Original Paper

DE GRUYTER OPEN

Biomedical Human Kinetics, 9, 146–157, 2017

DOI: 10.1515/bhk-2017-0021

Timing of electromyographic activity and ranges of motion during simple motor tasks of upper extremities

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Summary

Study aim: Improvement of the upper extremities' performance is one of the key aims in the rehabilitation process. In order to achieve high effectiveness of this process the amount of functional improvement achieved by a patient during the therapy needs to be assessed. The aim of this study was to obtain electromyographic (EMG) activity profiles of the upper extremity muscles during execution of simple tasks in healthy subjects. Additionally the ranges of wrist, elbow and shoulder joints were measured and reported during performed trials. The second aim was to determine whether the movement execution and ranges of movements and muscular activity depend on age.

Material and methods: Twenty-eight healthy adults, age range 21 to 65 years old, participated in the study. Surface electrodes were placed bilaterally on 7 upper extremity muscles. To obtain information about the beginning and end of the movement task and ranges of upper extremity joints, 13 markers were placed on the elbows and wrists of both upper extremities. The movements of the segments were calculated (distal vs proximal) in five simple functional tasks (each task involved only one joint), performed while sitting. Kinematic data were collected by the VICON 460 system, and electromyographic data with the Motion Lab EMG system.

Results: Charts of timing of EMG activity of the upper extremity muscles together with ranges of upper extremity joint motion were obtained.

Conclusion: The results show that the number of muscles activated and the time (or percentage) of the task during which they are active depend on the type of the task and age. These data can be used as a reference in evaluation of functional deficits of patients.

Key words: SEMG – Upper extremities – Simple motor tasks – Reference data

Introduction

In various neurological, rheumatoid and orthopaedic diseases patients experience problems with upper limb movements and thus considerable reduction of functional abilities. These problems could be caused by muscular strength deficiency, degenerative joint and soft tissue changes, and lack or disturbances in motor control. This restricts the independence of the patients in the performance of everyday tasks.

Therefore the improvement of the upper extremities' performance is one of the key aims in the rehabilitation process. In order to achieve high effectiveness of this process the amount of functional improvement achieved by a patient during the therapy needs to be assessed. There are several scoring systems used in clinical practice [9], but these systems are qualitative and depend on the experience and personal views of the evaluator.

Surface electromyography (EMG) could be used to objectively evaluate the upper extremity muscular activity during various motor tasks. In order to assess the motor deficits of the patients the reference EMG profiles should be obtained. Such reference databases were created by Kronberg and co-workers [10] They recorded muscular activity of eight shoulder muscles during various upper extremity tasks in five (ten upper extremities) healthy subjects. Subjects performed the desired tasks with external loads, applied either by gripping a weight or pulling a cord with controlled resistance. Wickham and co-workers

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increased the number of investigated muscles to 15 and the number of subjects to 28, but the activity of some of these muscles was recorded using needle (fine wire) electrodes [17]. Subjects performed seven tasks while standing, and the tasks were executed with constant speed enforced by the investigator. The EMG signals were normalised to % of the MVC (maximal voluntary contraction) recorded at separate trials in isometric conditions.

Hughes and co-workers investigated the activation patterns of upper extremity muscles during supported tracking tasks in healthy older subjects in order to establish a reference database for stroke patients [6].

The limitations of the published studies were: the limited number of subjects participating in the study [10], use of needle electrodes [10, 17], one age group of the subjects [6, 17], use of special devices [1, 2, 6, 10], enforced speed of the movement [17], standardization of the EMG signals by % of MVC recorded during isometric conditions [6, 17], restriction of normal, anticipatory activity of trunk muscles (lack of feedforward reactions) during upper extremity movements by external fixation (seat belts) or allowing subjects to flex the trunk laterally instead of maintain a stable trunk position [6, 17]. Other studies used tasks difficult to perform for patients, as they reflect daily life of healthy subjects [11, 14]. The EMG profiles collected as reference databases should be recorded during trials which could be reproduced by patients with various neurological and orthopaedic diseases. For instance, it would be extremely difficult for stroke patients to move an upper extremity into abduction in a standardized, forced movement plane [17]. The use of needle electrodes in everyday clinical practice is impossible. Patients perform motor tasks at varying speed, strongly dependent on their dysfunctions. In many neurological conditions standardization trials cannot be performed due to disturbed motor control. Therefore there is a need to create a reference database of EMG profiles obtained with surface electrodes during execution of simple motor tasks, easy to perform for a wide variety of patients, even those who cannot stand, and with no restriction on the speed of the movements. Age-associated loss of power and strength in the upper extremities has already been reported. The decline of strength and power begins by age 40 [12]. Deterioration of upper extremity function with age (increased time to complete the test) due to restricted elbow, forearm, wrist and fingers was found [3]. There is no information on whether patterns of muscles activity of upper extremities or their kinematic patterns change during the life span, but this is a subject of interest [4].

The aim of this study was to obtain such EMG activity profiles of the upper extremity muscles during execution of simple tasks in healthy subjects. Additionally the ranges of wrist, elbow and shoulder joints were measured and reported during performed trials. The second aim was to determine whether the movement execution and ranges of movements and muscular activity depend on age.

Material and methods

Subjects

Twenty-eight healthy adults participated in the study. They were 21 to 65 years old, 17 women, 11 men. All participants were informed about the purpose of the study and gave written informed consent and ethical approval was provided by the Local Ethical Committee at Józef Piłsudski's Academy of Physical Education, Warsaw, Poland.

The exclusion criteria at the subjects' recruitment were: neurological, orthopaedic, pain or any other problems (i.e. diabetes, previous fractures of the upper extremities, etc.) which might affect the functional abilities. Subjects with obesity or extremely low body mass were also excluded from the study. During recruitment the subjects answered questions and a skilled physiotherapist assessed their body posture.

Subjects were divided into three age groups:

– "young": from 21 to 35 years old (10 subjects),
– "middle aged" from 36 to 50 years old (8 subjects),
– "old" from 51 to 65 years old (10 subjects).

The subjects were recruited in such a way that their age was more or less evenly distributed within their age group.

The decision about participants' age selection and about classification was made arbitrarily, based on the literature data. Individuals over 65 years old most likely suffer from different orthopaedic disorders including restriction of range of movement and pain [4], and the first decrease of upper extremity function was noted around 40 years of age [5].

Methods

The surface electrodes were placed bilaterally on the following muscles: middle and frontal part of the deltoid, trapezius, biceps brachii, long caput of triceps brachii, brachioradialis, and long finger flexors, according to SENIAM recommendations (SENIAM – Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscles). To obtain information about the beginning and end of the movement task, and to evaluate the range of motion of upper extremities, markers were placed on the elbows and wrists of both upper extremities.

The protocol used in our study was described by Sibella et al. and consisted of thirteen markers whose placement is presented in Fig. 1 [15]. A model of the upper extremities was constructed in Visual3D software. The movements of the segments were calculated (distal vs proximal) in five simple functional tasks, performed while sitting.

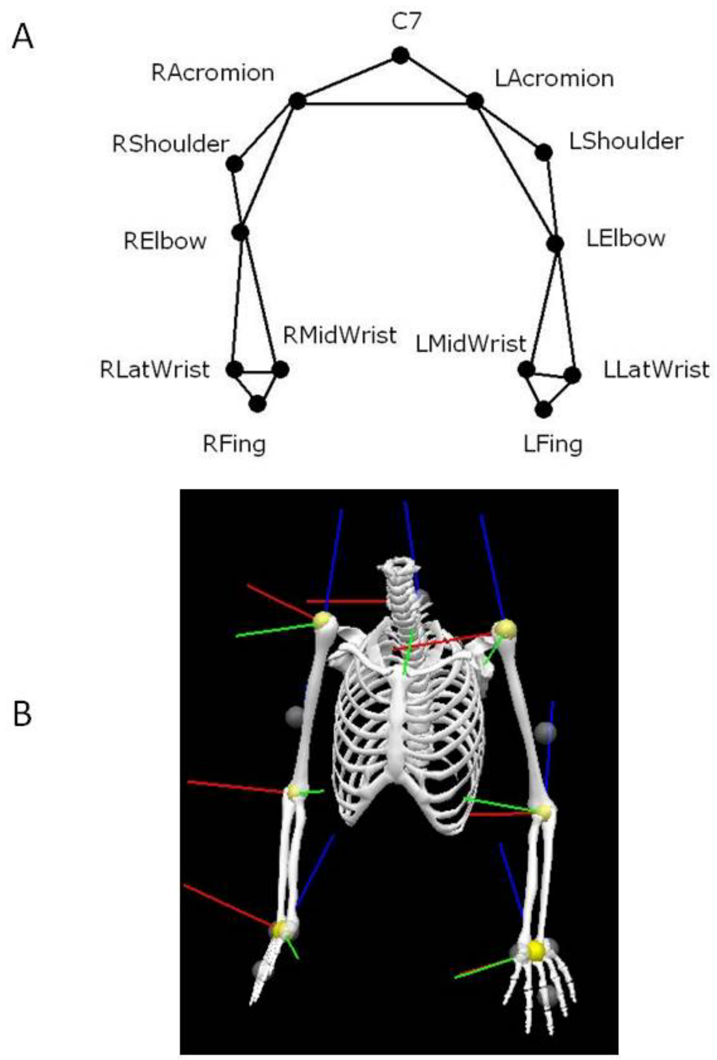

Fig. 1. A – marker protocol used during collection of data. B – marker based Visual3D model with local reference systems

Kinematic data were collected by the VICON 460 system (Oxford, UK), and electromyographic data with the Motion Lab EMG (Baton Rouge, USA) system. Kinematic and electromyographic data were collected synchronously, kinematic data with 60 Hz frequency, EMG with 1980 Hz.

During the session subjects were asked to perform (with both upper extremities) five simple functional tasks, performed in a sitting position:

- raise extremities parallel to the floor in the frontal plane, straight elbows (Task 1);
- raise extremities parallel to the floor in the sagittal plane, straight elbows (Task 2);
- maximal possible range of flexion of elbows in the sagittal plane (thumbs to shoulders) (Task 3);
- supination and pronation of forearms and rotation of wrists with free hanging extremities (Task 4);
- extension of wrists with forearms supported on the table (Task 5).

In each task the movement was limited to only one joint of the upper extremities (Tasks 1 and 2 – shoulder joints, Task 3 – elbow joints, Tasks 4 and 5 – wrist joints).

The aim of the selection of analysed movements in the study was the simplicity of performance and simplicity of analysis. Too complex movements would make both the performance and analysis difficult. In each of the tested movements isolated mobility (co-activation) in one or a maximum of two joints is expected and the rest of the extremity is expected to maintain static (co-contraction) There are different leading muscle groups in every movement (proximal or distal groups). Symmetric movements facilitated paretic upper limb activity and it was possible to compare both sides.

Data from left and right upper extremities were pooled together. As the time to perform the task varies from subject to subject all data were normalized to 100% of the movement cycle: 0% – beginning of the task execution, 100% – end of the movement. Identification of the beginning and end of the movement was done with tracking of the markers' trajectories.

Raw EMG data were exported from the Workstation and further processed in MATLAB (MathWorks Inc., USA): rectified and filtered to create envelopes, according to SENIAM recommendations [5, 18]. The envelopes were later averaged separately for the three age groups.

Based on the averaged curves the on-off time charts of the timing of EMG activity (similar to the charts used in clinical gait analysis) of the upper extremity muscles during five simple tasks in three age groups were created [16]. A threshold of muscle activity was defined as +3SD of the baseline noise [13]. Kinematic data (angles) were exported from Visual3D as text data and later smoothed (filtered) and averaged in MATLAB.

Results

Figure 1 presents the marker protocol used during the study, together with visualisation of the torso and upper extremities of the subjects, and local reference systems.

Figure 2 shows the example of the averaged envelopes (mean +/– standard deviation) during one task for one of the three age groups.

Figures 3–7 present the timing of EMG activity charts of the muscular activities of the upper extremity muscles for all five tasks, separately for the three age groups.

During Tasks 1 and 2 the frontal and medial part of the deltoid together with the trapezius muscle were active. During the third task the long head of the triceps brachii and brachioradialis were active. During the fourth task there was the highest variability of muscular activity: in the youngest group the active muscles were: middle part of deltoid, biceps brachii, long caput of triceps brachii, brachioradialis, and long finger flexors. In the middle group the frontal part of the deltoid was also active, while in the oldest group only the biceps brachii, long caput of triceps brachii, and brachioradialis were active. During the fifth task the youngest and middle group performed the task using the brachioradialis and long finger flexors, while the oldest used only the brachioradialis.

Only in Task 1 were there no differences between the age groups in muscular activity. In the second task all three groups differed from one another, with the longest activity in the oldest group. In the third task the youngest and middle group had similar activity of the muscles, while in the oldest group their activity was longer. In the fourth task the oldest group had short activity of only three muscles.

Table 1 presents the ranges of motion of wrist, elbow and shoulder.

Discussion

The results show that the number of muscles activated and the time (or percentage) of the task during which they are active depend on the type of the task and age.

During Task 1 all three groups had the same type of activity: middle and frontal parts of the deltoid muscle were active for 10 to 80% of the motor task together with the trapezius muscle.

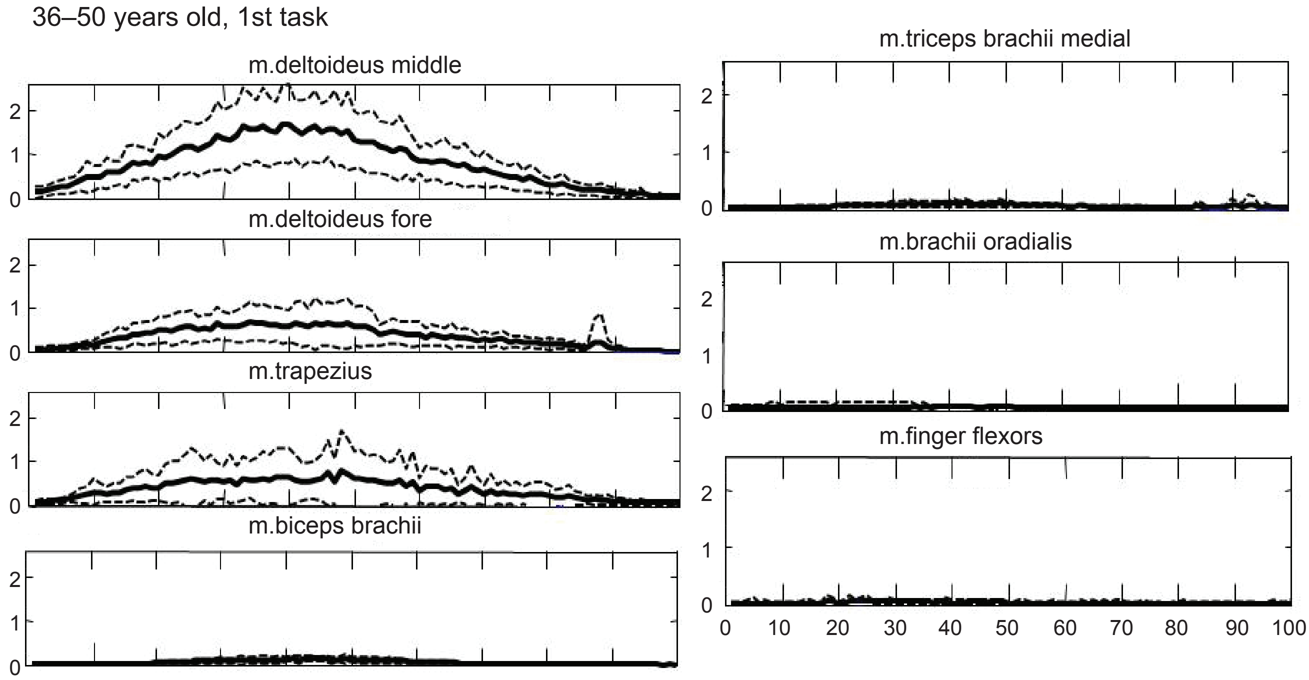

Fig. 2. Example of averaged EMG envelopes during one task (older group, Task 1)

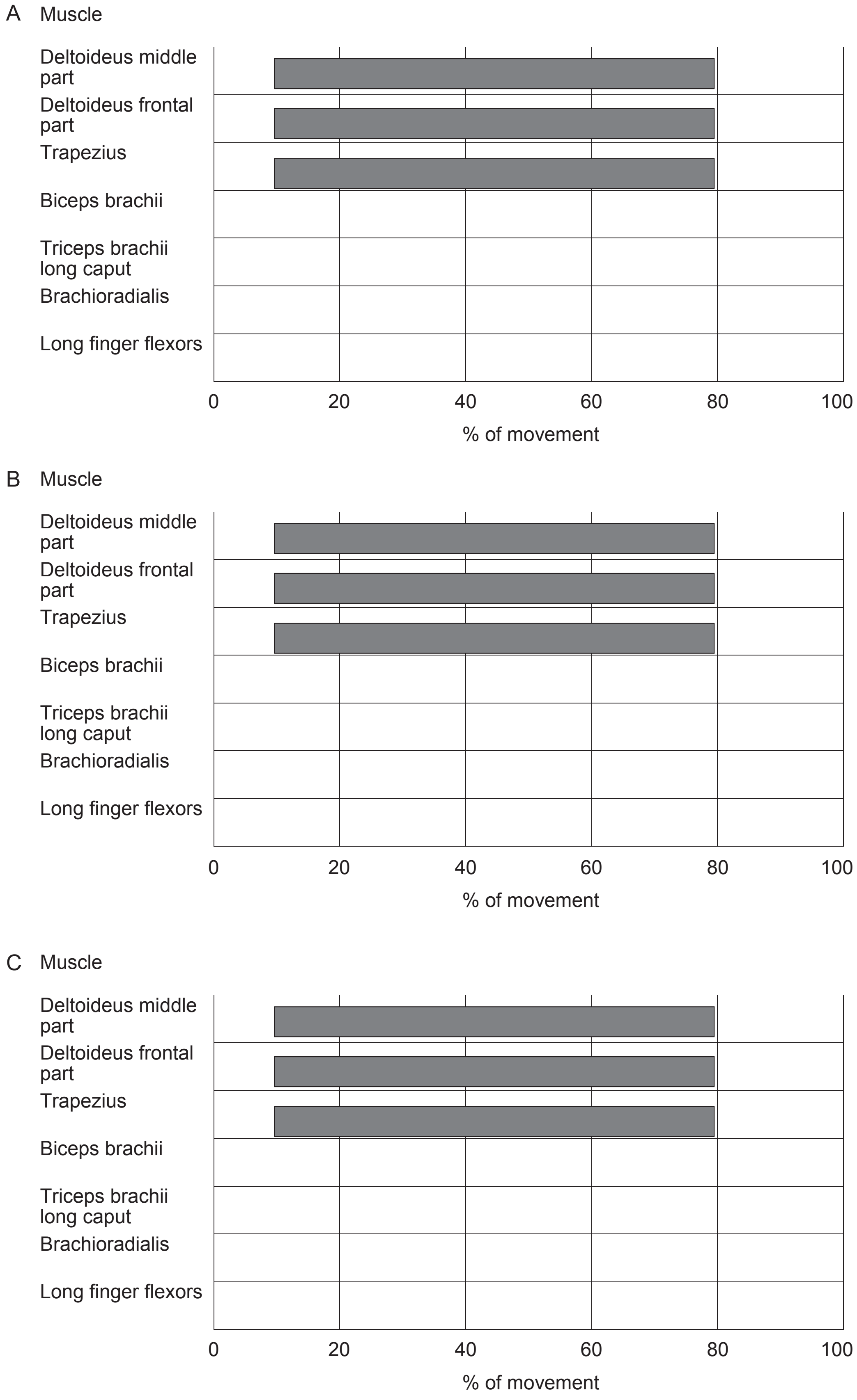

Fig. 3. Timing EMG activity chart for Task 1. A) “Young” group. B) “Middle aged” group. C) “Old” group

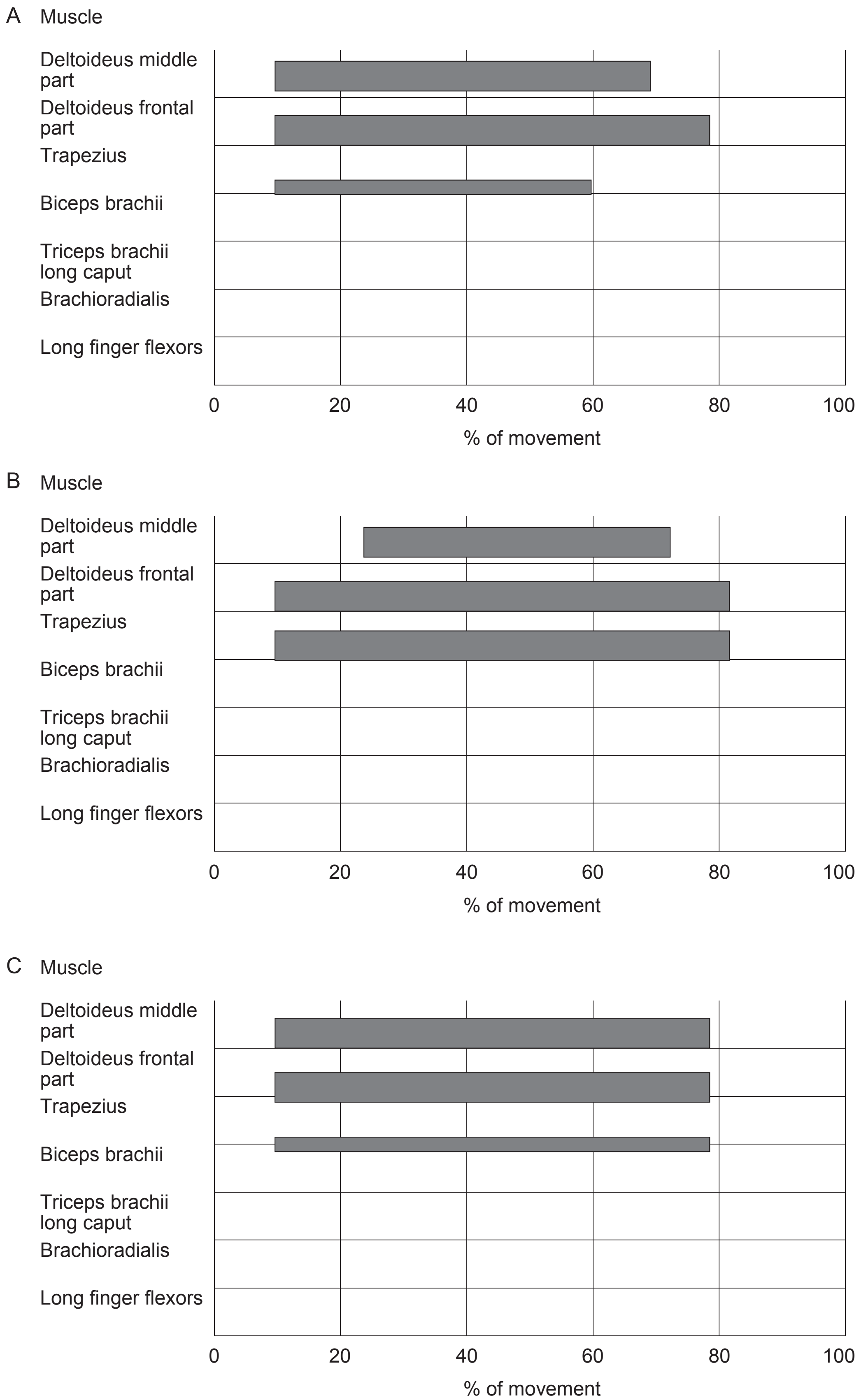

Fig.4. Timing EMG activity chart for Task2. A) "Young" group. B) "Middle" group. C) "Old" group

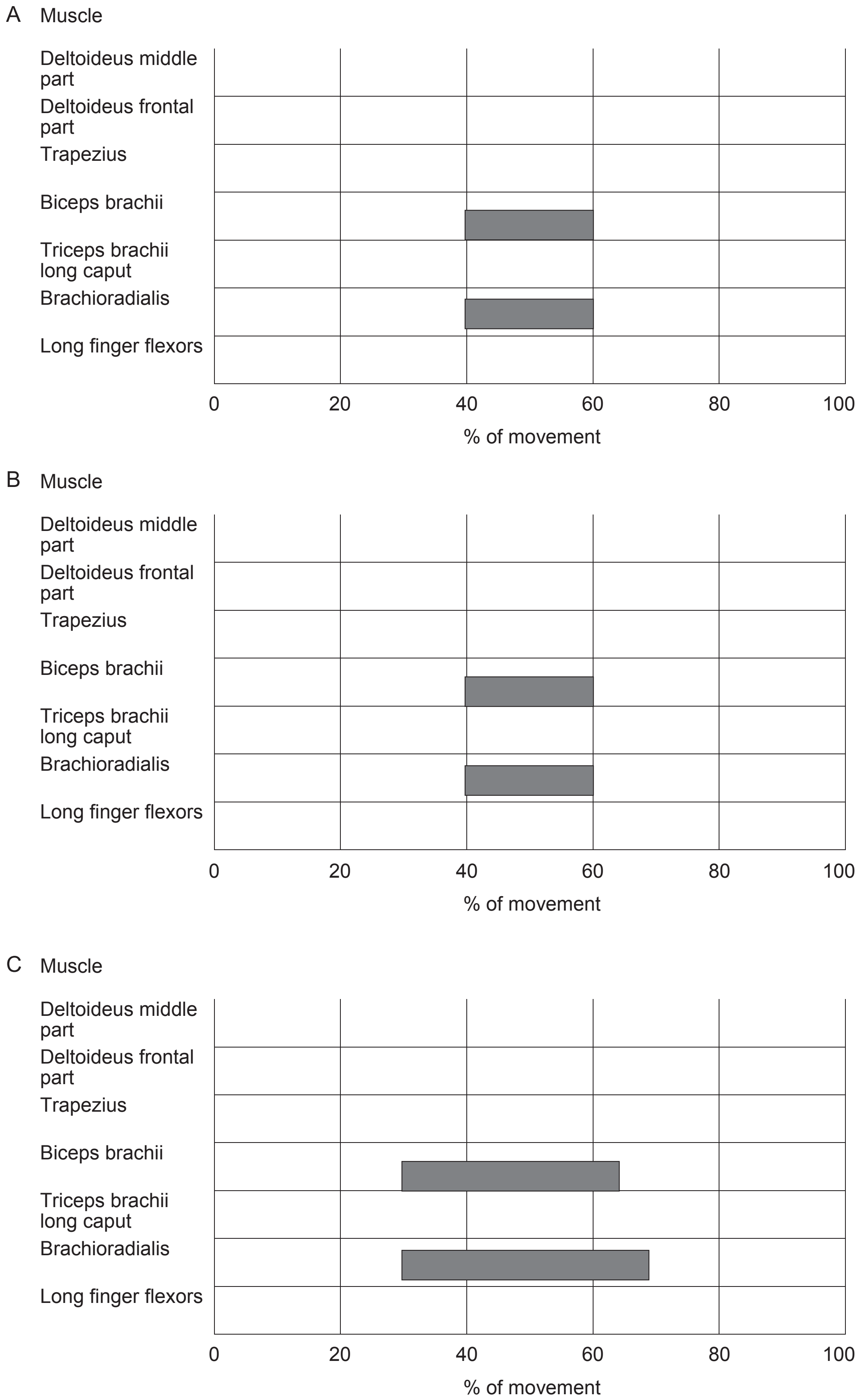

Fig.5. Timing EMG activity chart for Task3. A) “Young” group. B) “Middle” group. C) “Old” group

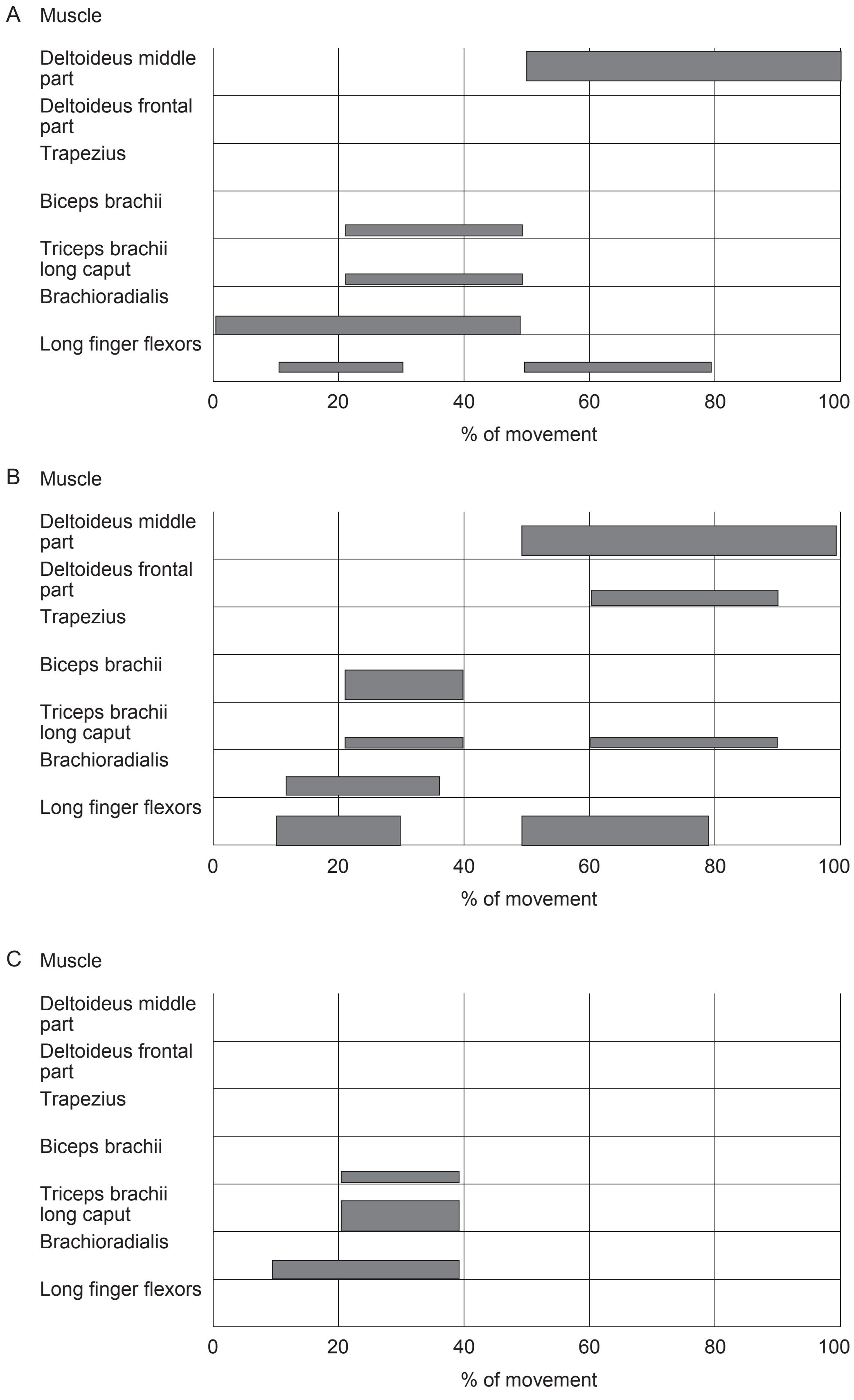

Fig.6. Timing EMG activity chart for Task4. A) "Young" group. B) "Middle" group. C) "Old" group.

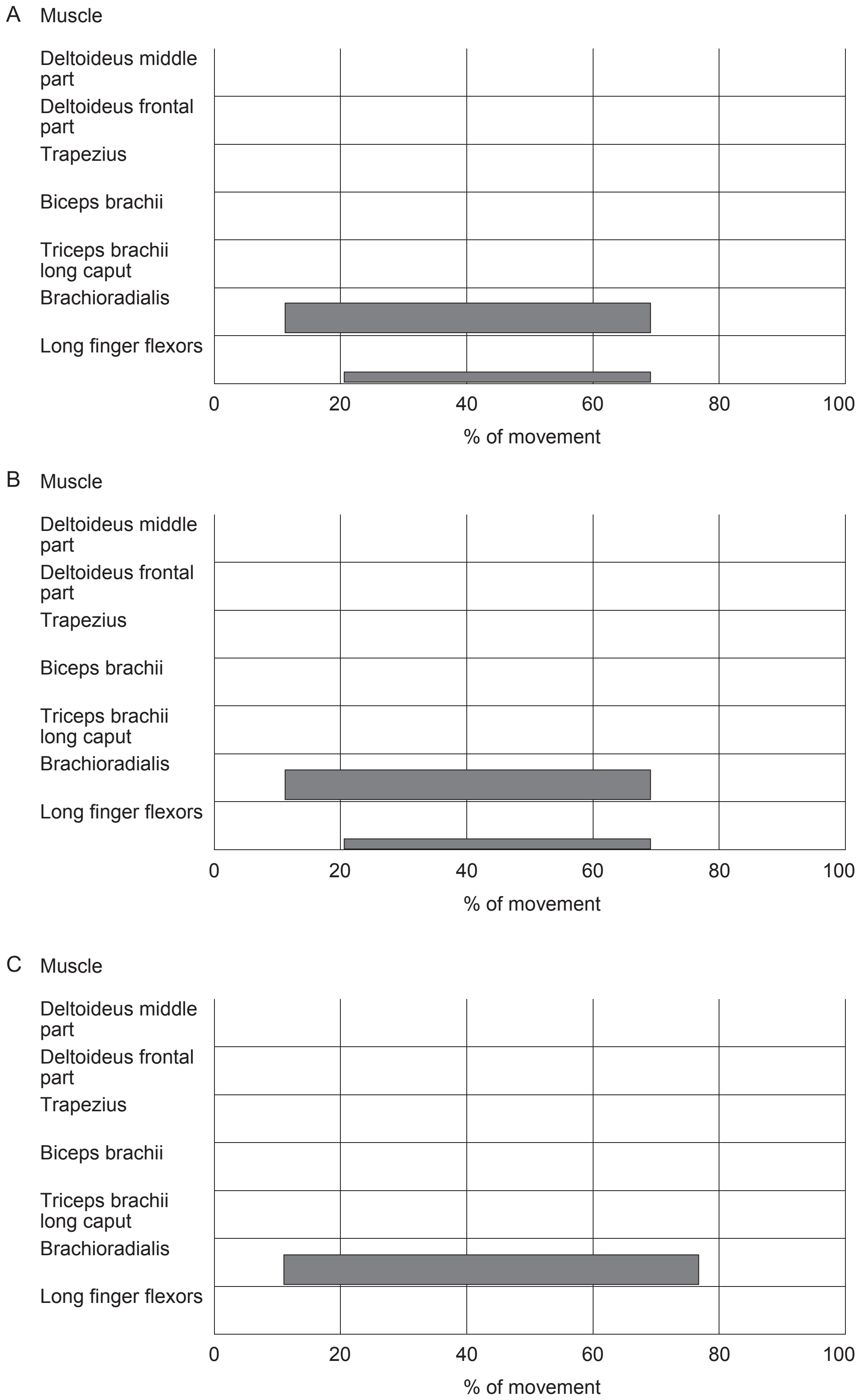

Fig.7. Timing EMG activity chart for Task5. A) “Young” group. B) “Middle” group. C) “Old” group

Table 1. Ranges of motion in wrist, elbow and shoulder motion in sagittal, frontal and transversal plane during five simple motor tasks. Angles in degrees. In Task 4 negative values represent range in supination motion, positive in pronation motion

	Shoulder			Elbow			Wrist		
	Sagittal	Frontal	Transv	Sagittal	Frontal	Transv	Sagittal	Frontal	Transv
Task 1									
young	80 ± 20	35 ± 20	80 ± 15	0	0	60 ± 20	0	0	0
middle	80 ± 20	35 ± 10	80 ± 15	0	0	60 ± 20	0	0	0
old	70 ± 20	35 ± 10	70 ± 15	0	0	40 ± 20	0	0	0
Task 2									
young	60 ± 15	60 ± 10	40 ± 10	0	0	0	0	0	0
middle	55 ± 20	60 ± 10	40 ± 10	0	0	35 ± 10	0	0	0
old	55 ± 20	45 ± 10	35 ± 10	0	0	15 ± 5	0	0	0
Task 3									
young	0	0	0	140 ± 20	60 ± 20	110 ± 20	10 ± 5	10 ± 5	5 ± 5
middle	0	0	0	140 ± 20	40 ± 20	100 ± 20	0	0	0
old	0	0	0	140 ± 20	40 ± 20	100 ± 30	20 ± 10	20 ± 10	10 ± 10
Task 4									
young	0	0	0	0	0	-60 / 20 ± 20	-5/10 ± 5	0	0
middle	0	0	0	0	0	-60 / 20 ± 20	0	0	0
old	0	0	0	0	0	-80 / 20 ± 20	0	0	0
Task 5									
young	0	0	40 ± 10	0	0	0	65 ± 20	50 ± 20	40 ± 20
middle	0	0	35 ± 10	0	0	0	60 ± 20	50 ± 20	40 ± 10
old	0	0	20 ± 10	0	0	0	45 ± 20	40 ± 15	10 ± 5

During Task 2 the same three muscles were active, but only the frontal part of deltoid was similarly active in all three age groups: from 10 to 80% of the motor task. In the young group the middle part of the deltoid was active for 10 to 70% of the motor task, and the trapezius from 10 to 60%. In the middle age group the middle part of the deltoid was active for a shorter time, from 20 to 70%, while trapezius was active longer: from 10 to 80%. In the oldest group all three muscles were active for the same time: from 10 to 80% of the motor task.

During Task 3 in all three groups only two muscles were active: the biceps brachii and brachioradialis. In the young and middle groups they were active for 40 to 60% of the motor task, and in the oldest group 30 to 65 and 70% respectively.

Task 4 revealed the largest differences between the age groups. The youngest subjects performed the task using the middle part of the deltoid for 50 to 100% of the motor task, the biceps brachii and long head of the triceps brachii for 20 to 50%, the brachioradialis for 0 to 50%, and long finger flexors in two bursts of activity: the first for 10 to 30%, and the second for 50 to 80% of the motor task. In the middle age group the timing of activity of the middle part of the deltoid and long finger flexors was the same. The biceps was active for a shorter time: for 20 to 40% of the motor task, similarly to the brachioradialis: for 10 to 35%. the triceps brachii had two bursts of activity, the first for 20 to 40%, the second for 60 to 90%. In this group also the frontal part of the deltoid muscle was active for 60 to 90% of the motor task. The oldest subjects performed the task using only three groups of muscles: the biceps brachii and triceps brachii for 20 to 40% of the motor task, and the long finger flexors for 10 to 40%.

During Task 5 the young and middle groups used the brachioradialis for 10 to 70% of the motor task, and the long finger flexors for 20 to 70%, while the oldest subjects used only the brachioradialis for 10 to 75% of the motor task.

The ranges of movement show that ranges of motion of the joints in the oldest subjects tend to be smaller than in younger groups, and in some cases (Tasks 2, 3 and 4) in the wrist joint the movements are performed in a slightly different manner between the groups. This could explain the differences in the timing of EMG activity of the muscles between the age groups.

The limitation of the study is use of the relative movements of the upper extremity segments defined by the markers placed on them. The anatomy and thus movements of the wrist, elbow, and most of all shoulder joints are much more complicated and require much more advanced models and markers set-ups [8]. These models enable much better measurement of real ranges of motion, but their application in clinical settings on quite often greatly affected patients is to date impossible. Therefore such simplistic models with established reference databases can be of value in clinical environments.

A limitation of the study is the number of subjects. The exclusion criteria made the recruitment of more healthy subjects difficult. The statistical power was between 60 and 75%.

Neurological patients demonstrate a variety of abnormal activation patterns. For example, stroke patients unintentionally activate the muscle of one limb while the homologous part of the second limb is moving. This phenomenon is called global synkinesis, and it could also occur in other groups of neurologically affected patients [7]. Most neurological problems, such as cerebral palsy, stroke, or brain damage, are characterized by abnormal motor control, spasticity, and lack of selectivity (these problems influence the abilities of the patients). Surface EMG is a relatively easy technique which could be used for the assessment of the functional status of the patient's upper extremities. Its non-invasiveness enables its frequent use during rehabilitative treatment, and thus monitoring of the patient's progress (or deterioration).

Our results are difficult to compare with the results presented in other papers, due to different methodology. Wickham et al. presented their results as the % of MVC (maximal voluntary contraction), their subjects were standing, and the timing of EMG activity charts was dependent on the shoulder angle [17]. Standing position and normalization of the muscular activity on the MVC are limiting factors for many neurological subjects. Many of them cannot stand or can stand only for a short period of time and with a lot of effort, and distorted motor control makes the normalization of MVC impossible. The use of surface electrodes only limits the number of muscles for which activity could be recorded, but it is much easier in everyday clinical work, and does not raise more critical ethical issues.

The tasks performed by subjects are easy to explain and do not require any special equipment (which is necessary in some studies) [1, 6]. Moreover, as they are not complicated, even patients with severe functional deficits could try to perform them. Also the inability of the patient to stand is not a limiting factor.

Conflict of interest: Authors state no conflict of interest.

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Received 28.02.2017
Accepted 06.10.2017

Acknowledgments

This study was supported by the research grant 404 02732/0521 of Polish Ministry of Science and Higher Education.