Increased range of motion and decreased muscle activity during maximal reach with gravity compensation in stroke patients

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Abstract — **To stimulate restoration of arm function after stroke, active movement is important, which can be facilitated by supporting the weight of the hemiparetic arm, either in conventional treatment or in other approaches such as robot-aided therapy. During arm support, the active range of motion during reach can increase with respect to unsupported movements. The present objective was to investigate the influence of gravity compensation on muscle activity and range of motion during maximal reach. Six stroke patients performed maximal reaching movements, once with and once without gravity compensation. When comparing these two conditions, muscle activity decreased while range of motion increased with gravity compensation. This implies that gravity compensation may facilitate active arm movements, by reducing the required muscle activity to maintain a particular arm orientation. This may be related to a reduction of an abnormal coupling between shoulder abduction and elbow flexion when arm movements are performed with gravity compensation.**

I. INTRODUCTION

Stroke is a sudden disturbance of the blood supply of brain tissue (either ischemic or hemorrhagic), which causes partial loss of brain function. Some of the consequences of a stroke are a reduction of the integration of sensory and motor information in the brain and a diminished motor output from the brain to the spinal cord. This may result in a limited ability for selective muscle activation, causing restrictions in arm function in many stroke patients [1].

Functional use of the arm and hand is very important for stroke patients to be independent in activities of daily living. Restoration of arm function after stroke can be stimulated by an intensive training program of exercise therapy, in which active movement of the affected arm is an important aspect [2-4]. An emerging approach in stroke rehabilitation during the last decade is the use of robotic devices to provide intensive repetitive, task-specific and interactive treatment of the impaired upper extremity. A recent systematic review showed that robot-aided therapy is beneficial for the improvement of arm function after stroke [5]. Robot-aided therapy enables several potential training modalities, such as passive, active-assisted, active-resisted and bi-manual training. Another feature that many existing robotic devices have in common is that the arm is supported by the device [6]. However, this function of arm support is not described as an explicit training modality, and is often not included in studies as such.

Support of the weight of the arm, or gravity compensation, to facilitate active arm movements is not only used in robotic applications, but also in conventional rehabilitation approaches. A few studies have recently provided some insight in the changes in movements when the influence of gravity on the arm is compensated. Several studies showed that the active range of motion during reach increased instantaneously with gravity compensation during multi-joint reaching movements with respect to unsupported movements [7,8]. Furthermore, preliminary results of Amirabdollahian et al. indicated that training while de-weighting the arm against gravity can improve motor function of the arm [9].

In addition, in previous studies we found that in both healthy elderly [10] and stroke patients [11] the level of muscle activity decreased when performing a predefined reaching movement with gravity compensation, primarily for those muscles that maintain a given arm posture against gravity. However, not much is known about the differences in muscle activity that accompany an increase in maximal range of motion with gravity compensation.

The objective of the present study is to obtain more insight in the influence of gravity compensation on muscle activity during maximal reaching movements of stroke patients. In addition, we investigated the relation between differences in muscle activity and differences in movement execution due to gravity compensation. This information will add to the understanding of the explicit effect of gravity compensation, or arm support, in post-stroke arm rehabilitation, both in conventional approaches and new applications such as robot-aided therapy.

The present study expands previously published results of Stienen et al. concerning the influence of gravity

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compensation on movement execution during maximal reaching movements [8].

II. Methods

A. Subjects

Six stroke patients were recruited from a local rehabilitation center and were included in this study, after verifying that they were able to lift their arm (partly) against gravity and were not suffering from shoulder pain. All subjects provided written informed consent and the study was approved by the local medical-ethical committee.

B. Apparatus

A mechanical device (Freebal) was used to counteract the influence of gravity on the upper extremity (figure 1). The device consisted of two independent springs, connected to pliable joint braces at the elbow and wrist via ropes and pulleys overhead. This system provided a constant amount of gravity compensation throughout the entire workspace (of approximately 1 m^3), irrespective of the position and orientation of the arm and without restricting movements to two dimensions. In other words, subjects felt like their arm was 'floating in the air' in each arm position. Furthermore, the amount of gravity compensation was individually adaptable. A more detailed description of the Freebal is published elsewhere [8,12].

Figure 1. Schematic image of the Freebal: device with a spring mechanism for gravity compensation of the upper extremity, supporting the elbow and wrist

C. Procedure

Subjects were seated at an in height adjustable table and were secured to the chair by straps to minimize compensatory movements of the trunk. Subjects were asked to perform a movement task twice with the affected arm, once with and once without gravity compensation. This movement task consisted of maximal multi-joint forward directed reaching movements.

D. Measurements and data recording

The upper extremity portion of the Fugl-Meyer assessment (maximal score of 66) was performed prior to the movement task as a clinical measure of the current arm function [13]. Bi-polar surface electromyography (EMG) was recorded of 6 superficial muscles of the upper extremity (biceps (BIC), triceps (TRI), anterior (DA), middle (DM) and posterior (DP) parts of deltoid and upper trapezius (TRA)) according to guidelines of the SENIAM project [14]. Per subject, smooth rectified EMG (SRE) was calculated for each muscle. Elbow and shoulder angles were derived from positions of arm segments, recorded using an infrared 3D-motion analysis system, with reflective markers on 10 bony landmarks of the trunk, upper and lower arm [15]. Maximal reaching distance was calculated as the largest distance between shoulder and wrist, averaged over all repetitions per subject (in mm). In addition, movements were quantified by calculating movement time (duration of reaching movement averaged over all repetitions per subject, in ms) and joint excursions of elbow and shoulder angles (difference between minimal and maximal joint angles averaged over all repetitions per subject, in degrees).

E. Data analysis

The non-parametric equivalent of the paired-samples t-test (Wilcoxon signed ranks test) was used to examine differences in SRE-values per muscle, maximal reaching distance, movement time and joint excursions of elbow and shoulder angles during movements with and without gravity compensation.

III. Results

A. Subjects

For the 6 subjects, median time post-stroke was 10 months, with a range from 1 to 42 months. Fugl-Meyer scores ranged from 33 to 49, with a median score of 41 (out of a maximal score of 66 for the upper extremity portion).

B. Movement execution

Movement time, excursions of shoulder plane and angle of elevation were similar for movements with and without gravity compensation. In contrast, elbow excursion was larger with gravity compensation. This difference in elbow excursion approached significance (p=0.075) and was due to a larger amount of elbow extension at the end of reach with gravity compensation.

The comparison of maximal reaching distances with and without gravity compensation is illustrated in figure 2. The maximal reaching distance was larger with gravity compensation (536 ± 48 mm), in comparison to unsupported movements (488 ± 48 mm), which was a significant difference (p=0.026).

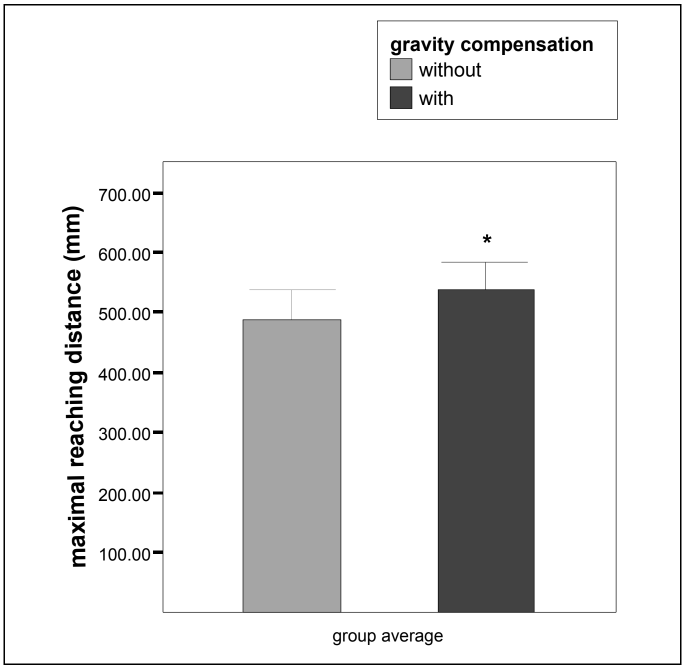

Figure 2. Comparison of mean (± standard deviation) maximal reaching distance during movements without gravity compensation (light bars) and during movements with gravity compensation (dark bars); asterisk (*) represents significant differences (p≤0.05)

C. *Muscle activity*

Figure 3 displays mean SRE-values during maximal reaching movements with and without gravity compensation for each muscle. These data show that the influence of gravity compensation resulted in a reduction of SRE-values in all muscles. The difference in SRE-values between movements with and without gravity compensation was smallest in TRI.

These observations were supported by the statistical analysis. The differences in SRE-values between maximal reaching movements with and without gravity compensation were significant in BIC, DA, DM and TRA (p≤0.004). The difference in SRE-values of DP approached significance (p=0.053).

IV. Discussion

Although a few studies have recently provided some insight in the changes in movements with gravity compensation, the differences in muscle activity during maximal range of motion reaches with and without gravity compensation are largely unknown. Therefore, the objective of the present study was to investigate the influence of gravity compensation on muscle activity during a maximal reaching movement and the relation of changes in muscle activity with changes in movement execution due to gravity compensation.

Our findings show that the level of muscle activity was lower during movements with gravity compensation, in predominantly those muscles that act against gravity during forward-directed reach (BIC, DA, DM and TRA). This reduction in muscle activity occurred despite increases in maximal reaching distance of the hand. When looking at specific joint angles, this increased maximal reaching distance was related to an increase in excursion of elbow extension during movements with gravity compensation, while the excursions of the shoulder angles did not change.

In contrast, muscle activity of TRI was only slightly decreased with gravity compensation, which is in line with a larger elbow extension and an increased maximal reaching distance, for which some muscle activity must be generated.

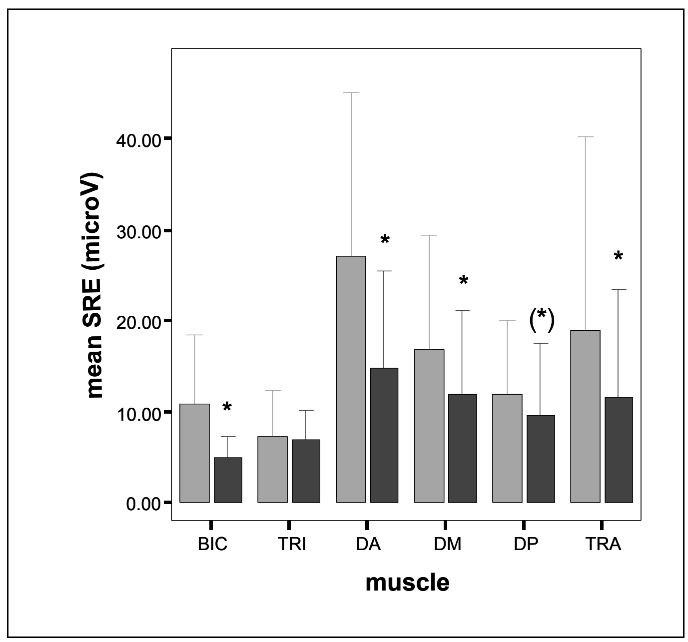

Figure 3. Comparison of mean (± standard deviation) SRE-values per muscle during movements without gravity compensation (light bars) and during movements with gravity compensation (dark bars); asterisks (*) represent significant differences (p≤0.05), asterisk in brackets represents p≤0.10

A. Muscle activity

The findings concerning the reduction in muscle activity are in line with the findings of previous studies, showing that muscle activity decreased in most muscles (except TRI) of both healthy elderly [10] and stroke patients [11] during repeated reach and retrieval movements of a predefined amplitude. In the present study, applying maximal reaching movements instead of a predefined, sub-maximal reaching distance, gravity compensation also reduced the generated amount of muscle activity in anti-gravity muscles, even though elbow extension increased. Moreover, the increase in maximal reaching distance did not correspond with an increase of TRI activity. Instead, even TRI activity slightly decreased. This indicates that gravity compensation reduced the requirements for muscle activity to hold the arm in a certain orientation with respect to gravity, but did not affect the activity needed for the desired movement in these stroke patients. This may be an indication that with gravity compensation a higher selectivity of muscle activation is possible.

B. Range of motion

The increases in elbow extension and in maximal reaching distance of the hand are in line with findings of Beer et al., who reported an increased range of elbow extension with arm support during two-dimensional movements, when compared to unsupported movements [7]. They related this increased range of motion to a reduction of the strength of an abnormal coupling that occurred between shoulder abduction and elbow flexion during unsupported movements [16]. In addition, the occurrence of this abnormal coupling was found to be dependent on the magnitude of generated torques, such that when a larger shoulder abduction torque was generated, less elbow extension could be achieved [17]. During movements with gravity compensation, less shoulder abduction was required, leading to a less strong coupling with elbow flexion. Consequently a larger elbow extension was enabled during movements with gravity compensation.

The increase in reaching distance reported by Beer et al. [7] was much larger than we found in the present study. However, in the present study, patients had a better arm function than patients in the study of Beer et al. as indicated by the Fugl-Meyer score. A patient with a better arm function experiences less limitations in movement (e.g., by a less strong abnormal coupling) and would benefit less from gravity compensation. But even in this group of patients with relatively good arm function, maximal reaching distance increased with gravity compensation.

C. Implications

The present findings imply that gravity compensation may facilitate arm movements, by reducing the need to generate postural activity to hold the arm in a certain orientation with respect to gravity. Furthermore, gravity compensation may have the ability to reduce the abnormal coupling between shoulder abduction and elbow flexion, decreasing the limitations in arm movements that may exist without arm support and increasing the selectivity of movement.

This means that gravity compensation may have the ability to enable an earlier start of arm training than would be possible without gravity compensation. In addition, it enables practicing of arm movements in more frequent or longer sessions. These implications will then result in an increased training intensity, which is beneficial for restoration of arm function during post-stroke rehabilitation [2,18].

In addition, the present findings enhance the understanding of the explicit effect of gravity compensation, or arm support, on muscle activity and movements of stroke patients. When arm support is used during post-stroke rehabilitation, either in conventional approaches or in new applications such as robot-aided therapy, this alone may influence the movement and the corresponding muscle activation pattern.

Taken together, this study implies that gravity compensation would be a valuable modality to incorporate in post-stroke arm rehabilitation.

D. Conclusions

Comparison of movement execution and muscle activity during maximal reaching movements with and without gravity compensation of stroke patients, showed that with gravity compensation maximal reaching distance increased by almost 5 cm, due to an increase in excursion of elbow extension. Simultaneously, the level of muscle activity decreased in BIC, DA, DM and TRA, and in DP to a lesser extent, during movements with gravity compensation. In addition, the increase in maximal reaching distance did not correspond with an increase in TRI activity.

These findings suggest that gravity compensation reduced the requirements for muscle activity to hold the arm in a certain orientation with respect to gravity during reaching movements, but did not affect the ability to generate activity needed for the desired movement in these stroke patients. Thus, gravity compensation may facilitate active arm movements by reducing the required muscle activity to maintain a particular arm orientation, which allows commencing training of active movements at an early stage and training of those movements at a high intensity.

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