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FACULTEIT GENEESKUNDE EN LEVENSWETENSCHAPPEN
master in de revalidatiewetenschappen en de kinesitherapie

Masterproef

Scapular muscle timing and three-dimensional kinematics in stroke patients during anteflexion tasks

Promotor :
dr. Sara VAN DEUN

Copromotor :
dr. Liesbet DE BAETS

Michiel Reynders , Jérémy Vanderhoeven

Scriptie ingediend tot het behalen van de graad van master in de revalidatiewetenschappen en de kinesitherapie

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Acknowledgement

Situated in our second master of science of rehabilitation and kinesitherapy at the University of Hasselt, we were instructed to write a scientific article concerning shoulder muscle activity in stroke patients. First of all we like to thank the University of Hasselt for the education and possibility to write this article. Secondly, we like to thank our promotor, dr. Sara Van Deun, for the guidance of our literature search in our first master year. We also like to thank our co-promotor, dr. Liesbet De Baets, for helping with the collection of data and the guidance in writing this article. The collection of this data wouldn't have been possible without the infrastructure of the University Hospital Leuven, Campus Pellenberg. Lastly, we like to thank our family and friends for the support they've provided during the writing of this article.

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Research context

This study discusses shoulder kinematics and muscle activity of different muscles around the shoulder during anteflexion tasks in stroke patients. The study is situated in the domain of neurological rehabilitation and is a part of the doctoral project of Liesbet De Baets. The title of this study is: scapular muscle timing and three-dimensional kinematics in stroke patients during anteflexion tasks. The measurements were performed at the University Hospital Leuven, Campus Pellenberg. The promotor of this thesis is Prof. Dr. S. Van Deun.

The elevation movement of the arm is a very complex movement that takes place at four different joints: the sternoclavicular joint, the acromioclavicular joint, the scapulathoracic joint and the glenohumeral joint. The sternoclavicular and the acromioclavicular joint have to function properly to assure correct and sufficient movement at the scapulothoracic joint. When the function of these four joints is optimal, the shoulder can move freely and without pain. This optimal function can only be achieved through correct muscle activation patterns around the shoulder complex. These muscles have to contract and relax at the right time and function as one synchronized unit.

Stroke patients often suffers from pain and a limited function of the shoulder joint. Stroke is caused by a blockage of blood flow or a rupture of an important artery to the brain and results in damage to a certain part of the brain. Hemiparesis, muscle weakness and altered muscle tone at one side of the body, is the most common symptom and affects both the upper and lower limbs. This can also mean that the normal muscle synergies are altered and that the muscles contract in a different order compared to healthy people. Because of this, tasks of daily living become difficult to execute and often painful.

When looking at current evidence on shoulder function in stroke, we found that there was a lack of evidence regarding the role of the scapulothoracic joint in this population. That is why this study aims to map the anteflexion movements by studying the muscle activity around the shoulder by EMG and the scapular movements by 3D kinematics.

The research question we chose for our study is the following: “Is there a difference in muscle activation patterns and joint angles at the scapulothoracic joint between stroke patients and healthy control subjects during a low and a high anteflexion task?”

This study aims to be an added value to the rehabilitation of stroke patients. We chose a case series as format and the research question was chosen by both students and approved by the promotors.

Abstract

Background This study is situated in the domain of neurological rehabilitation and aims to gain insight in muscle activity of the shoulder and scapular movement in patients with hemiparesis after stroke.

Aim To compare muscle onset and offset of different shoulder muscles (upper trapezius, lower trapezius, infraspinatus, serrratus anterior and anterior deltoideus) and scapular movements (protraction, retraction, lateral rotation, medial rotation, anterior tilting and posterior tilting) between stroke patients and healthy subjects during anteflexion tasks.

Method The participants were eighteen stroke patients and fifteen healthy control subjects. Electromyographical data of the upper trapezius, lower trapezius, infraspinatus, serrratus anterior and anterior deltoideus were collected during a high (90°) and low (45°) anteflexion task using surface EMG. The relative differences in onset and offset time between each muscle were calculated and the sequencing was also determined. Moreover, 3D kinematics of the scapular joint were measured and the differences in protraction, retraction, lateral rotation, medial rotation, anterior tilting and posterior tilting were compared between stroke patients and healthy subjects.

Results Significant differences were found in EMG for low anteflexion tasks, namely a later onset and earlier offset of the serratus anterior, an earlier onset of the lower trapezius and a later offset of the infraspinatus. Regarding the 3D kinematics, more laterorotation and less posterior tilting was visible during the high tasks.

Conclusion The time the serratus anterior muscle is active is shorter in stroke patients what leads to less stability while performing low anteflexion tasks.

Keywords Shoulder joint, Electromyography, 3D Kinematics, Scapula, Stroke, hemiparesis

Introduction

The World Health Organization describes stroke as: “rapidly developing clinical signs of focal (or global) disturbance of cerebral function, with symptoms lasting 24 hours or longer or leading to death, with no apparent cause other than of vascular origin” (Truelsen T., Begg S., Mathers C., 2000). Besides the risk factors age and gender, which are non-modifiable, there are a lot of modifiable risk factors such as high blood pressure, smoking, diet, alcohol consumption and physical inactivity (Marmot MG et al. 1992). Besides countless prevention programs, stroke remains the second leading cause of death above 60 years of age (Mendis S., Puska P., Norrving N., 2011). Of those people, 29 percent dies within five years post stroke (De Wit L et al., 2012). When we look at Belgian statistics, the number of stroke patients is 185 per 100.000 inhabitants. Up to 47 percent of the stroke patients in Belgium dies within twelve months, which brings the mortality rate up to 88 inhabitants per 100.000 (Devroey D et al., 2003). Stroke has a large impact on the patient and the people close to him or her, like family and friends. Stroke adversely affects activities of daily living because survivors are often deconditioned and are more sedentary than their healthy equivalents.

Hemiparesis is a common consequence of stroke and affects approximately 85 percent of stroke patients (Sterr A. et al., 2014). It is a weakness of the muscles on one side of the body and affects both the upper and lower body. People with hemiparesis generally have trouble initiating a movement and keeping that movement under control. (O’Sullivan, Schmitz, Physical Rehabilitation fifth edition, chapter …, 2007). Specifically towards the upper limb and shoulder, this hemiparesis has a large impact on the upper extremity function. Lang et al., 2007 stated that people with stroke and hemiparesis used their affected and unaffected upper extremities 3.3 to 6 hours a day, while their healthy equivalents used their upper extremities eight to nine hours a day. The shoulder is a stable base that controls and guides all movements of the arm and when compromised, it becomes difficult to execute reaching movements necessary in activities of daily living (Galloway et al., 2002). Because of this, quality of life will eventually be seriously affected (Massie L., Malcolm P., Greene D., Browning R., 2012).

Furthermore shoulder pain appears to be one of the most common complications after stroke: one third of stroke patients suffer from shoulder pain (Adey-Wakeling et al., 2015). There are several risk factors that can predict shoulder pain: (1) less functionality, (2) biomechanical factors (more depression and retraction of the scapula) due to (3) spasticity and contractures.

Assessment of the shoulder joint is thus crucial in stroke patients. A correct shoulder function relies on a proper interaction between the glenohumeral and scapulothoracic joint and enables persons to perform shoulder movements (e.g. abduction, anteflexion) in a proper way. People need the glenohumeral muscles and the scapulothoracic muscles to function properly. Important glenohumeral muscles are the “rotator cuff” muscles: subscapularis, supraspinatus, infraspinatus and teres minor. They make sure the humeral head is stabilized in its socket. Scapulothoracic muscles necessary to perform shoulder movement with correct control are the upper and lower part of the trapezius muscle and the serratus anterior muscle. These muscles are the primary upward rotation muscles of the scapula. Upward rotation is an essential component of the elevation of the arm (Neumann p 156 Chapter 5). When functioning in a correct way, these muscles perform the “dynamic” control of the shoulder, while the “static” control is maintained by the ligaments and bony structures (Yang et al., 2010). It is not only necessary for these muscles to be able to contract strongly, but also to contract in time and in the best possible sequencing. The timing and the sequencing of muscle activation is different in stroke patients. De Baets et al. studied the time of muscular on- and offset of the stabilizing musculature relative to the time of muscular on- and offset of the anterior deltoideus (prime mover of anteflexion). A significantly earlier onset of serratus anterior muscle in stroke patients was observed.

A normal kinematic sequence of the scapula in healthy subjects lifting the arm to 180° of glenohumeral elevation consists of upward rotation, posterior tilt, retraction, external rotation and scapuloclavicular elevation (Ludewig et al., 2009). The scapulohumeral rhythm occurs at a ratio of 2:1, which means that for 180° of abduction, 120° occur at the glenohumeral joint and 60° occur by the scapula rotating upwards. (Neumann p146, 2010 Chapter 5). Meskers et al. showed a diminished scapular protraction during humeral elevation in the sagittal plane in patients with shoulder pain. These patients are also more likely to have more lateral rotation of the scapula according to Niessen. et al..

Currently there is not much information regarding shoulder function in stroke patients. No studies exist today that investigate shoulder function using EMG and 3D kinematics combined. It is useful combining these two methods of measurement to achieve a more complete understanding of the shoulder function of stroke patients compared to healthy control subjects. Therefore the aim of this study is to investigate scapular kinematics, sequence of muscle timing and synchronized muscle timing around the shoulder post-stroke and to compare these data with healthy control subjects. In this way, we hope to contribute to the rehabilitation of stroke patients.

Method

Participants

The patients that participated in this study were all recruited from various rehabilitation centers in Belgium. Patients had to meet the following criteria to be included in this study: (1) be older than eighteen years of age and (2) at least six weeks post stroke (first stroke); (3) suffer from hemiparesis; (4) understand instructions and perform the requested movements; (5) be able to lift the arm to 45° of anteflexion (measured with goniometer). The healthy control subjects were recruited to match in age and gender to the stroke patients. Exclusion criteria that were applied to all subjects who took part in the study were: (1) other diseases of the shoulder girdle that may influence the lifting of the arm; (2) other diseases that limit the sight of patients; (3) not being able to sit up straight on a chair without arm support; (4) Allergic reactions to surface EMG. After applying these criteria, eighteen stroke patients remained eligible for participation in the study and were compared to fifteen healthy control subjects (Table 1).

Table 1. Participant's characteristics

	Healthy controls	Stroke patients
Subjects	15	18
Male/female	8/7	13/5
Age (years)	51 SD 13,13	51 SD 13,73
Body mass Index	24 SD 2,14	24 SD 2,08
Dominant side (left/right)	14/1	18/0
Time since stroke (weeks)	/	15,62
Hemiplegic side (left/right)	/	9/9
Fugl-Meyer score (max 66)	/	56,44

Medical ethics

In advance of the study we requested permission from the patients and asked them to sign informed consent in which they agree to the terms and conditions of the study. The study was approved by the ethical committee of the University Hospitals Leuven.

Procedure

The electromyographical data were collected at the hemiplegic side in stroke patients and the dominant side in healthy control subjects using the Aurion AMG system. The sensors were placed at the following muscles: anterior deltoideus (2-4 cm below the lateral clavicula, parallel to the muscle fibers), upper trapezius (midpoint of the line between angulus acromialis and processus spinosus C7), lower trapezius (at one-third of the line between trigonum scapula and processus spinosus T8), infraspinatus (approximately 4 cm below the spina, over the infrascapular fossa, parallel to the scapular spine) and serratus anterior (anterior to the latissimus dorsi at the level of the scapular inferior angle). To make sure the placement of the sensors was uniform for all patients, they were applied by the same researcher. The skin was cleaned and prepared with alcohol. Muscle activity was recorded with a sampling rate of 2000 Hz. To ensure the electromyographic sensors were placed correctly and the quality of the signal was sufficient, the participant performed muscle specific movements that were checked visually by the researchers.

3D kinematic data were recorded using fifteen infrared cameras sampling at 100 Hz (Vicon, Oxford metrics, UK) and filtered with spline-interpolation. The markers were applied bilaterally at the sternum, acromion, and upper arm in clusters of three or four markers (Figure 1). Anatomical landmarks were digitized during static trials, using a pointer with four linear markers. Those landmarks were defined within their respective segmental marker cluster (CAST-procedure) (Cappozzo et al. 1995), and afterwards used to construct anatomical coordinate systems and calculate joint kinematics. To make sure the palpation of all landmarks was correct we followed specific palpation guidelines (van Sint Jan 2007). The movements of interest were protraction/retraction, lateral rotation/medial rotation and anterior/posterior tilt (Figure 2).

Figure 1. Marker placement

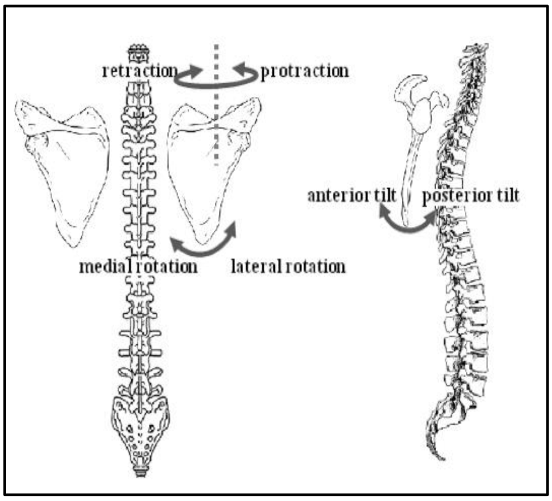

Figure 2. Overview of scapular movements (De Baets et al., 2014)

All of the measurements were performed at the Clinical Motion Analysis Laboratory of the University Hospital Pellenberg. The following measurement procedure was used. The patients sat down on a chair without arm support, but with low back support, while making anteflexion movements from 0-60° (low task) and 0-120° (high task). The reaching height was measured using a goniometer and was clearly indicated to the patient. There was a researcher next to the patient who corrected and gave instructions when necessary. The patient performed each movement while muscle activity was measured as well as 3D kinematics using the protocols described above. Both tasks were performed actively and repeated eight times each. The pace of task execution was set for both tasks to ensure a proper pace and correct performance. The low task was performed as follows: one second lifting the arm, one second lowering the arm and three seconds rest. The high task was performed differently: three seconds lifting the arm, three seconds lowering the arm and three seconds rest between repetitions. All patients were allowed to perform some practice trials.

Data analysis

Raw EMG data were first high-pass filtered with a sixth-order Butterworth filter of 20 Hz to avoid movement and cardiac artifacts. The onset and the offset of muscle activity were the parameters of interest in this study and were determined using the staude method. The onset as well as the offset of each muscle was defined and was compared to the beginning of the performed movement. These data were shown as a percentage of total movement time (a negative value meant there was activity before the movement started). A second parameter of interest was the sequencing of muscle activation, based on the average per group.

For the kinematic data, the range of the scapular movement (ROM) was the parameter of interest. ROM was defined as the absolute difference between highest and lowest recorded joint angle per movement cycle. Only the middle six repetitions were used for the analysis of the data. The start of the movement and the highest arm position were used to define a movement cycle. Data was further processed with Matlab and ULEMA.

Statistical analysis

A 2 (group) x 2 (height) x 5 (muscle) Mixed Model (Litell et al., 2002) was used to analyze differences in onset and offset timing between groups (stroke patients and healthy control subjects), anteflexion heights (45° and 90°), and muscles (infraspinatus, upper trapezius, serratus anterior, lower trapezius and anterior deltoideus). The Mixed Model design was used because of the robustness in analyzing semi-normally distributed data (Verbeke and Lesaffre, 1997) and allows for repeated measures analysis and can handle missing data. These statistics were all done using SAS software version 9.4 Foundation and Enterprise guide.

The 3D kinematic data was processed using an unpaired t-test. This test was used to compare the differences in ROM angles between stroke patients and healthy control subjects. These statistics were processed using IBM SPSS statistics data editor.

Results

Onset/Offset

During low anteflexion tasks (45°), a significant main effect for muscle ($p<0.0001$) and a significant interaction effect for group*muscle (onset $p=0.0015$; offset $p=0.006$) was found. When performing the low anteflexion task, the serratus anterior had a significantly later onset in stroke patients compared to healthy control subjects ($p=0.012$). The lower trapezius had a significantly earlier onset in stroke patients compared to healthy control subjects during the low anteflexion task ($p=0.017$). The offset of the serratus anterior was also significantly earlier in stroke patients compared to healthy control subjects during the low anteflexion task ($p=0.02$). The infraspinatus showed a significantly later offset during the low anteflexion task in stroke patients compared to healthy control subjects ($p=0.012$). For onset and offset timing during high anteflexion tasks, only a significant main effect for muscle ($p<0.0001$) was observed. All these results can be found in figure 3 and 4.

Sequencing

In stroke patients during the low anteflexion task, first the upper trapezius, anterior deltoideus and infraspinatus were active, followed by the lower trapezius and the serratus anterior. The lower trapezius and the serratus anterior were the first muscles that were inactive, followed by the upper trapezius, anterior deltoideus and infraspinatus. In healthy control subjects during the low anteflexion task first the upper trapezius, serratus anterior, anterior deltoideus and infraspinatus were active followed by the lower trapezius. In these healthy control subjects, first the lower trapezius and the infraspinatus became inactive, followed by the upper trapezius, anterior deltoideus and the serratus anterior.

During the high anteflexion task in stroke patients, first the upper trapezius, anterior deltoideus and infraspinatus were active, followed by the lower trapezius and the serratus anterior. The lower trapezius and serratus anterior became inactive first, followed by the infraspinatus, anterior deltoideus and upper trapezius. The sequencing was the same for the low and the high anteflexion task in stroke patients. In healthy control subjects, the sequencing differed between both tasks. During the high anteflexion task, first the infraspinatus, upper trapezius and the anterior deltoideus were active, followed by the lower trapezius and the serratus anterior. The first muscles that became inactive were the serratus anterior and the lower trapezius, followed by the upper trapezius, infraspinatus and anterior deltoideus.

3D Kinematics scapula

During the low task there was no significant difference between stroke patients and healthy control subjects in ROM of the scapula for elevation and lowering of the arm.

During the high task there was a significant difference in tilting of the scapula between stroke patients and healthy control subjects for elevation of the arm ($p=0.49$). There was significantly less posterior tilting in stroke patients compared to healthy control subjects. There was also a significant difference between stroke patients and healthy control subjects for rotation of the scapula during lowering of the arm (p=0.008). There was more laterorotation in stroke patients compared to healthy control subjects.

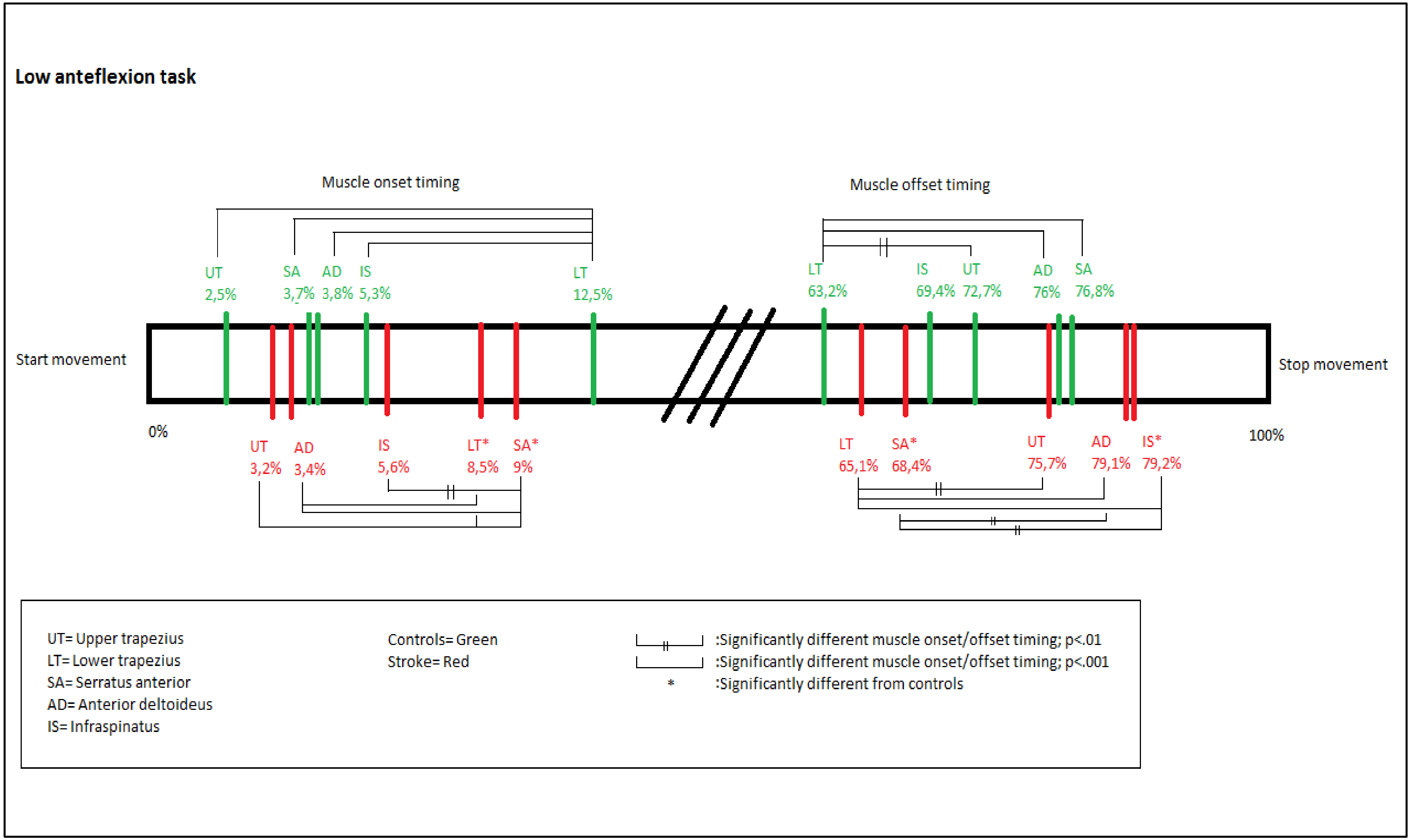

Figure 3. Low anteflexion task onset/offset timing

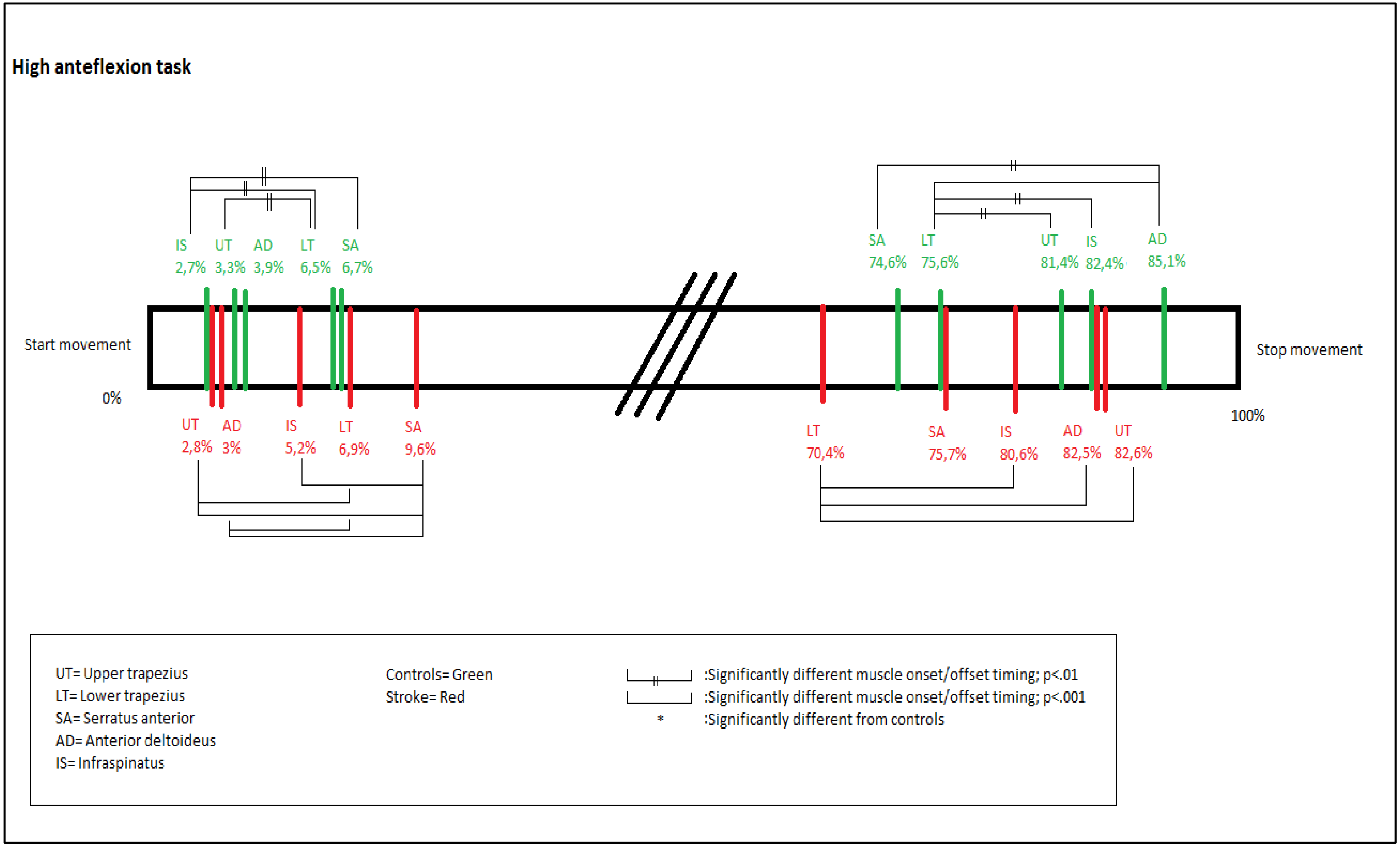

Figure 4. High anteflexion task onset/offset timing

Discussion

A good coordination between the proximal stabilizers (serratus anterior and upper and lower trapezius) and the distal movers (anterior deltoideus and infraspinatus) is needed to correctly and efficiently move in the shoulder joint (Neumann, 2010). To perform a correct elevation in the glenohumeral joint, the scapula has to be stabilized against the thorax by the serratus anterior and the trapezius muscle to ensure a correct performance. The anterior deltoideus is the most important mover in the anteflexion of the arm. The force of the anterior deltoideus is matched by a counterforce of the infraspinatus, that makes sure the humeral head is stabilized in the glenoid fossa. Since hemiparesis can weaken or change the function of one or more of these muscles, it is useful to investigate the impact these changes have and how this differs compared to healthy test subjects. The many different functions and tasks the shoulder has to perform in daily life make it impossible to test and list all these movements. The scapula has to be able to adapt to the movement that is being executed. This means the main function of the scapula during low elevation tasks is providing a good setting, while during high elevation tasks the scapula has to move synchronized to the other joints of the shoulder to be able to execute the movement. Because of the different functions the scapula has to fulfil, the muscle activity is often very different. This is why a low elevation task as well as a high elevation task was chosen. The anteflexion movement of the shoulder was chosen since this is a movement that is utilized a lot in daily activities. Ludwig et al. states that the anteflexion movement is similar to the abduction movement regarding scapular kinematics.

Looking at the low elevation task (45°), there is a significant difference in EMG results between stroke patients and healthy control subjects. During this low task, there is no significant difference in 3D kinematics. During the high elevation task (90°) there was a significant difference noticeable in 3D kinematics, but not in EMG results. When performing the high elevation task, 3D kinematics are significantly different between stroke patients and healthy control subjects concerning laterorotation and posterior tilting of the scapula. The reason this difference is noticeable during the high anteflexion task but not during the low anteflexion task can be due to passive structures like adhesions or stiffness of the capsule or due to shortened muscles. These alterations might move the scapula passively into more laterorotation and less to posterior tilt. A possible explanation for the fact that there is no significant difference in 3D kinematics during the low task is that there are less passive structures that can change the course of movement of the scapula due to the small range of motion.

Regarding the muscle activation, it is striking that the serratus anterior has a significantly later onset time and a significantly earlier offset time in stroke patients during the low anteflexion task. This results in a shorter active period of this muscle. Being an important stabilizing muscle, this means there is less stability of the scapula in stroke patients during low anteflexion tasks. The fact that there are differences in EMG timing can be explained by the low movement with a limited ROM that the patient has to perform. Subconsciously the patient provides less muscle activation for this smaller movement, while during the high anteflexion task more muscle activation is provided to be able to complete the movement.

This study showed a few limitations. The possibility to lift the arm at least 45° was an inclusion criteria that lead to the exclusion of stroke patients who could not lift their arm this high. Therefore the results cannot be generalized to the whole stroke population. It was not taken into account what kind of stroke the subjects had been through and the area of the brain that had been affected. This could affect the results in multiple ways because the effects of stroke can be very different for various parts of the brain. Some patients may experience a weakness of the muscles and others can experience a loss of coordination, what as one can imagine has a large impact on the muscle activity. Also other impairments following stroke (impaired vision, difficulties understanding speech,…) can make stroke patients perform differently during anteflexion tasks. Lastly, the usage of surface EMG has led to some missing data because of the sensitivity of this technique to signal noise by motion or cardiac artifacts. The technique of surface EMG was chosen because this is the golden standard for measuring muscle activity of superficial muscles and has a high reliability (Meskers et al., 2014). Other techniques, such as needle EMG, are invasive and less opportune to use in this study.

Recommendations for future studies include implementing real reaching tasks that represent daily movements even more than elevation in one plane. This would definitely mean an addition to the rehabilitation of stroke patients. A future study should also be performed on stroke patients during the acute stage because there are no compensation mechanisms visible yet.

By providing more insight in the function of different shoulder muscles and the relation to the kinematics of the scapula, this study provides an addition to the rehabilitation of shoulder problems in stroke patients. Like stated in this study the scapula has an important function in stabilizing the scapula during low anteflexion tasks. Often the importance of the scapula is overlooked during the rehabilitation of stroke patients. Low anteflexion tasks are useful for training stroke patients to efficiently activate their muscles and to correctly stabilize their scapula. The therapists should be careful while advancing to higher reaching tasks and should only perform these tasks once a good control of scapular setting is achieved during lower tasks.

Conclusion

This study shows that there are differences between stroke patients and healthy control subjects during anteflexion tasks in muscle activation patterns and 3D kinematics. The electromyographical data of the serratus anterior show a later onset and an earlier offset timing in stroke patients, which results in a shorter working period of this muscle and less stability while elevating the arm. Differences in 3D kinematics of the high elevation task can be due to adhesions of the capsule or shortened muscles that cause the scapula to move passively.

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Auteursrechtelijke overeenkomst

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Richting: **master in de revalidatiewetenschappen en de kinesitherapie-revalidatiewetenschappen en kinesitherapie bij musculoskeletale aandoeningen**
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Voor akkoord,

Reynders, Michiel **Vanderhoeven, Jérémy**