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The differences in shoulder muscle activity between injured and uninjured rugby players during player- and bag-tackling

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Abstract

Introduction. **Rugby is a physically demanding game involving multiple body contacts and collisions accompanied by a large number of shoulder injuries, 51% of which occur during tackling.** Aim of Study. **The aim of this cross-sectional study was to compare shoulder girdle muscle activation between injured (IN) and uninjured (UN) rugby players during bag-tackling and player-tackling. Fourteen rugby players were divided into the injured (IN) (n = 8) and uninjured (UN) (n = 6) groups. The players performed five maximal effort tackles against a tackling bag and against a fellow player.** Material and Methods. **The tackle momentum, time of impact, and peak surface electromyography amplitude expressed as maximum voluntary isometric contraction (MVIC) were measured on eight muscles: the latissimus dorsi, lower trapezius, pectoralis major, anterior deltoid, serratus anterior, posterior deltoid, middle trapezius, and upper trapezius.** Results. **The ANOVA revealed significant differences between the IN and UN groups in terms of tackling, with the pectoralis major showing a greater peak in IN (181 ± 18% MVIC) compared to UN (141 ± 43% MVIC), the lower trapezius showed showing a greater peak in IN (127 ± 46% MVIC) compared to UN (54 ± 25% MVIC), and the serratus anterior – a greater peak in IN (157 ± 35% MVIC) compared to UN (87 ± 55% MVIC).** Conclusions. **Injured players display higher excitation levels in the serratus anterior, pectoralis major, and lower trapezius, which support the communal function of the muscles surrounding the shoulder joint during tackling. Testing and treatment of these muscles is recommended for injured rugby players.**

KEYWORDS: serratus anterior, lower trapezius, pectoralis major, impact, fitness.

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What is already known on this topic?
Two thirds of upper limb injuries in rugby occur in the acromioclavicular and glenohumeral joints, where impact-related shoulder injuries may influence subsequent muscle function in the surrounding area. Two researchers have estimated the serratus anterior, infraspiunatus, biceps brachii, latisimus dorsi and pectoralis major onset during tackling in injured and uninjured players, however, there is still a lack of data regarding the magnitude of muscle activity during rugby tackling.

Introduction

Rugby is a physically demanding game with multiple body contacts and collisions accompanied by a large number of injuries, which can be related to training load, intensity, and duration [1]. The average injury rate in rugby is 86 incidents per 1000 match hours, 51% of which occur during tackling [2]. Furthermore, 65% of all injuries affect the shoulder girdle, 86% of which are slap lesions, with 43% resulting in rotator cuff rupture and 34% in labral damage [2, 3]. Although scrums and rucks result in higher injury rates [4, 5], the greatest number of injuries occur during tackling. Another study [6] stated that upper limb injuries make up 14-28% of all rugby injuries. Approximately two-thirds of upper limb injuries occur in the acromioclavicular and glenohumeral joints, typically requiring a player to abstain from participating in matches and training for approximately four weeks [3].

In rugby, tackling occurs in many forms such as direct collision, shoulder tackles, arm tackles, or jersey tackles [7]. The collision tackle tends to elicit the greatest amount of impact forces due to rapid acceleration before a collision followed by high impact forces and a transfer of momentum between opposing players. Partly due to such extreme mechanical variables, the most frequent cause of injury in game situations is the direct impact of tackling [8]. However, not only is tackling part of rugby games, but it is also an important part of rugby training. During training, tackles are more likely to occur in a controlled environment and include two main tackle foci: tackling technique drills, and tackling used as a conditioning exercise. During training, it is common for players to tackle either (i) another player or (ii) a tackling bag. For training purposes, it would be optimal to know whether there are differences between bag tackling and player tackling. Moreover, direct measurements of muscle activation may provide insight into which muscles surrounding the shoulder should be strengthened to improve tackling performance and decrease the risk of injury.

After investigating the effects of tackling-induced muscle damage on shoulder muscle function, Takarada [9] stated that impact-related shoulder injuries may influence subsequent muscle function in the surrounding area. Since then, researchers [10, 11] have estimated the normative values of serratus anterior (SA), infraspiunatus, biceps brachii (BB), latisimus dorsi (LD) and pectoralis major (PM) activity during tackling in injured and uninjured players. However, there have been no data regarding the magnitude of muscle activity during rugby tackling, particularly between different tackling methods.

During training, the injury history of players should be considered when designing tackle training methodologies, especially as a previous injury is at risk of becoming reinjured [12]. Insight into shoulder muscle activity could be valuable when assessing a player’s readiness to return to play and may also provide information regarding muscle activity and coordination during tackling. Furthermore, to our knowledge, shoulder girdle muscle activity has not been compared between uninjured and recently injured players during bag-tackling and player-tackling. Such an investigation could shed light on whether tackle bag training may be more appropriate for recently injured players than player-to-player tackling.

Aim of Study

The aim of this study was to compare shoulder girdle muscle activation between injured and uninjured rugby players during bag-tackling and player-tackling.

Material and Methods

The present investigation was a cross-sectional study during a rugby season. Following a familiarization session, subjects performed maximal effort tackles against a tackling bag or against a fellow player. Selected subjects were then met by a physiotherapist and took part in manual shoulder muscle screening tests which also included basic anthropometric measurements. Once the subjects were assigned to their respective groups (details below), they attended a familiarization session and an experimental session. To assess muscle activity during front shoulder tackles (FST), subjects were instructed to perform a total of ten maximal-effort FSTs, inclusive of five bag-tackles and five player-tackles. The order of these 10 tackles was randomized and involved approximately 90 seconds between attempts. The muscle activity of each tackle attempt was recorded using EMG and a pressure sensor, and a high speed camera.

A total of 14 players were divided into two groups: injured players (IN), and uninjured players (UN)

Table 1. Description of study participants

Variable	All subjects (n = 14)	UN (n = 6)	IN (n = 8)
Age (years)	17.5 ± 1.7	17.3 ± 1.9	17.6 ± 1.2
Body mass (kg)	90.5 ± 12.1	91.5 ± 11.5	87.25 ± 6.7
Height (cm)	181.9 ± 6.4	182.5 ± 6.96	181.4 ± 3.6
Training sessions per week	3.5 ± 1.00	3.6 ± 1.0	3.4 ± 0.7
Training age	7.4 ± 2.7	8.3 ± 2.3	6.6 ± 2.0
Bench press 1RM (kg)	102.5 ± 22.2	107.5 ± 19.2	98.6 ± 14.7
Back Squat 1RM (kg)	131.8 ± 26.2	140.0 ± 25.0	125.6 ± 15.8

RM = repetition maximum; the back squat and bench press 1 repetition maximum (1RM) was not acquired during the present study; it was provided by the coaches, and is presented merely as a description of subject strength levels

(Table 1). Written informed consent was provided by all participants or by their parental guardians (in the case of players under 18 years old), and the testing protocols were approved by the local Committee of Ethics at Charles University no. 235/2014 in accordance with the ethical standards of the Declaration of Helsinki. All of the participants were informed of and shown the testing protocols and all details of the study before they provided their written informed consent.

Before the tackling measurements, selected participants were divided in two groups according to the results of the physiotherapy manual muscle testing. The IN group consisted of participants who had experienced a previous shoulder injury within the last 6 months on their dominant upper limb caused by impact during rugby, resulting in the player missing training and matches for at least four weeks. Additionally, the subjects in the IN group displayed a positive score for either sub-acromial impingement syndrome or acromioclavicular joint pain. The UN consisted of players who did not have a previous shoulder injury and displayed a negative score for sub-acromial impingement syndrome and acromioclavicular joint pain. The initial interview and muscle testing included 28 other players who did not match the inclusion criteria (e.g. players who reported a recent injury but displayed a negative muscle test, or vice versa). Due to the unclear condition of their shoulders, those participants were excluded from the study. The following six manual muscle tests were conducted and were evaluated by two physiotherapists using a two-point scale (negative or positive): the Apley "scratch test", [13] Cyriaxe arc pain test [14], Neer test, Hawkins test, hyper-abduction test [15], and the speed test [16].

The FST was chosen for the study as it contains a direct shoulder impact resulting from a tackle performed as hard and fast as possible. For each tackle, the tackler tackled either a stationary player of similar body mass, or a standard tackle bag (Gilbert, England; diameter 46 cm, height 170 cm, and mass 15 kg). Upon a command from the examiner, the tackler accelerated and hit the respective tackle bag or player with maximal volitional force, using his dominant shoulder. In each case, the tackler's shoulder was to make contact with the bag or the player at hip-height. Two expert coaches immediately evaluated tackling technique in accordance with the guidelines set forth by Gabbett [1]. Following these tackling criteria tacklers should obtain a body position with the trunk flexed to approximately 90°, knees flexed to 45°, and the tackling shoulder abducted to about 60° (Figure 1).

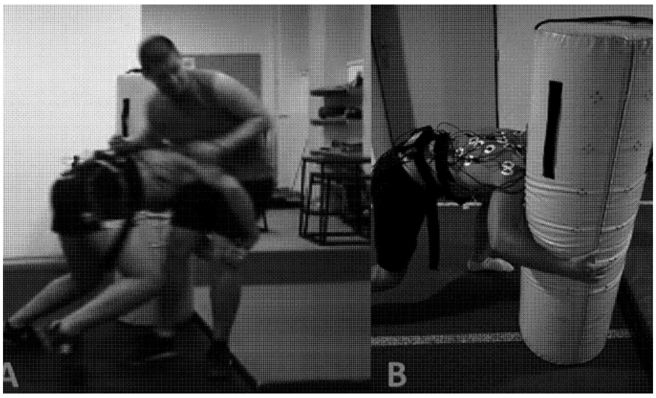


Figure 1. Bag-tackling and player-tackling during measurement

The EMG data were collected with a MegaWin 6000 device (Mega Electronics, Finland). Raw EMG signals were recorded unilaterally on the dominant side with eight leads with a sampling frequency of 2000 Hz. Two bipolar surface electrodes (Kendall, Mansfield, MA, USA) were secured over each muscle belly in accordance with the SENIAM guidelines [17]. The input impedance was greater than 10 MΩ at 100 Hz, with a frequency bandwidth of 16–1000 Hz, and a common mode rejection ratio of 50 Hz (80 dB).

The electrode placement was performed when participant simulated the impact tackle position (Figure 1), to support the EMG gathering during this movement pattern. Each muscle's EMG signal was detected using two active gathering electrodes and one ground electrode. After electrode placement, the EMG during maximal voluntary isometric contraction (MVIC) was determined using specific body positions for each muscle. The following movements were resisted in the middle of a concentric muscle action using a rope: the pull up for latissimus dorsi (LD) and lower trapezius (LT); the dumbbell chest press for pectoralis major (PM) and anterior deltoid (AD); resisted protraction of the arm at 90 degrees flexion for serratus anterior (SA); bent over dumbbell row for posterior deltoid (PD), middle trapezius (MT), and upper trapezius (UT).

The time of impact was assessed by a pressure sensor (Tekscan, Boston, USA) fully synchronized with EMG and processed with EMG signals by the software. The sensor data were manually checked with movement artifacts during first 100 ms of impact to ensure that shoulder impact was detected.

The EMG data were band-pass filtered and smoothed using a root mean square algorithm with a sliding window function and a time constant of 25 ms, and the peak value from 25 ms following the impact was normalized to the EMG during MVIC and expressed as a percentage of MVIC (%MVIC). Momentum was calculated and expressed in (kg · m · s^{-1}). High speed cameras were placed 4 m perpendicular to the point of impact to record 2D kinematics with a sampling frequency of 1000 Hz. Dartfish (Version 4.0.9.0, Switzerland) was used to determine the point at which the player began to accelerate [18]. The average velocity over the 3 m acceleratory period was calculated using the change in time between the onset of acceleration and the time of shoulder impact (Δt). Using an equation from a previous study, linear momentum was calculated using average velocity and tackling-player mass (Equation 1) [19]. Due to the stationary position of the tackle bag or the opposing player, its momentum was not taken into consideration.

Equation 1

$$p = m \cdot v; \quad p = \frac{m \cdot s}{t} \quad (kg \cdot m \cdot s^{-1})$$

p = momentum; m = object mass; v = object velocity; s = trajectory; t = time

All statistical analyses were performed with STATISTICA version 12 (StatSoft, Inc., Tulsa, OK, USA) with the alpha level set at 0.05. The five tackling attempts of each type (bag or player) were averaged together, and the mean values were used for further statistical analyses. The intraclass correlation coefficient (ICC) across five repetitions for each individual was determined to confirm whether the EMG and momentum were stable within each subject. Further, the Sharpio-Wilk test and Kolmogorov-Smirnov test were performed to determine the normality of data distribution. To determine whether the EMG amplitude and momentum varied between groups or tackling conditions, repeated measures analysis of variance (ANOVA) tests were performed (condition × momentum; group × condition × × muscles;). This analysis was repeated for each EMG and momentum measurement separately while regarding between-subject (group or condition) factors as a result. The ANOVAs were followed by Tukey's post hoc tests. The effect size (partial eta square – η^2) of each test was calculated for all analyses and was classified according to Larson-Hall [20], where η^2: 0.01, 0.06, 0.14 were estimated for small, moderate, and large effect respectively. The effect-size correlation, r_{Yl}, using the means and standard deviations of two groups (IN and UN), were calculated for significant results of ANOVA.

Results

The initial interview was performed with 42 players, but only 14 matched the selection criteria after the manual muscle tests. The within-subject reliability analyses across the five repetitions of each trial condition for the individuals resulted in ICC values ranging from 0.45 to 0.94 (Table 2) for both EMG amplitude and momentum, which indicate moderate to very high reliability [21] of the measurements. The normality test showed normal data distribution for EMG in most muscles (Table 2);

Table 2. Measurement reliability and data normality by tackling condition

	Tackle to bag				Tackle to player			
	ICC	SEM (%MVIC)	KS ($p < 0.01$)	SW ($p < 0.01$)	ICC	SEM (%MVIC)	KS ($p < 0.01$)	SW ($p < 0.01$)
UT	0.77	35.98	0.08	0.98	0.84	27.60	0.10	0.93
MT	0.80	3.29	0.11	0.94	0.90	11.32	0.90	0.94
LT	0.94	16.42	0.18	0.85	0.45	11.90	0.22	0.67
PM	0.69	50.72	0.19	0.89	0.76	66.24	0.20	0.80
PD	0.79	9.82	0.11	0.92	0.54	7.53	0.12	0.89
LD	0.55	35.12	0.27	0.50	0.68	42.96	0.28	0.58
SA	0.63	12.68	0.16	0.84	0.63	8.94	0.66	0.81
AD	0.46	32.13	0.31	0.48	0.51	25.20	0.26	0.56
momentum	0.71	7.43	0.14	0.87	0.77	7.63	0.14	0.79

UT = upper trapezius; MT = middle trapezius; LT = lower trapezius; PM = pectoralis major; PD = posterior deltoid; LD = latisimus dorsi; SA = serratus anterior; AD = anterior deltoid; p = momentum; ICC = intraclass correlation coefficient; SEM = standard error of mean; KS = Kolmogorow Smirnov test; SW = Sharpio-Wilk test

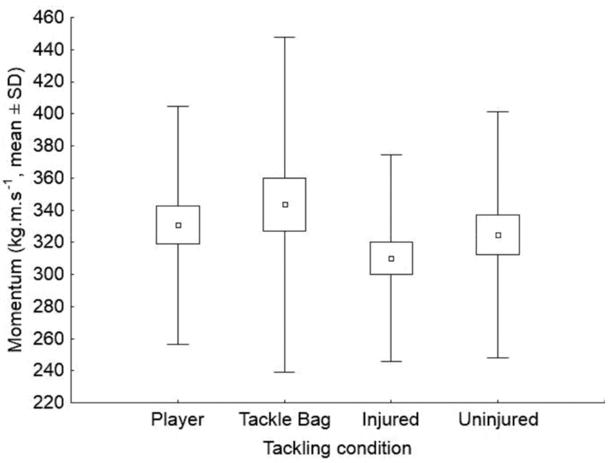
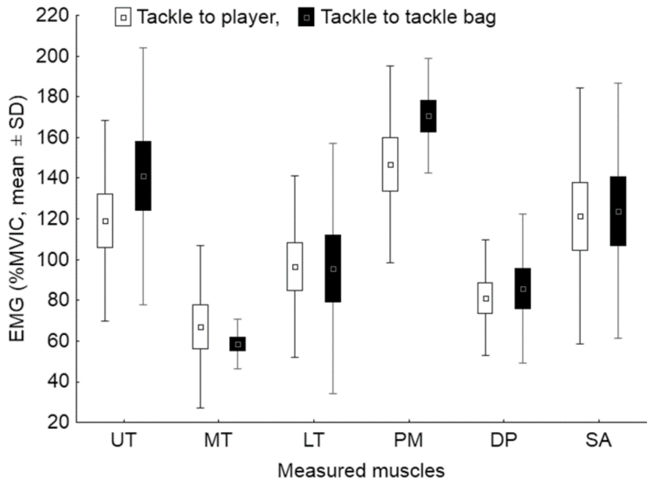


Figure 2. Momentum collapsed between groups and collapsed between tackling conditions

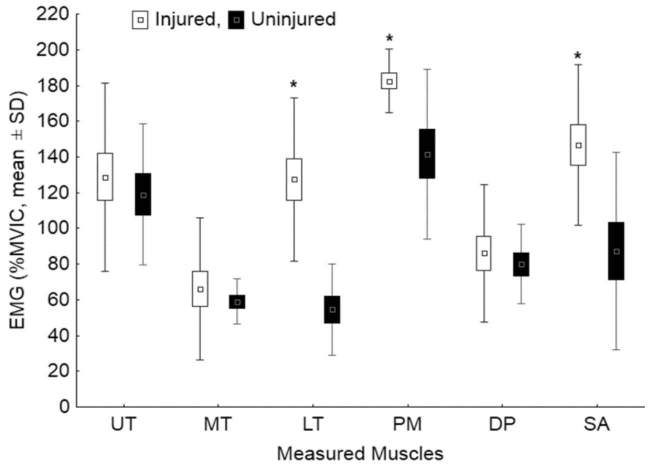


UT = upper trapezius; MT = middle trapezius; LT = lower trapezius; PM = pectoralis major; DP = deltoid posterior; SA = serratus anterior; SD = standard deviation; EMG = electromyography; %MVIC = = percentage of maximum voluntary isometric contraction

Figure 3. Muscle activity during tackle to player and tackle to tackle bag, collapsed between groups

only LD and AD were rejected from ANOVA analyses because they were not normally distributed [22].

The ANOVA showed no differences in momentum between UN and IN ($F_{1, 26} = 0.62$, $p = 0.44$, $\eta^2 = 0.02$), or between tackling a player and a tackle bag ($F_{1, 25} = 0.13$, $p = 0.72$, $\eta^2 = 0.01$), (Figure 2). Additionally, there were no differences in EMG amplitude between tackling a player and a tackle bag ($F_{5, 130} = 0.28$, $p = 0.92$, $\eta^2 = 0.01$) (Figure 3). However, the ANOVA revealed significant differences between IN and UN for EMG amplitude when collapsed across tackling conditions (i.e. tackling a bag and tackling a player) ($F_{5, 130} = 5.50$, $p < 0.001$,



UT = upper trapezius; MT = middle trapezius; LT = lower trapezius; PM = pectoralis major; DP = deltoid posterior; SA = serratus anterior; SD = standard deviation; EMG = electromyography; %MVIC = = percentage of maximum voluntary isometric contraction

Figure 4. ANOVA results for muscle activity in injured and uninjured groups, collapsed across tackling condition

$\eta^2 = 0.17$), in three muscles (Figure 4). The PM showed significantly greater peak EMG values in IN (181 ± ± 18% MVIC) compared to UN (141 ± 43% MVIC) with $r_{Yl} = 0.52$, the LT showed significantly greater peak values in IN (127 ± 46% MVIC) compared to UN (54 ± ± 25% MVIC) with $r_{Yl} = 0.70$, and SA showed significantly greater peak values in IN (157 ± 35% MVIC) compared to UN (87 ± 55% MVIC) with $r_{Yl} = 0.61$.

Discussion

Significant differences in EMG amplitude were noted in three muscle groups when comparing IN and UN players. However, there were no significant differences in momentum or EMG activity between tackling a bag and tackling a player. Therefore, on the sole basis of EMG and momentum data in the present study, tackling a bag can be recommended during training, as it results in the same muscle activity and momentum as tackling a fellow (stationary) player. With this being the case, tackling bags may be preferred during training to avoid the risk injuring a stationary tackled player. At first glance, the momentum values in the present study (p = 330 ± ± 114 kg · m · s^{-1}) may seem to be low compared to the values by Hendricks [19] (p = 536 ± 217 kg · m · s^{-1}). However, it is important to note that the players tested by Hendricks experienced tackles in a game situation during which a dynamic opposing player's momentum was also taken into consideration.

Some of the EMG values recorded during the present study exceeded 100% MVIC, which is reasonable because the MVIC was measured in an isometric (not eccentric or impact) condition. It is not uncommon to have dynamic EMG values above 100% MVIC [23-25]; however, PM activity was 141% of MVIC in UN and 181% in IN. Such extreme values may indicate that the clavicular fibers of the PM are very important for producing and absorbing impact forces during an FST. Therefore, the PM and other muscles exceeding 100% MVIC activity should be strengthened to support shoulder stability during an FST. Furthermore, this strengthening should also include eccentric actions, mimicking the actions that occur during a tackle. Similarly, the UT and SA significantly exceeded 100% MVIC, which should be transferred into practice by their eccentric strengthening or physiotherapy treatment as well.

The finding that muscle activity does not differ between tackling a stationary player and tackling a tackle bag leads us to believe that the level of muscle activity during a tackle is mostly dependent on the velocity of the tackling player (e.g. momentum), rather than the properties of the tackled object. The mass of the tackle bag used in our study was 15 kg, but the stationary players weighed significantly more. Since it is possible that the stationary player reflexively reacted to absorb the tackle force, the only parameter similar in both cases was the acceleration distance and the elicited speed and momentum of the tackling player. Therefore, it seems that muscle activity is largely dependent on impact momentum.

The percentage of EMG amplitude (%MVIC) in the IN group was greater than in the UN group for the LT and PM; and the LT and SA are considered to be the key shoulder stabilizers [26]. The difference in muscle activation may be the source of remaining shoulder instability, where key stabilizers are activated close to their excitation limit. Therefore, the strengthening of SA, PM, and LT might increase their maximal limits, decreasing their normalized activity. A previous study showed that the muscles surrounding an injured player's shoulder had a later onset of PM, SA, UT, LD, biceps brachii and infraspinatus activity [10] before tackle impact, and the SA was activated before the other muscles [10]. This further supports the idea of focusing on special strengthening of the SA to improve shoulder stability during tackling. For this purpose, the onset of muscle activation might be improved best by neuromuscular training [3], while muscle strengthening may influence the level of muscle activation. However, the implication of both should result in improved shoulder stability. Injury prevention programs for rugby players include many exercises targeting the SA such as dynamic cable "hugs" (scapular protraction during crunch position used for tackling) and variations of pushups or cable rows [3]. On the other hand, the implication of LT exercises and clavicular PM exercises are not sufficient in these injury prevention programs. Moreover, the PM seems to be largely involved during the FST, thus increasing the maximum strength of the PM might be very important for tackling success.

One limitation of the present study is that our protocol model only considered tackler momentum, but game conditions also include the momentum of the tackled player (ball-carrier), which is superior to momentum of the tackler in 60% of all front-on tackles [19]. Another limitation is that only surface EMG was used, meaning deeper stabilizing muscles like the infraspinatus, supraspinatus, and perhaps the sternocleidomastoids [27], could not be measured. Lastly, only six players met the criteria to be included in the UN group. It would be ideal to include more UN players, but the nature of the sport made it difficult to find high-level players who could be classified as "uninjured".

Conclusions

Tackle-specific training using a tackle bag may be appropriate when trying to eliminate the risk of tackled player injury without decreasing the tackling player's shoulder muscle activation. The clavicular part of pectoralis major, lower trapezius, and serratus anterior are highly exposed in order to resist impact forces during shoulder tackling. Injured players display higher excitation levels in the serratus anterior, pectoralis major, and lower trapezius, which support the communal function of the muscles surrounding the shoulder joint during tackling. Testing and treatment of these muscles are recommended for injured rugby players.

- Testing and treatment of the serratus anterior, pectoralis major, and lower trapezius should be used on injured rugby players.
- The muscle activity variables remain the same during training with a stationary player and a tackling.
- The clavicular part of pectoralis major, lower trapezius, and serratus anterior are highly exposed to resist impact forces during shoulder tackling.

What this study adds?

This study adds the knowledge about shoulder muscle contribution during rugby tackling. The clavicular part of pectoralis major, lower trapezius and serratus anterior are highly exposed in order to resist impact forces during shoulder tackling, and tackle training performed with stationary player or tackling bag does not differ in terms of muscle activity.

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