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Isometric muscle activation of the serratus anterior and trapezius muscles varies by arm position: A pilot study with healthy volunteers with implications for rehabilitation

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Isometric activation of the periscapular muscles

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6 Running Title:

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Isometric activation of the periscapular muscles

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37

Isometric activation of the periscapular muscles

Abstract

Background: This study aimed to determine the most appropriate angle and moving direction of the arm for improving coordination of the periscapular muscles, including the serratus anterior (SA) and the upper (UT), middle (MT), and lower trapezius (LT).

Methods: Muscle activation amplitudes were evaluated in the SA, UT, MT, and LT in 11 healthy subjects using surface electromyography. The subjects were asked to maintain the arm position at five elevated positions with maximal effort against applied manual forces, which were directed from upper to lower (Test 1), lower to upper (Test 2), posterior to anterior in the frontal plane and lateral to medial in the sagittal plane (Test 3), and anterior to posterior in the frontal plane and medial to lateral in the sagittal plane (Test 4). The relative activity of the UT with respect to the SA, MT, and LT was calculated, resulting in the UT/SA, UT/MT, and UT/LT ratios.

Results: Test 4 in all positions but 150° of elevation in the frontal plane showed high activity of the SA with a low UT/SA ratio. High MT activity with a low UT/MT ratio was observed during Test 3 at the 90° elevated position, whereas high LT activity without UT hyperactivation was not found.

Discussion: To strengthen the periscapular muscles in the balanced condition, horizontal adduction is recommended for the SA. Horizontal abduction at the 90° elevated position

Isometric activation of the periscapular muscles

56 should be effective for the MT. Since no technique in this study was effective for the LT,

57 further studies are needed.

58

59 Level of evidence: Basic science, kinesiology

60 Key Words: Electromyography; shoulder; exercise; muscle activation; muscle balance;

61 periscapular muscles

62

63

Isometric activation of the periscapular muscles

64 **Introduction**

65 The scapula plays an important role in achieving effective stability and motion of the
66 normal shoulder. For glenohumeral joint stability, the scapula works as a base for the
67 humerus in the glenohumeral joint as well as a moving component of the
68 scapulothoracic joint. Efficient shoulder motion requires coordination of both the
69 scapula and the humerus, collectively referred to as scapulohumeral rhythm¹⁷.

70 Altered static scapular position and loss of dynamic control of the scapular motion,
71 termed “scapular dyskinesis,” are associated with a variety of shoulder disorders^{2,19}.
72 Alterations in periscapular muscle activation in particular have drawn attention as a
73 major cause of scapular dyskinesis: Specifically, excessive activity of the upper
74 trapezius muscle (UT) combined with reduced activity of other portions of the trapezius
75 muscle and the serratus anterior muscle (SA) contributes to loss of posterior tilt and
76 upward scapular rotation of the scapula^{3,5-7,21,23}.

77 Rehabilitation protocols focusing on correcting those abnormal muscle activities have
78 been designed. Some exercises have been proposed to strengthen the SA, middle
79 trapezius muscle (MT), and lower trapezius muscle (LT)^{4,8,20}. Others have intended to
80 restore scapular muscle balance by eliciting the greatest amount of SA and LT activity
81 while minimizing UT activation^{1,10,14,16,22,25}. To evaluate scapular muscle balance,

Isometric activation of the periscapular muscles

82 UT/SA, UT/MT, and UT/LT ratios were recently introduced: Those muscle activities are
83 measured by electromyography (EMG), and lower ratios demonstrate higher activities
84 of the SA, MT, and LT compared with that of the UT ^{4,22}. According to Cools et al. and
85 Ludewig et al., side-lying forward flexion (subject performing forward flexion to 135°),
86 prone horizontal abduction with external rotation (subject performing horizontal
87 abduction from 90° forward flexion with an additional external rotation of the shoulder
88 at the end of the movement), and push-up plus (subject performing a standard push-up
89 with full shoulder protraction after achieving full-elbow extension) were recommended
90 to promote the MT, LT, and SA ^{4,22}.

91 These exercises should be performed in an elevated arm position, which may cause
92 subacromial impingement. In addition, the subject should hold dumbbells or support
93 one's own weight while performing these exercises, which may cause overload-related
94 pain in patients with shoulder problems. To identify safe exercises for such patients,
95 details about the ideal shoulder position and direction to move the arm should be
96 obtained. The purpose of the present study was to determine the most appropriate
97 position and moving direction of the arm for strengthening and coordinating the SA, MT,
98 and LT while considering muscle balance ratios. We hypothesized that there were
99 specific arm positions and isometric contractions that highly activate the SA, MT, and

Isometric activation of the periscapular muscles

100 LT with low activity of the UT.

101

Isometric activation of the periscapular muscles

102 **Materials and methods**

103 Subjects

104 Eleven men (mean age, 23.9 ± 4.3 years; mean height, 171.9 ± 5.8 cm; mean weight,
105 64.6 ± 6.4 kg) were studied. None of the subjects had a history of shoulder injury
106 requiring activity restriction or demonstrated scapular dyskinesis on clinical
107 examination. All subjects were well informed and fully consented to participate in the
108 study. This study was approved by the Ethical Review Board of Kyoto University
109 Graduate School of Medicine.

110

111 EMG recording

112 Muscle activities of the SA, UT, MT, and LT were recorded using surface EMG. The
113 skin at the electrode placement points was shaved and washed with an alcohol swab to
114 reduce skin impedance (<10 k Ω). Blue sensor bipolar surface electrodes (Ambu A/S,
115 Ballerup, Denmark) were placed at a 2-cm inter-electrode distance on the SA, UT, MT,
116 and LT as described by Cools, Ekstrom, and Kibler^{4,13,20}. A reference electrode was
117 placed on the lateral end of the clavicle. The dominant arm was tested in each subject,
118 and all subjects were right-handed. Each set of bipolar recording electrodes was
119 connected to a multi-channel bioamplifier EMG system (BA-1008; Nihonsanteku Co.,

Isometric activation of the periscapular muscles

Ltd., Osaka, Japan). The sampling rate was 2048 Hz. All of the raw myoelectric signals were pre-amplified (overall gain, 1000; common rate rejection ratio, 80 dB; signal-to-noise ratio < 4 μ V; peak-to-peak baseline noise filtered to produce a bandwidth of 5–3000 Hz). The BA-1008 was interfaced with the computer via an eight-channel, 16-bit MaP211 A/D card (Nihonsanteku Co., Ltd.). All of the raw EMG signals were converted from analog to digital via the MaP211 A/D card at 2048 Hz. All data were recorded, stored, and analyzed on a personal computer using the EMG multi-analysis program MaP1038 software (Nihonsanteku Co., Ltd.).

Testing procedure

During the testing, the subjects were asked to sit looking straight ahead with their pelvis and trunk fastened to the chair. The examiners held each subject's arm at five elevated positions of 30°, 60°, 90°, 120°, and 150° in the frontal and sagittal planes (Fig. 1). The subjects were asked to maintain the arm position for 3 seconds with maximal effort against the applied manual forces, which were directed from the upper to lower (Test 1), lower to upper (Test 2), posterior to anterior in the frontal plane and lateral to medial in the sagittal plane (Test 3), and anterior to posterior in the frontal plane and medial to lateral in the sagittal plane (Test 4) positions. Arm positions and applied force

Isometric activation of the periscapular muscles

directions were randomized to avoid systematic influences of fatigue and learning effects. Subjects were allowed to rest for 3 minutes between tests.

Data reduction

All of the raw EMG signals were filtered to a bandwidth of 20–500 Hz. The root mean square of the raw data was determined. To normalize the obtained electrical signal values of the muscle activities during testing protocol, the value at maximal voluntary isometric contraction (MVIC) of each muscle in the recommended posture¹⁵ was recorded. MVIC was sustained for 3 seconds. Each MVIC task was repeated two times and their mean was used as a reference. For normalization, the percentage MVIC (% MVIC) was calculated for the SA, UT, MT, and LT.

To choose the appropriate exertion method as training exercises, we selected pairs of the arm position and test in the SA, MT, and LT that showed EMG activity >60% MVIC. One previous study showed that the >60% MVIC activation level is very high activity sufficient to strengthen muscles¹¹.

Categorization of muscle activity according to muscle balance ratio

To demonstrate exercises with a highly activated SA, MT, or LT and low UT activity,

Isometric activation of the periscapular muscles

we calculated the UT/SA, UT/MT, and UT/LT muscle balance ratios using the normalized EMG values ^{4,22} and classified those extracted pairs into four categories based on the muscle balance ratios: Category 1, <60%; Category 2, 60–80%; Category 3, 80–100%; and Category 4, >100%. According to a previous study, Categories 1, 2, and 3 corresponded to excellent, good, and moderate ⁴.

Statistical Analysis

To compare the efficiency of each position and test, two-way analysis of variance was calculated. The level of statistical significance was set to .05. A Tukey post hoc analysis with a .05 α level was added to positions or tests that showed statistical significance. All of the statistical analyses were performed using SPSS version 17.0 (SPSS Science, Chicago, IL, USA).

Isometric activation of the periscapular muscles

170 **Results**

171 Muscle activation

172 The % MVIC of the SA, UT, MT, and LT of the four shoulder tests at every arm
173 position are shown in Table I (frontal plane) and Table II (sagittal plane).

174 The SA was activated at >60% MVIC during Tests 1 and 4 in both planes of all of the
175 elevated positions but 150° of Test 4 in the frontal plane. The UT showed high EMG
176 activity during Test 1 of all of the arm positions in both planes but 30° of Test 1 in the
177 sagittal plane and Test 3 at the 120° and 150° elevated positions in the frontal plane. The
178 MT showed high EMG activity during Test 1 at the 30°, 60°, and 90° elevated positions
179 in the frontal plane and at the 90°, 120°, and 150° elevated positions in the sagittal plane.
180 The MT was also activated at >60% MVIC during Test 3 in both planes of all of the
181 elevated positions but at the 120° and 150° positions in the sagittal plane. The LT
182 showed high EMG activity during Test 1 at the 120° elevated position in the frontal
183 plane and Test 1 at the 120° and 150° elevated positions in the sagittal plane. The LT
184 was also activated at >60% MVIC during Test 3 at the 120° and 150° elevated positions
185 in the frontal plane.

186

187 Categories of muscle balance ratio

Isometric activation of the periscapular muscles

188 The muscle balance ratios of UT/SA, UT/MT, and UT/LT of the four shoulder tests at
189 every arm position are shown in Table III (frontal plane) and Table IV (sagittal plane).

190 *Serratus anterior (UT/SA)*

191 On the frontal plane: Category 1 consisted of all situations of Tests 2 and 4; and
192 Category 3 consisted of Test 1 at the 60°, 90°, and 120° elevated positions.

193 On the sagittal plane: Category 1 consisted of Test 2 at the 60°, 90°, 120°, and 150°
194 elevated positions and Test 4 at the 30°, 60°, 90°, and 120° positions; Category 2
195 consisted of Test 1 at 30° and Test 4 at 150°; and Category 3 consisted of Test 1 at 60°
196 and 90° and Test 2 at 30°.

197 The results of other situations were all included in Category 4.

198 *Middle trapezius (UT/MT)*

199 On the frontal plane: Category 1 consisted of all Test 2 positions; Category 2
200 consisted of Test 3 at the 30°, 60°, and 90° elevated positions; and Category 3 consisted
201 of Test 4 at 30° and 150°.

202 On the sagittal plane: Category 1 consisted of Test 2 at the 30°, 60°, 90°, and 120°
203 elevated positions and Test 3 at the 90°, 120°, and 150° positions; Category 2 consisted
204 of Test 3 at 30° and 60°; and Category 3 consisted of Test 2 at 150°.

205 The results of other situations were all included in Category 4.

Isometric activation of the periscapular muscles

206 *Lower trapezius (UT/LT)*

207 On the frontal plane: Category 1 consisted of all Test 2 and Test 4 at the 30° and 150°
208 elevated positions; and Category 2 consisted of Test 4 at 60°.

209 On the sagittal plane: Category 1 consisted of Test 2 at the 60°, 90°, and 120°
210 elevated positions and Test 3 at 150°; Category 2 consisted of Test 2 at 150°; and
211 Category 3 consisted of Test 2 at 30° and Test 3 at 90°.

212 The results of other situations were all included in Category 4.

213

214 Favorably categorized situations with higher muscle activation

215 The situations categorized 1-3 with muscle activation >60% MVIC were as follows.

216 *Serratus anterior*

217 On the frontal plane: Test 4 at the 30°, 60°, 90°, and 120° elevated positions were
218 classified into Category 1; and Test 1 at the 60°, 90°, and 120° elevated positions were
219 classified into Category 3.

220 On the sagittal plane: Test 4 at the 30°, 60°, 90°, and 120° elevated positions were in
221 Category 1; Test 1 at 30° and Test 4 at 150° were in Category 2; and Test 1 at the 60°
222 and 90° elevated positions were classified into Category 3.

223 *Middle trapezius*

Isometric activation of the periscapular muscles

224 On the frontal plane: No test situation was classified into Category 1; and Test 3 at
225 the 30°, 60°, and 90° elevated positions were classified into Category 2.

226 On the sagittal plane: Test 3 at 90° of elevation was classified into Category 1; and
227 Test 3 at the 30° and 60° elevated positions were classified into Category 2.

228 *Lower trapezius*

229 No test situation with LT activation >60% MVIC was classified into Categories 1–3.

230

231 Statistical comparison

232 *Serratus anterior*

233 There were significant main effects for the tests in both planes. In the frontal plane,
234 the SA was activated to a greater degree during Test 1 than during the other tests (p
235 $< .001$). In addition, the SA was activated to a greater degree during Test 4 than during
236 Tests 2 and 3 ($p = .009$ and $p = .016$, respectively). In the sagittal plane, the SA was
237 activated to a greater degree during Test 1 than during Tests 2 and 3 ($p < .001$) and
238 during Test 4 than during Tests 2 and 3 ($p < .001$).

239 *Upper trapezius*

240 A significant interaction between arm positions and the tests was found in the frontal
241 and sagittal planes ($p < .001$). In both planes, the UT activities were greater during Test

Isometric activation of the periscapular muscles

242 1 than during Tests 2, 3, and 4 ($p < .001$).

243 *Middle trapezius*

244 A significant interaction between arm positions and the tests was found in the frontal
245 and sagittal planes ($p < .001$). In the frontal plane, the MT activities were greater during
246 Test 3 than during the other tests ($p < .001$). In the sagittal plane, the MT was activated
247 to a greater degree during Test 1 than during Tests 2 and 4 ($p < .001$) as well as during
248 Test 3 than during Tests 2 and 4 ($p < .001$).

249 *Lower trapezius*

250 A significant interaction between arm positions and the tests was found in the frontal
251 and sagittal planes ($p < .001$, $p = .009$, respectively). In the frontal plane, the LT was
252 more activated to a greater degree during Test 1 than during Tests 2 and 4 ($p < .001$) as
253 well as during Test 3 than during Tests 2 and 4 ($p < .001$). In the sagittal plane, the LT
254 was activated to a greater degree during Test 1 than during other tests ($p < .001$) as well
255 as during Test 3 than during Tests 2 and 4 ($p < .001$).

256

257

Isometric activation of the periscapular muscles

258 **Discussion**

259 Muscle activation amplitude

260 Very high EMG activities (>60% MVIC) of the SA, UT, MT, and LT were
261 simultaneously generated during Test 1 at the 120° and 150° elevated positions in the
262 sagittal plane. In the normal shoulder elevation, the SA, UT, MT, and LT stabilize the
263 scapula to the chest wall and are considered its primary upward rotators ^{12,26}. In the
264 present study, we did not evaluate scapular movement. However, the scapula would be
265 kept at a constant position with the arm during Test 1 at the 120° and 150° elevated
266 positions against the maximum force applied from the upper side on the arm in the
267 sagittal plane. The activations of the periscapular muscles by isometric contractions as
268 shown in this study are thought to differ from those evoked during isokinetic arm
269 elevation ^{21,23,24}, but all of the periscapular muscles would be elicited to hold the
270 appropriate scapular position. To simply strengthen all of the periscapular muscles,
271 exercises like Test 1 at the 120° and 150° elevated positions would be effective. In daily
272 clinical practice, however, patients with shoulder problems tend to be unable to raise
273 their arms more than 120° due to subacromial impingement.

274 Prone horizontal abduction at the 90° and 135° elevated positions in the frontal plane
275 and the wide-grip rowing at shoulder level were previously reported to enhance

Isometric activation of the periscapular muscles

276 trapezius muscle activation^{14, 16, 25, 29}. These exercises have similar motion patterns as
277 Test 3 performed at the 90°, 120°, and 150° elevated positions in the frontal plane. Test
278 3 at positions >90° in the frontal plane, particularly 120° and 150°, demonstrated higher
279 EMG activities in all of the trapezius muscles. Test 3 in this current study proved the
280 efficacy of well-known exercises for the trapezius muscle. In contrast, it was interesting
281 that high EMG activity of the SA was generated during Test 4 in both planes and was
282 46.3–123.3% MVIC.

283 A number of exercises for the SA have been advocated to date, such as the forward
284 punch, military press, push-up plus (push-up with full shoulder protraction),
285 glenohumeral internal and external rotation at 90° abduction, and shoulder flexion,
286 abduction, and scaption >120°^{10, 14, 16, 25, 27}, but none except the dynamic hug exercise
287 showed the efficacy of horizontal adduction. The dynamic hug exercise begins with the
288 elbows in approximately 45° of flexion and the shoulder abducted 60° and internally
289 rotated 45°. The humerus is then horizontally adducted until full shoulder protraction is
290 reached¹⁰. Test 4 was isometric contraction that direction was toward horizontal
291 adduction and this direction was similar to dynamic hug exercise. The high EMG
292 activity of the SA during Test 4 showed the importance of the SA during shoulder
293 protraction and elevation as well as horizontal adduction.

Isometric activation of the periscapular muscles

294

295 Muscle activity categorization according to muscle balance ratio

296 *Serratus anterior*

297 Cools et al.⁴ reported that none of the commonly prescribed exercises for the
298 trapezius muscle training showed a low UT/SA ratio. Kibler et al.²⁰ recommended
299 inferior glide (IG) and low row (LR) exercises for the SA training without UT
300 hyperactivity. However, since the greatest EMG activity of the SA was only 23.4%
301 MVIC during IG and 28.2% MVIC during LR, these activation levels were too low to
302 improve SA strength. Ludewig et al.²² reported that the push-up plus exercise
303 demonstrated high activation as well as low UT/SA ratios, but the exercise load would
304 be excessive for patients with shoulder pain. Test 4 of this study demonstrated larger SA
305 activation >60% MVIC without UT hyperactivation, even in the low arm positions such
306 as 30° or 60°. In daily clinical situations, Test 4 in the lower position should be easily
307 performed by patients with shoulder problems.

308 *Middle trapezius*

309 Only Test 3 at the 90° elevated position in the sagittal plane was classified into
310 Category 1. Our result indicated that this exercise method would be the most effective
311 for strengthening the MT without hyperactivating the UT. However, in daily practice,

Isometric activation of the periscapular muscles

312 there is concern that subacromial impingement might occur at the 90° arm position.
313 Although these tests were classified into Category 2, we recommend Test 3 at the 30° or
314 60° elevated positions in the sagittal plane in the early phase of rehabilitation.

315 In the frontal plane, data of Test 3 at the 30°, 60°, and 90° elevated positions were
316 also classified into Category 2 and can be recommended. Test 3 at highly elevated
317 positions such as 120° or 150° elicited MT activities >60% MVIC; these results were
318 consistent with those of previous studies ^{14, 25}. However, they also activated the UT and
319 were not classified into categories.

320 *Lower trapezius*

321 The LT was highly activated during Tests 1 and 3 in both planes, but all of the tests
322 were classified into Category 4 because of high UT/LT ratios. These results indicated
323 the difficulty of selectively strengthening the LT. Cools et al. ⁴ reported that the LT
324 showed relatively high EMG activity with a low UT/LT ratio while the subjects in the
325 prone position performed horizontal abduction holding a 1–3 kg dumbbell with external
326 rotation from the 90° elevated position in the frontal plane. This exercise was similar to
327 our Test 3 at the 90° elevated position in the frontal plane, but their LT activity was
328 higher and UT/LT ratio was lower than ours. The difference between Cools's and our
329 method was body position (prone or sitting position) with or without external rotation.

Isometric activation of the periscapular muscles

In our Test 3, the UT might be more activated to maintain the elevated position against gravity in sitting position. The role of the UT is to draw the clavicle and scapula backward¹⁸. Therefore, this UT activity might support horizontal abduction contraction and reduce LT activity. In addition, the external rotation in Cools's method might elicit scapular posterior tilting and effectively activate LT. Considering LT activation, some recent studies focused on multi-joint exercises with hip and trunk extension or diagonal movement in scapular retraction^{9,20}. Further studies of these kinetic chain exercises are needed for LT activation with a low UT/LT ratio.

In some situations classified into favorable categories, the SA, MT, or LT was not sufficiently activated to be strengthened but the UT activation was very low. For example, Test 2 at 30° of humeral elevation in the frontal plane demonstrated no more than 14.4% of the UT/SA ratio (Category 1), but the SA was activated in only 43.6% MVIC. In such situations, the SA, MT, or LT is not strengthened but may be facilitated safely, and they could be reasonable choices in the early phase of rehabilitation.

Statistical examination

Although shoulder elevation is a primary objective for most of the patients, Test 1 more significantly activated the UT than the other tests in both planes. Considering the

Isometric activation of the periscapular muscles

selective activation of the periscapular muscles, it is better to routinely avoid Test 1. For the SA, Test 4 showed significantly higher activation than Tests 2 and 3 in both planes. Similarly, for the MT, Test 3 demonstrated significantly higher activation than Tests 2 and 4 in both planes. In view of the statistical comparison, Test 4 for the SA and Test 3 for the MT should be reasonable options for strengthening.

This study is a first step in examining the most effective movement for activating the SA, MT, and LT without hyperactivating the UT. We demonstrated that the horizontal adduction exercise might effectively strengthen the SA muscle, even at low arm angles, and that the horizontal abduction exercise at the 90° elevated position might also be effective for the MT. However, we found no appropriate procedure for the LT. The difficulty achieving proper activation of the LT persists, which might suggest the need to reconsider the efficacy of already known LT exercises. Further studies including multi-joint exercises focusing on the kinetic chain are needed for LT exercise. Our results will contribute to rehabilitation programs for improving scapular muscle strength or treating imbalances such as scapular dyskinesis.

Limitation

Isometric activation of the periscapular muscles

366 This study has some limitations. First, the sample size of 11 subjects was small and
367 the data in Tables I–IV included high standard deviation values. We demonstrated the
368 standard deviation in each cell as well as the mean value to prevent readers from
369 overestimating our data. In all tables, however, many situations of extraordinary value
370 were evident in the surveyed muscles, and it seems not to be difficult to avoid
371 non-active exercise patterns.

372 Second, we researched SA activity as described in previous studies ^{4,13,20}; in reality,
373 this method recorded only activation of the lower part of the SA instead of the entire SA.
374 This is because our pilot study demonstrated that the recording of the middle and upper
375 SA must be affected by the latissimus dorsi or pectoralis major muscles; this
376 phenomenon is known as cross-talk in surface EMG ³⁰. Considering that the long
377 thoracic nerve ramifies into more branches in the lower part of the SA ²⁸, activation of
378 the lower SA can represent the entire SA. Third, we studied a sample of young, healthy
379 adults. Clinical patients may have different characteristics than those of our subjects,
380 and we cannot tell whether the muscle activation of the healthy volunteers in this study
381 would be generated in the patients. However, the basic functions of the periscapular
382 muscles such as the upward rotator should be maintained, and we could expect the
383 functional recovery of such patients by applying the accomplishments to our daily

Isometric activation of the periscapular muscles

384 practice. To prove the clinical efficiency of our method, further clinical studies are

385 needed.

386

387

Isometric activation of the periscapular muscles

388 **Conclusion**

389 Here we investigated surface EMG findings of the lower SA, UT, MT, and LT
390 muscles during several shoulder muscle force tests. We found that horizontal adduction
391 should effectively improve SA strength. For the MT, muscle horizontal abduction at 90°
392 of arm elevation should be the most effective. However, we found no ideal exercise for
393 the LT muscle, so future studies are warranted.

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Isometric activation of the periscapular muscles

396 **References**

- 397 1 Ballantyne BT, O'Hare SJ, Paschall JL, Pavia-Smith MM, Pitz AM, Gillon JF et
398 al. Electromyographic activity of selected shoulder muscles in commonly used
399 therapeutic exercises. *Phys Ther* 1993;73:668-682.
- 400 2 Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder:
401 spectrum of pathology Part III: The SICK scapula, scapular dyskinesis, the
402 kinetic chain, and rehabilitation. *Arthroscopy* 2003;19:641-661.
403 S074980630300389X [pii]
- 404 3 Cools AM, Declercq GA, Cambier DC, Mahieu NN, Witvrouw EE. Trapezius
405 activity and intramuscular balance during isokinetic exercise in overhead
406 athletes with impingement symptoms. *Scand J Med Sci Sports* 2007;17:25-33.
407 10.1111/j.1600-0838.2006.00570.x
- 408 4 Cools AM, Dewitte V, Lanszweert F, Notebaert D, Roets A, Soetens B et al.
409 Rehabilitation of scapular muscle balance - Which exercises to prescribe? *Am J*
410 *Sports Med* 2007;35:1744-1751. 10.1177/0363546507303560
- 411 5 Cools AM, Witvrouw EE, Declercq GA, Danneels LA, Cambier DC. Scapular
412 muscle recruitment patterns: Trapezius muscle latency with and without
413 impingement symptoms. *Am J Sports Med* 2003;31:542-549.

Isometric activation of the periscapular muscles

- 414 6 Cools AM, Witvrouw EE, Declercq GA, Vanderstraeten GG, Cambier DC.
415 Evaluation of isokinetic force production and associated muscle activity in the
416 scapular rotators during a protraction-retraction movement in overhead athletes
417 with impingement symptoms. Br J Sports Med 2004;38:64-68. doi:
418 10.1136/bjsm.2003.004952
- 419 7 Cools AM, Witvrouw EE, Mahieu NN, Danneels LA. Isokinetic scapular muscle
420 performance in overhead athletes with and without impingement symptoms. J
421 Athl Train 2005;40:104-110.
- 422 8 De Mey K, Cagnie B, Danneels LA, Cools AM, Van de Velde A. Trapezius
423 muscle timing during selected shoulder rehabilitation exercises. J Orthop Sports
424 Phys Ther 2009;39:743-752. 2353 [pii] 10.2519/jospt.2009.3089
- 425 9 De Mey K, Danneels L, Cagnie B, Van den Bosch L, Flier J, Cools AM. Kinetic
426 chain influences on upper and lower trapezius muscle activation during eight
427 variations of a scapular retraction exercise in overhead athletes. J Sci Med Sport
428 2013;16:65-70. 10.1016/j.jsams.2012.04.008
- 429 10 Decker MJ, Hintermeister RA, Faber KJ, Hawkins RJ. Serratus anterior muscle
430 activity during selected rehabilitation exercises. Am J Sports Med
431 1999;27:784-791.

Isometric activation of the periscapular muscles

- 432 11 DiGiovine NM, Jobe FW, Pink M, Perry J. An electromyographic analysis of the
433 upper extremity in pitching. J Shoulder Elbow Surg 1992;1:15-25.
434 10.1016/s1058-2746(09)80011-6
- 435 12 Ebaugh DD, McClure PW, Karduna AR. Three-dimensional scapulothoracic
436 motion during active and passive arm elevation. Clin Biomech 2005;20:700-709.
437 10.1016/j.clinbiomech.2005.03.008
- 438 13 Ekstrom RA, Bifulco KM, Lopau CJ, Andersen CF, Gough JR. Comparing the
439 function of the upper and lower parts of the serratus anterior muscle using
440 surface electromyography. J Orthop Sports Phys Ther 2004;34:235-243.
- 441 14 Ekstrom RA, Donatelli RA, Soderberg GL. Surface electromyographic analysis
442 of exercises for the trapezius and serratus anterior muscles. J Orthop Sports Phys
443 Ther 2003;33:247-258.
- 444 15 Kendall FP, McCreary EK, Provance PG, Rodgers MM, Romani WA. Muscles:
445 testing and function, with posture and pain. North American edition. Baltimore:
446 Lippincott Williams & Wilkins, ISBN0-7817-4780-5; 2005, 297-341.
- 447 16 Hintermeister RA, Lange GW, Schultheis JM, Bey MJ, Hawkins RJ.
448 Electromyographic activity and applied load during shoulder rehabilitation
449 exercises using elastic resistance. Am J Sports Med 1998;26:210-220.

Isometric activation of the periscapular muscles

- 450 17 Inman VT, Saunders JBD, Abbott LC. Observations on the function of the
451 shoulder joint. *J Bone Joint Surg* 1944;26:1-30.
- 452 18 Johnson G, Bogduk N, Nowitzke A, House D. Anatomy and actions of the
453 trapezius muscle. *Clin Biomech* 1994;9:44-50. 10.1016/0268-0033(94)90057-4
- 454 19 Kibler WB, Sciascia A. Current concepts: scapular dyskinesis. *Br J Sports Med*
455 2010;44:300-305. *bjsm*.2009.058834 [pii] 10.1136/bjsm.2009.058834
- 456 20 Kibler WB, Sciascia AD, Uhl TL, Tambay N, Cunningham T.
457 Electromyographic analysis of specific exercises for scapular control in early
458 phases of shoulder rehabilitation. *Am J Sports Med* 2008;36:1789-1798.
459 0363546508316281 [pii] 10.1177/0363546508316281
- 460 21 Ludewig PM, Cook TM. Alterations in shoulder kinematics and associated
461 muscle activity in people with symptoms of shoulder impingement. *Phys Ther*
462 2000;80:276-291.
- 463 22 Ludewig PM, Hoff MS, Osowski EE, Meschke SA, Rundquist PJ. Relative
464 balance of serratus anterior and upper trapezius muscle activity during push-up
465 exercises. *Am J Sports Med* 2004;32:484-493.
- 466 23 Lukasiewicz AC, McClure P, Michener L, Pratt N, Sennett B. Comparison of
467 3-dimensional scapular position and orientation between subjects with and

Isometric activation of the periscapular muscles

- 468 without shoulder impingement. *J Orthop Sports Phys Ther* 1999;29:574-583.
- 469 24 McClure PW, Michener LA, Sennet BJ, Karduna AR. Direct 3-dimensional
470 measurement of scapular kinematics during dynamic movements in vivo. *J*
471 *Shoulder Elbow Surg* 2001;10:269-277. 10.1067/mse.2001.112954
- 472 25 Moseley JB, Jobe FW, Pink M, Perry J, Tibone J. EMG analysis of the scapular
473 muscles during a shoulder rehabilitation program. *Am J Sports Med*
474 1992;20:128-134.
- 475 26 Mottram SL. Dynamic stability of the scapula. *Man Ther* 1997;2:123-131.
476 S1356-689X(97)90292-7 [pii] 10.1054/math.1997.0292
- 477 27 Myers JB, Pasquale MR, Laudner KG, Sell TC, Bradley JP, Lephart SM.
478 On-the-Field Resistance-Tubing Exercises for Throwers: An Electromyographic
479 Analysis. *J Athl Train* 2005;40:15-22.
- 480 28 Nasu H, Yamaguchi K, Nimura A, Akita K. An anatomic study of structure and
481 innervation of the serratus anterior muscle. *Surg Radiol Anat* 2012;34:921-928.
482 10.1007/s00276-012-0984-1
- 483 29 Oyama S, Myers JB, Wassinger CA, Lephart SM. Three-dimensional scapular
484 and clavicular kinematics and scapular muscle activity during retraction
485 exercises. *J Orthop Sports Phys Ther* 2010;40:169-179. 10.2519/jospt.2010.3018

Isometric activation of the periscapular muscles

486 30 Winter DA, Fuglevand AJ, Archer SE. Crosstalk in surface electromyography:
487 Theoretical and practical estimates. J Electromyogr Kinesiol 1994;4:15-26.
488 10.1016/1050-6411(94)90023-X
489
490
491

Isometric activation of the periscapular muscles

Figure and Table Legends

Figure 1. Tests 1–4 performed in the sitting position. Arrows indicate directions of the applied forces. (A) In the frontal plane (at the 90° elevated position). (B) In the sagittal plane (at the 90° elevated position).

Isometric activation of the periscapular muscles

499

Isometric activation of the periscapular muscles

	Test 1 (% MVIC)		Test 2 (% MVIC)		Test 3 (% MVIC)		Test 4 (% MVIC)		Angle effect	Test effect	Interaction
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P-value	P-value	P-value
Serratus anterior											
30° humeral elevation	87.0	± 43.6	43.6	± 31.7	45.7	± 55.5	70.5	± 24.8	.713	<.001	.417
60° humeral elevation	109.7	± 49.9	48.6	± 46.4	40.3	± 51.9	86.1	± 43.9			
90° humeral elevation	133.1	± 82.5	38.9	± 36.7	35.2	± 55.3	77.9	± 35.9			
120° humeral elevation	124.1	± 57.3	34.9	± 35.3	27.3	± 41.8	60.0	± 38.2			
150° humeral elevation	111.4	± 48.3	32.9	± 34.0	58.6	± 56.9	46.3	± 31.0			
Upper Trapezius											
30° humeral elevation	78.6	± 25.5	3.7	± 1.1	34.4	± 19.0	22.7	± 18.3	.037	<.001	<.001
60° humeral elevation	87.4	± 13.1	6.8	± 7.5	51.8	± 21.8	16.8	± 17.5			
90° humeral elevation	89.3	± 18.7	6.2	± 8.4	55.7	± 18.1	13.9	± 15.0			
120° humeral elevation	82.0	± 17.3	6.1	± 10.4	72.9	± 23.7	13.6	± 19.4			
150° humeral elevation	82.9	± 21.2	5.9	± 9.0	88.8	± 19.6	5.1	± 6.3			
Middle Trapezius											
30° humeral elevation	66.8	± 21.2	15.8	± 8.7	61.1	± 18.3	24.4	± 12.0	.229	<.001	<.001
60° humeral elevation	69.2	± 21.0	17.8	± 9.4	69.7	± 20.8	13.6	± 6.0			
90° humeral elevation	61.0	± 24.8	13.0	± 6.0	80.2	± 29.6	8.2	± 4.5			
120° humeral elevation	44.1	± 23.0	9.8	± 6.5	78.9	± 26.7	7.1	± 5.7			
150° humeral elevation	35.6	± 22.6	16.1	± 12.0	93.3	± 27.7	6.1	± 3.7			
Lower Trapezius											
30° humeral elevation	52.8	± 25.3	25.4	± 17.5	33.4	± 19.4	43.3	± 13.3	.743	<.001	<.001
60° humeral elevation	59.6	± 25.4	26.4	± 22.7	44.1	± 27.0	24.6	± 13.9			
90° humeral elevation	53.3	± 20.7	16.6	± 11.2	50.4	± 35.0	13.4	± 8.0			
120° humeral elevation	61.9	± 32.3	17.8	± 12.1	64.7	± 33.6	10.5	± 8.9			
150° humeral elevation	40.2	± 19.1	20.9	± 12.2	85.9	± 40.5	7.6	± 3.9			

500

501 Table I. Electromyographic activities in the frontal plane

502 *Test 1*, applied force to the arm from the upper to lower side; *Test 2*, from the lower to upper side; *Test 3*, from the lateral to medial

503 side; *Test 4*, from the medial to lateral side. MVIC, maximal voluntary isometric contraction; SD, standard deviation

Isometric activation of the periscapular muscles

	Test 1 (% MVIC)		Test 2 (% MVIC)		Test 3 (% MVIC)		Test 4 (% MVIC)		Angle effect	Test effect	Interaction
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	P-value	P-value	P-value
Serratus anterior											
30° humeral elevation	89.1	± 34.2	47.2	± 44.8	44.4	± 56.3	62.5	± 26.4	.683	<.001	.082
60° humeral elevation	104.7	± 43.1	45.9	± 47.3	32.6	± 34.5	91.8	± 41.9			
90° humeral elevation	110.0	± 63.6	27.9	± 26.6	20.4	± 17.3	80.8	± 45.6			
120° humeral elevation	95.1	± 35.4	24.8	± 18.6	20.1	± 17.4	81.9	± 41.5			
150° humeral elevation	84.2	± 59.4	23.5	± 14.9	16.3	± 12.5	123.3	± 81.6			
Upper Trapezius											
30° humeral elevation	57.5	± 10.0	17.1	± 11.7	57.2	± 15.5	9.1	± 8.0	.162	<.001	<.001
60° humeral elevation	73.5	± 15.1	8.5	± 8.8	53.9	± 16.5	14.6	± 18.2			
90° humeral elevation	88.8	± 16.2	3.4	± 2.9	39.1	± 19.1	24.6	± 24.7			
120° humeral elevation	93.4	± 22.0	5.2	± 4.8	30.8	± 17.2	37.6	± 20.0			
150° humeral elevation	93.6	± 24.6	7.7	± 10.0	14.3	± 14.5	57.3	± 25.7			
Middle Trapezius											
30° humeral elevation	47.2	± 13.4	39.1	± 17.8	82.9	± 23.9	8.4	± 4.0	.0499	<.001	<.001
60° humeral elevation	52.1	± 20.3	26.2	± 15.0	90.4	± 27.2	7.9	± 4.0			
90° humeral elevation	62.3	± 23.8	17.5	± 16.6	75.8	± 27.4	8.9	± 6.5			
120° humeral elevation	76.8	± 23.2	9.2	± 6.6	57.0	± 19.6	8.9	± 3.7			
150° humeral elevation	81.0	± 25.5	8.9	± 8.6	36.4	± 24.3	12.1	± 2.9			
Lower Trapezius											
30° humeral elevation	54.2	± 34.3	29.0	± 23.8	50.5	± 37.4	21.1	± 24.5	.953	<.001	.009
60° humeral elevation	59.2	± 29.3	16.5	± 10.9	58.1	± 45.1	10.4	± 7.5			
90° humeral elevation	58.0	± 21.1	15.0	± 11.8	51.6	± 29.5	13.8	± 11.7			
120° humeral elevation	85.5	± 36.3	9.4	± 6.0	37.4	± 18.0	9.2	± 6.2			
150° humeral elevation	84.7	± 40.3	10.8	± 8.4	37.0	± 24.6	14.3	± 13.1			

504

505 Table II. Electromyographic activities in the sagittal plane

506

Isometric activation of the periscapular muscles

507

	Test 1			Test 2			Test 3			Test 4		
	Mean	SD		Mean	SD		Mean	SD		Mean	SD	
UT/SA												
30° humeral elevation	110.3	± 66.5		14.4	± 9.6		206.2	± 181.1		35.0	± 32.1	
60° humeral elevation	89.7	± 30.6		57.6	± 117.1		321.7	± 236.7		20.4	± 22.2	
90° humeral elevation	82.6	± 39.3		48.3	± 98.1		450.5	± 383.7		22.1	± 22.5	
120° humeral elevation	84.9	± 48.9		56.9	± 140.0		747.9	± 629.4		24.9	± 30.7	
150° humeral elevation	102.2	± 82.5		43.4	± 75.5		394.6	± 423.1		18.9	± 32.8	
UT/MT												
30° humeral elevation	124.7	± 41.2		28.8	± 15.6		61.3	± 39.6		88.8	± 49.4	
60° humeral elevation	135.1	± 36.6		58.5	± 96.5		77.6	± 29.3		104.9	± 72.5	
90° humeral elevation	176.3	± 105.1		40.5	± 31.5		79.3	± 39.9		160.6	± 111.5	
120° humeral elevation	223.2	± 102.6		50.4	± 37.3		112.7	± 83.2		158.4	± 133.7	
150° humeral elevation	305.7	± 199.3		36.7	± 29.8		104.7	± 45.4		85.7	± 52.0	
UT/LT												
30° humeral elevation	202.3	± 191.4		22.7	± 19.0		139.4	± 110.5		49.1	± 34.6	
60° humeral elevation	180.5	± 97.6		51.3	± 88.6		149.6	± 84.5		67.8	± 55.3	
90° humeral elevation	203.2	± 115.5		33.4	± 19.9		145.5	± 71.5		106.7	± 92.7	
120° humeral elevation	181.1	± 116.9		32.1	± 27.8		148.8	± 90.8		167.0	± 305.5	
150° humeral elevation	357.7	± 457.8		29.2	± 26.1		125.0	± 61.0		59.1	± 29.6	

508

509 Table III. The balance ratio in the frontal plane

510

511

Isometric activation of the periscapular muscles

512

	Test 1			Test 2			Test 3			Test 4		
	Mean	SD		Mean	SD		Mean	SD		Mean	SD	
UT/SA												
30° humeral elevation	76.1	± 40.0		83.4	± 94.5		334.0	± 264.9		15.3	± 11.1	
60° humeral elevation	80.3	± 34.5		28.9	± 17.9		359.6	± 358.2		15.1	± 15.0	
90° humeral elevation	95.4	± 39.5		16.5	± 11.2		338.4	± 278.8		30.6	± 27.5	
120° humeral elevation	111.5	± 50.5		25.7	± 26.8		231.6	± 162.9		50.1	± 29.5	
150° humeral elevation	141.3	± 65.0		40.1	± 41.4		150.5	± 157.8		72.8	± 51.4	
UT/MT												
30° humeral elevation	128.7	± 30.0		54.1	± 55.6		72.1	± 21.2		130.8	± 146.8	
60° humeral elevation	155.6	± 51.5		32.9	± 20.1		61.3	± 17.0		199.0	± 230.0	
90° humeral elevation	162.9	± 68.5		25.5	± 13.2		58.1	± 38.0		280.5	± 212.2	
120° humeral elevation	129.7	± 40.6		55.7	± 30.9		58.9	± 35.7		441.8	± 218.9	
150° humeral elevation	125.3	± 46.0		94.0	± 80.1		39.6	± 21.4		472.7	± 202.0	
UT/LT												
30° humeral elevation	133.3	± 60.5		89.1	± 79.8		155.9	± 101.6		100.5	± 148.3	
60° humeral elevation	165.5	± 103.3		55.2	± 47.6		130.3	± 96.5		141.9	± 147.7	
90° humeral elevation	169.6	± 59.4		31.2	± 33.1		89.5	± 59.5		182.3	± 138.4	
120° humeral elevation	127.3	± 56.5		54.7	± 37.6		108.6	± 111.0		463.5	± 285.1	
150° humeral elevation	127.6	± 49.6		70.5	± 55.2		39.4	± 21.2		603.0	± 353.1	

513

514 Table IV. The balance ratio in the sagittal plane

515