8.7) 5.0	(5.5–7.0–) 3.2	–0.9, 0.355	–0.212
<b>Triceps</b>	<b>Muscle activity in the first 5 m (mV)</b>	<b>(1.4–6.2) 2.2</b>	<b>(3.5–16.8) 5.1</b>	<b>–2.2, 0.030</b>	<b>–0.484</b>
	Changes in the level of activity (%)	<b>(59.9–204.4) 112.2</b>	<b>(40.5–96.3) 70.5**</b>	<b>–2.6, 0.010</b>	<b>–0.591</b>
	Fatigue (Hz)	(1.7–51.6) 17.9*	<sup>†</sup> (1.2–42.3–) 3.1	–0.1, 0.881	–0.033
<b>Biceps</b>	<b>Muscle activity in the first 5 m (mV)</b>	<b>(3.2–6.9) 3.9</b>	<b>(1.7–3.7) 2.5</b>	<b>–2.6, 0.009</b>	<b>–0.548</b>
	Changes in the level of activity (%)	(39.9–81.0) 64.8**	<sup>†</sup> (40.6–75.5) 67.2	–0.2, 0.983	–0.005
	Fatigue (Hz)	(3.4–10.2–) 2.1	(16.8–30.4–) 7.6	–1.4, 0.159	–0.323
<b>Serratus Anterior</b>	<b>Muscle activity in the first 5 m (mV)</b>	<b>(1.0–2.3) 1.8</b>	<b>(0.9–2.4) 1.4</b>	–0.4, 0.647	–0.105
	Changes in the level of activity (%)	(69.6–107.0) 82.1*	(37.3–138.5) 68.2	–0.2, 0.807	–0.068
	Fatigue (Hz)	(0.1–13.8–) 3.6*	(12.6–18.6–) 2.7	–0.5, 0.619	–0.121

TST = Task-Specific Training; RAT = Robot Assisted Training.

Within group statistical differences of activity or fatigue are marked with \* $p < .05$ . \*\* $p < .01$

Variables where statistical significant difference was found between the TST and RAT conditions is mark in bold fonts.

<sup>∇</sup> Effect size calculated according to (Fritz et al., 2012).

to compare these two exercises although they are clearly different since both of them may be chosen and used as high-intensity, repetitive exercises in the clinical settings. This biomechanical study, which emphasizes some differences between the two methods, can help direct the decision of the clinician towards the more appropriate treatment choice for each patient. Our main finding partially support the first hypothesis, as the muscle activity in the first five minutes was significantly higher in the anterior deltoid, upper trapezius and biceps muscles in the TST compared to RAT, while the activity of the triceps muscle was significantly higher during RAT compared to TST. Moreover, the activity of the triceps muscle was significantly increased toward the end of TST compared with the change in activity during RAT. No differences were found in the muscle fatigue between TST and RAT, refuting our hypothesis. However, three muscles fatigued during TST, whereas only one muscle fatigued during RAT. The number of repetitions was higher in TST and the pain level increased after the training in TST, proving our hypothesis.

The differences in muscle activity patterns found herein are likely caused by the inherent differences between the two exercises. For example, during RAT, the hand and arm can rest on the device (Fig. 1) when lifting of the handle is not required, but during TST, the subject raises the arm against gravity, without support, for the majority of the exercise. This difference in conditions between RAT and TST may explain the difference in initial muscle activity patterns. Previous reports show that gravity compensation with arm support during reach and retrieval activities in healthy elderly decreased the activity of the biceps, triceps, deltoid and upper trapezius muscles but did not affect the muscle activation timings (Prange et al., 2009). In addition to the difference in arm support, a second difference between TST and RAT is that some activities in TST incorporate lifting of objects above head level, whereas the RAT allows arm lifting to shoulder level. Other factors that may have influenced the difference in muscle activity patterns between the two exercises are the different in target locations and movement velocity. Reaching performed towards different targets produced different muscle activity patterns (Coscia et al., 2014; Pirondini et al., 2016). The speed of the reaching movement also affected the level of muscle activity. In a study where the subjects were asked to move the limb “as fast as they could”, higher muscular activity was recorded compared to slow movement (Coscia et al., 2014). In this study, since there were more repetitions during TST, we assume that the movements were performed at a higher velocity, which resulted in higher levels of muscle activity. However, an alternate explanation for the higher number of repetitions in the TST may not be related to the movement velocity itself but to the design of each protocol: the TST is of block design as the subject performs a series of the same task so that the reaction time before each repetition is expected to be low. However, in the RAT, the next movement on the screen cannot be predicted by the subject so that after reaching to one location, the next target may be different from the previous, thereby elongating the reaction time before the subject initiates the movement. Furthermore, in the RAT, the subject has to reach an exact location presented on the screen in order to receive virtual confirmation that the task was completed and so the higher requirements of accuracy during RAT might have caused movement corrections during the tasks, which were not required during the TST. Hence, the higher number of repetitions in the TST may be caused by the shorter reaction times before each repetition, even if the actual movement time was similar, i.e. similar velocity between TST and RAT.

To the best of our knowledge, no previous studies compared muscle fatigue during functional UE activities. The levels of reduction in the median frequency, reported in our study, are similar to those recently reported by (Dabholkar et al., 2017). The authors used sEMG applied to two forearm muscles in dentists performing

various dental procedures and reported a reduction of approximately 5–6 Hz in the median frequency, suggesting muscle fatigue. In this study, the triceps was fatigued during both treatments. This result may indicate the importance of this muscle while performing repetitive reaching and retracting tasks. The triceps is responsible for the alignment of the elbow and functions as an antagonist for the elbow flexors when performing a reaching movement (Tokuda et al., 2016). When comparing the muscle activity with and without wrist support, it was found that the activity of the biceps and triceps muscles increased (Jung et al., 2013). In our study, the use of platform handle which restricted the movement of the wrist in RAT might have caused the increase in the activity of the triceps muscle. Despite the increased activity of this muscle, we found no differences in muscle fatigue between the two treatments. This may be explained by compensatory movements performed by each subject during the tasks that allowed recovery for other muscles. Another aspect concerning muscle fatigue is its morphology and fibre composition ratio. Muscles with a higher content of fast-twitch fibres exhibit greater reduction in median frequency following fatiguing contraction (Kupa et al., 1995). Therefore, it is not expected that the muscles monitored herein fatigue in a similar manner. However, in this intra-subject study design, we compared a detected reduction in an EMG spectral measure of a selected muscle between the two types of intervention so that the data allowed us to assess a difference in muscle fatigue between the two conditions.

Pain in the affected UE is one of the most common symptoms after stroke (Caglar et al., 2016). The pain levels increased after TST but not after RAT. However, there were no differences in the pain levels between TST and RAT. Therefore, patients with shoulder pain might prefer RAT to TST, as the latter is more likely to produce shoulder pain. Similarly, in a randomized control trial that examined the effect of weight-supported arm training compared with conventional reach training in individuals with subacute stroke, the pain levels did not differ between groups, even though pain levels increased after both trainings (Prange et al., 2015). Counting repetitions can be accurate measure of intensity of training (Connell et al., 2014). It can be assumed that the pain levels after TST increased due to the high-intensity training caused by the high number of repetitions of each task. Similar to the findings in our study, Waddell et al (Waddell et al., 2014) found that individuals post stroke can achieve hundreds of repetitions of task-specific training with their hemiparetic UE during a 1-hr session. Considering that there might be a relation between pain levels and muscle activity, we performed Spearman correlation tests to explore correlations between the reported pain levels, i.e. the VAS scores, and the three muscle activity parameters (activation, change in activation and fatigue). We found no correlation between the VAS scores and the muscle activity parameters, suggesting that the different muscle activation demands of TST and RAT may not be related to the elevated pain levels in TST. However, since the most discussed source for shoulder pain and treated muscles in hemiplegic post stroke patients are the posterior deltoid and supraspinatus muscles (Turner-Stokes and Jackson, 2002), this might be expected. One might assume that the higher levels of pain reported following TST were related to a strenuous activity of the posterior deltoid and supraspinatus muscles, which did not occur in RAT, possibly due to the hand support and differences in requirements of range of motion.

The high scores in the subjective assessment questionnaire indicate a high satisfaction level of the subjects following both treatments. While the subjects found interest in practicing functional and meaningful tasks during TST, they also enjoyed using a new technology during RAT. Similarly, in a study that examines the efficacy of the REO-Go for motor rehabilitation, high compliance, motivation and satisfaction were reported by the participants (Sale et al., 2014).

Several limitations of this study should be considered. First, the small sample size of the study may not represent the entire population of individuals post stroke. Second, an effort was made to simulate real clinical settings during both exercises, for ecological validity, so that the number of repetitions was not matched between the treatment sessions. In spite of this limitation that might have caused fatigue in one session and not the other, we found no differences in muscle fatigue. Third, the tasks of each treatment were modified according to the motor ability of the subject so that the intensity of the treatment varied between subjects. Finally, the use of new technology that the subjects were not familiar with, might have been more difficult for some subjects to comprehend.

Considering the results of this study, we believe that, when possible, a combination of both treatments can activate different muscle synergies and therefore contribute to the motor rehabilitation program post stroke. The TST should not be replaced by RAT, due to its lower intensity levels and movement limitations. Other factors such as pain levels and the functional abilities of the patient should be considered for optimization of the rehabilitation program.

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