

The effect of cervical spine rotation on electromyographic activity of the trapezius and serratus anterior during selected shoulder complex movements

ALICJA JURECKA^{1*}, KINGA ŻMIJEWSKA¹, MAŁGORZATA PAPLACZYK², ARTUR GADEK¹

¹ Jagiellonian University Medical College, Faculty of Health Sciences, Institute of Physiotherapy,
Department of Orthopedics and Physiotherapy, Kraków, Poland.

² Jagiellonian University Medical College, Faculty of Health Sciences, Institute of Nursing and Midwifery,
Department of Clinical Nursing, Kraków, Poland.

Purpose: The purpose of the study was the assessment of the effect of cervical spine rotation on the activity of the upper (UT) and lower (LT) trapezius and serratus anterior (SA) muscles during selected shoulder movements. *Methods:* The investigation included 33 healthy individuals (mean age \pm SD: 22 \pm 1.73 years). Bioelectrical activity of the right (R) and left (L) UT, LT, SA muscles was assessed during the following movements: elevation, flexion, abduction in the scapular and right coronal planes of the dominant (right) arm accompanied by three cervical spine positions (neutral, right rotation, left rotation). *Results:* RLT EMG activity was higher during right shoulder abduction with right spine rotation vs. that registered during abduction without cervical spine rotation ($p < 0.001$). RUT EMG activity during right shoulder abduction was higher when abduction was associated with left cervical spine rotation ($p < 0.01$) and lower during right shoulder flexing with right cervical spine rotation, compared to shoulder movements with neutral spine position ($p < 0.001$). A higher RSA EMG activity was seen during shoulder flexing ($p < 0.001$) and abducting ($p < 0.05$) (both in the frontal and scapular plane) when the movement was performed with right cervical spine rotation, compared to RSA activity during shoulder movements without spinal rotation. *Conclusions:* The present results suggest that inclusion of appropriate cervical spine rotation during shoulder movements may result in improved activity of the trapezius and serratus anterior.

Key words: sEMG, shoulder muscles, arm movements, head rotation

1. Introduction

Pain and functional abnormalities within the shoulder complex and cervical spine are commonly diagnosed in physically active individuals [2]. Investigations indicate a relation between strength training, snowboarding, downhill skiing, as well as gymnastics and athletics, and ailments observed in young athletes [11], [34]. Overloading the locomotor system may lead to damages of the shoulder complex and, in consequence, to pain development [2]. Available science-

based evidence supports the effect of incorrectly performed physical activity on pathological muscle tensions development leading to muscle disbalance and shoulder complex destabilization [13], [15]. Lesions most often involve the shoulder joint axis and shoulder blade position. In consequence, the biomechanics and function of the arm and cervical spine are disturbed, which may generate headaches [15]. Studies performed in swimmers suggest that repeated overhead shoulder movements may lead to changes in muscle length, increased pathological tension of the upper trapezius and pectoral muscles, as well as changes in

* Corresponding author: Alicja Jurecka, Jagiellonian University Medical College, Faculty of Health Sciences, Institute of Physiotherapy, Department of Orthopedics and Physiotherapy, ul. Michałowskiego 12, 31-126 Kraków, Poland, e-mail: alicja.jurecka@uj.edu.pl

Received: November 22nd, 2021

Accepted for publication: January 19th, 2022

serratus anterior activity [13]. Simultaneously, evidence confirms that in order to increase the effectiveness of a given activity, in athletes performing movements above their heads, a high activity of the shoulder joint is particularly important [39]. In turn, proper stabilization of the shoulder blade affects the efficiency of muscle activity in the entire shoulder complex what provides conditions for reaching maximum movement strength and velocity [26].

High activity at rest is commonly observed within the upper trapezius. The background of such changes is not uniform, as they may result from both training overload, stress or be a consequence of a pathological posture pattern involving head protraction [23], [38]. A slight bone stabilization accompanied by a wide range of shoulder movement requires a high activity of muscles that provide complex stability. Each instance of disbalance in muscle activity and sensorimotor control creates favorable conditions for injuries [26].

Muscles that play an important role in proper functioning of the shoulder complex include the serratus anterior and trapezius. They are believed to be the principal muscles that rotate the shoulder blades upward when the arm is elevated above the horizontal plane. They also play the stabilizer role for the scapulocostal joint [19].

In the case of shoulder injuries, the initial symptoms include abnormalities in the complex stabilization and shoulder blade dyskinesia. Disturbances of the proper biomechanics of the scapulocostal complex are often a consequence of overloading or past sports-associated injuries such as superior labrum from anterior to posterior lesion (SLAP), damage of the caput longum of the biceps brachii muscle, impingement syndrome, or damage to the elbow joint [27]. It is the consequence of restricted activity of interacting muscles responsible for shoulder blade elevation, depression, retraction and protraction. The mechanism is commonly associated with an increased activity of the lower parts of the trapezius and serratus anterior. Additionally, the tension of the upper trapezius may be often excessive [23]. Patients with shoulder impingement syndrome have been demonstrated to manifest pathologically increased activity of the trapezius and pathologically decreased activity of its lower part and serratus anterior [8]. In absence of normal scapulocostal joint function, translation of the scapula head is increased during arm elevation and, therefore, while rehabilitating individuals with scapulocostal complex dysfunction, restoring proper scapulohumeral rhythm is significant. Working on restoring activity of the serratus anterior and lower part of the trapezius seems to be necessary [19].

Few studies are available in the scientific literature that evaluated the effect of head position on the bioelectrical activity of selected muscles that cooperate in performing global movements within the shoulder complex [9], [10], [29]. Ekstrom et al. [9] observed a positive correlation between the position of the cervical spine and the activity of the trapezius. Yamauchi et al. [40], in turn, determined the influence of global trunk rotation on the activity of the trapezius and serratus anterior muscles. The results of the study suggest that shoulder exercises combined with trunk rotation should be recommended both for people whose lower trapezius activity is weakened and for those whose upper trapezius is pathologically tense. However, it is still unclear whether the activity of the muscles studied depends on global or segmental spinal rotation [40].

The purpose of the study was evaluating the effect of cervical spine rotation on activity of the upper and lower parts of the trapezius and serratus anterior muscles during the following movements of the shoulder complex: elevation, flexion and abduction in the frontal and scapular planes (hereafter referred to as “abduction”). The following hypotheses were proposed: 1. Cervical spine rotation combined with motions involving elevation, abduction and flexion affect the activity of the upper and lower trapezius and serratus anterior muscles. 2. Combination of elevation, flexion and abduction with shoulder flexion with cervical spine rotation results in a decreased activity of the upper trapezius, what may be significant in the case of pathologic muscle hyperactivity. 3. Cervical spine rotation during elevation, abduction and flexion within the shoulder complex results in increasing activity of the upper serratus anterior and lower trapezius.

2. Materials and methods

The study included 33 healthy volunteers (10 females and 23 males, mean \pm standard deviation (SD), 22 ± 1.73 years, body height: 179.6 ± 5.8 cm; body mass: 70.35 ± 2.4 kg). All participants were requested to assess their level of physical activity using the International Physical Activity Questionnaire – Short Form (IPAQ – SF) [16] and the presence of pain using the visual analog scale (VAS). The inclusion criteria were: age between 18 and 35 years, low level of physical activity (according to IPAQ) in the week before the study, no shoulder or cervical spine pain (VAS = 0), consent to participate in the study. The exclusion criteria were: failure to meet the inclusion

criterion and the presence of overload lesions of the cervical spine and/or shoulder or other conditions or pathologies that could have influenced the study and measurement results. Information concerning the possibility of participation in the planned study was disseminated among students of the Jagiellonian University Medical College by members of the Student's Scientific Society. Participation in the study was voluntary. All the participants received detailed information on the course of the study and granted their written consent. The investigation was approved by the Bioethics Committee at the Jagiellonian University Medical College in Kraków, Poland and was run in accordance with the Helsinki declaration and with implications for replacement, refinement or reduction (the 3Rs) principle.

Bioelectrical activity of the trapezius and serratus anterior was performed using surface electromyography (sEMG) and a TeleMyo 2400 G2 unit (Noraxon, the US), keeping with the SENIAM recommendations [27], [37]. The result was registered during the subject's performing movements using the dominant arm (all the individuals were right-handed). Prior to the study, to reduce signal impedance, the skin was shaved and degreased with isopropyl alcohol.

Surface electrodes (Ag/AgCl) (Bio Lead Lok B Sp. z o.o., Polska) were attached with a 2 cm inter-electrode spacing and in keeping with the SENIAM [27], [37] recommendations, i.e., parallel to muscle fibers on the belly of the upper (UT) and lower trapezius (LT) and lower serratus anterior (SA) of the right and left sides of the body. The reference electrode was placed on the C7 or Th1 spinous process depending on the vertebrae structure of the study subject. sEMG signal registration and analysis was done using the MyoResearch XP Master Edition software (Noraxon, the US).

sEMG signal was registered and processed in keeping with the SENIAM recommendations [27], [37]. Each time the signal was filtered (the assumed bandwidth was 10–500 Hz), followed by rectification and smoothing employing the Root Mean Square (RMS) algorithm. A mobile time window was defined with the maximum width of 300 ms [27], [37]. All the measurements were implemented during a single meeting. The normalization method, specific for this study, was a comparison of the test results: shoulder movement with neutral cervical spine position vs. shoulder movement with appropriate (right or left) cervical spine rotation. No control group was formed and the comparison involved solely the results obtained under various measurement conditions in the same subject.

To minimize the diurnal variability of bioelectric muscle activity, all the measurements were done in the

morning hours. The measurement commenced with recording sEMG with the subject at rest with the head positioned neutrally. The reading allowed for excluding pathological rest muscle tension.

The right stage of the study consisted in recording sEMG signal while the subject performed movements involving the shoulder complex of the dominant arm and accompanied by a closely defined cervical spine position. All the subjects were right-handed. Each one was asked to perform the following movement sequence:

- shoulder elevation of the dominant (right) arm involving three cervical spine positions: neutral, with rotation towards the moving arm (right) and rotation towards the side opposite to the examined arm (left),
- shoulder flexion of the dominant (right) arm involving three cervical spine positions: neutral, with rotation towards the moving arm (right) and rotation towards the side opposite to the examined arm (left),
- shoulder abduction of the dominant (right) arm involving three cervical spine positions: neutral, with rotation towards the moving arm (right) and rotation towards the side opposite to the examined arm (left),
- abduction of the dominant (right) arm involving three cervical spine positions: neutral, with rotation towards the moving arm (right) and rotation towards the side opposite to the examined arm (left).

Full scope of motion cervical spine rotation each time preceded the shoulder complex movement. Subsequent sequences of shoulder movements were separated by 3-minute intervals. All participants in the study were requested to perform each movement through its full range of motion, stopping the movement for 3 seconds at the obtained final position of the range of motion. The speed of each movement was natural and self-selected by each subject. In each study condition (each cervical spine positioning), the subject was asked to move the shoulder six times. During the measurement-taking, the subjects were standing. The remaining joints of the arm and all the contralateral (left) arm joints were positioned neutrally.

The statistical analysis of the results was performed using the STATISTICA 13.1 PL software. The fitting goodness of the observed distributions with the theoretical normal distribution was analyzed using the Shapiro–Wilk test. The results of muscle bioelectrical activity achieved during shoulder movements involving particular cervical spine positions (with and without rotation) were compared employing the Wilcoxon matched-pairs test. The T and Z -statistical values were calculated, as well as the significance coefficient (p). Test probability of $p < 0.05$ was regarded significant.

3. Results

EMG activity of the right lower trapezius (RLT) was significantly higher during right shoulder abduc-

tion accompanied by right shoulder rotation in the frontal plane, compared to EMG RLT activity registered during abduction without cervical spine rotation ($p < 0.001$) (Fig. 1). In turn, when right shoulder flexion was combined with left cervical spine rotation,

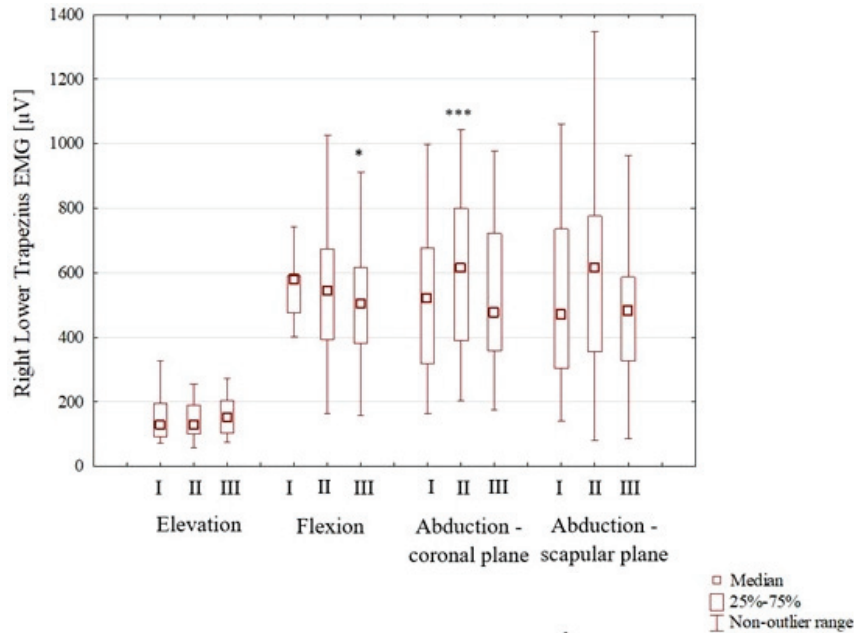


Fig. 1. The effect of cervical spine rotation on mean electromyographic (EMG) activity of the right lower trapezius (RLT) during selected movements of the dominant (right) shoulder. * statistically significant in comparison with RLT EMG activity during shoulder movement without cervical spine rotation ($* p < 0.05$, $*** p < 0.001$) I – right shoulder movement and neutral cervical spine position II – right shoulder movement and right cervical spine rotation III – right shoulder movement and left cervical spine rotation

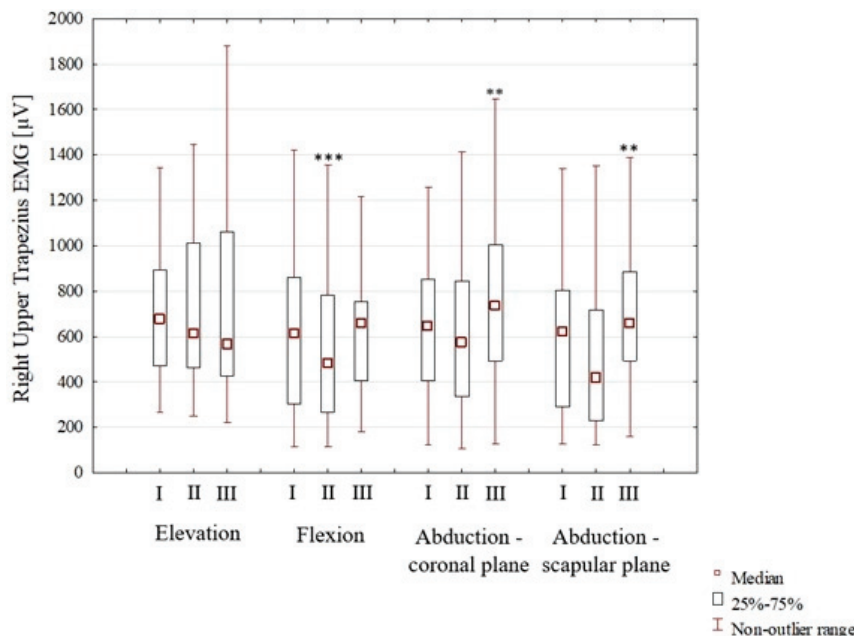


Fig. 2. The effect of cervical spine rotation on mean electromyographic (EMG) activity of the upper right trapezius (RUT) during selected movements of the dominant (right) shoulder. * statistically significant in comparison with RLT EMG activity during shoulder movement without cervical spine rotation ($** p < 0.01$, $*** p < 0.001$) I – right shoulder movement and neutral cervical spine position II – right shoulder movement and right cervical spine rotation III – right shoulder movement and left cervical spine rotation

RLT EMG activity was lower as compared to shoulder flexion accompanied by neutral cervical spine position ($p < 0.05$) (Fig. 1).

EMG activity of the right upper trapezius (RUT) during right shoulder abduction was higher when the abduction was combined with left cervical spine rota-

tion as compared to neutral spine position ($p < 0.01$) (Fig. 2). During right shoulder flexion with right spinal cord rotation, EMG RUT activity was lower, compared to flexion without spinal rotation ($p < 0.001$) (Fig. 2).

In turn, an increased EMG activity of the left lower trapezius (LLT) was demonstrated when right shoul-

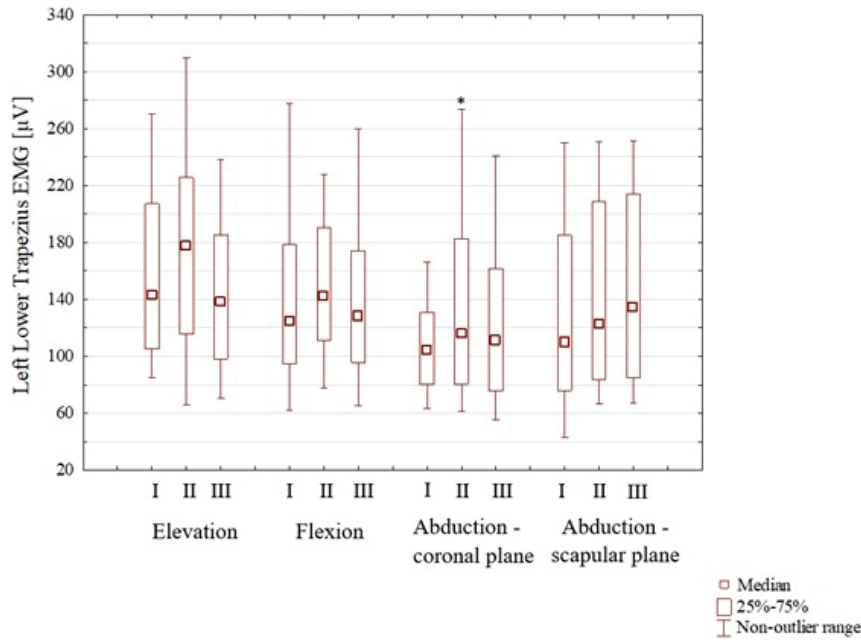


Fig. 3. The effect of cervical spine rotation on mean electromyographic (EMG) activity of the lower left trapezius (LLT) during selected movements of the dominant (right) shoulder. * statistically significant in comparison with RLT EMG activity during shoulder movement without cervical spine rotation ($* p < 0.05$) I – right shoulder movement and neutral cervical spine position II – right shoulder movement and right cervical spine rotation III – right shoulder movement and left cervical spine rotation

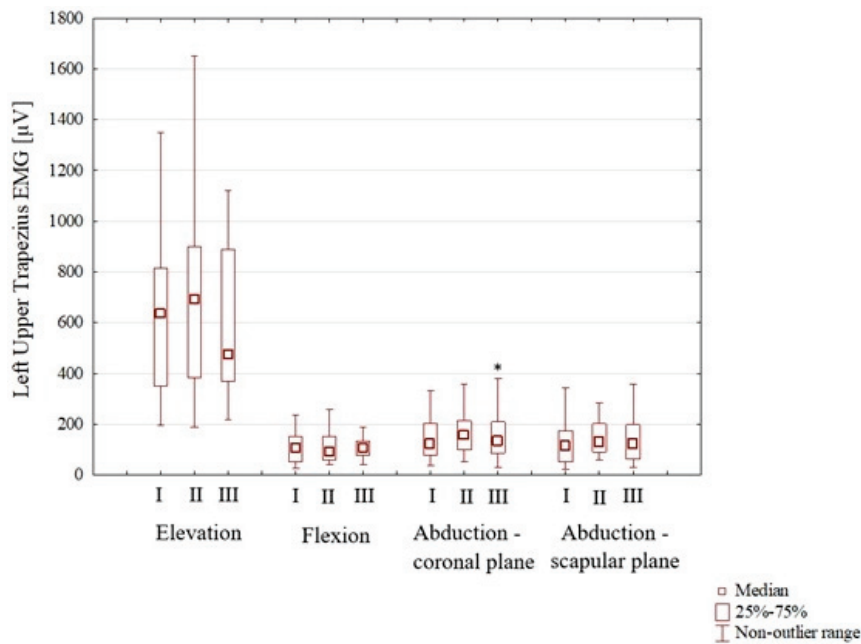


Fig. 4. The effect of cervical spine rotation on mean electromyographic (EMG) activity of the upper left trapezius (LUT) during selected movements of the dominant (right) shoulder. * statistically significant in comparison with RLT EMG activity during shoulder movement without cervical spine rotation ($* p < 0.05$) I – right shoulder movement and neutral cervical spine position II – right shoulder movement and right cervical spine rotation III – right shoulder movement and left cervical spine rotation

der abduction was accompanied by right cervical spine rotation, compared to abduction with neutral spine position ($p < 0.05$) (Fig. 3).

In the case of the left upper trapezius (LUT), a significant difference in EMG activity was seen only in combination of right shoulder abduction without cervical spine rotation and abduction movement with left spine rotation ($p < 0.05$). EMG LUT activity was higher with right shoulder abduction combined with left rotation (Fig. 4).

The right serratus anterior (RSA) EMG activity during flexion of the right (dominating) shoulder was significantly higher when the movement was accompanied by right cervical spine rotation as compared to flexion without rotation ($p < 0.001$). A lower, although still significant difference, in EMG RSA activity depending on cervical spine position was noted during right arm abduction. In the course of abduction with neutral cervical spine position, EMG RSA activity was lower compared to abduction accompanied by right cervical spine flexion ($p < 0.01$). Right shoulder abduction accompanied by right cervical spine rotation generated a higher EMG activity of the RSA muscle as compared to its EMG activity registered during shoulder movement without cervical spine rotation ($p < 0.05$). However, EMG RSA activity was lower with the movement accompanied by right cervical spine rotation as compared to shoulder elevation with neutral cervical spine position ($p < 0.05$) (Fig. 5).

In the case of the left serratus anterior (LSA), no combination of the investigated dominant shoulder movements with or without cervical spine rotation generated significant differences in EMG activity of the muscle ($p > 0.05$).

4. Discussion

Numerous discussions and research studies have concentrated on activity of the cervico-brachial complex [3], [8], [12]. Abnormalities of EMG activity of the trapezius and serratus anterior have been demonstrated to directly affect shoulder function [9], [18] and thus may become the cause of permanent structural changes. Pain involving the shoulder is one of the most common ailments resulting from motor system injuries in the general population [38]. They are also commonly associated with upper cervical spine dysfunction [25], [39]. The risk factors include repeated and long-lasting movements of the arm above one's head, head protraction, abnormalities of shoulder blade kinematics, or muscle activity and stress [38]. Generating muscle disbalance, pathological upper trapezius hyperactivity leads to shoulder complex dysfunction or headaches [15]. The aim of the study was assessing the effect of cervical spine rotation on activity of the trapezius and serratus anterior during

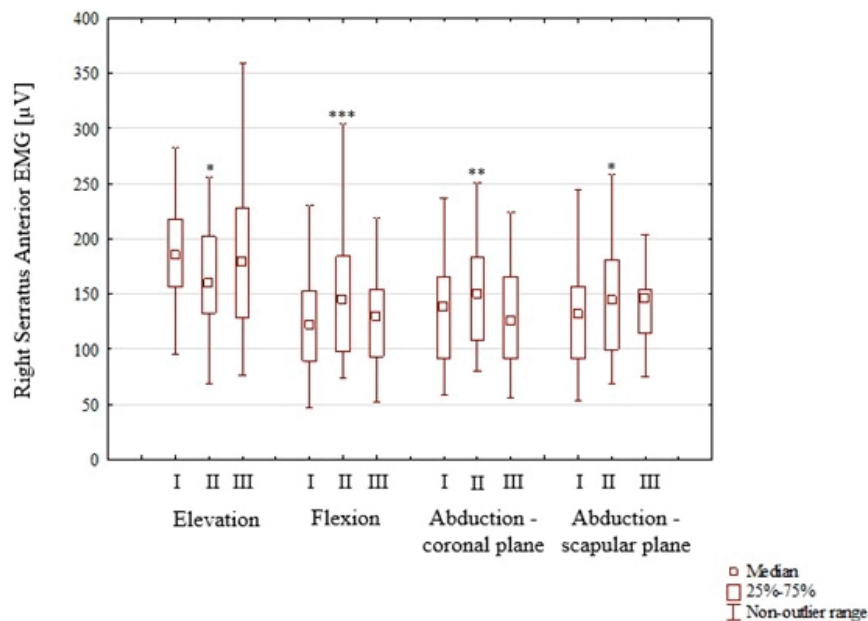


Fig. 5. The effect of cervical spine rotation on mean electromyographic (EMG) activity of the right serratus anterior (RSA) during selected movements of the dominant (right) shoulder. * statistically significant in comparison with RLT EMG activity during shoulder movement without cervical spine rotation ($* p < 0.05$, $** p < 0.01$, $*** p < 0.001$) I – right shoulder movement and neutral cervical spine position II – right shoulder movement and right cervical spine rotation III – right shoulder movement and left cervical spine rotation

the following movements involving the shoulder, i.e., elevation, flexion, abduction.

The authors of the present study evaluated the effect of cervical spine rotation in the full range of motion on activity of the trapezius and serratus anterior during shoulder elevation and flexion, as well as abduction. The results point out to a significant role of cervical spine rotation in muscle activity. The present studies performed in the population of young subjects without any pain and structural lesions of the shoulder and cervical spine demonstrated the effect of cervical spine rotation on decreasing activity of the upper trapezius and serratus anterior with the arm performing selected movements.

The present study has several noteworthy limitations. It included solely the population of healthy individuals without headaches, pain involving cervical spine and shoulder and without structural changes in the investigated location that would require conservative or surgical treatment. The group did not include professional athletes who might demonstrate motor system overload-associated changes or consequences of soft tissue microinjuries. The sEMG signal is highly sensitive to external interference or other artefacts. Thus, the investigator's significant role is minimizing such phenomena through appropriate skin preparation (providing good conditions for impedance) and fixing the electrodes and wires. The electromyographic evaluation included the trapezius and serratus anterior what – in view of the results – created some interpretation-related problems. In addition, there was no detailed evaluation of the activity of the tested muscles in relation to the range of scapular elevation (shoulder range of motion).

RLT electromyographic activity was proven to be higher during right shoulder abduction accompanied by right cervical spine rotation as compared to EMG activity recorded in abduction without rotation. It seems that explaining the mechanism involved in increased LT activity begins with the anatomical function of the upper and lower trapezius. The inter-muscle activity is both antagonistic (during shoulder blade elevation/depression) and agonistic in upper shoulder blade rotation necessary for performing shoulder abduction [7]. RUT preload may occur during right cervical spine rotation what generates activation of the Golgi tendon organs that transmit signals via type Ib sensory nerve fibers to neurons of the non-reciprocal innervation (neurotransmitter-glycine) that inhibit alpha motoneurons for the muscle and stimulate alpha motoneurons of antagonistic muscles *alfa* [1], [21]. Some RUT activity limitations due to the Golgi tendon activity simultaneously contribute to increased RLT activity

(stimulation). Concurrently, weakened RUT function for upper shoulder blade rotation may contribute to the necessity of a higher RLT muscle involvement during the movement. The afore-mentioned autogenic inhibition mechanism was probably the cause of decreased RUT electromyographic activity during right shoulder flexion to the right side vs. flexion without spine rotation.

In turn, muscle stretching or relative changes of its length are detected by another kind of proprioceptors, i.e., muscle spindles [28], containing two types of nerve endings, with the first – annulospiral endings – reacting to muscle stretching. The stimulation travels to spinal cord motor neurons through Ia myelin fibers, participating in the monosynaptic reflex arch [1], [21]. Left cervical spine rotation might have contributed to RUT stretching and stimulation of its muscle spindles resulting in reflective stimulation of motor neurons manifested as the stretched muscle contraction. The myotatic reflex is thus a likely physiological mechanism responsible for increased RUT activity during right shoulder abduction associated with left cervical spine rotation as compared to abduction movements with neutral cervical spine position.

The present results may also reflect the activity of specific myofascial junctions. The posterior myofascial train originates from the occipital protuberance and consists of the back trapezius with its ascending part cooperating with the serratus anterior during scapulo-costal stabilization and shoulder girdle activity [31]. Cervical spine rotation results in increasing or shortening the distance between anatomical muscle attachments to the bone what affects stretching or decreasing tension within structural myofascial junctions. Important for the present results is undoubtedly the close fascial junction of the trapezius and deltoid muscles resulting in formation of functional and energetic trapezius-deltoid complex [30].

Interestingly, the present authors also demonstrated spine rotation to affect changes in LLT electromyographic activity. Increased activity of the muscle was shown when right shoulder abduction was accompanied by right cervical spine rotation compared to abduction with neutral spine position. Observations of functional dependencies between anatomical structures show that during right head rotation there occurs tension of contralateral muscles, i.e., the posterior upper serratus and rhomboids [36]. In turn, the anterior fasciae of the rhomboids form an integrated whole with the serratus anterior fascia [6]. Together the muscles form a spiral starting at the head and extending to the contralateral side of the back and pelvis [32]. The musculofascial continuity may explain

the observed LLT activity increase during right head rotation. It has been already proven that the direction of activity changes for the anterior serratus and lower trapezius is similar [8].

The aforementioned fascial junction of the rhomboid and anterior serratus muscles might also have affected the presently demonstrated RSA activity increase during flexion and abduction of the right shoulder when accompanied by right cervical spine rotation compared to shoulder movement without spinal rotation. Motor units in the sternocleidomastoid and anterior serratus muscles are activated during head rotation what might have additionally increased RSA activity during arm elevation [35]. It should be also mentioned that right head rotation results in stimulation of cervical muscle proprioceptors, which generates a tonic neck reflex response that facilitates right arm abductors contraction [28].

The literature on the subject includes infrequent publications addressing the study subject. Investigators mostly concentrate on evaluating muscle activity within the shoulder complex during active or shoulder structure-loading movements without simultaneous cervical spine rotation [5], [10], [38], [39]. The effect of segmental spine rotation on activity of muscles significant both for proper mobility and shoulder complex stability has not been fully explained. Investigators mostly concentrate on evaluating muscle activity during isometric contraction [4], which results from the fact that isometric exercises are often employed in clinical practice in acute phase in patients with muscle structure damage. Isometric exercises are regarded safe and are often the only possible exercises when placing a load on or stretching the damaged or operated on structures [4], [9], [22].

Yamauchi et al. [40] studied the effects of ipsilateral trunk rotation on the activity of the upper trapezius, middle trapezius, lower trapezius and serratus anterior muscles and scapular kinematics during shoulder movements. The participants of the experiment were asked to perform a maximal shoulder lift in the plane of the scapula, followed by external rotation in the neutral position and an abduction to 90 degrees. The movement task was performed in a standing position with and without global trunk rotation. The influence of trunk rotation on the activity of selected muscles was also assessed in the supine position, in which the subjects performed scapular retraction movements with arm abduction to: 45, 90 and 145 degrees. The inclusion of trunk rotation in the standing exercises generated an increase in LT activity and increased scapular external rotation and posterior tilt. On the other hand, during exercises of shoulder abduction (with scapular retraction at 90° and 145°) significantly

decreased the UT/LT ratio compared to exercises without trunk rotation [40].

McLean et al. [29] drew attention to the significance of head positioning during humeral joint movements observing that head position may affect the results of determining upper trapezius activity. Head rotation may affect upper trapezius activity based on primitive reflex activity, especially on asymmetrical tonic neck reflex (ATNR), leading to shoulder abduction and elbow extension on the rotation side and contralateral shoulder abduction and elbow flexion [22]. The authors suggest ATNR reflex to be capable of increasing excitability of the upper trapezius manifested by increased EMG activity during arm movement with contralateral head rotation.

Evaluating the trapezius activity during selected motor activities, Ekstrom et al. [9] also observed dependence between cervical spine position and muscle activity. Nine positions were tested, each with manual resistance applied while moving the cervical spine and arm. The highest UT activity was noted when the arm was abducted reaching the horizontal position and the cervical spine was flexed and rotated contralaterally with resistance applied to the head and above the elbow [9]. The results were in accordance with the present findings. Despite lack of external resistance, a similar increase of UT activity was noted during abduction of the dominant (right) shoulder in the frontal and coronal planes when the movement was combined with cervical left spine rotation (compared to abduction with neutral spine position) [9]. The effect of cervical spine positioning on trapezius activity was also demonstrated by Gaffney et al. [10]. The results were obtained using three shoulder positions (together with shoulder blade position) aiming at activating various muscle parts: elevation (upper part), abduction (central part) and abduction with shoulder blade depression (lower part). Each movement was full-range and the final motion range was maintained for 30 seconds. The results suggest the effect of selective activation of the trapezius parts on improvement of cervical spine and shoulder blade positions and a decreased risk of injuries resulting from pathological trapezius tension [10]. The study did not include the effect of cervical spine rotation on muscle activity; only the spine position in the sagittal plane was evaluated [10].

McLean et al. [29], however, obtained contrary results. Their measurements aimed at investigating the upper trapezius in three initial positions accompanied by neutrally positioned cervical spine: the arm abducted to the horizontal position and internally rotated with 90° flexion at the elbow, the arm abducted to the horizontal position with 90° flexion of the elbow with-

out rotation and the arms elevated up to one-half of movement range. In the next test stage, the same positions were used and the head was rotated contrariwise to the examined arm at 45°. Isometric muscle tension was achieved using belts: for the first and second position, resistance-generating belt was applied near the elbow joint and for the third – near the acromion. The investigators failed to note the effect of cervical spine position on trapezius activity. They demonstrated, however, that electrode distribution seemed to be of a key importance in evaluating the muscle activity [22]. Jensen et al. [17] observed similar results, showing that estimating the power of the upper trapezius depended on electrode placement along the muscle fibers. Ludweg et al. [25] examined the effect of cervical spine flexion on the activity of the trapezius and serratus anterior, failing to observe results that would support the effect of spine flexion on muscle activity.

Contrary to the results achieved by Ludweg et al. [25] and McLean et al. [29], the present authors demonstrated increased RUT activity during abduction when the cervical spine movement was contralateral to the active shoulder as compared to the muscle activity registered during the same arm movements without cervical spine rotation. In turn, decreased RUT activity was noted when combining elbow flexion with head rotation towards the active arm.

The authors of the present paper assessed both the activity of the trapezius and serratus anterior, demonstrating that with right cervical spine rotation, RSA activity was increased during arm flexion and abduction (compared to the same shoulder movements with neutral cervical spine position). Thus, cervical spine rotation was crucial for activity of the investigated muscles. Similarly, Jung et al. [18] observed concomitant increased activity of the serratus anterior and trapezius during arm abduction. The subjects performed 90, 120, 150 and 180° shoulder abduction combined with oscillation movements triggered by an external apparatus. When arm abduction was 120°, the investigators noted higher activity of the serratus anterior compared to the trapezius. The investigators did not take into consideration cervical spine position during shoulder movements, yet additional oscillatory tissue stimulation might have evoked an effect similar to that resulting from cervical spine rotation towards the active arm [18].

Demonstrating the dependence between activity of the trapezius and serratus anterior during cervical spine rotation seems to play a significant role in treating shoulder complex dysfunctions observed in many conditions. Various manual interventions are often employed therapeutically leading to decreasing pathologi-

cal muscle tension, while exercises are rarely used [20]. Appropriate physiotherapy, either preventive or directed at pain reduction within the brachial complex or cervical spine through decreasing the tension of hyperactive muscles and improving the myasthenic muscles, may prove to be the key to prevention of permanent structural injuries of the shoulder complex, achieving desired post-injury treatment effects or increasing exercise effectiveness during sports training sessions.

5. Conclusions

The present results suggest that inclusion of appropriate cervical spine rotation during shoulder movements may result in improved activity of the trapezius and serratus anterior. Increased activity of the lower trapezius and serratus anterior in consequence of combining appropriate shoulder movement with cervical spine rotation towards active arm suggests the legitimacy of including cervical spine movement in exercises aiming at improving muscle activity. Simultaneously, decreasing upper trapezius activity during shoulder flexion with cervical spine rotation towards the active arm points to the possibility of employing the movement pattern in individuals with pathological hypertension of this part of the trapezius.

References

- [1] AKAY T., MURRAY A.J., *Relative Contribution of Proprioceptive and Vestibular Sensory Systems to Locomotion: Opportunities for Discovery in the Age of Molecular Science*, Int. J. Mol. Sci., 2021 Feb. 2, 22(3), 1467, PubMed ID: 33540567, DOI: 10.3390/ijms22031467.
- [2] AUVINEN J.A., TAMMELIN T.H., TAIMELA S.P., ZITTING P.J., MUTANEN P.O.A., KARPPINEN J.I., *Musculoskeletal pains in relation to different sport and exercise activities in youth*, Med. Sci. Sports Exerc., 2008, 40 (11), 1890–900, PubMed ID: 18845965, DOI: 0.1249/MSS.0b013e31818047a2.
- [3] BOHLOOLI N., AHMADI A., MAROUFI N., SARRAFZADEH J., JABERZADEH S., *Differential activation of scapular muscles, during arm elevation, with and without trigger points*, J. Bodyw. Mov. Ther., 2016 Jan., 20 (1), 26–34, PubMed ID: 26891634, DOI: 10.1016/j.jbmt.2015.02.004.
- [4] CHOI H., VANDERBY R., *Muscle forces and spinal loads at C4/5 level during isometric voluntary efforts*, Med. Sci. Sports Exerc., 2000, 32 (4), 830–838, PubMed ID: 10776903, DOI: 10.1097/00005768-200004000-00016.
- [5] COOLS A.M., DEWITTE V., LANSZWEERT F., NOTEBAERT D., ROETS A., SOETENS B., CAGNIE B., WITVROUW E.E., *Rehabilitation of scapular muscle balance: which exercises to prescribe?*, Am. J. Sports Med., 2007, 35 (10), 1744–1751, PubMed ID: 17606671, DOI: 10.1177/0363546507303560.

- [6] DRAKE R.L., VOGL A.W., MITCHELL A.W.M., *Gray's Anatomy for Students*, Vol. 1, Edra Urban & Partner, Wrocław 2020.
- [7] DRAKE R.L., VOGL A.W., MITCHELL A.W.M., *Gray's Anatomy for Students*, Vol. 2, Edra Urban & Partner, Wrocław 2020, 41.
- [8] EKSTROM R.A., DONATELLI R.A., SODERBERG G.L., *Surface electromyographic analysis of exercises for the trapezius and serratus anterior muscles*, J. Orthop. Sports Phys. Ther., 2003, 33 (5), 247–258, PubMed ID: 12774999, DOI: 10.2519/jospt.2003.33.5.247.
- [9] EKSTROM R.A., SODERBERG G.L., DONATELLI R.A., *Normalization procedures using maximum voluntary isometric contractions for the serratus anterior and trapezius muscles during surface EMG analysis*, J. Electromyogr. Kinesiol., 2005, 15 (4), 418–428, PubMed ID: 15811612, DOI: 10.1016/j.jelekin.2004.09.006.
- [10] GAFFNEY B.M., MALUF K.S., CURRAN-EVERETT D., DAVIDSON B.S., *Associations between cervical and scapular posture and the spatial distribution of trapezius muscle activity*, J. Electromyogr. Kinesiol., 2014, 24 (4), 542–549, PubMed: 24875461, DOI: 10.1016/j.jelekin.2014.04.008.
- [11] GUDDAL M.H., STENSLAND S.Ø., SMÅSTUEN M.C., JOHNSEN M.B., ZWART J.A., STORHEIM K., *Physical activity level and sport participation in relation to musculoskeletal pain in a population-based study of adolescents*, Orthop. J. Sports Med., 2017, 5 (1), 2325967116685543, PubMed ID: 28203603, DOI: 10.1177/2325967116685543.
- [12] HEDENSTIERN S., HALLDIN P., SIEGMUND G.P., *Neck muscle load distribution in lateral, frontal, and rear-end impacts: a three-dimensional finite element analysis*, Spine (Phila Pa 1976), 2009, 34 (24), 2626–2633, PubMed ID: 19910765, DOI: 10.1097/BRS.0b013e3181b46bdd.
- [13] HIBBERD E.E., LAUDNER K.G., KUCERA K.L., BERKOFF D.J., YU B., MYERS J.B., *Effect of swim training on the physical characteristics of competitive adolescent swimmers*, Am. J. Sports Med., 2016, 44 (11), 2813–2819, PubMed ID: 27756724, DOI: 10.1177/0363546516669506.
- [14] HUANG H.Y., LIN J.J., GUO Y.L., WANG W.T.J., CHEN Y.J., *EMG biofeedback effectiveness to alter muscle activity pattern and scapular kinematics in subjects with and without shoulder impingement*, J. Electromyogr. Kinesiol., 2013, 23 (1), 267–274, PubMed ID: 23123099, DOI: 10.1016/j.jelekin.2012.09.007.
- [15] HUBER J., LISIŃSKI P., POLOWCZYK A., *Reinvestigation of the dysfunction in neck and shoulder girdle muscles as the reason of cervicogenic headache among office workers*, Disabil. Rehabil., 2013, 35 (10), 793–802, PubMed ID: 22888759, DOI: 10.3109/09638288.2012.709306.
- [16] IPAQ Questionnaire, <https://www.sralab.org/rehabilitation-measures/international-physical-activity-questionnaire-long-form>. Accessed: 10.11.2021.
- [17] JENSEN C., VASSELJEN O., WESTGAARD R.H., *The influence of electrode position on bipolar surface electromyogram recordings of the upper trapezius muscle*, Eur. J. Appl. Physiol. Occup. Physiol., 1993, 67 (3), 266–273, PubMed ID, 8223542, DOI: 10.1007/BF00864227.
- [18] JUNG D.E., MOON D.Ch., *The effects of shoulder joint abduction angles on the muscle activity of the serratus anterior muscle and the upper trapezius muscle while vibrations are applied*, J. Phys. Ther. Sci., 2015, 27 (1), 117–119, PubMed ID: 25642052, DOI: 10.1589/jpts.27.117.
- [19] KANG F.J., OU H.L., LIN K.Y., LIN J.J., *Serratus anterior and upper trapezius electromyographic analysis of the push-up plus exercise: a systematic review and meta-analysis*, J. Athl. Train., 2019, 54 (11), 1156–1164, PubMed ID: 31584855, DOI: 10.4085/1062-6050-237-18.
- [20] KOCH S.C., *Motor task-selective spinal sensorimotor interneurons in mammalian circuits*, Curr. Opin. Physiol., 2019, 8, 129–135.
- [21] KIM Y., HONG Y., PARK H.S., *A soft massage tool is advantageous for compressing deep soft tissue with low muscle tension: Therapeutic evidence for self-myofascial release*, Complement Ther. Med., 2019, 43, 312–318, PubMed ID: 30935551, DOI: 10.1016/j.ctim.2019.01.001.
- [22] KUMAR S., FERRARI R., NARAYAN Y., *Effect of head rotation in whiplash-type rear impacts*, Spine J., 2005, 5 (2), 130–139, PubMed ID: 15749612, DOI: 10.1016/j.spinee.2004.10.042.
- [23] LEE J.H., PARK S.J., NA S.S., *The effect of proprioceptive neuromuscular facilitation therapy on pain and function*, J. Phys. Ther. Sci., 2013, 25 (6), 713–716, PubMed ID: 24259836, DOI: 10.1589/jpts.25.713.
- [24] LOPES A.D., TIMMONS M.K., GROVER M., CICONELLI R.M., MICHENER L.A., *Visual Scapular Dyskinesia: Kinematics and Muscle Activity Alterations in Patients with Subacromial Impingement Syndrome*, Arch. Phys. Med. Rehabil., 2015, 96 (2), 298–306, PubMed ID: 25449194, DOI: 10.1016/j.apmr.2014.09.029.
- [25] LUDEWIG P.M., COOK T.M., *The effect of head position on scapular orientation and muscle activity during shoulder elevation*, J. Occup. Rehabil., 1996, 6 (3), 147–158, PubMed ID: 24234976, DOI: 10.1007/BF02110752.
- [26] MAENHOUT A., BENZOR M., WERIN M., COOLS A., *Scapular muscle activity in a variety of plyometric exercises*, J. Electromyogr. Kinesiol., 2016, 27, 39–45, PubMed ID: 26894494, DOI: 10.1016/j.jelekin.2016.01.003.
- [27] MERLETTI R., PARKER P., *Electromyography: Physiology, Engineering and Non-Invasive Applications*, Wiley – IEEE Press, 2004.
- [28] MCGINNIS P.M., *Biomechanics of sport and exercise*, Polish ed., Edra Urban & Partner, Wrocław, 2021, 310–317.
- [29] MCLEAN L., CHISLETT M., KEITH M., MURPHY M., WALTON P., *The effect of head position, electrode site, movement and smoothing window in the determination of a reliable maximum voluntary activation of the upper trapezius muscle*, J. Electromyogr. Kinesiol., 2003, 13 (2), 169–180, PubMed ID: 12586522, DOI: 10.1016/s1050-6411(02)00051-2.
- [30] MYERS T., *Anatomy trains: myofascial meridians for manual and movement therapists*, Churchill Livingstone, Edinburgh, London, New York, Oxford, Philadelphia, St Louis, Sydney, Toronto, 2009, 178–183, 311.
- [31] NOBUHARA K., *The shoulder: its function and clinical aspect*, World Scientific, Singapore, 2003.
- [32] OATIS C., *Kinesiology The mechanics and pathomechanics of the human movement*, Lippincott Williams & Wilkins, Philadelphia, 2004.
- [33] PARK K., KWON O., HA S., KIM S., CHOI H., WEON J., *Comparison of electromyographic activity and range of neck motion in violin students with and without neck pain during playing*, Med. Probl. Perform. Art., 2012, 27 (4), 188–192, PubMed ID: 23247874.
- [34] ROSSI M., PASANEN K., KOKKO S., ALANKO L., HEINONEN O.J., KORPELAINEN R., SAVONEN K., SELÄNNE H., VASANKARI T., KANNAS L., VILLBERG J., PARKKARI J., *Low back and neck and shoulder pain in members and non-members of adolescents' sports clubs: the Finnish Health Promoting Sports Club (FHPSC) study*, BMC Musculoskelet. Disord., 2016, 17, 263, PubMed ID: 27370945, DOI: 10.1186/s12891-016-1114-8.

- [35] STECCO L., *Atlas of physiology of the muscular fascia*, Polish ed., Odnova-Med., Szczecin, 2019, 190–191.
- [36] STECCO L., STECCO A., *Fascial Manipulation for Musculoskeletal Pain*, Polish ed., Odnova-Med., Bełchatów, 2019, 118–119.
- [37] The SENIAM project (*Surface electromyography for the non-invasive assessment of muscles*), <http://www.seniam.org/> (10.04.2021).
- [38] THIGPEN CH.A., PADUA D.A., MICHENER L.A., GUSKIEWICZ K., GIULIANI C., KEENER J.D., STERGIU N., *Head and shoulder posture affect scapular mechanics and muscle activity in overhead tasks*, J. Electromyogr. Kinesiol., 2010, 20 (4), 701–709, PubMed ID: 20097090, DOI: 10.1016/j.jelekin.2009.12.003.
- [39] TSURUIKE M., ELLENBECKER T.S., *Adaptation of muscle activity in scapular dyskinesis test for collegiate baseball players*, J. Shoulder Elbow Surg., 2016, 25 (10), 1583–1591, DOI: 10.1016/j.jse.2016.03.004.
- [40] YAMAUCHI T., HASEGAWA S., MATSUMURA A. et al., *The effect of trunk rotation during shoulder exercises on the activity of the scapular muscle and scapular kinematics*, J. Shoulder Elbow Surg., 2015, 24 (6), 955–964, DOI: 10.1016/j.jse.2014.10.010.