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The making of our master thesis often felt like a journey with no ending, accompanied with the appropriate dose of stress. But in the end we managed and we are very proud of the result. Therefore, I want to thank my partner, Loredana, for the excellent collaboration. Special thanks goes to my parents, Annemie Van Vlierden en Werner Wouters, and my boyfriend, Kristof Beyen for supporting and encouraging me during this year. (Elien Wouters)

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Situating

This article is situated within the domain of musculoskeletal rehabilitation and is part of a larger research project, guided by Prof. Sara Van Deun (promoter) and Drs. Liesbet De Baets (co-promoter). This research project contains three different objectives. First of all, the relationship between the occurrence of post stroke shoulder pain (PSSP), aberrant scapular movement and muscle control will be determined. Secondly, the development and clinical evaluation of a treatment protocol for PSSP is pursued. At last, training effects of the developed treatment protocol on exercise performance will be evaluated, supported by technological feedback.

Our study is focused on the first objective. The objective of this study is to assess how scapular movements, in stroke patients without shoulder pain, are influenced by commonly prescribed range of motion exercises: active, active-arm-assisted, and active-scapula-assisted arm movements. We hypothesize that assisting the movement could have beneficial effects on the muscle activation pattern, generating a more correct kinematic movement pattern. Knowledge of scapular movement during the prescribed exercises is crucial to improve rehabilitation of the upper limb. Clinicians could be better guided in the process of identifying which exercises need to be avoided and which can be implemented without risk.

Patients often report functional impairment of the paretic upper limb after stroke. Remaining impairments are reported to vary between 21% and 67%.[1,2] Several post-stroke impairments, such as loss of motor control, spasticity and paresis adversely affect shoulder girdle characteristics.[3] Previous studies already revealed altered scapular movement patterns in stroke patients, which could lead to the development of PSSP.[4,5] Therefore a normal scapular position and scapulohumeral rhythm should be pursued.

Three dimensions (protraction - upward rotation - tilting) are used to describe scapular movements with respect to the thorax and these movements are guided through coordinated muscle activations. On the basis of the 3D measurement findings, we want to develop specific guidelines on how to optimize shoulder girdle function in stroke patients during commonly prescribed range of motion exercises which are mentioned above.

With regard to our contribution in each phase of the study, most parts were done largely individually with guidance of our promoter (Prof. Sara Van Deun) and co-promoter (Drs. Liesbet De Baets), e.g. the recruitment of subjects, the data acquisition, the data analysis and the academical writing process. However, both the research protocol en method was already determined. After terminating the first part of our master proof, some adjustments were made concerning the research protocol. An addition was made regarding the type of range of motion exercise, active-assisted-exercises were added, e.g. active-arm-assisted and active-scapula-assisted range of motion exercises.

Thus, our interest lies in these commonly prescribed range of motion exercises: active, active-arm-assisted, and active-scapula-assisted and to assess how these exercises influence scapular movement in stroke patients without shoulder pain.

3D upper limb kinematics of people with stroke during different types of elevation tasks.

1. Abstract

Background and Purpose: Upper limb dysfunctions are common after stroke and are often related to factors, including hemiparesis or hemiplegia. To induce optimal function of the upper limb, normal shoulder and scapulothoracic kinematics are essential. The objective of this study is to assess how scapular movement in stroke patients without shoulder pain are influenced by commonly prescribed range of motion exercises: active, active-arm-assisted, and active-scapula-assisted.

Methods: Thirteen stroke patients, without shoulder pain, were included in the study. Three-dimensional kinematics of the trunk, shoulder girdle and elbow, were determined from infra-red markers attached to the sternum, acromion and on the upper arm during active, active-arm-assisted and active-scapula-assisted arm elevation (45° and 120°).

Results: During active arm elevation more protraction of the scapula (p=0.001) and more pronation of the elbow (p=0.003) was found at a joint angle of 45° during 120° arm elevation. Concerning the active-arm-assisted elevation, more internal rotation at the trunk and more protraction of the scapula was seen at a joint angle of 45° (P=0.008). Active-scapula-assisted elevation was accompanied by a decreased amount of protraction and a greater amount of posterior tilting of the scapula (p=0.001), and an increased pronation of the elbow (p=0.003).

Discussion and Conclusions: Active-assisted range of motion exercises create more optimal shoulder and scapulothoracic kinematics compared to active range of motion exercises. Active-scapula-assisted elevation is superior to active-arm-assisted elevation because it generates a better scapulohumeral rhythm. Clinicians can use these data in the process of identifying which exercises need to be avoided and which can be implemented without risk.

2. Introduction

Upper limb dysfunctions are common after stroke. Between 21% and 67% of patients report remaining impairments of the affected arm.[1,2] Dysfunction of the upper limb is often related to a longer hospital stay, a prolonged recovery process, reduced independence and quality of life of the patients, and interference with balance and walking. [5,6] Therefore, restoring the upper limb function is a major concern in the rehabilitation after stroke.

Upper limb dysfunctions have been related to different factors, including hemiparesis or hemiplegia, which involve a loss of spontaneous muscle activation at one side of the human body.[7] This decreased voluntary neural drive can cause prolonged periods of immobilization. Shoulder internal rotators, shoulder extenders, and elbow flexors are held in a shortened position, which leads to contractures and loss of range of motion at the upper limb.[8] Therefore, stroke patients are often treated with passive mobilization techniques to restore normal mobility. However, there is still no study that supports the effectiveness of passive treatment techniques, like passive mobilization and stretching, in stroke patients.[8-11] Moreover, it should be emphasized that a skilled therapist is a prerequisite to ensure more normal shoulder kinematics.[7] A reduced humeral external rotation is seen in patients after stroke. This leads to an increased rotator cuff compression against the greater tuberosity which in turn may lead to hemiparetic shoulder pain when performing range of motion exercises. Therefore, attention should be paid to externally rotating the humerus and manually assisting the scapula into upward rotation.[7]

To induce optimal function of the upper limb, normal glenohumeral and scapulothoracic kinematics are essential. To achieve these normal movements, good muscle control of the scapular and glenohumeral muscles is needed.[12] Normal scapulothoracic kinematics, together with elevation/depression of the clavicula, facilitate and enhance movements at the glenohumeral joint. As a result, the hand and arm can be placed in many positions.[13] Post-stroke impairments, such as paralysis, spasticity or loss of motor control, can have a negative impact on the normal scapular movement with respect to the thorax.[6]

Previous studies already revealed altered scapular movement patterns in stroke patients. In the study of Niessen et al. (2008), stroke patients showed an increased scapular lateral rotation relative to the thorax, during arm abduction and forward flexion, compared to asymptomatic subjects. Also, a decreased glenohumeral elevation was seen during passive abduction in stroke patients.[4,5]

When including range of motion exercises in the rehabilitation of patients after stroke with upper limb dysfunctions, these exercises should generate correct scapulothoracic and shoulder kinematics instead of reinforcing abnormal patterns.[7]

The objective of this study is therefore to assess how thoracic, scapulothoracic and glenohumeral movement in stroke patients without shoulder pain is influenced by commonly prescribed range of motion exercises: active, active-arm-assisted, and active-scapula-assisted. We hypothesize that assisting the movement could have beneficial effects on the muscle activation pattern, generating a correct kinematic movement pattern. Knowledge of scapular movement during the prescribed exercises is crucial to improve rehabilitation of the upper limb. Clinicians could be better guided in the process of identifying which exercises need to be avoided and which can be implemented without risk for developing post stroke shoulder pain.

3. Methods

3.1. Participants

Thirteen stroke patients, without shoulder pain, were included in the study (Table 1).

Table 1: Participant characteristics

Number of subjects (men/women)	13 (8/5)
Age range (years)	25-68
Hand dominance before lesion (left/right)	0/13
Side of hemiplegia (left/right)	7/6
Time since stroke, range (weeks)	6-48,3
Upper limb motor section Brunström-Fugl-Meyer score (0-66), range	45-65

Stroke patients were recruited from the Rehabilitation Centre of the University Hospital Pellenberg. They were included if they met the following inclusion criteria: 1) they experienced a first, (sub)cortical stroke, 2) reported no history of shoulder complaints before stroke, 3) were between 2 months and 1 year post stroke, and 4) were able to actively perform 45° of humerothoracic elevation in the sagittal plane. They were excluded if: 1) they experienced other neurological or orthopedic pathologies that could have affected the upper extremity function, 2) if they were not able to understand the instructions.

Before inclusion, all subjects signed the informed consent, approved by the ethical committee of the University Hospital Leuven.

3.2. Measurement procedure

Three-dimensional kinematics of the trunk, shoulder girdle and elbow, were measured during active, active-arm-assisted and active-scapula-assisted arm elevation.

Before measuring three-dimensional kinematics during arm elevation, patients were subjected to a clinical examination. In this examination the upper extremity motor section of the Brunström-Fugl-Meyer scale was conducted (Table 1).

All measurements were conducted at the clinical motion analysis laboratory of the University Hospital Pellenberg.

Subjects were seated on a chair, with a low back rest and without arm rests, with the arms neutral to the side of the body. The movement protocol consisted of two different movements: 0-45° and 0-120° of forward flexion. These movements were executed in three different ways: active, active-scapula-assisted and active-arm-assisted. Active-scapula-assisted arm elevation included scapular assistance by the researcher during the active movement assistance to upward rotation and posterior tilt (Figure 1). Active-arm-assisted elevation was induced by the researcher by supporting the involved upper and lower arm of the patient in neutral rotation (Figure 2).
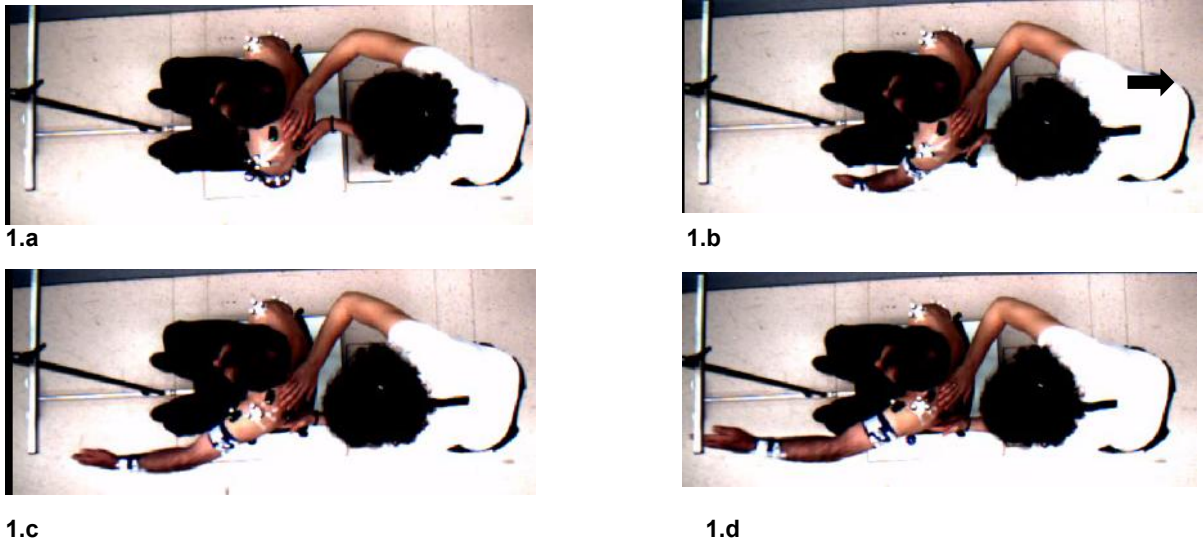

1.a

1.b

1.c

1.d

Figure 1 – Active-scapula-assisted arm elevation
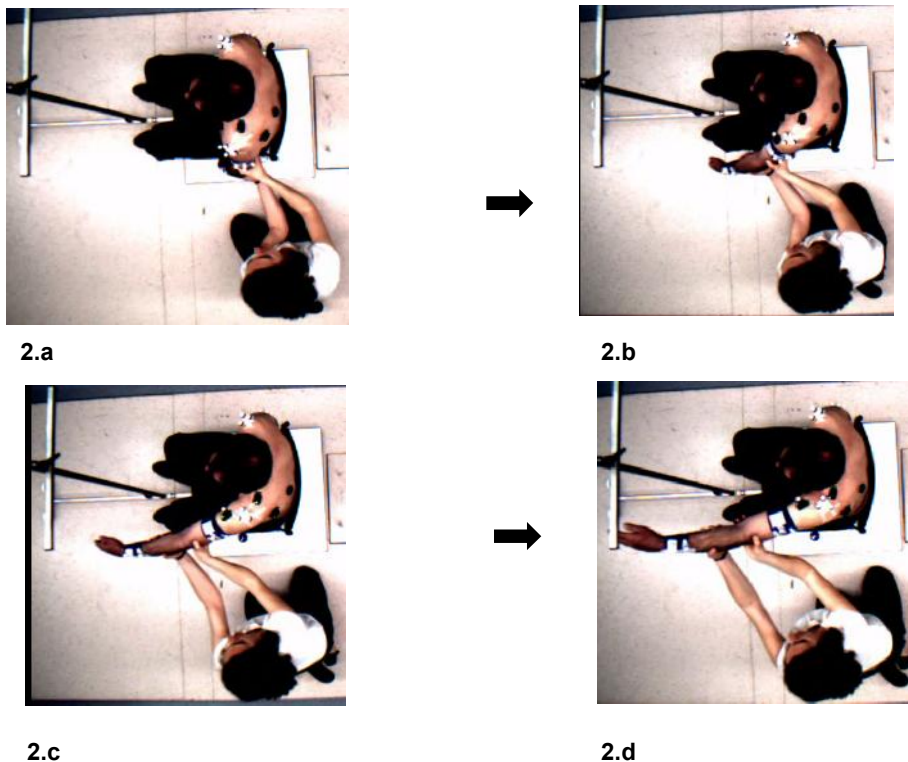

2.a

2.b

2.c

2.d

Figure 2 – Active-arm-assisted arm elevation

The sequence of the movement protocol was as follows: 45° active forward flexion – 45° active-arm assisted forward flexion - 45° active-scapular assisted forward flexion. The same sequence was subsequently repeated for the 120° tasks.

One researcher was seated in front of the subject to demonstrate the movements and to check the subject's position. The subject followed the same speed of movement as the researcher and focused on a target that indicated the correct height of the motion. The correct height of motion was established by means of a rod. Firstly the rod was placed at a height which corresponded to 45° of humerothoracic elevation. Next, it was placed at 120° of humerothoracic elevation. In this way the participant received visual and tactile feedback about the elevation height. The pace of the 45° of forward flexion movement consisted of the following rhythmic pattern: one count (elevation/up), one count (lowering/down), followed by two counts rest. For the 120° forward flexion movement, the rhythmic pattern was as follows: two counts (elevation/up), two counts (lowering/down), followed by three counts rest.

Regarding the three-dimensional measurements, fifteen infra-red Vicon cameras (Oxford Metrics, UK) were used. Infra-red markers, grouped in clusters, were placed on the sternum, acromion, and the upper arm and the forearm, to define the segments trunk, scapula, and upper arm (Figure 3). In this way three-dimensional movements of the trunk, scapula and upper extremity were registered. To prevent these markers of coming loose, they were secured with tape.

Figure 3 – Infra-red markers, grouped in clusters,
placed on the sternum, acromion, on the upper arm
and on the forearm.

Additionally, anatomical landmarks were palpated and digitized during static trials, using a pointer with four linear markers (Figure 4). These anatomical landmarks were then defined within their respective segmental marker cluster (Capozzo 1995), and subsequently used to construct the anatomical coordinate systems and to calculate joint angles of the trunk, scapulothoracic joint, humerothoracic joint and elbow.

Figure 4 – Anatomical landmarks, palpated and digitized during static trials.

Three-dimensional trunk, scapulothoracic, humerothoracic and elbow joint angles for active, active-scapula-assisted and active-arm-assisted arm elevation at 45° and 120° of forward flexion were the primary outcome measures of interest (Figure 5). Joint angles of (1) the trunk were defined as: flexion/extension, lateral rotation and internal/external axial rotation, of (2) the scapulothoracic joints as protraction/retraction, medial/lateral rotation and tilting, of (3) the humerothoracic joints as plane of elevation and humeral rotation, and of (4) the elbow joints as flexion/extension and pronation/supination.
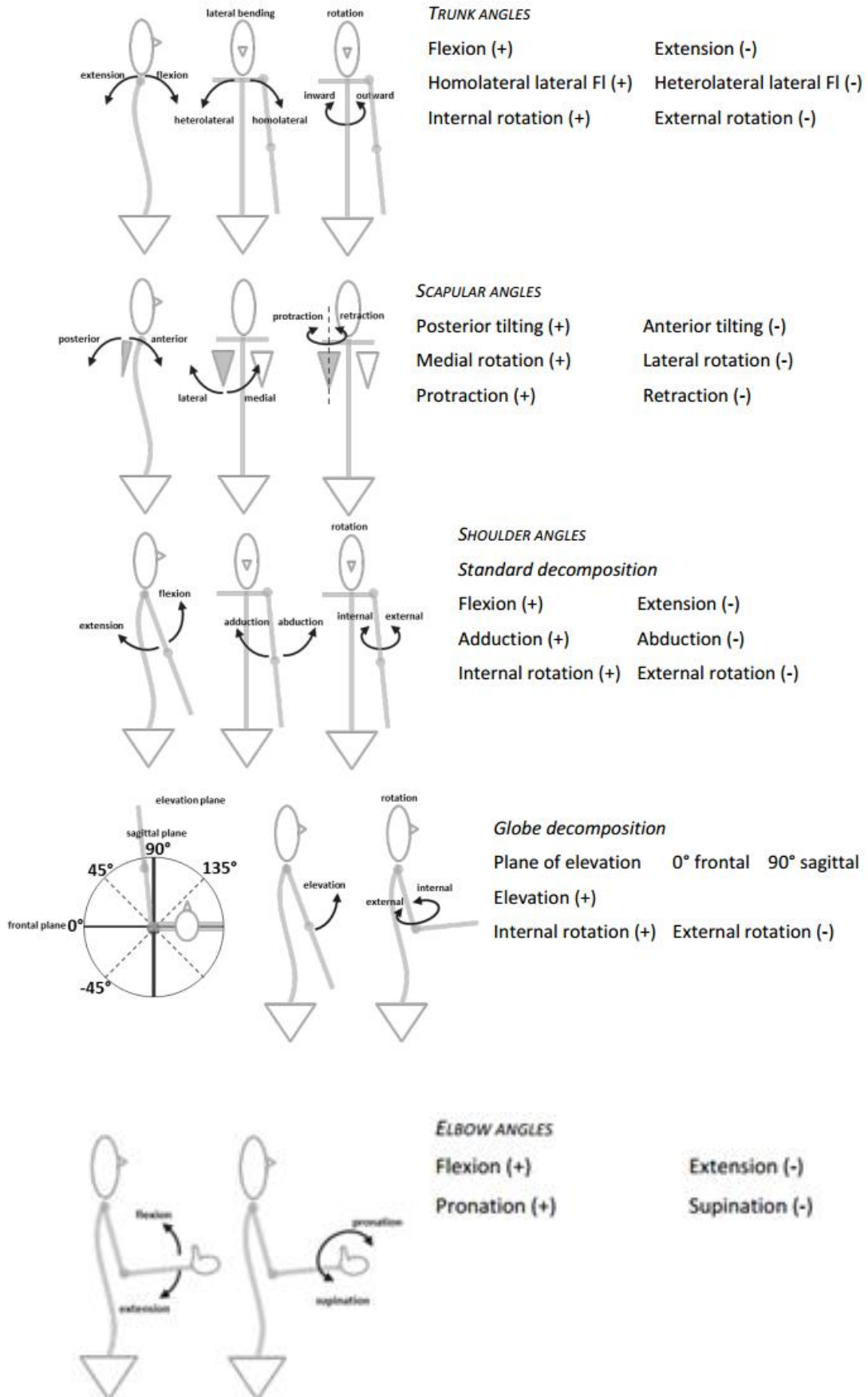
Figure 5 – Three-dimensional trunk, scapulothoracic, humerothoracic and elbow joint angles.

Joint angles of the trunk, scapulothoracic joint, humerothoracic joint and elbow were compared (1) at 45° of humerothoracic elevation during the 45° forward flexion task, (2) at 45° of humerothoracic elevation during the 120° forward flexion task, and (3) at 90° of humerothoracic elevation during the 120° forward flexion task.

3.3. Data analysis

Each movement trial consisted of eight repetitions. Only the middle six repetitions were selected for data-analysis. Of these repetitions the start, highest position and stop of the movement were visually marked. Data was further analyzed by Matlab, with the use of BodyMech and other custom written programs.

3.4. Statistical analysis

For the statistical analysis, SPSS software was used. First a Shapiro-Wilk test of normality was conducted. In case of normal distribution, an ANOVA repeated measures design was used, with post-hoc Bonferroni tests. For the other conditions a non-parametric Friedman test was used, with post-hoc Wilcoxon signed ranks tests. The significance level was set at $p < 0.05$.

4. Results

Joint angles of the trunk, scapulothoracic joint, humerothoracic joint and elbow were compared (1) at 45° of humerothoracic elevation during the 45° forward flexion task, (2) at 45° of humerothoracic elevation during the 120° forward flexion task, and (3) at 90° of humerothoracic elevation during the 120° forward flexion task.

4.1. Trunk

During the 45° forward flexion task, at a joint angle of 45° humerothoracic flexion, there was a main effect for lateroflexion (p=0.031). Post-hoc Bonferroni tests showed no significant differences between the three conditions of active, active-scapula-assisted and active-arm-assisted arm elevation.

For axial rotation we found a main effect (p=0,009). There were significant differences between active and active-arm-assisted elevation (p=0.008) and between active-arm-assisted and active-scapula-assisted elevation (p=0.008) during 45° elevation at a joint angle of 45°, with a greater amount of internal rotation during active-arm-assisted elevation. For the 120° task there were no significant differences.

4.2. Scapulothoracic joint angles:

During the 45° forward flexion task, at a joint angle of 45° humerothoracic flexion, there was a main effect for protraction (p = 0.000) and tilting (p=0.000).

Post-hoc Bonferroni tests revealed a significant difference between active and active-scapula-assisted elevation for protraction (p=0.001), with more protraction during active arm elevation. Secondly, there was a significant difference between active-arm-assisted and active-scapula-assisted elevation (p=0.008), with more protraction during active-arm-assisted elevation.

For tilting there was a significant difference between active and active-scapula-assisted elevation (p=0.001), with a greater amount of posterior tilting during active-scapula-assisted elevation. Furthermore, a significant difference between active-arm-assisted and active-scapula-assisted elevation (p=0.003) was found, with again more posterior tilting during active-scapula-assisted elevation. For the 120° task, there were no significant differences.

4.3. Humerothoracic joint angles

No significant differences were found for humerothoracic joint angles.

4.4. Elbow

During 45° elevation, at a joint angle of 45° of humerothoracic flexion, we found a main effect for flexion and extension (p=0.036) Post-hoc Bonferroni tests showed no significant differences.

At a joint angle of 45° during the 120° forward flexion task, there was a main effect for flexion and extension (p=0.039). Post-hoc Wilcoxon Signed Ranks Test showed no significant differences. Furthermore, there was a main effect for pro- and supination (p=0.002). There were significant differences between active and active-arm-assisted elevation (p=0.003) and between active-arm-assisted and active-scapula-assisted elevation (p=0.003) with respectively a greater amount of pronation during active elevation and during active-scapula-assisted elevation. For flexion or extension there were no significant differences.

At a joint angle of 90° during the 120° forward flexion task, there was a main effect for flexion and extension (p=0.003). There were significant differences between active-arm-assisted and active-scapula-assisted elevation (p=0.008), with more elbow flexion during active-scapula-assisted elevation.

Table 2: Mean and SD of the different joint angles during the different tasks

		Active	Active-arm-assisted	Active-scapula-assisted
45° anteflexion, measured at 45°				
trunk	Flexion/extension	-4,2 (4,3)	-3,3 (4,7)	-4,7 (4,6)
	Lateral rotation	-1,1 (1,7)	-2,3 (2,1)	-1,3 (2,8)
	Internal/external rotation	1,8 (6)*	4,3 (5,6)*	0,7 (6,9)*
Scapulothoracic joint	Protraction/retraction	36,7 (6,4)*	35,6 (6,1)*	28,9 (8,5)*
	Medial/lateral rotation	-7,4 (6,9)	-8,2 (6,7)	-7,4 (7)
	Tilting	-2,9 (8,5)*	-2,3 (8,2)*	5,9 (12,3)*
Humerothoracic joint	Elevation plane	-44,2 (2,9)	-44,9 (0,2)	-44,1 (3,3)
	Internal/external rotation	-49,5 (12,1)	-50,5 (21,4)	-51,5 (16,1)
Elbow	Flexion/extension	26,3 (8,6)	19,5 (8,2)	25,8 (12,7)
	Pronation/supination	94, 6 (28)	92,01 (23,4)	96,9 (25,5)
90° anteflexion, measured at 45°				
trunk	Flexion/extension	-5,3 (5,3)	-3,6 (4,4)	-5,1 (5,1)
	Lateral rotation	-1,8 (2,1)	-2,4 (2,1)	-1,2 (4,1)
	Internal/external rotation	1,9 (6,7)	4,6 (3,7)	4,1 (8,2)
Scapulothoracic joint	Protraction/retraction	35,7 (6,8)	36 (7,3)	34,3 (6,2)
	Medial/lateral rotation	-10,2 (7,4)	-12,4 (10)	-12,4 (8,1)
	Tilting	-4,3 (7,7)	-3,6 (7,8)	-2,7 (10,2)
Humerothoracic joint	Elevation plane	-44,9 (0,6)	-45,3 (0,5)	-45,1 (0,5)
	Internal/external rotation	-44,2 (11,8)	-45,3 (22,9)	-41,7 (11,4)

Table 2 continued

		Active	Active arm- assisted	Active scapula assisted
Elbow	Flexion/extension	21,3 (11,3)	27,4 (34,2)	21,6 (10,6)
	Pronation/supination	94 (24,7)*	67,4 (60,2)*	102,5 (17,8)*
120° anteflexion, measured at 90°				
trunk	Flexion/extension	-3,9 (7,9)	-2,7 (6,6)	-4,4 (6,9)
	Lateral rotation	-3,2 (3,6)	-4,6 (3,7)	-3,6 (5,1)
	Internal/external rotation	2,3 (6,9)	4,2 (4,3)	5,2 (8,5)
Scapulothoracic joint	Protraction/retraction	47,5 (11,7)	46,3 (10)	46,8 (9,6)
	Medial/lateral rotation	-29,7 (11,6)	-29,3 (9,9)	-31,2 (11,2)
	Tilting	0,2 (10,6)	-0,1 (10,6)	0,9 (15,9)
Humerothoracic joint	Elevation plane	-90,02 (0,3)	-90,04 (0,3)	-90 (0,4)
	Internal/external rotation	-49,3 (11,6)	-52,3 (18,9)	-46,1 (13,7)
Elbow	Flexion/extension	22,2 (7,9)	22,3 (9,6)*	22,3 (9,7)*
	Pronation/supination	88,7 (22,9)	80,3 (18,1)	90,8 (19)

(*) indicates significant difference

5. Discussion

Three dimensions (protraction - upward rotation - tilting) are used to describe scapular movements with respect to the thorax. These movements are guided by coordinated muscle activity. By means of more advanced assessment methods, namely 3D movement analysis, it is possible to measure movements of the scapula with respect to the thorax. In comparison with current clinical assessment, this assessment method provides a detailed description of the scapulothoracic function. Movement of the scapula in all three dimensions is a prerequisite in order to fulfill its function as steady base for movements of the upper arm.

5.1. Interpretation of results

The present study compared joint angles of the trunk, scapulothoracic joint, humerothoracic joint and elbow during active, active-scapula-assisted and active-arm-assisted arm elevation at 45° and 90° of elevation during a 45° and 120° forward flexion task.

As to the trunk, a greater amount of internal rotation was seen during active-arm-assisted elevation in comparison to active-scapula-assisted elevation at a joint angle of 45°. A previous study reported that internal rotation of the trunk decreased scapular internal rotation and increased the upward rotation of the scapula.[14] The increased upward rotation and decreased internal rotation of the scapula that is present with internal rotation of the trunk will only benefit the scapulohumeral rhythm since this creates a reduced chance on developing impingement at the shoulder joint.

Concerning the scapulothoracic joint angles, a greater amount of protraction was found during active arm elevation in comparison to active-scapula-assisted arm elevation at a joint angle of 45°. Also, more protraction was seen during active-arm-assisted elevation compared to active-scapula-assisted arm elevation. Scapular protraction appears to be a combination of scapular anterior tilt and internal rotation and is accompanied by a reduction of the subacromial space.[15] Hereby, it should be emphasized that during active-scapula elevation, a reduced amount of protraction is seen, so there is less chance of developing impingement at the shoulder. Furthermore, active-scapula-assisted arm elevation was accompanied by more posterior tilting compared to active and active-arm-assisted elevation. This finding highlights the role of a skilled therapist who can assist and guide a normal scapulothoracic joint, which consists of external rotation, upward rotation and posterior tilting relative to the thorax, during humeral elevation.

On top of these findings it should be emphasized that the assistance of a skilled therapist is better than for example a cane-assisted exercise. With a cane-assisted range of motion exercise, if an overhand grip is used, the forearm is placed in pronation which in turn can contribute to a less externally rotated humerus and thus a faulty scapulohumeral rhythm.[7] A decreased humeral external rotation is associated with an increased rotator cuff compression. This compression primarily takes place against the greater tuberosity.[16-18]

At last we took a closer look at the elbow and discovered more pronation during active arm elevation compared to active-arm-assisted elevation at a joint angle of 45° during 120° arm elevation. Also, a greater amount of pronation was found during active-scapula-assisted elevation during 120° arm elevation at a joint angle of 45°. The underlying cause can be that during these movements where more pronation is seen, the arm is not supported by the therapist. We suggest that the therapist should make sure to support the arm while assisting the scapula during the movement. The increased forearm pronation during active arm elevation and active-scapula-assisted elevation leads to a less externally rotated humerus which in turn can lead to an incorrect scapulohumeral rhythm.[7]

5.2. Limitations

This study has some limitations. First, the participants who were included could reach a range of humeral elevation of at least 45°. Therefore, the results cannot be generalized to stroke patient who are less functional and who cannot reach this range. Secondly, the sample size in this study was small. The ability to generalize findings is hereby limited. Finally, only three different types of elevation tasks were performed during this study. Other functional tasks were not included. These other functional tasks could have a different influence on the scapular kinematics.

5.3. Recommendation future studies

We suggest that in future research studies include a larger sample size in order to avoid limitations concerning the generalisation of findings. Also people with stroke could benefit from future research concerning scapular assessment during functional tasks instead of during a simple elevation task. Hereby they can improve their functional abilities in real life situations.[6] Nonetheless, this study has yielded important information with regard to the understanding of deficits and mechanisms, during commonly prescribed range of motion exercises, that could contribute to impaired scapular function. In this way therapists are better guided when prescribing exercises for people with stroke.

6. Conclusion

Active-assisted range of motion exercises, especially active-scapula-assisted, create more optimal shoulder and scapulothoracic kinematics compared to active range of motion exercises.

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