The effect of Scapular Assistance on the scapular muscle timing and three-dimensional kinematics during a low and high elevation task in stroke patients compared to healthy controls

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Research context

The shoulder is one of the main dysfunctions and causes of pain in stroke patients. Due to a diminished neural stimulation of the shoulder muscles, an altered timing and coordination of the stabilizing muscles and rotator cuff emerges. This imbalance creates a lack in scapulothoracic stabilization, what could be a cause of shoulder pain.

This study aims to improve the rehabilitation of scapular muscle imbalance and prevention of shoulder pain after stroke. It is oriented in the musculoskeletal rehabilitation, but in addition the neurological part of post stroke shoulder pain needs to be considered to achieve an overall view.

This master project has the purpose to investigate the effect of manual scapula assistance during elevation tasks on the muscle timing and shoulder kinematics in stroke patients and healthy controls, compared with an unassisted elevation. Therefore, several healthy controls and stroke patients will be recruited to participate in this study. With standardized protocols in both EMG and 3D kinematics, a low and high elevation task will be performed.

It is written by two master students (Andrea Biesmans and Marijn Vanbuel) in the context of graduation for a master degree in 'rehabilitation sciences and physiotherapy' at the University of Hasselt, Belgium. It is a part of the doctoral project of co-promotor dr. L. De Baets, titled: "Movement and muscle activation patterns of the shoulder girdle after stroke".

Co-promotor L. De Baets recruited the participants and performed the standardized placement and movement procedure to ensure reliable measurements. Major part of data analysis and interpretation of results was executed by both students. Co-promotor L. De Baets helped with the statistical analysis of the results.

The distribution of the writing parts was as follows: research context, abstract and methods was executed by Andrea Biesmans while results, reference list and creating of the tables were performed by Marijn Vanbuel. The other parts, introduction and discussion, was done by the both of us.

Abstract

Objective: To determine the effect of Scapular Assistance (SA) on scapulothoracic movements during elevation tasks in stroke patients and in healthy controls.

Design: Cross-sectional study

Setting: The study included stroke patients from a rehabilitation center located in Belgium and healthy controls.

Patients: Fifteen stroke patients without shoulder pain were included if they were at least 6 weeks after a first time stroke, had mild to moderate upper limb motor impairment and were able to perform 45° of active humerothoracic anteflexion. Twelve healthy controls were also included.

Interventions: Both groups performed a SA and unassisted arm elevation task from 0° to 45° and 0° to 90° anteflexion with their dominant (controls) / hemiplegic (stroke patients) arm.

Main outcome measures: A 3D kinematic protocol was used to calculate scapular rotations at 45° and 90° of anteflexion. Scapular rotations were described through three rotations (protraction/ laterorotation/tilting). The muscle timing (onset/offset) of the upper trapezius, lower trapezius and serratus anterior, relative to the muscle timing of the prime mover for anteflexion, anterior deltoid, was simultaneously measured by surface electromyography (sEMG).

Results: No significant differences were found in muscle timing between the assisted and unassisted condition. Both controls and stroke patients showed significantly ($p<.001$) less protraction and more posterior tilt at 45° of anteflexion in the SA condition.

Conclusion: SA has no effect on the muscle activation during a low or high elevation task. Tactile feedback results in less protraction and anterior tilt during a low anteflexion in the scapulothoracic joint, but does not stimulate active support of the stabilizing scapulothoracic muscles.

Introduction

Stroke is an important cause of health costs and impairment in the world because it creates a high number of victims each year with additional costs for each of them.[1] Most stroke patients (up to 75%) regain the possibility to walk, but regaining function in the affected upper limb is more difficult.[2] Approximately 30% of the victims develop shoulder pain within the first year after stroke[3], due to muscle weakness and paralysis, spasticity and/or decreased sensation and proprioception.[4-9] Hemiplegic patients have a limited range of rotation in scapula, resulting in movement that is responsible for impingement.[10] *Lang, C.E. et al. (2007)* concluded that the activity of the upper limb in hemiplegic stroke patients was significant reduced, i.e. 3,3 to 6 hours a day in stroke patients in comparison to 8 to 9 hours in controls. The hemiplegic upper limb is thus significantly less used than the non-hemiplegic side.[11] In order to preserve functionality, an independent synergic movement of the arm is crucial.[12]

The scapula, as a stable base for rotator cuff muscles and as a strong link in the kinetic chain of the upper limb, plays an important role in the movement of arm and shoulder.[13] A diminished neural drive as a result of stroke can cause an alteration in activation and timing of the scapulothoracic and rotator cuff muscles[14], with a disturbed scapulohumeral movement as a result.[15] *Rundquist, P.J. et al. (2012)* also reported that stroke patients had an overall altered ratio of glenohumeral elevation and scapular upward rotation. *Niessen, M. et al. (2008)* furthermore concluded that there was a significant increase in lateral rotation (+10°) on the hemiplegic side of stroke patients compared to a control group. No significant differences were found in the pattern of tilting and protraction/retraction.[7] When performing a reaching task, stroke patients had a significant difference in timing (triceps, anterior deltoid, upper/ middle trapezius and pectoralis major) and/or amplitude (biceps, lower/middle trapezius and pectoralis major) of peak activity.[16] An analysis of muscle recruitment patterns by *De Baets L, et al. (2014)* indicated moreover that stroke patients without pain had an earlier and prolonged activity of the infraspinatus, and earlier activity in the lower trapezius than stroke patients with shoulder pain. Stroke patients with pain had a delayed activity and an earlier inactivity of the serratus anterior, which is an important stabilizer of the scapula.[17] *Kibler, W.B., Sciascia, A. & Wilkes, T. (2012)* concluded that in healthy subjects, the recovery of scapular force couples could lead to a better scapular position and movement. This could lead to diminished chance for acromial impingement, a common shoulder injury/disorder/dysfunction.

Results of previous studies demonstrate altered scapular distribution to shoulder movement in stroke patients what can lead to shoulder pain. It is therefore important that rehabilitation is not only focused on movement of the glenohumeral joint, but also has attention for the abnormalities in the scapulothoracic joint.[1]

Up to now, no research investigated the effect of providing manual scapular assistance (SA) on the scapulothoracic movement patterns and muscle timing during therapy for upper limb function in stroke patients. It might be of interest to investigate whether providing SA can stimulate the serratus anterior/lower trapezius force couple and ameliorate as such scapular movement patterns during stroke patients' arm movements.[19,20]

The aim of this paper is therefore to investigate the effect of assistance and manual guidance provided at the level of the scapula during arm movement on the muscle timing of important scapulothoracic stabilizing musculature and on scapular kinematics in stroke patients with moderate shoulder dysfunction. Results of this paper will have added value for the rehabilitation and prevention of shoulder dysfunction in stroke patients.

Materials and methods

Participants

The stroke group was recruited at the University Hospital Pellenberg, Belgium. They received standard care and physiotherapy according to their special needs. The group of healthy controls, without self-reported shoulder pain, was recruited through family and relatives.
The Ethical Committee of the University Hospital Leuven approved the study and all participants read and signed an informed consent prior to participation.

Stroke patients had the following inclusion criteria: (1) at least 6 week after a first time stroke (cortical or subcortical lesion); (2) mild to moderate upper limb motor impairment (score of at least 30 on the Fugl-Meyer upper limb motor part[21]; and (3) able to perform 45° of active humerothoracic anteflexion (measured with goniometry). Patients were excluded according to following exclusion criteria: (1) body mass index higher than 28; (2) inability to understand the instructions; (3) known history of shoulder and/ or neck pain or discomfort in the last six months prior to stroke; (4) an event of shoulder dislocation, fracture or surgery during lifetime; or (5) other systemic and/-or neurologic diseases. *Table 1* shows the participant's characteristics and differences between healthy controls and stroke patients.

Table 1: Participants' characteristics

	Healthy controls	Stroke patients
Subjects	12	15
Gender (male/female)	7/5	10/5
Mean age (years)	51	51
Mean height (m)	1,74	1,76
Mean weight (kg)	72	73
Body mass index	24	23
Dominant side (left/right)	1/11	0/15
Hemiplegic side (left/right)	/	8/7
Time since stroke (weeks)	/	15
Fugl-Meyer score (max 66)	/	56

Measurement procedure

3D kinematic

With 15 infrared cameras sampling at 100 Hz (Vicon, Oxford Metrics, UK), the 3D kinematic data of the three scapular rotations, i.e. protraction/retraction, medial/lateral rotation, anterior/posterior tilting *(fig. 1)*, was captured and filtered with spline-interpolation.[22] On the sternum, scapula (flat part of the acromion) and upper arm (proximal, lateral) clusters of three or four markers were placed. A pointer with four linear markers was used to digitize anatomical landmarks during static trails. Anatomical landmarks were defined with the CAST-procedure within their respective segmental marker cluster[23] and subsequently used to construct anatomical coordinate systems and calculate joint kinematics.

Specific palpation guidelines[24] ensured correct and accurate location of all anatomical landmarks. All kinematics calculations were done according to the ISB-guidelines.[25]

The same assessor, who was trained in correctly conducting the measurement procedure and performing the anatomical palpation properly, performed the measurements. In this way a repeatable and accurate placement of the marker clusters and palpation of anatomical landmarks was ensured.

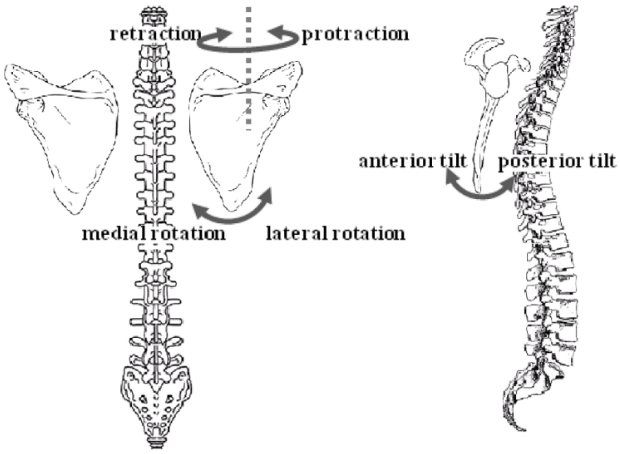

Fig. 1. Overview of the 3D scapular rotations. (doi:10.1371/journal.pone.0079046.g001)

EMG

EMG measurement was recorded using surface EMG sensors on the hemiplegic side (stroke patients) and dominant side (controls). Measured muscles were: upper trapezius (midpoint on the line between angulus acromialis and C7 processus spinosus), lower trapezius (at one-third of the line between trigonum scapula and T8 processus spinosus), serratus anterior (anterior to the latissimus dorsi at the level of the scapular inferior angle), and anterior deltoid (2-4 cm below the lateral clavicular, parallel to the muscle fibers)[26,27] *(fig. 2).* Prior to the placement of sensors, the skin over the muscle of interest was prepared and cleaned with alcohol, followed by placing the EMG-sensors according to a standardized protocol, which was performed by the same investigator for all participants. Visual inspection of the correct sensor positioning and signal quality was done during muscle specific movements. The sampling rate for recording muscle activity was 2000 Hz.

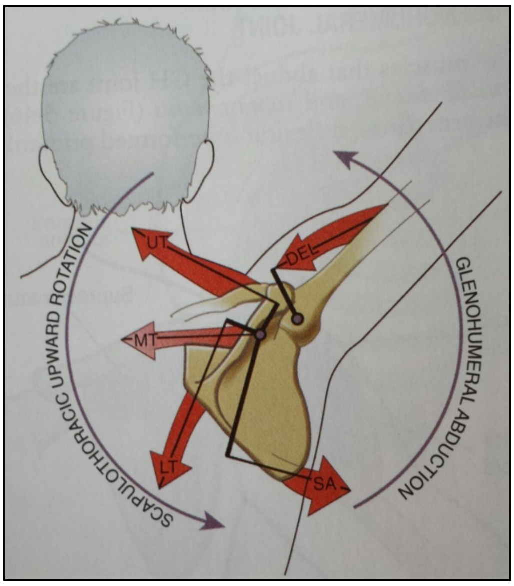

Fig. 2: Posterior view of a healthy shoulder showing the muscular interaction between the scapulothoracic laterorotators and the gleno-humeral abductors [28](from Neumann DA: kinesiology of the musculoskeletal system: foundation for rehabilitation,2nd ed., St. Louis, 2010, Mosby, Figure 5-48)

Movement protocol

The movement protocol consisted of a low (±60° of anteflexion) and high (±120° of anteflexion) seated anteflexion task. Both the stroke and the control group performed the anteflexion tasks in a SA and an unassisted condition. Each task was performed 8 times. A pole (at 60°/120° of anteflexion) was placed in front of the participant to ensure visual information about the correct anteflexion height of the task. The elbow was fully extended, with the thumb pointing upward. This start position was maintained till the end of movement. The investigator stood behind the participant during the scapular assisted anteflexions. One hand was placed on the superior aspect of the scapula while the other hand was placed on the inferior angle of the scapula with the fingers wrapped around the lateral aspect of the thorax *(fig. 3).* During the movement, the investigator facilitated lateral rotation and posterior tilting by pushing the scapula upward and laterally on the inferior angle and pulling the superior aspect of the scapula backward *(fig. 4).*

The investigator also ensured a proper pace and execution of the task by guiding the rhythm of performance (1s up, 1s down, 3s rest for low tasks; 3s up, 3s down, 4s rest for high tasks). Each participant was given some practical trails.

Fig. 3: Scapular Assistance starting position. The examiner places one hand over the superior aspect of the involved scapula. The other hand is placed over the inferior angle of the scapula.[20]

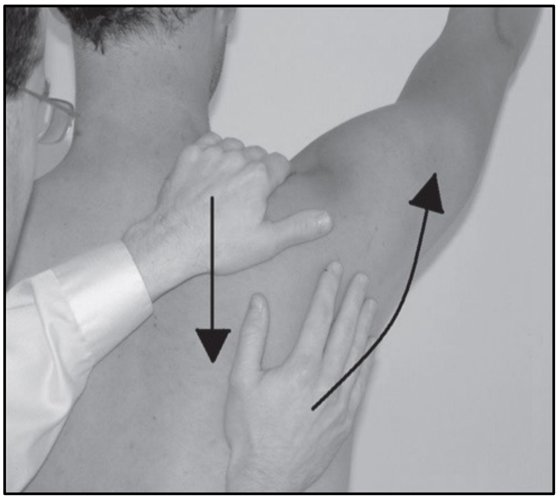

Fig. 4.: Scapular Assistance through movement. The examiner facilitates lateral rotation and posterior tilting of the scapula by pushing upward and laterally on the inferior angle of the scapula and by pulling the superior aspect of the scapula posteriorly.[20]

Data analysis

Only the middle 6 of the 8 repetitions were selected for data-analysis, as they are considered free from initiation or completion strategies.

<u>3D kinematic</u>

Movement cycles were visually defined from start to highest arm position (end of movement). Thereafter, the data was processed with Matlab®, using U.L.E.M.A. ULEMA (20. https://github.com/u0078867/ulema-ul-analyzer). Each movement cycle was time-normalized and joint angles were visualized in function of time to check for erroneous signals.

Measured parameters were the three scapular rotations (protraction/retraction, laterorotation/mediorotation and tilting) at 45° (low anteflexion task) and 90° (high anteflexion task).

EMG

A sixth–order Butterworth filter of 20 Hz was used to high-pass filter the raw data, in order to avoid movement and cardiac artifacts. Next, the data was rectified and filtered with a low-pass filter (cut-off frequency of 45 Hz) to smooth the data. Both filters were implemented as bidirectional filters to diminish the phase-error.

An increase in muscle activity of at least 2 SD on top of the mean baseline activity (as measured 10s before start of movement) for 50ms was defined as muscle onset. The offset of muscle activity was defined when the measured activity was 2 SD lower than the mean baseline activity for 50ms *(fig. 4).*[29]

The recorded onset and offset were visually screened to detect erroneous signals caused by cardiac or other movement artifacts. [30]

Timing parameters of interest were the time of muscle onset and offset of upper trapezius, lower trapezius and serratus anterior relative to respectively the time of onset and offset of the anterior deltoid (prime mover of anteflexion). Data from these timing parameters were compared between the condition with and without SA for the low and high anteflexion task. A positive onset/offset time (milliseconds) indicated an activity before m. anterior deltoid onset or inactivity before m. anterior deltoid offset *(fig. 5)*.

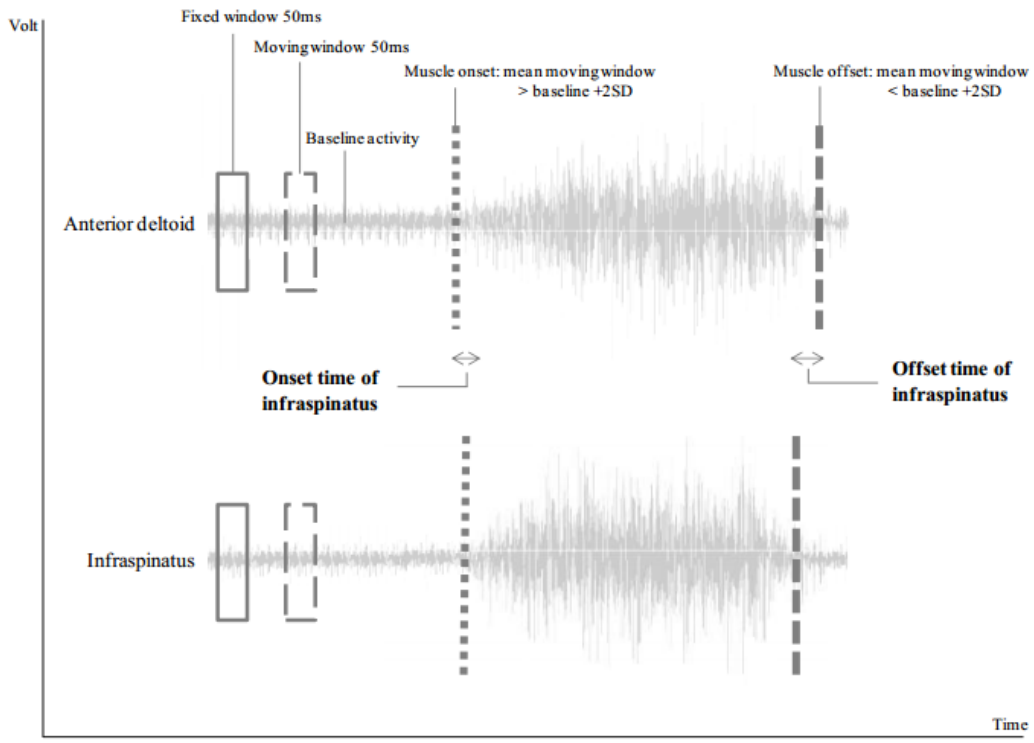

Fig. 5: This example shows an active infraspinatus after the onset of anterior deltoid, which results in a negative onset time, and an inactive infraspinatus before offset of the anterior deltoid, resulting in a positive offset time.

Statistical analysis

Repeated measures t-tests (SPSS version 2.2) compared the muscle onset time, the muscle offset time, and the three scapular rotations between the scapula assisted and the unassisted anteflexion tasks (both heights). This was done for each group separately.

Results

Tables 2a and 2b show the mean onset and offset time of the different muscles during a high and low task, in assisted and unassisted condition, for both controls *(table 2a)* and stroke patients *(table 2b)*.

Tables 3a and 3b show the mean amount of movement of the scapula during a low and high task, in assisted and unassisted condition, for both controls *(table 3a)* and stroke patients *(table 3b)*.

EMG

No significant differences were found between the assisted and unassisted condition in both groups *(table 2).* There was a tendency towards significance (p=.06) in the onset of lower trapezius for the low task and in the offset of lower trapezius for the high task in controls. In the low anteflexion task, the lower trapezius had furthermore an onset time prior to the onset of anterior deltoid and an offset after the offset of the anterior deltoid in the assisted condition. This was not the case in the unassisted position were the lower trapezius was active after the start of the anterior deltoid and inactive before the anterior deltoid. However, these differences were not significant.

Table 2: EMG analysis

A. Control group, time of muscle onset and offset relative to respectively the time of onset and offset of the anterior deltoid (ms); positive onset and offset time = activity and inactivity before anterior deltoid; *UT: upper trapezius, LT: lower trapezius; SA: serratus anterior; ON: onset; Off: offset*

		UT/ON	UT/OFF	LT/ON	LT/OFF	SA/ON	SA/OFF
45°	Unassisted	0,236	-0,256	**-0,242**	0,008	0,181	-0,15
	Assisted	0,328	-0,217	**0,084**	-0,205	0,256	-0,371
90°	Unassisted	0,125	-0,122	-0,1	**0,238**	0,044	0,041
	Assisted	0,083	-0,24	-0,14	**0,504**	0,03	0,04

Bold: p-value = .06 *(tendency to significant difference)*

B. Stroke group, time of muscle onset and offset relative to respectively the time of onset and offset of the anterior deltoid (ms); positive onset and offset time = activity and inactivity before anterior deltoid onset and offset; *UT: upper trapezius, LT: lower trapezius; SA: serratus anterior; ON: onset; Off: offset*

		UT/ON	UT/OFF	LT/ON	LT/OFF	SA/ON	SA/OFF
45°	Unassisted	0,161	-0,071	-0,048	0,316	-0,023	0,8
	Assisted	0,019	-0,1	-0,046	0,137	-0,274	0,331
90°	Unassisted	0,103	-0,187	-0,11	0,303	-0,082	0,331
	Assisted	0,187	-0,295	-0,203	0,288	-0,155	0,733

3D kinematic

Significantly (p<.001) less protraction and anterior tilt was shown in the low anteflexion task in the assisted condition in both control and stroke group. For high tasks (90°), there was no significant difference in scapular rotations between the unassisted and assisted elevation.

Table 3: 3D analysis

A. Control group, mean amount of movement in scapula (°); positive mean = protraction, mediorotation & posterior tilting; *Pro: protraction; Lat: lateral rotation; Tilt: anterior/posterior tilt*

Movement scapula / task	Pro / 45°	Pro / 90°	Lat / 45°	Lat / 90°	Tilt / 45°	Tilt / 90°
unassisted, mean	**39,03**	45,777	-9,864	-31,136	**-4,124**	2,694
assisted, mean	**36,185**	44,497	-9,531	-31,18	**2,788**	3,21

Bold: p-value <.001 *(significant difference)*

A. Stroke group, mean amount of movement in scapula (°); positive mean = protraction, mediorotation & posterior tilting; *Pro: protraction; Lat: lateral rotation; Tilt: anterior/posterior tilt*

Movement scapula / task	Pro / 45°	Pro / 90°	Lat / 45°	Lat / 90°	Tilt / 45°	Tilt / 90°
unassisted, mean	**37,584**	46,895	-8,101	-34,33	**-3,078**	-0,87
assisted group, mean	**31,198**	46,991	-8,179	-34,053	**5,889**	-0,323

Bold: p-value <.001 *(significant difference)*

Discussion

This is the first study that investigated the effect of SA on scapular kinematics and muscle timing in stroke patients during an elevation task. The influence of this tactile feedback appears to have no significant effect on the muscle timing of the force couple. However, an increase in posterior tilt and decrease in protraction during SA in the low task was seen in both groups.

A positive influence of tactile feedback on scapular stabilization muscles, i.e. earlier onset and later offset for the stabilizing muscles to form a stable base for the mobilizing muscles was expected in assisted elevation tasks. However, this hypothesis that tactile stimulation could have an activating effect of the stabilizing muscles, was rejected in this study. Even though there was significantly more retraction and posterior tilting in the assisted low anteflexion task, there was no earlier onset and later offset time of the serratus anterior in a SA condition compared to an unassisted condition, for both anteflexion tasks and in stroke patients. SA doesn't alter the muscle timing in serratus anterior in stroke patients for the low and the high anteflexion tasks. The alterations in scapular movement are thus assumed to be caused by the applied manual assistance itself, rather than by earlier and longer activation of stabilizing muscles.

Previous research on SA in healthy persons with primary shoulder pain only studied the relation to shoulder injury, like impingement or scapular dyskinesis. *Seitz A.L. et al. (2012)* collected three types of data: 3-D scapular kinematics with a 3SPACE FASTRAK electromagnetic-based motion capture system, subacromial space using ultrasound images and shoulder strength in the form of a maximum isometric force production measured with a dynamometer. He concluded that there was no effect of SA on scapular movement. *Kibler, W.B. et al. (2012)* used a clinical observation of the medial border to investigate the biomechanical effect of SA in relieving painful symptoms of impingement in an arm elevation task, and found a significant increase in posterior tilting (7-10°) during SA. However, due to a different sample population and different method, these data can't predict the outcomes of this study.

When using EMG and kinematic measurements in research, one should pay attention to maximize task standardization. This was done in this study by using a standardized protocol, which was already proven reliable in stroke patients.[31] The measurements were performed by the same experienced researcher, and the in- and exclusion criteria were based on the protocol terms of the reliability study.[31] Each participant performed eight repetitions from which only the middle six were analyzed to minimalize the influence of start and stop strategies. Practice trails and indicating the pace by the researcher excluded the influence of different velocities.

Limitations

A possible reason that we did not find significant results in EMG timing is that we included only patients with mild to moderate shoulder dysfunctions and without shoulder pain. Also, type of stroke and side of brain damage was not taken into account. *Robertson & Roch, 2012* suggested that stroke patients with left hemisphere brain damage had more upper limb movement problems, with less scapular protraction and more anterior tilting as result. Furthermore, the differences in post-stroke time, with a mean of 15 weeks and a minimum of 6 weeks and maximum of 48,3 weeks, could have influenced the results. EMG measurement is also prone to signal noise what led to some loss of data, mainly for upper trapezius and serratus anterior. Moreover, two unexperienced investigators executed the analysis of EMG data. One of them analyzed the EMG of the stroke group whilst the other analyzed the EMG of the control group. As such, the interpretation of data remained the same within each group. Finally, this study had a limited sample size.

Future research

Most likely, SA is insufficient to stimulate active support of the stabilizing scapulothoracic muscles.
Future research on the influence of SA on scapular movement should incorporate a larger sample size and should investigate the effect of SA in stroke patients with severe motor impairments and with shoulder pain, with a minimum of activation of the stabilizing shoulder muscles. Other muscles such as infraspinatus and middle trapezius can be investigated to view their reaction to the SA. More standardization is needed during the entire study, with investigators who are specialized in analyzing the EMG data and scapular kinematics. Future research could also incorporate other types of feedback to enhance a better muscle timing. Temperature stimuli or a combination of different feedback types like visual feedback and tactile feedback could be efficient, as well as a change of hand positioning in SA with special attention to latent myofascial trigger points. The latter could lead to inefficient muscle recruitment, changes in muscle activation and muscle patterns in scapular abduction.[34] Also, a startling acoustic stimuli before a reaction time task will lead to a diminished latency time in the sternocleidomastoideus.[35] Reflexive startle activation thus can lead to a triggering of muscle activation and could be of interest for future studies. Furthermore, *Matthew A. Edwardson (2015)* concluded that ballistic muscle activity in combination with transcranial magnetic stimulation leads to corticospinal excitability, as in a change of motor evoked potential. This could be of interest as the goal of this study was to enhance the muscle timing of the stabilizing scapulothoracic muscles. The purpose of future research should be to achieve a better scapular muscle timing, with functional appliance and cost-effectiveness in mind.

Conclusion

SA has no effect on the activation of upper trapezius, lower trapezius and serratus anterior in low or high tasks. Tactile feedback facilitates the movement of the shoulder girdle without cooperation of the participants' muscles.

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