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Normalizing shoulder EMG: an optimal set of maximum isometric voluntary contraction tests considering reproducibility

Cédric Schwartz [1] (*), François Tubez [1,2], François-Charles Wang [3], Jean-Louis Croisier [1,2], Olivier Brüls [1,4], Vincent Denoël [1,5], Bénédicte Forthomme [1,2]

1. Laboratoire d'Analyse du Mouvement Humain, University of Liège, Liège, Belgium
2. Department of Physical Medicine and Rehabilitation, University of Liège, Liège, Belgium
3. Department of Physical Medicine and Sports Traumatology, University Hospital of Liège, Liège, Belgium
4. Department of Aerospace and Mechanical Engineering, University of Liège, Liège, Belgium
5. Department of Architecture, Geology, Environment and Constructions, University of Liège, Liège, Belgium

(*) Corresponding author

Abstract

Normalization of the electromyography (EMG) signal is often performed relatively to maximal voluntary activations (MVA) obtained during maximum isometric voluntary contraction (MVIC). The first aim was to provide an inter-session reproducible protocol to normalize the signal of eight shoulder muscles. The protocol should also lead to a level of activation >90% of MVA for >90% of the volunteers. The second aim was to evaluate the influence of the method used to extract the MVA from the EMG envelope on the normalized EMG signal. Thirteen volunteers performed 12 MVICs twice (one-week interval). Several time constants (100 ms to 2 s) were compared when extracting the MVA from the EMG envelope. The EMG activity was also acquired during an arm elevation. Our results show that a combination of nine MVIC tests was required to meet our requirements including reproducibility. Both the number of MVIC tests and the size of the time constant influence the normalized EMG signal during the dynamic activity (variations up to 15%). A time constant of 1 s was a good compromise to extract the MVA. These findings are valuable to improve the reproducibility of EMG signal normalization.

1 Introduction

The shoulder muscles play an important part in the stability of the shoulder joint and are involved in shoulder related pathologies. Electromyography (EMG) is a common tool to evaluate the muscle contraction intensity (De Luca, 1993). There is, however, no unequivocal relationship between the amplitude of the electrical signal and the force exerted by the muscle because of intrinsic and extrinsic factors (Halaki and Ginn, 2012). Consequently, electromyographic recordings need to be normalized if comparisons between subjects or of one subject at different times are sought. Several methods have been used to normalize the EMG signal (including maximal and submaximal contractions). The reader can refer to (Burden, 2010) and (Halaki and Ginn, 2012) for more insights concerning the advantages and disadvantages of each method. Rather than expressing the EMG signal relatively to a reference EMG activation, the EMG signal is also sometimes expressed relatively to the maximal voluntary contraction (force) using a power regression model derived from the measurements made during a ramp procedure (Mathiassen et al., 1995). Maximum voluntary isometric contractions (MVIC) are commonly used (Burden, 2010) because it allows to compare muscle activity levels between muscles, tasks and individuals (Halaki and Ginn, 2012).

A key factor to use EMG evaluations for rehabilitation or clinical trials is the ability to obtain reliable measurements over time. Previous studies on the normalization of the EMG signal of the shoulder have mainly focused on the tests leading to maximal activations (Boettcher et al., 2008; Castelein et al., 2015; Dal Maso et al., 2016; Ekstrom et al., 2005). To our knowledge, little has been done to evaluate the reproducibility of the normalization procedures. Ekstrom et al. showed that a good intra-session repeatability can be expected (Ekstrom et al., 2005). Power regression procedures present a lower intra-day repeatability than a maximal voluntary activation (MVA) (Bao et al., 1995). However, and despite its importance, no studies have investigated the inter-session repeatability of the MVA determination.

The raw EMG signal is usually not directly used and is first post-processed to obtain the signal linear envelope (i.e. Root Mean Square - RMS, Low Pass filtering, …). As demonstrated by Fischer et al. for the deltoid muscle during a sub-maximal exertion, the method used to extract the peak activation from the EMG envelope influences the intra-session repeatability (Fischer et al., 2010). The influence of these choices on the inter-session repeatability of the normalization procedure has not been evaluated yet. Furthermore, it should be underlined that no consensus exists on how the MVA should then be extracted from the EMG envelope and the exact process varies from one author to another.

The first objective of this study was to test the inter-session reproducibility of several combinations of MVIC tests. The second objective was to evaluate the influence of some MVA peak extraction techniques on the reproducibility. In addition to these two main goals, the influence of the choice of the retained MVIC tests and of the MVA peak extraction technique on the interpretation of the muscle level of activity was evaluated during arm elevation.

2 Material and methods

2.1 Participants

Thirteen male volunteers (25.3 ± 3.7 years, 76.2 ± 11.5 kg, 1.80 ± 0.05 m) were recruited. None of them had a painful shoulder or a history of surgery or injury at their dominant (tested) shoulder. The study was approved by the local ethics committee and each participant was informed of the details of the study and provided signed consent before participation.

2.2 Instrumentation

The EMG signal was collected with Trigno Standard and Trigno Mini sensors (Delsys, Boston, MA, USA) using silver-contact wireless bipolar bar electrodes with fixed 10 mm inter-electrode spacing. Eight of the main superficial muscles of the shoulder were investigated: upper and lower trapezius, serratus anterior, pectoralis major, latissimus dorsi, anterior and middle deltoid and infraspinatus. This set of muscles includes a major motor muscle of the shoulder (deltoid) as well as agonist and antagonist rotators of the shoulder (pectoralis major, latissimus dorsi, infraspinatus). Scapula stabilizer muscles (trapezius, serratus anterior), which are key muscles for studying scapular dyskinesis, are also included. Data was acquired at a sample frequency of 1000 Hz. Surface electrodes were positioned following Barbero et al. recommendations (Barbero et al., 2012).

The kinematics of the arm was measured using a 3D optoelectronic system (Charnwood Dynamics, Rothley, UK) composed of four CX1 units and two active (infrared) markers. Each CX1 alone is able to evaluate the 3D position of a marker. Using several units improve the overall accuracy of the measurements (Schwartz et al., 2015). This 3D system has been shown to be an accurate evaluation tool (Schwartz et al., 2015). The 2 markers were placed 3 cm below the roof of the acromion and on the lateral humeral epicondyle. Data was acquired at 100 Hz.

2.3 MVIC tests

Twelve MVIC tests were used in this study as described in Table 1 and illustrated in Figure 1. To limit a possible influence of the investigator, the MVIC test positions were maintained using a steel structure rather than manual pressure. It was possible to adapt the structure to both the test positions and the specific size of the volunteers. Before starting the MVIC tests, the volunteers performed a warm-up composed of 15 elevations in the sagittal and frontal planes, 15 abductions in the horizontal plane and finally 15 internal and external rotations with an elastic band. Before each test position, the volunteers were asked to perform three increasing sub-maximum trials to get used to the exercise and effort. Then, three trials of 5 s were performed for each test position. The volunteers were asked to increase the exerted force during the first two seconds and maintain maximal force during the last three seconds. During the trials, the volunteers were given verbal encouragement. To avoid fatigue, a minimum of 30 s and 3 min rest intervals were provided between each trial and each MVIC test position respectively. The order of the positions was randomized across the volunteers.

Table 1: Description of the Maximum Voluntary Isometric Contraction (MVIC) tests.

Id	Name	Position	Description
1	Empty can *(Dal Maso et al., 2016)*	Seated	Shoulder abducted at 90° in the scapular plane, internally rotated and elbow extended. Arm abduction with resistance applied at the wrist.
2	Extension prone (*Park and Yoo, 2013)*	Prone	Arm along the body. Arm extension with resistance applied at the wrist.
3	Seated U 90° *(Kelly et al., 1996)*	Seated	Arm flexed at 90°. Arm flexion with resistance applied at the elbow.
4	Palm press *(Boettcher et al., 2008)*	Seated	Arms flexed at 90°. Arms horizontal adduction with resistance applied at the hands.
5	Prone V-thumbs up *(Castelein et al., 2015)*	Prone	Arm flexed and in line with lower trapezius muscle fibers. Scapular retraction with resistance applied on the upper part of the scapular spine.
6	Pull down *(Park and Yoo, 2013)*	Seated	Arm abducted at 90° and elbow flexed at 90°. Arm adduction with resistance applied at the elbow.
7	Push forward *(Ekstrom et al., 2005)*	Prone	Arm flexed at 90° with forearm extended. Scapular protraction with resistance applied at the hand.
8	Rotation 0° *(Boettcher et al., 2008)*	Seated	Arm along the side with elbow flexed at 90°. Arm external rotation with resistance applied at the wrist.
9	Rotation 90° *(Johnson et al., 2011)*	Seated	Shoulder abducted at 90° and externally rotated at 45° and elbow flexed at 90°. Arm external rotation with resistance applied at the wrist.
10	Seated T *(Castelein et al., 2015)*	Seated	Arm abducted at 90°. Arm abduction with resistance applied at the elbow.
11	Seated U 125° *(Boettcher et al., 2008)*	Seated	Arm flexed at 125°. Arm flexion with resistance applied at the elbow.
12	Shoulder shrug *(Ekstrom et al., 2005)*	Seated	Arm along the side. Scapular elevation with resistance applied at the acromion.

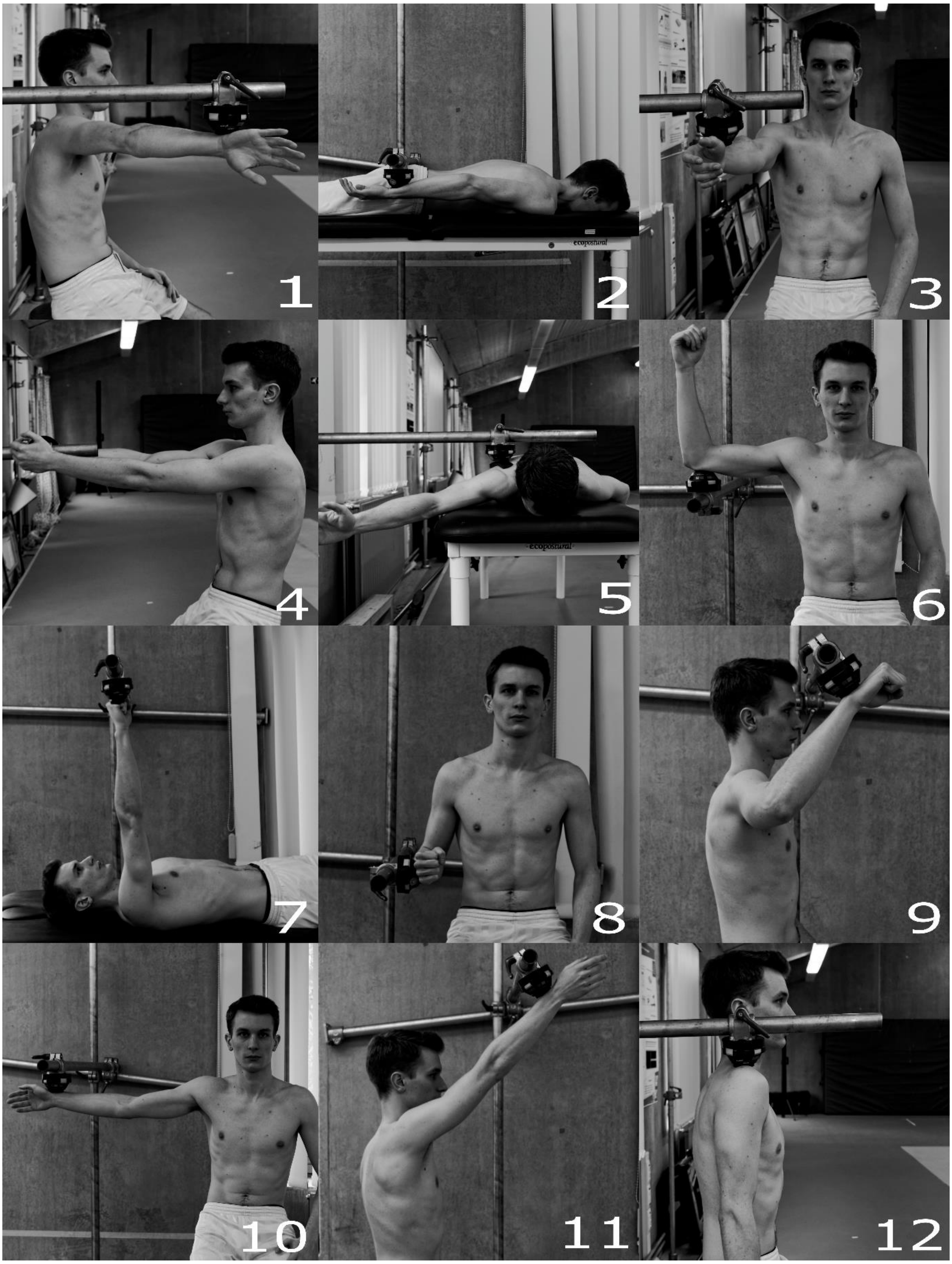

Figure 1: Illustration of the Maximum Voluntary Isometric Contraction tests: (1) empty can, (2) extension prone, (3) seated U 90°, (4) palm press, (5) prone V-thumb up, (6) pull down, (7) push forward, (8) rotation 0°, (9) rotation 90°, (10) seated T, (11) seated U 125°, (12) shoulder shrug.

To evaluate the repeatability of the MVA estimations, the volunteers were evaluated again with the same protocol (same MVIC tests order than during the first session) seven days after the first test.

2.4 Kinematics tests

The volunteers were asked to perform five consecutive arm elevations in the scapular plane on their dominant side at a self-selected speed. The mean arm elevation speed was 87.5 +/- 30.2 °/s. The volunteers moved actively their arm up to their maximal range of motion. They were also asked to avoid thoracic compensation when maximal amplitude was reached. A vertical bar served as a guide during the arm raising and lowering. The kinematic tests were only performed during the first evaluation session.

2.5 Signal and statistical analyses

The EMG signal was first band pass filtered (20 - 500 Hz, zero-phase 4th order Butterworth) and then processed using a root-mean-square algorithm (100 ms moving window) (Castelein et al., 2015). Then, the average EMG envelope over a time window (moving average filter) was calculated during each MVIC trial for each muscle. Four window sizes were tested: 100 ms, 500 ms, 1 s and 2 s. The activation level of each muscle was then defined as the peak value of the processed signal among the three trials. The muscle activation level during each MVIC trial was then expressed as a percentage of the MVA found among all the MVIC trials.

The optimal combinations of MVIC tests for the two following acceptance criteria were investigated. Criterion 1 consisted in finding the minimal number of MVIC tests necessary to obtain a muscle activation level >90% MVA for at least 90% of the volunteers (same as in (Dal Maso et al., 2016)). Criterion 2 consisted in the same requirements as criterion 1 plus a defined inter-session reproducibility (variations inferior to 5% of MVA). The reproducibility (variation between pre- and post-tests results) was based on a Bland and Altman approach. Bland and Altman's approach plot "the individual subject differences between the tests against the respective individual means" (Atkinson and Nevill, 1998). The 90% limits of agreement were computed. Then, the maximum of the absolute value of the upper and lower bounds of the limits of agreement was kept (a measure of 'total error' (Atkinson and Nevill, 1998)). This approach ensures that, for at least 90% of the volunteers, an activation level difference <5% of MVA between the pre- and post-tests can be expected. The systematic procedure described by Dal Maso et al. (Dal Maso et al., 2016) was then used to identify the optimal combinations. Dal Maso's procedure consists in systematically testing all combinations of MVIC tests. With 12 MVIC tests, a total of 4095 combinations is possible. If several combinations were found that met the criterion, the combination which required the smallest number of tests and then which was valid for the largest number of volunteers was retained. The same procedure was also applied to all muscle combinations which led to a total of more than 1 million tested situations. One should however remain aware that, due to the size of the population and the substantial number of combinations, these supplementary results may be partially biased.

A combination of 4 normalization tests (4NT) based on Boettcher et al. recommendation (Boettcher et al., 2008) – palm press, empty can, seated U 125 and internal rotation 90° - was taken as a reference. The “internal rotation 90°” test from (Boettcher et al., 2008) was however replaced by the “extension prone” test from (Park and Yoo, 2013). Indeed, the “internal rotation 90°” test was performed to evaluate the MVA of the upper and lower subscapularis muscle, which was not evaluated in the present study as only surface EMG sensors were used.

The elevation of the arm was expressed with respect to the laboratory reference frame. The EMG signals were normalized with the values obtained during the MVIC tests and then expressed relatively to humeral motion and percentage of movement (arm raising: 0 to 100%; arm lowering: 100 to 0%). For each subject, the kinematic and EMG data were average over the five repetitions of the dynamic trial.

3 Results

3.1 Optimal combination of MVIC tests for MVA

Two single tests (palm press and extension prone) met criterion 1 (for major pectoralis and latissimus dorsi respectively) (Figure 2). Two to four tests were needed to meet criterion 1 for the other individual muscles (Table 2). Additional tests (between one and five) were needed to meet criterion 2. When criterion 2 was met, all the volunteers achieved a level of muscle activation equal to 100% of MVA. Nine MVIC normalization tests (9NT: empty can, extension prone, seated U 90°, palm press, prone V-thumb up, rotation 0°, rotation 90°, seated T, seated U 125°) were needed to meet criteria 1 and 2 for all the eight muscles. The combination of MVIC tests needed to meet criterion 1 or 2 for a specific combination of muscles can be found in the supplementary file S1.

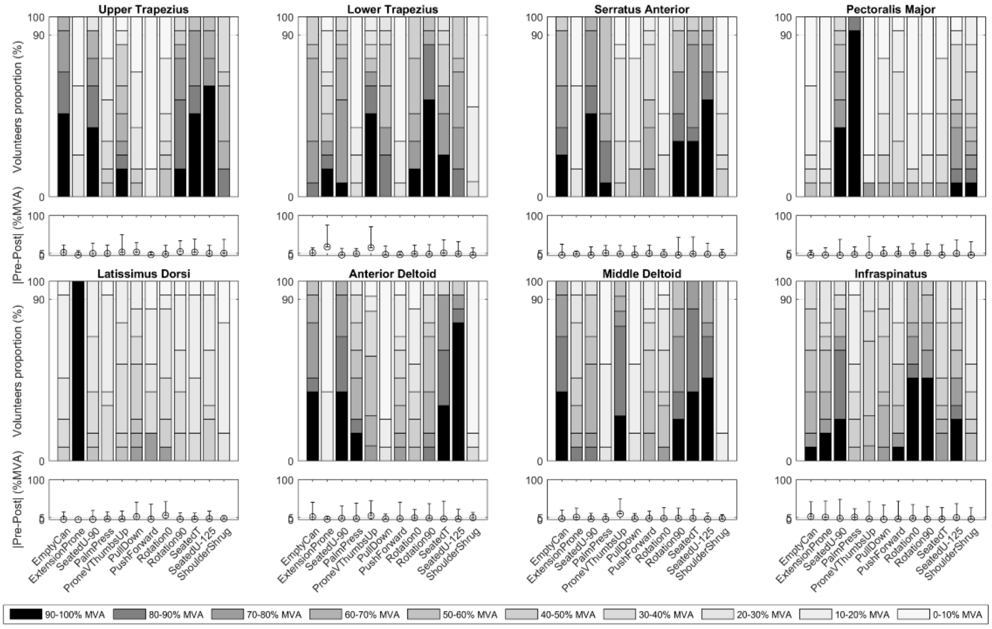

Figure 2: Level of muscles maximal voluntary activation and reproducibility during individual isometric tests. The stacked bars represent the percentage of volunteers within activation level ranges of 10%. The error bars represent the absolute value of the difference (and 90% confidence interval) of normalized activation between the pre- and post-tests.

Table 2: Combination of MVIC tests meeting criterion 1 (minimum number of MVIC tests for > 90% MVA for > 90% volunteers) and criterion 2 (criterion 1 plus a difference of muscle activation < 5% MVA between pre- and post-tests for 90% of the volunteers). Size of the window of the moving average filter: 1 s. MVIC: Maximum Voluntary Isometric Contraction. (1) empty can, (2) extension prone, (3) seated U 90°, (4) palm press, (5) prone V-thumb up, (6) pull down, (7) push forward, (8) rotation 0°, (9) rotation 90°, (10) seated T, (11) seated U 125°, (12) shoulder shrug.

	Criterion 1				**Criterion 2**			
Muscles	*MVIC tests*	*# of subjects (%)*	*Level of activation (% MVA)*	*Variation (% MVA)*	*MVIC tests*	*# of subjects (%)*	*Level of activation (% MVA)*	*Variation (% MVA)*
Upper Trapezius	1 3 5 11	92	99	14.0	1 3 5 10 11	100	100	0.5
Lower Trapezius	5 9	92	98	8.8	3 5 9 10	100	100	0.9
Seratus Anterior	3 10 11	100	99	7.8	3 4 9 10 11	100	100	3.7
Pectoralis Major	4	92	98	21.2	3 4	100	100	0.3
Latissimus Dorsi	2	100	100	0.0	2	100	100	0.0
Anterior Deltoid	10 11	92	97	15.3	3 4 10 11	100	100	4.5
Middle Deltoid	1 10 11	100	99	5.7	1 5 10 11	100	100	0.0
Infraspinatus	2 3 8 9	92	98	12.3	2 3 8 9 11	100	100	1.2
All muscles	1 2 3 4 5 8 9 10 11	100	100	1.2	1 2 3 4 5 8 9 10 11	100	100	1.2

Contrary to the 9NT combination, the 4NT combination met only criterion 1 for three of the eight muscles (pectoralis major, latissimus dorsi and anterior deltoid) (Figure 3). For other muscles, between 15% (lower trapezius) and 77% (upper trapezius, middle deltoid) of the volunteers achieved 90% of the MVA. The reproducibility, as defined in this study, was as large as 40% of MVA (lower trapezius). This means that during the re-test, 10% of the volunteers had a variation of the muscle level of activity larger than 40% of MVA when using the 4NT combination.

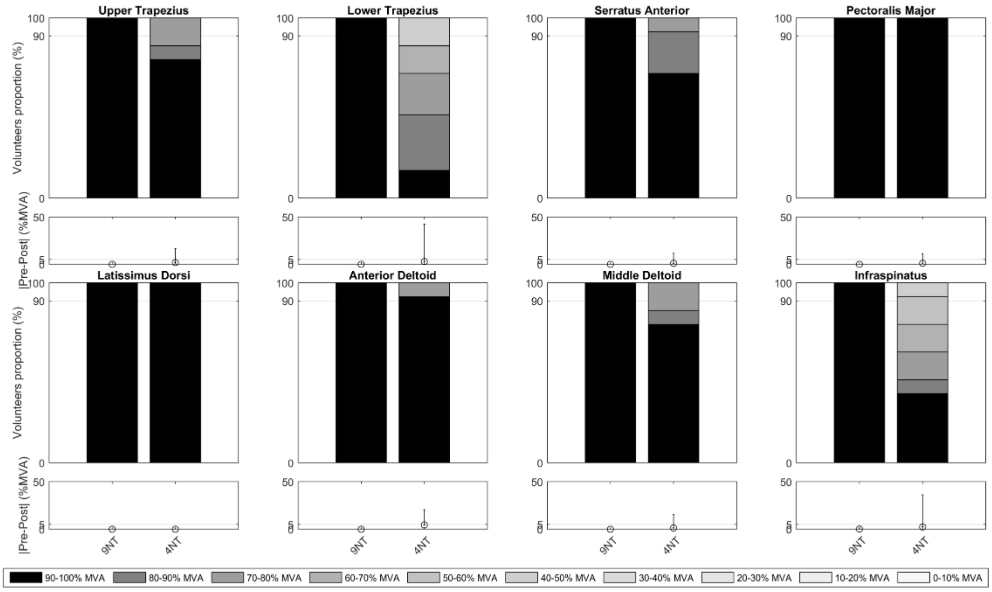

Figure 3: Level of muscles maximal voluntary activation and reproducibility expressed as a fraction of the Maximum Voluntary Activation (MVA) achieved across either 9 tests (9NT: empty can, extension prone, seated U 90°, palm press, prone V-thumb up, rotation 0°, rotation 90°, seated T, seated U 125°) or 4 tests (4NT: empty can, extension prone, palm press, seated U 125°). The stacked bars represent the percentage of volunteers within activation level ranges of 10%. The error bars represent the absolute value of the difference (and 90% confidence interval) of activation between the pre- and post-tests.

Using either the 9NT combination or all the 12 MVIC tests led to similar muscle levels of activation during the raising and lowering of the arm in the scapular plane (Figure 4). Using only the 4NT combination led to an overestimation of the level of activation for several muscles including the lower trapezius (16% of MVA) and the middle deltoid (5% of MVA) muscles.

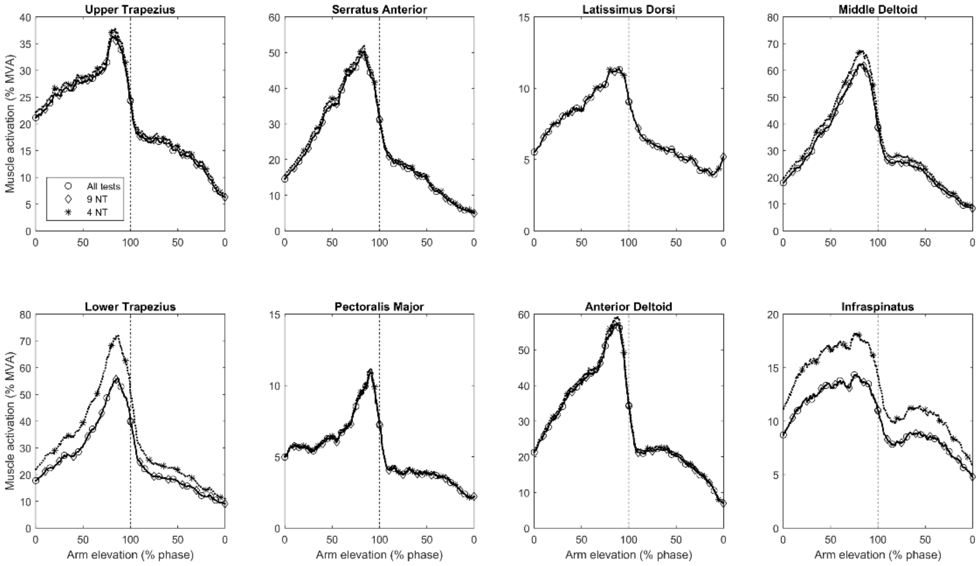

Figure 4: Level of muscle activation when raising and lowering the arm in the scapular plane expressed as a fraction of the Maximum Voluntary Activation (MVA) achieved across either 1/ all tests, 2/ 9 tests (9NT: empty can, extension prone, seated U 90°, palm press, prone V-thumb up, rotation 0°, rotation 90°, seated T, seated U 125°) or 3/ 4 tests (4NT: empty can, extension prone, palm press, seated U 125°). The motion is expressed relatively to the percentage of movement (100% being the maximal elevation).

3.2 Influence of the moving average filter on the MVA

When the size of the window used to perform the moving average filter to obtain the MVA was inferior to 1 s, 10 MVIC tests (and no longer nine) were needed to meet criteria 2 for all muscles (supplementary file S2).

The size of the window used for the moving average filter to evaluate the MVA had a strong influence on the estimation of the muscle level of activation during arm elevation. Increasing the size of the window increased the estimation of the level of activation of the muscles (Figure 5). For the upper trapezius, the maximal levels of activation were equal to 27% and 39% of MVA for the 100 ms and 2 s window sizes respectively. For the middle deltoid, the maximal levels of activation were equal to 50% and 65% of MVA for the 100 ms and 2 s window sizes respectively.

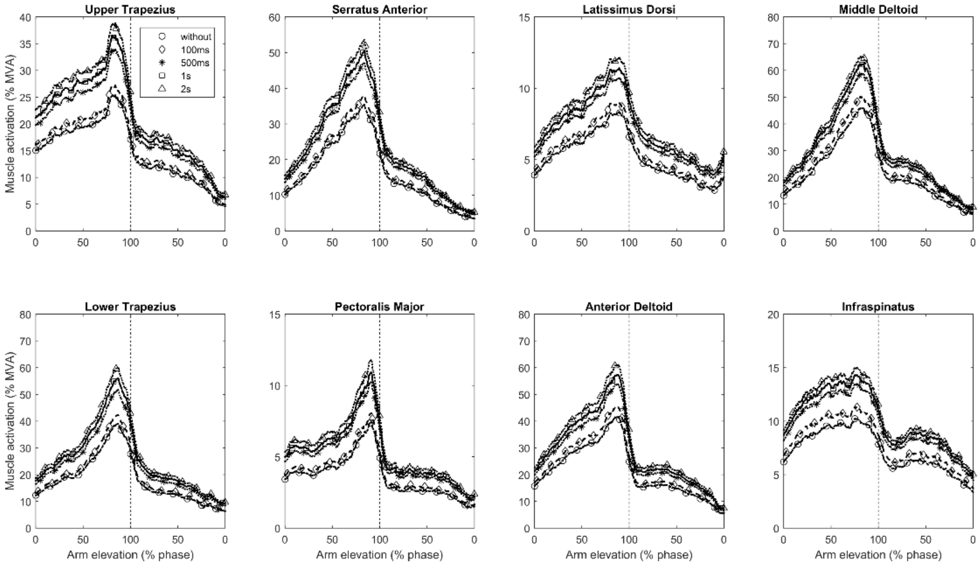

Figure 5: Level of muscle activation when raising and lowering the arm in the scapular plane expressed as a fraction of the Maximum Voluntary Activation (MVA) achieved across all tests. Averaging window size was equal to either: without additional filtering, 100 ms, 500 ms, 1 s or 2 s. The motion is expressed relatively to the percentage of movement (100% being the maximal elevation). The normalization of the muscle activation is performed using all the MVIC tests.

4 Discussion

The normalization of the EMG signal is mandatory when comparison between subjects or trials is needed. Previous studies which identified optimal combinations of MVIC tests to obtain the MVA of shoulder muscles did not consider the inter-session reproducibility in the procedure. This contribution is of importance as it will contribute to the definition of modalities able to evaluate the effect, over time, of clinical interventions on the muscle activation patterns. Another aim was to provide a preliminary evaluation of the influence of the EMG signal processing on the MVA estimation and to show that recommendations are needed to improve the possibility to compare studies in the literature.

4.1 Optimal combination of MVIC tests for MVA

As stated by Boettcher et al. (Boettcher et al., 2008), the community of EMG users would benefit from a standardization of the protocol used to normalize EMG data. Indeed, results normalized using different protocols may not be comparable. Moreover, the overestimation of the level of activity of a muscle may complexify the clinical interpretation of some results. Our data during an elevation of the arm in the scapular plane demonstrated, for two protocols, that variations of 15% of MVA can be expected for some muscles.

Performing MVIC tests is both time consuming and may induce fatigue. There is consequently a large consensus in the literature that an optimal set of MVIC tests containing a limited number of tests should be identified. As underlined in Boettcher's study (Boettcher et al., 2008), we found that single MVIC tests usually activate several muscles. Recording all muscle signals for all the MVIC tests is therefore recommended. Several combinations have been proposed in the literature. Kelly et al. (Kelly et al., 1996), for eight shoulder muscles, and Boettcher et al. (Boettcher et al., 2008), for 13 shoulder muscles, identified combinations of four tests. Castelein et al. (Castelein et al., 2015), for seven shoulder muscles, described a combination of five tests. Ekstrom et al. (Ekstrom et al., 2005) described two to three tests for each of the 4 muscles they studied. Even if some authors (Castelein et al., 2015; Ekstrom et al., 2005) reported the number of volunteers in which the muscle produced MVA, this information was not considered as a primary criterion for the choice of a combination of tests in most studies. Adding this criterion (Dal Maso et al., 2016) led to propositions including two to six MVIC tests per muscle. For all the 12 muscles, 12 MVIC tests were needed to obtain more than 90% of MVA for more than 90% of the volunteers. For eight muscles and the same criterion, we found that one to four tests were needed for each muscle and nine tests for all of them (empty can, extension prone, seated U 90°, palm press, prone V-thumb up, rotation 0°, rotation 90°, seated T, seated U 125°). Our results therefore confirm that four to five tests are probably not enough to obtain a MVA for most of the volunteers.

Boettcher et al. (Boettcher et al., 2008) found that the "internal rotation 90°" test maximally activate the latissimus dorsi muscle. However, similar results were not obtained in the present study. Similarly, four MVIC tests were found to be necessary in Dal Maso's study (Dal Maso et al., 2016) but none of them were the "internal rotation 90°" test. The "extension prone" test was found to generate a large activation of the latissimus dorsi muscle (Park and Yoo, 2013) but was not evaluated in Dal Maso's study (Dal Maso et al., 2016). Our results showed that this test alone is sufficient to obtain a MVA of the latissimus dorsi muscle. This test seems therefore a valuable addition to an optimal set of MVIC tests. On the contrary, the "pull down", "push forward" and "shoulder shrug" tests were not used in any combination and should not be favoured.

The reproducibility of the EMG evaluation has been studied in the literature but less has been done concerning the specific reproducibility of the MVA evaluations. Fauth et al. (Fauth et al., 2010) found relatively good inter-session reliability (mean Intra Class Correlation – ICC- ranging from 0.69 to 0.99) for lower limb muscles. Ekstrom et al. (Ekstrom et al., 2005) found a good intra-session reliability (ICC ranging from 0.91 to 0.96 for the recommended MVIC tests). To our knowledge, no specific study has specifically investigated the inter-session reproducibility of the shoulder muscles MVA evaluation. Moreover, a limitation of the ICC statistic is the difficulty to define a clear threshold for what should be an acceptable reproducibility (Atkinson and Nevill, 1998). The approach we chose, based on Bland and Altman plot (Bartlett and Frost, 2008), has the advantage to define a threshold that has a clinical meaning: the test re-test difference of the muscle level of activation should not be larger than 5% of MVA for 90% of the volunteers. Adding this criterion led to an increase of the number of MVIC tests needed to evaluate individual muscles (one to five MVIC tests). The increase was however limited and the same nine MVIC combination (9NT) was still valid for all the muscles. As the cost to obtain a consistent reproducibility in terms of time is limited, we would recommend to take this variable into account in the future when defining a set of MVIC tests.

Numerous MVIC test positions have been evaluated in the literature (Boettcher et al., 2008; Castelein et al., 2015; Dal Maso et al., 2016; Ekstrom et al., 2005; Park and Yoo, 2013) and all were not tested in the present study. It is therefore conceivable that a better combination of MVIC tests exists. The present study was performed on young male adults and the optimal MVIC combination which is reported here may not be optimal for other populations. Morphological differences, such as the thickness of the adipose tissue in females or older populations, may modify the diffusion of the EMG signal and consequently reduce its amplitude and increase cross talk (Lowery et al., 2001). Moreover, clinical interventions may modify the muscle activation patterns of the patients. One should therefore remain careful when extrapolating the results of reproducibility obtained in this study to other contexts. Eight superficial muscles were evaluated in this study and our conclusions cannot be extended to the other shoulder muscles. Bilateral testing may provide a way to get larger muscle activations (even if the same forces are exerted (Bao et al., 1995)). Indeed, Fischer et al. (Fischer et al., 2011) showed that bilateral exertion tests lead to an increase of the upper trapezius and supraspinatus muscle of approximately 15%. Similar results were obtained by Bao et al. for the upper trapezius (Bao et al., 1995). Furthermore, bilateral testing represents a gain of time when evaluating both the dominant and the non-dominant shoulder.

4.2 Influence of the moving average filter on the MVA

Whereas the matter of the choice of the combination of MVIC tests has been raised in the literature, little has been done concerning the influence of the processing of the signal to obtain the MVA value. The usual procedure consists in two steps: 1/ the EMG signal is processed similarly as during the dynamic (or static) evaluations (i.e. RMS extraction of the EMG linear envelope); this step was not studied in the present study but some indications can be found in (Fischer et al., 2010) 2/ the MVA may then be directly extracted from the envelope (peak value) (Burden, 2010) or defined as the mean peak of the signal further filtered using a moving average filter. The cutoff frequency of the filter is related to the window size (or time constant (Merletti and Torino, 2015)). Window sizes ranging from 2 to 3 s are commonly used in the literature (Castelein et al., 2015; Dal Maso et al., 2016; Ekstrom et al., 2005). In the present study, we used window sizes ranging from 100 ms (limited smoothing) to 2 s (large smoothing). The obtained results demonstrate that the choice of the size of the window can have a significant impact on the interpretation of the level of activation of the muscles as the level of activation can be multiplied by 1.5 between 100 ms and 2 s. These results show that comparison of EMG values between studies may not be always possible. Similar results were obtained for the deltoid muscle and different window sizes (Fischer et al., 2010). For the RMS approach, they found variations of 10% between the peak extraction methods. The effect of the size of the window is homogeneous among all the muscles, which was not the case concerning the choice of the combination of MVIC tests chosen for normalization. Along with the choice of the MVIC tests, physiological and anatomical factors (Halaki and Ginn, 2012), verbal encouragements and feedbacks (Fischer et al., 2010), the filtering choices may therefore also explain why some studies report activations level larger than 100% of MVA (Selkowitz et al., 2007).

It should however be noted that reduced filtering led to an increase of the MVIC tests needed to meet the criterion acceptance limits. For inter-session repeatability, our results showed that with window sizes smaller than 1 s, additional MVIC tests are needed. Fischer et al. (Fischer et al., 2010) identified that a 500 ms window size improves intra-session repeatability in comparison with a simple peak value extraction method. Based on Fischer's results (Fischer et al., 2010) on intra-session repeatability and ours on inter-session repeatability, a peak extraction technique based on moving average window with a window size comprises between 500 ms and 1 s seems reasonable. One should however remain aware that, when interpreting the normalized EMG signal, that the level of activation of the muscles will be overestimated. The influence of the post-processing on the evaluation of the MVA as reported in this study should be seen as preliminary. Indeed, other parameters such as the size of the RMS window, the number of trials considered, using a consecutive or non-consecutive (Dal Maso et al., 2016) window for moving average filtering should be further investigated before identifying a standardized procedure. The results of this study, however, emphasize the influence of this signal processing step on the final interpretation of the results and the possibility to compare studies.

5 Conclusion

Our results show that more than four or five MVIC tests are needed to obtain a reproducible MVA for all the studied shoulder muscles. A combination of nine MVIC tests was found to maximally activate eight shoulder muscles. One major output of this study is that the same combination of nine MVIC tests also provides a good inter-session reproducibility. For individual muscles, the reproducibility criterion imposes a few additional MVIC tests in comparison with previous recommendations. Our study also demonstrates that the process used to extract the MVA from the EMG envelope has a large effect on the estimation of the level of activation of the shoulder muscles during a dynamic gesture. These results emphasize the need to standardize the EMG signal normalization procedure.

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Supplementary file S1: For all combination of muscles, combination of MVIC tests meeting criterion 1 (minimum number of MVIC tests for > 90% MVA for > 90% volunteers) and criterion 2 (criterion 1 plus a difference of muscle activation < 5% MVA between pre- and post-tests for 90% of the volunteers). Size of the window of the moving average filter: 1 s. MVIC: Maximum Voluntary Isometric Contraction. (1) empty can, (2) extension prone, (3) seated U 90°, (4) palm press, (5) prone V-thumb up, (6) pull down, (7) push forward, (8) rotation 0°, (9) rotation 90°, (10) seated T, (11) seated U 125°, (12) shoulder shrug.

	90% of subjects - 90% of MVA				**90% of subjects - 90% of MVA - delta repro < 5%**			
Muscles' combinaison	*NT combination*	*# subjects (%)*	*Mean activation (% MVA)*	*Variation (% MVA)*	*NT combination*	*# subjects (%)*	*Mean activation (% MVA)*	*Variation (% MVA)*
1 muscle								
Upper Trapezius	1 3 5 11	92.3	98.7	14.0	1 3 5 10 11	100.0	100.0	0.5
Lower Trapezius	5 9	92.3	97.9	8.8	3 5 9 10	100.0	99.9	0.9
Seratus Anterior	3 10 11	100.0	98.9	7.8	3 4 9 10 11	100.0	99.6	3.7
Pectoralis Major	4	92.3	98.3	21.2	3 4	100.0	100.0	0.3
Latissimus Dorsi	2	100.0	100.0	0.0	2	100.0	100.0	0.0
Anterior Deltoid	10 11	92.3	96.5	15.3	3 4 10 11	100.0	99.9	4.5
Middle Deltoid	1 10 11	100.0	98.9	5.7	1 5 10 11	100.0	100.0	0.0
Infraspinatus	2 3 8 9	92.3	98.3	12.3	2 3 8 9 11	100.0	99.8	1.2
2 muscles								
Upper Trapezius, Lower Trapezius	1 5 9 11	92.3	97.9	14.1	1 3 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Seratus Anterior	1 3 10 11	92.3	98.3	11.5	1 3 5 9 10 11	100.0	99.4	4.1
Upper Trapezius, Pectoralis Major	1 3 4 5 11	92.3	98.7	14.0	1 3 4 5 10 11	100.0	100.0	0.5
Upper Trapezius, Latissimus Dorsi	1 2 3 5 11	92.3	98.7	14.0	1 2 3 5 10 11	100.0	100.0	0.5

Upper Trapezius, Anterior Deltoid	1 3 5 11	92.3	98.7	18.7	1 3 4 5 10 11	100.0	100.0	0.5
Upper Trapezius, Middle Deltoid	1 3 10 11	92.3	98.3	11.5	1 3 5 10 11	100.0	100.0	0.5
Upper Trapezius, Infraspinatus	1 3 5 8 9 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Seratus Anterior	3 5 9 10	92.3	95.8	25.4	3 4 5 9 10 11	100.0	99.6	3.7
Lower Trapezius, Pectoralis Major	4 5 9	92.3	97.9	21.2	3 4 5 9 10	100.0	99.9	0.9
Lower Trapezius, Latissimus Dorsi	2 5 9	92.3	97.9	8.8	2 3 5 9 10	100.0	99.9	0.2
Lower Trapezius, Anterior Deltoid	5 9 10 11	92.3	96.5	15.3	3 4 5 9 10 11	100.0	99.9	4.5
Lower Trapezius, Middle Deltoid	1 5 9 10 11	92.3	99.0	5.8	1 3 5 9 10 11	100.0	99.9	0.9
Lower Trapezius, Infraspinatus	2 3 5 8 9	92.3	98.3	12.3	2 3 5 8 9 10 11	100.0	99.8	1.2
Seratus Anterior, Pectoralis Major	4 10 11	92.3	98.7	13.8	3 4 9 10 11	100.0	99.6	3.7
Seratus Anterior, Latissimus Dorsi	2 3 10 11	100.0	98.9	7.8	2 3 4 9 10 11	100.0	99.6	3.7
Seratus Anterior, Anterior Deltoid	3 10 11	92.3	98.5	9.8	3 4 9 10 11	100.0	99.6	4.5
Seratus Anterior, Middle Deltoid	1 3 10 11	100.0	98.9	6.7	1 3 5 9 10 11	100.0	99.4	4.1
Seratus Anterior, Infraspinatus	3 8 9 10 11	92.3	97.0	17.2	2 3 4 8 9 10 11	100.0	99.6	3.7
Pectoralis Major, Latissimus Dorsi	2 4	92.3	98.3	21.2	2 3 4	100.0	100.0	0.3
Pectoralis Major, Anterior Deltoid	4 10 11	100.0	97.9	14.4	3 4 10 11	100.0	99.9	4.5
Pectoralis Major, Middle Deltoid	1 4 10 11	100.0	98.9	11.2	1 3 4 5 10 11	100.0	100.0	0.0
Pectoralis Major, Infraspinatus	2 3 4 8 9	92.3	98.3	12.3	2 3 4 8 9 11	100.0	99.8	1.2
Latissimus Dorsi, Anterior Deltoid	2 10 11	92.3	96.5	15.3	2 3 4 10 11	100.0	99.9	4.5
Latissimus Dorsi, Middle Deltoid	1 2 10 11	100.0	98.9	5.7	1 2 5 10 11	100.0	100.0	0.0
Latissimus Dorsi, Infraspinatus	2 3 8 9	92.3	98.3	12.3	2 3 8 9 11	100.0	99.8	1.2

Anterior Deltoid, Middle Deltoid	1 10 11	92.3	96.7	15.9	1 3 4 5 10 11	100.0	100.0	0.0
Anterior Deltoid, Infraspinatus	1 3 8 9 11	92.3	97.0	18.7	2 3 4 8 9 10 11	100.0	99.8	4.5
Middle Deltoid, Infraspinatus	1 3 8 9 10 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.8	1.2
3 muscles								
Upper Trapezius, Lower Trapezius, Seratus Anterior	3 5 9 10 11	92.3	97.2	14.3	1 3 5 9 10 11	100.0	99.4	4.1
Upper Trapezius, Lower Trapezius, Pectoralis Major	1 4 5 9 11	92.3	97.9	14.1	1 3 4 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Latissimus Dorsi	1 2 5 9 11	92.3	97.9	14.1	1 2 3 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Anterior Deltoid	5 9 10 11	92.3	96.5	15.3	1 3 4 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Middle Deltoid	1 5 9 10 11	92.3	99.0	5.8	1 3 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Infraspinatus	1 3 5 8 9 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Pectoralis Major	1 3 4 10 11	92.3	98.3	11.5	1 3 4 5 9 10 11	100.0	100.0	0.0
Upper Trapezius, Seratus Anterior, Latissimus Dorsi	1 2 3 10 11	92.3	98.3	11.5	1 2 3 5 9 10 11	100.0	99.4	4.1
Upper Trapezius, Seratus Anterior, Anterior Deltoid	1 3 10 11	92.3	98.3	11.5	1 3 4 5 9 10 11	100.0	100.0	0.0
Upper Trapezius, Seratus Anterior, Middle Deltoid	1 3 10 11	92.3	98.3	11.5	1 3 5 9 10 11	100.0	99.4	4.1
Upper Trapezius, Seratus Anterior, Infraspinatus	1 3 8 9 10 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.4	4.1
Upper Trapezius, Pectoralis Major, Latissimus Dorsi	1 2 3 4 5 11	92.3	98.7	14.0	1 2 3 4 5 10 11	100.0	100.0	0.5

Upper Trapezius, Pectoralis Major, Anterior Deltoid	1 3 4 5 11	92.3	98.7	16.7	1 3 4 5 10 11	100.0	100.0	0.5
Upper Trapezius, Pectoralis Major, Middle Deltoid	1 3 4 10 11	92.3	98.3	11.5	1 3 4 5 10 11	100.0	100.0	0.5
Upper Trapezius, Pectoralis Major, Infraspinatus	1 3 4 5 8 9 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Latissimus Dorsi, Anterior Deltoid	1 2 3 5 11	92.3	98.7	18.7	1 2 3 4 5 10 11	100.0	100.0	0.5
Upper Trapezius, Latissimus Dorsi, Middle Deltoid	1 2 3 10 11	92.3	98.3	11.5	1 2 3 5 10 11	100.0	100.0	0.5
Upper Trapezius, Latissimus Dorsi, Infraspinatus	1 2 3 5 8 9 11	92.3	98.7	13.5	1 2 3 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Anterior Deltoid, Middle Deltoid	1 3 10 11	92.3	98.3	11.5	1 3 4 5 10 11	100.0	100.0	0.5
Upper Trapezius, Anterior Deltoid, Infraspinatus	1 3 5 8 9 11	92.3	97.0	18.7	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Middle Deltoid, Infraspinatus	1 3 8 9 10 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Seratus Anterior, Pectoralis Major	4 5 9 10 11	92.3	98.8	12.0	3 4 5 9 10 11	100.0	99.6	3.7
Lower Trapezius, Seratus Anterior, Latissimus Dorsi	2 3 5 9 10	92.3	95.8	25.4	2 3 4 5 9 10 11	100.0	99.6	3.7
Lower Trapezius, Seratus Anterior, Anterior Deltoid	3 5 9 10 11	92.3	98.5	9.8	3 4 5 9 10 11	100.0	99.6	4.5
Lower Trapezius, Seratus Anterior, Middle Deltoid	1 3 5 9 10 11	100.0	99.4	4.1	1 3 5 9 10 11	100.0	99.4	4.1
Lower Trapezius, Seratus Anterior, Infraspinatus	3 5 8 9 10 11	92.3	97.0	17.2	2 3 4 5 8 9 10 11	100.0	99.6	3.7
Lower Trapezius, Pectoralis Major, Latissimus Dorsi	2 4 5 9	92.3	97.9	21.2	2 3 4 5 9 10	100.0	99.9	0.3
Lower Trapezius, Pectoralis Major, Anterior Deltoid	3 4 5 9 11	92.3	98.0	23.7	3 4 5 9 10 11	100.0	99.9	4.5

Lower Trapezius, Pectoralis Major, Middle Deltoid	1 4 5 9 10 11	92.3	99.0	11.2	1 3 4 5 9 10 11	100.0	99.9	0.9
Lower Trapezius, Pectoralis Major, Infraspinatus	2 3 4 5 8 9	92.3	98.3	12.3	2 3 4 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Latissimus Dorsi, Anterior Deltoid	2 5 9 10 11	92.3	96.5	15.3	2 3 4 5 9 10 11	100.0	99.9	4.5
Lower Trapezius, Latissimus Dorsi, Middle Deltoid	1 2 5 9 10 11	92.3	99.0	5.8	1 2 3 5 9 10 11	100.0	99.9	0.2
Lower Trapezius, Latissimus Dorsi, Infraspinatus	2 3 5 8 9	92.3	98.3	12.3	2 3 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Anterior Deltoid, Middle Deltoid	1 5 9 10 11	92.3	96.7	15.9	1 3 4 5 9 10 11	100.0	99.9	0.9
Lower Trapezius, Anterior Deltoid, Infraspinatus	1 3 5 8 9 11	92.3	97.0	18.7	2 3 4 5 8 9 10 11	100.0	99.8	4.5
Lower Trapezius, Middle Deltoid, Infraspinatus	1 3 5 8 9 10 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.8	1.2
Seratus Anterior, Pectoralis Major, Latissimus Dorsi	2 4 10 11	92.3	98.7	13.8	2 3 4 9 10 11	100.0	99.6	3.7
Seratus Anterior, Pectoralis Major, Anterior Deltoid	4 10 11	92.3	97.9	14.4	3 4 9 10 11	100.0	99.6	4.5
Seratus Anterior, Pectoralis Major, Middle Deltoid	1 4 10 11	92.3	98.9	11.2	1 3 4 5 9 10 11	100.0	100.0	0.0
Seratus Anterior, Pectoralis Major, Infraspinatus	3 4 8 9 10 11	92.3	97.0	17.2	2 3 4 8 9 10 11	100.0	99.6	3.7
Seratus Anterior, Latissimus Dorsi, Anterior Deltoid	2 3 10 11	92.3	98.5	9.8	2 3 4 9 10 11	100.0	99.6	4.5
Seratus Anterior, Latissimus Dorsi, Middle Deltoid	1 2 3 10 11	100.0	98.9	6.7	1 2 3 5 9 10 11	100.0	99.4	4.1
Seratus Anterior, Latissimus Dorsi, Infraspinatus	2 3 8 9 10	92.3	95.8	25.4	2 3 4 8 9 10 11	100.0	99.6	3.7
Seratus Anterior, Anterior Deltoid, Middle Deltoid	1 3 10 11	92.3	98.7	9.1	1 3 4 5 9 10 11	100.0	100.0	0.0

Seratus Anterior, Anterior Deltoid, Infraspinatus	3 8 9 10 11	92.3	97.0	17.2	2 3 4 8 9 10 11	100.0	99.6	4.5
Seratus Anterior, Middle Deltoid, Infraspinatus	1 3 8 9 10 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.4	4.1
Pectoralis Major, Latissimus Dorsi, Anterior Deltoid	2 4 10 11	100.0	97.9	14.4	2 3 4 10 11	100.0	99.9	4.5
Pectoralis Major, Latissimus Dorsi, Middle Deltoid	1 2 4 10 11	100.0	98.9	11.2	1 2 3 4 5 10 11	100.0	100.0	0.0
Pectoralis Major, Latissimus Dorsi, Infraspinatus	2 3 4 8 9	92.3	98.3	12.3	2 3 4 8 9 11	100.0	99.8	1.2
Pectoralis Major, Anterior Deltoid, Middle Deltoid	1 4 10 11	100.0	98.0	14.2	1 3 4 5 10 11	100.0	100.0	0.0
Pectoralis Major, Anterior Deltoid, Infraspinatus	3 4 8 9 11	92.3	97.0	25.3	2 3 4 8 9 10 11	100.0	99.8	4.5
Pectoralis Major, Middle Deltoid, Infraspinatus	1 3 4 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 10 11	92.3	96.7	15.9	1 2 3 4 5 10 11	100.0	100.0	0.0
Latissimus Dorsi, Anterior Deltoid, Infraspinatus	1 2 3 8 9 11	92.3	98.7	18.7	2 3 4 8 9 10 11	100.0	99.8	4.5
Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 8 9 10 11	100.0	99.0	5.2	1 2 3 5 8 9 10 11	100.0	99.8	1.2
Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
4 muscles								
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major	4 5 9 10 11	92.3	96.7	14.9	1 3 4 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Seratus Anterior, Latissimus Dorsi	2 3 5 9 10 11	92.3	97.2	14.3	1 2 3 5 9 10 11	100.0	99.4	4.1
Upper Trapezius, Lower Trapezius, Seratus Anterior, Anterior Deltoid	3 5 9 10 11	92.3	97.2	14.3	1 3 4 5 9 10 11	100.0	99.9	0.9

Upper Trapezius, Lower Trapezius, Seratus Anterior, Middle Deltoid	1 3 5 9 10 11	100.0	99.4	4.1	1 3 5 9 10 11	100.0	99.4	4.1
Upper Trapezius, Lower Trapezius, Seratus Anterior, Infraspinatus	3 5 8 9 10 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.4	4.1
Upper Trapezius, Lower Trapezius, Pectoralis Major, Latissimus Dorsi	1 2 4 5 9 11	92.3	97.9	14.1	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Pectoralis Major, Anterior Deltoid	1 4 5 9 11	92.3	97.1	20.5	1 3 4 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Pectoralis Major, Middle Deltoid	1 4 5 9 10 11	92.3	99.0	11.2	1 3 4 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Pectoralis Major, Infraspinatus	1 3 4 5 8 9 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Latissimus Dorsi, Anterior Deltoid	2 5 9 10 11	92.3	96.5	15.3	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Latissimus Dorsi, Middle Deltoid	1 2 5 9 10 11	92.3	99.0	5.8	1 2 3 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Latissimus Dorsi, Infraspinatus	1 2 3 5 8 9 11	92.3	98.7	13.5	1 2 3 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Anterior Deltoid, Middle Deltoid	1 5 9 10 11	92.3	96.7	15.9	1 3 4 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Anterior Deltoid, Infraspinatus	1 3 5 8 9 11	92.3	97.0	18.7	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Middle Deltoid, Infraspinatus	1 3 5 8 9 10 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi	1 2 3 4 10 11	92.3	98.3	11.5	1 2 3 4 5 9 10 11	100.0	100.0	0.0
Upper Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid	1 3 4 10 11	92.3	98.3	11.5	1 3 4 5 9 10 11	100.0	100.0	0.0
Upper Trapezius, Seratus Anterior, Pectoralis Major, Middle Deltoid	1 3 4 10 11	92.3	98.3	11.5	1 3 4 5 9 10 11	100.0	100.0	0.0

Upper Trapezius, Seratus Anterior, Pectoralis Major, Infraspinatus	1 3 4 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid	1 2 3 10 11	92.3	98.3	11.5	1 2 3 4 5 9 10 11	100.0	100.0	0.0
Upper Trapezius, Seratus Anterior, Latissimus Dorsi, Middle Deltoid	1 2 3 10 11	92.3	98.3	11.5	1 2 3 5 9 10 11	100.0	99.4	4.1
Upper Trapezius, Seratus Anterior, Latissimus Dorsi, Infraspinatus	1 2 3 8 9 10 11	92.3	98.3	11.5	1 2 3 5 8 9 10 11	100.0	99.4	4.1
Upper Trapezius, Seratus Anterior, Anterior Deltoid, Middle Deltoid	1 3 10 11	92.3	98.3	11.5	1 3 4 5 9 10 11	100.0	100.0	0.0
Upper Trapezius, Seratus Anterior, Anterior Deltoid, Infraspinatus	1 3 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Middle Deltoid, Infraspinatus	1 3 8 9 10 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.4	4.1
Upper Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid	1 2 3 4 5 11	92.3	98.7	16.7	1 2 3 4 5 10 11	100.0	100.0	0.5
Upper Trapezius, Pectoralis Major, Latissimus Dorsi, Middle Deltoid	1 2 3 4 10 11	92.3	98.3	11.5	1 2 3 4 5 10 11	100.0	100.0	0.5
Upper Trapezius, Pectoralis Major, Latissimus Dorsi, Infraspinatus	1 2 3 4 5 8 9 11	92.3	98.7	13.5	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Pectoralis Major, Anterior Deltoid, Middle Deltoid	1 3 4 10 11	92.3	98.3	11.5	1 3 4 5 10 11	100.0	100.0	0.5
Upper Trapezius, Pectoralis Major, Anterior Deltoid, Infraspinatus	1 3 4 5 8 9 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Pectoralis Major, Middle Deltoid, Infraspinatus	1 3 4 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 3 10 11	92.3	98.3	11.5	1 2 3 4 5 10 11	100.0	100.0	0.5
Upper Trapezius, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	1 2 3 5 8 9 11	92.3	98.7	18.7	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2

Upper Trapezius, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 8 9 10 11	92.3	98.3	11.5	1 2 3 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi	2 4 5 9 10 11	92.3	98.8	12.0	2 3 4 5 9 10 11	100.0	99.6	3.7
Lower Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid	4 5 9 10 11	92.3	97.9	14.4	3 4 5 9 10 11	100.0	99.6	4.5
Lower Trapezius, Seratus Anterior, Pectoralis Major, Middle Deltoid	1 4 5 9 10 11	92.3	99.0	11.2	1 3 4 5 9 10 11	100.0	99.9	0.9
Lower Trapezius, Seratus Anterior, Pectoralis Major, Infraspinatus	3 4 5 8 9 10 11	92.3	97.0	17.2	2 3 4 5 8 9 10 11	100.0	99.6	3.7
Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid	2 3 5 9 10 11	92.3	98.5	9.8	2 3 4 5 9 10 11	100.0	99.6	4.5
Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Middle Deltoid	1 2 3 5 9 10 11	100.0	99.4	4.1	1 2 3 5 9 10 11	100.0	99.4	4.1
Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Infraspinatus	2 3 5 8 9 10	92.3	95.8	25.4	2 3 4 5 8 9 10 11	100.0	99.6	3.7
Lower Trapezius, Seratus Anterior, Anterior Deltoid, Middle Deltoid	1 3 5 9 10 11	92.3	98.7	9.1	1 3 4 5 9 10 11	100.0	99.9	0.9
Lower Trapezius, Seratus Anterior, Anterior Deltoid, Infraspinatus	3 5 8 9 10 11	92.3	97.0	17.2	2 3 4 5 8 9 10 11	100.0	99.6	4.5
Lower Trapezius, Seratus Anterior, Middle Deltoid, Infraspinatus	1 3 5 8 9 10 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.4	4.1
Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid	2 3 4 5 9 11	92.3	98.0	23.7	2 3 4 5 9 10 11	100.0	99.9	4.5
Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Middle Deltoid	1 2 4 5 9 10 11	92.3	99.0	11.2	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Infraspinatus	2 3 4 5 8 9	92.3	98.3	12.3	2 3 4 5 8 9 10 11	100.0	99.8	1.2

Lower Trapezius, Pectoralis Major, Anterior Deltoid, Middle Deltoid	1 4 5 9 10 11	92.3	98.0	14.2	1 3 4 5 9 10 11	100.0	99.9	0.9
Lower Trapezius, Pectoralis Major, Anterior Deltoid, Infraspinatus	3 4 5 8 9 11	92.3	97.0	23.7	2 3 4 5 8 9 10 11	100.0	99.8	4.5
Lower Trapezius, Pectoralis Major, Middle Deltoid, Infraspinatus	1 3 4 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 5 9 10 11	92.3	96.7	15.9	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Lower Trapezius, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	1 2 3 5 8 9 11	92.3	98.7	18.7	2 3 4 5 8 9 10 11	100.0	99.8	4.5
Lower Trapezius, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 5 8 9 10 11	100.0	99.8	1.2	1 2 3 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid	2 4 10 11	92.3	97.9	14.4	2 3 4 9 10 11	100.0	99.6	4.5
Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Middle Deltoid	1 2 4 10 11	92.3	98.9	11.2	1 2 3 4 5 9 10 11	100.0	100.0	0.0
Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Infraspinatus	2 3 4 8 9 10	92.3	96.4	24.5	2 3 4 8 9 10 11	100.0	99.6	3.7
Seratus Anterior, Pectoralis Major, Anterior Deltoid, Middle Deltoid	1 4 10 11	92.3	98.0	14.2	1 3 4 5 9 10 11	100.0	100.0	0.0
Seratus Anterior, Pectoralis Major, Anterior Deltoid, Infraspinatus	3 4 8 9 10 11	92.3	97.0	17.2	2 3 4 8 9 10 11	100.0	99.6	4.5
Seratus Anterior, Pectoralis Major, Middle Deltoid, Infraspinatus	1 3 4 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 3 10 11	92.3	98.7	9.1	1 2 3 4 5 9 10 11	100.0	100.0	0.0
Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	2 3 8 9 10 11	92.3	98.5	9.8	2 3 4 8 9 10 11	100.0	99.6	4.5

Seratus Anterior, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 8 9 10 11	100.0	99.0	5.2	1 2 3 5 8 9 10 11	100.0	99.4	4.1
Seratus Anterior, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 4 10 11	100.0	98.0	14.2	1 2 3 4 5 10 11	100.0	100.0	0.0
Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	2 3 4 8 9 11	92.3	97.5	25.3	2 3 4 8 9 10 11	100.0	99.8	4.5
Pectoralis Major, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 4 8 9 10 11	100.0	99.0	5.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Pectoralis Major, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 4 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 8 9 10 11	92.3	98.7	9.1	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
5 muscles								
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi	2 4 5 9 10 11	92.3	96.7	14.9	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid	4 5 9 10 11	92.3	96.7	14.9	1 3 4 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Middle Deltoid	1 4 5 9 10 11	92.3	99.0	11.2	1 3 4 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Infraspinatus	3 4 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid	2 3 5 9 10 11	92.3	97.2	14.3	1 2 3 4 5 9 10 11	100.0	99.9	0.2

Upper Trapezius, Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Middle Deltoid	1 2 3 5 9 10 11	100.0	99.4	4.1	1 2 3 5 9 10 11	100.0	99.4	4.1
Upper Trapezius, Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Infraspinatus	2 3 5 8 9 10 11	92.3	97.2	14.3	1 2 3 5 8 9 10 11	100.0	99.4	4.1
Upper Trapezius, Lower Trapezius, Seratus Anterior, Anterior Deltoid, Middle Deltoid	1 3 5 9 10 11	92.3	98.7	9.1	1 3 4 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Seratus Anterior, Anterior Deltoid, Infraspinatus	3 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Middle Deltoid, Infraspinatus	1 3 5 8 9 10 11	92.3	97.0	17.2	1 2 3 5 8 9 10 11	100.0	99.4	4.1
Upper Trapezius, Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid	1 2 4 5 9 11	92.3	97.1	20.5	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Middle Deltoid	1 2 4 5 9 10 11	92.3	99.0	11.2	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Infraspinatus	1 2 3 4 5 8 9 11	92.3	98.7	13.5	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Pectoralis Major, Anterior Deltoid, Middle Deltoid	1 4 5 9 10 11	92.3	98.0	14.2	1 3 4 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Pectoralis Major, Anterior Deltoid, Infraspinatus	1 3 4 5 8 9 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2

Upper Trapezius, Lower Trapezius, Pectoralis Major, Middle Deltoid, Infraspinatus	1 3 4 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 5 9 10 11	92.3	96.7	15.9	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	1 2 3 5 8 9 11	92.3	98.7	18.7	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 5 8 9 10 11	100.0	99.8	1.2	1 2 3 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid	1 2 3 4 10 11	92.3	98.3	11.5	1 2 3 4 5 9 10 11	100.0	100.0	0.0
Upper Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Middle Deltoid	1 2 3 4 10 11	92.3	98.3	11.5	1 2 3 4 5 9 10 11	100.0	100.0	0.0
Upper Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Infraspinatus	1 2 3 4 8 9 10 11	92.3	98.3	11.5	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid, Middle Deltoid	1 3 4 10 11	92.3	98.3	11.5	1 3 4 5 9 10 11	100.0	100.0	0.0
Upper Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid, Infraspinatus	1 3 4 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2

Upper Trapezius, Seratus Anterior, Pectoralis Major, Middle Deltoid, Infraspinatus	1 3 4 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 3 10 11	92.3	98.3	11.5	1 2 3 4 5 9 10 11	100.0	100.0	0.0
Upper Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	1 2 3 8 9 10 11	92.3	98.3	11.5	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 8 9 10 11	92.3	98.3	11.5	1 2 3 5 8 9 10 11	100.0	99.4	4.1
Upper Trapezius, Seratus Anterior, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 3 4 10 11	92.3	98.3	11.5	1 2 3 4 5 10 11	100.0	100.0	0.5
Upper Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	1 2 3 4 5 8 9 11	92.3	98.7	16.7	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Pectoralis Major, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 4 8 9 10 11	92.3	98.3	11.5	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Pectoralis Major, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 4 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 8 9 10 11	92.3	98.3	11.5	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2

Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid	2 4 5 9 10 11	92.3	97.9	14.4	2 3 4 5 9 10 11	100.0	99.6	4.5
Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Middle Deltoid	1 2 4 5 9 10 11	92.3	99.0	11.2	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Infraspinatus	2 3 4 5 8 9 10	92.3	96.4	24.5	2 3 4 5 8 9 10 11	100.0	99.6	3.7
Lower Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid, Middle Deltoid	1 4 5 9 10 11	92.3	98.0	14.2	1 3 4 5 9 10 11	100.0	99.9	0.9
Lower Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid, Infraspinatus	3 4 5 8 9 10 11	92.3	97.0	17.2	2 3 4 5 8 9 10 11	100.0	99.6	4.5
Lower Trapezius, Seratus Anterior, Pectoralis Major, Middle Deltoid, Infraspinatus	1 3 4 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 3 5 9 10 11	92.3	98.7	9.1	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	2 3 5 8 9 10 11	92.3	98.5	9.8	2 3 4 5 8 9 10 11	100.0	99.6	4.5
Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 5 8 9 10 11	100.0	99.4	4.1	1 2 3 5 8 9 10 11	100.0	99.4	4.1
Lower Trapezius, Seratus Anterior, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2

Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 4 5 9 10 11	92.3	98.0	14.2	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	2 3 4 5 8 9 11	92.3	98.0	23.7	2 3 4 5 8 9 10 11	100.0	99.8	4.5
Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Pectoralis Major, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 4 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 5 8 9 10 11	92.3	98.7	9.1	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 4 10 11	92.3	98.0	14.2	1 2 3 4 5 9 10 11	100.0	100.0	0.0
Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	2 3 4 8 9 10 11	100.0	99.6	4.5	2 3 4 8 9 10 11	100.0	99.6	4.5
Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 4 8 9 10 11	100.0	99.0	5.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Seratus Anterior, Pectoralis Major, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 4 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 8 9 10 11	92.3	98.7	9.1	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2

Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 4 8 9 10 11	100.0	99.0	5.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
6 muscles								
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid	2 4 5 9 10 11	92.3	96.7	14.9	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Middle Deltoid	1 2 4 5 9 10 11	92.3	99.0	11.2	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Infraspinatus	2 3 4 5 8 9 10 11	92.3	97.2	14.3	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid, Middle Deltoid	1 4 5 9 10 11	92.3	98.0	14.2	1 3 4 5 9 10 11	100.0	99.9	0.9
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid, Infraspinatus	3 4 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Middle Deltoid, Infraspinatus	1 3 4 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 3 5 9 10 11	92.3	98.7	9.1	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	2 3 5 8 9 10 11	92.3	97.2	14.3	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 5 8 9 10 11	100.0	99.4	4.1	1 2 3 5 8 9 10 11	100.0	99.4	4.1

Upper Trapezius, Lower Trapezius, Seratus Anterior, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 4 5 9 10 11	92.3	98.0	14.2	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Upper Trapezius, Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	1 2 3 4 5 8 9 11	92.3	98.7	16.7	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Pectoralis Major, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 4 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 5 8 9 10 11	92.3	98.7	9.1	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 3 4 10 11	92.3	98.3	11.5	1 2 3 4 5 9 10 11	100.0	100.0	0.0
Upper Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	1 2 3 4 8 9 10 11	92.3	98.3	11.5	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 4 8 9 10 11	92.3	98.3	11.5	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 4 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2

Upper Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 8 9 10 11	92.3	98.3	11.5	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 4 8 9 10 11	92.3	98.3	11.5	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 4 5 9 10 11	92.3	98.0	14.2	1 2 3 4 5 9 10 11	100.0	99.9	0.2
Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	2 3 4 5 8 9 10 11	100.0	99.6	4.5	2 3 4 5 8 9 10 11	100.0	99.6	4.5
Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 4 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 5 8 9 10 11	92.3	98.7	9.1	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 4 8 9 10 11	100.0	99.0	5.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
7 muscles								
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid	1 2 4 5 9 10 11	92.3	98.0	14.2	1 2 3 4 5 9 10 11	100.0	99.9	0.2

Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Infraspinatus	2 3 4 5 8 9 10 11	92.3	97.2	14.3	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Middle Deltoid, Infraspinatus	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 3 4 5 8 9 10 11	92.3	97.0	17.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Seratus Anterior, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 5 8 9 10 11	92.3	98.7	9.1	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Lower Trapezius, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Upper Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 4 8 9 10 11	92.3	98.3	11.5	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2
8 muscles								

Upper Trapezius, Lower Trapezius, Seratus Anterior, Pectoralis Major, Latissimus Dorsi, Anterior Deltoid, Middle Deltoid, Infraspinatus	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2	1 2 3 4 5 8 9 10 11	100.0	99.8	1.2

Supplementary file S2: Combination of MVIC tests meeting criterion 1 (minimum number of MVIC tests for > 90% MVA for > 90% volunteers) and criterion 2 (criterion 1 plus a difference of muscle activation < 5% MVA between pre- and post-tests for 90% of the volunteers). Size of the window of the moving average filter: 500 ms and 2 s. MVIC: Maximum Voluntary Isometric Contraction. (1) empty can, (2) extension prone, (3) seated U 90°, (4) palm press, (5) prone V-thumb up, (6) pull down, (7) push forward, (8) rotation 0°, (9) rotation 90°, (10) seated T, (11) seated U 125°, (12) shoulder shrug.

	Criterion 1				**Criterion 2**			
Muscles	*MVIC tests*	*# of subjects (%)*	*Level of activation (% MVA)*	*Variation (% MVA)*	*MVIC tests*	*# of subjects (%)*	*Level of activation (% MVA)*	*Variation (% MVA)*
500 ms								
Upper Trapezius	1 5 10 11	92	99	8.0	1 3 5 10 11	100	100	1.4
Lower Trapezius	5 9	100	98	13.8	2 5 9 10	100	100	3.7
Seratus Anterior	3 10 11	100	99	10.9	1 3 9 10 11	100	100	2.1
Pectoralis Major	4	100	99	19.5	3 4	100	100	1.9
Latissimus Dorsi	2	100	100	0.0	2	100	100	0.0
Anterior Deltoid	1 3 11	92	98	21.1	1 3 4 10 11	100	100	0.0
Middle Deltoid	1 5 10 11	100	100	0.0	1 5 10 11	100	100	0.0
Infraspinatus	2 7 8 9	92	98	30.6	2 3 6 8 9 11	100	99	4.0
All muscles	1 2 3 4 8 9 10 11	92	96	24.8	1 2 3 4 5 7 8 9 10 11	100	100	3.9
2 s								
Upper Trapezius	1 3 11	92	98	8.3	1 3 5 10 11	100	100	1.0
Lower Trapezius	5 9	100	98	8.8	3 5 6 9 10	100	99	4.2

Seratus Anterior	10 11	92	97	21.9	3 9 10 11	100	99	4.0
Pectoralis Major	4	100	99	19.4	3 4	100	100	0.0
Latissimus Dorsi	2	100	100	0.0	2	100	100	0.0
Anterior Deltoid	1 3 11	92	99	15.4	3 4 10 11	100	99	3.9
Middle Deltoid	1 10 11	92	98	9.1	1 5 10 11	100	100	0.0
Infraspinatus	2 3 8 9	92	98	11.8	2 3 8 9 11	100	100	2.1
All muscles	1 2 3 4 5 8 9 10 11	100	100	0.0	1 2 3 4 5 8 9 10 11	100	100	0.0