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Research article

The Acute Effects of Pectoralis Major Foam Ball Rolling on Shoulder Extension Range of Motion, Isometric Contraction Torque, and Muscle Stiffness

Marina M. Reiner [1], Anna Gabriel [2], Markus Tilp [1] and Andreas Konrad [1]✉
[1] Institute of Human Movement Science, Sports and Health, University of Graz, Graz, Austria; [2] Professorship of Conservative and Rehabilitative Orthopedics, Department of Sport and Health Science, Technical University of Munich, Munich, Germany

Abstract

Although it is well known that foam rolling (FR) of the lower extremities can increase the range of motion (ROM) of a joint while likely having no detrimental effect on muscle performance, to date, this is not clear if this is the case for the upper body. Therefore, the purpose of this study was to analyze the effects of a 2-min FR intervention of the pectoralis major (PMa) muscle on muscle stiffness of the PMa, shoulder extension ROM, and maximal voluntary isometric contraction (MVIC) peak torque. Thirty-eight (n = 15 females) healthy, physically active participants were randomly assigned to either an intervention (n = 18) or a control group (n = 20). The intervention group performed a 2-min foam ball rolling (FBR) intervention of the PMa muscle (FB-PMa-rolling), while the control group rested for 2 min. Before and after the intervention, muscle stiffness of the PMa was measured with shear wave elastography, while shoulder extension ROM was recorded with a 3D-motion capture system, and shoulder flexion MVIC peak torque was measured with a force sensor. MVIC peak torque decreased in both groups (time effect: $p = 0.01$; $\eta^2 = 0.16$), without any difference between groups (interaction effect: $p = 0.49$, $\eta^2 = 0.013$). ROM ($p = 0.24$; $\eta^2 = 0.04$) and muscle stiffness (FB-PMa-rolling $p = 0.86$; $Z = -0.38$; control group $p = 0.7$, $Z = -0.17$) did not change due to the intervention. The lack of changes in ROM and muscle stiffness following the FBR intervention might be explained by the small area of applied pressure with the FBR on the PMa muscle. Moreover, the decrease in MVIC peak torque is likely more related to the uncommon test situation of the upper limbs, rather than the FBR intervention itself.

Key words: Myofascial release, joint flexibility, muscle force, shear wave elastography, tissue stiffness.

Introduction

The pectoralis muscles are part of the shoulder stabilizing structures. The coordinated interaction of these muscles provides a great range of motion (ROM) in the glenohumeral joint (Yang et al., 2021). Several tissues and structures are involved in ROM and force-producing tasks in a sequenced and coordinated way, allowing complex movements such as overhead throwing, which is one of the fastest movements a human body can perform (Cools et al., 2021). Prior to physical exercise, athletes perform different warm-up routines to prepare the tissues, with the goal to maximize performance (McCrary et al., 2015). For example, a high-load dynamic warm-up can increase power and strength performance, while short duration static stretching (SS) has no effect on performance in the upper body (McCrary et al., 2015).

In the lower extremities, different warm-up methods, such as stretching and foam rolling (FR), have been studied extensively to establish their influence on functional parameters such as ROM (Behm et al., 2016; Konrad et al., 2017; 2021) and physical performance (Behm et al., 2016; 2021; Konrad et al., 2017; 2021). When comparing the effects of FR and static SS on ROM and physical performance tasks, recent meta-analyses have reported no difference between these methods (Wilke et al., 2020; Konrad et al., 2021; 2022), although FR has been found to be more effective under specific conditions (e.g., on the quadriceps muscles, applied for longer than 60 s, or with included vibration) (Konrad et al., 2021). Moreover, a potential mechanism for the increase in ROM following the two techniques is a decrease in muscle stiffness (Konrad et al., 2017; Iwata et al., 2019; Reiner et al., 2021; 2022). In contrast to the numerous studies of the lower limbs, only a few studies have examined the stiffness of the muscles surrounding the shoulder (Heredia-Rizo et al., 2020; Mifune et al., 2020). To date, we are not aware of any study that has examined the effects of a foam ball rolling (FBR) intervention of the pectoralis muscle on its stiffness, as well as shoulder extension ROM and muscle strength.

Therefore, the aim of this study was to examine, if a 2-min FBR intervention of the pectoralis major (PMa) muscle (pars clavicularis) benefits shoulder extension ROM and performance, and if such possible changes are related to changes in muscle stiffness. We hypothesized no changes in maximal voluntary isometric contraction (MVIC) peak torque, but an increase in shoulder extension ROM, which is related to a decrease in muscle stiffness of the clavicular part of the PMa.

Methods

Each participant visited the laboratory twice, for a familiarization session and a measurement session. At both appointments, the participants were asked to arrive in a rested state, which meant no high-intensity training at least 24 h before the testing. In the measurement session, participants were stratified by sex and randomly assigned to either the FBR intervention of the PMa muscle (FB-PMa-rolling) group or the control group. Each participant performed a standardized warm-up of 4 min of parallel arm rotations with both arms (alternating direction every minute), at a speed of 120°/s (= 20 rotations per minute). A metronome provided an auditory signal to maintain the frequency. The PMa and glenohumeral joint of the dominant arm (used for

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writing) was chosen as the intervention and measurement side. Muscle shear modulus of the PMa, shoulder extension ROM, and MVIC peak torque were measured in a sitting position at 45° shoulder abduction on a custom-made testing device (Figure 1). Muscle shear modulus and MVIC peak torque measurement was performed with elbow flexion of 90° ± 5° and shoulder flexion of 31° ± 7.5° (mean ± standard deviation (sd)). Shoulder extension ROM was performed with elbow flexion fixed at 90°. The participant's position in the custom-made testing device (Figure 1) was individually adapted. Surface electromyography (sEMG) was performed on the medial part of the PMa to measure the muscle activity during all the tests. The test procedure was the same before and after the intervention (Figure 2). The study was approved by the Ethics Committee of the University of Graz (approval code GZ. 39/4/63 ex 2021/22), and was carried out in agreement with the standards of the Declaration of Helsinki.

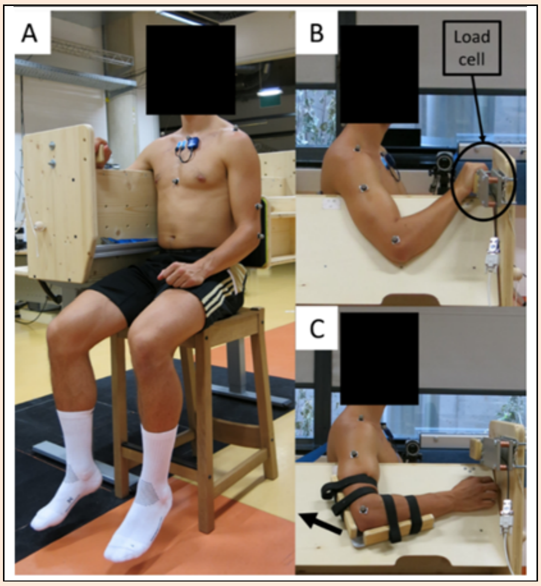

Figure 1. Participant's positions during the test on the custom-made testing device. A – Measurement position for the maximal voluntary isometric contraction test. B – Measurement position for the shear wave elastography measurement, with the hand positioned on the load cell. C – Starting position for the range of motion measurement.

Participants

In a previous study, we performed an FR exercise of the hamstring muscles, and observed a large effect size (Cohen's d = 1.12) for the increased ROM (Konrad et al., 2022). Hence, with the power to detect a large effect size, we calculated a minimum sample size of 15 participants for each group for this study (difference between two dependent means, effect size = 0.8, α = 0.05, 1-β = 0.8) using G*Power software (G*Power version 3.1, Heinrich-Heine-University Düsseldorf, Germany) (Faul et al., 2009). Thirty-eight healthy, physically active participants (average weekly training duration: 16.1 ± 7.2 h; male: n = 24, age: 26.6 ± 5.3 years, height: 183 ± 6.8 cm, and body mass: 82.1 ± 7.7 kg; female: n = 15, age: 27.5 ± 4.1 years, height: 169 ± 4.8 cm, and body mass: 62.9 ± 7.3 kg; sports: CrossFit, soccer, overhead sports, or endurance sports) took part in this study. All participants were free of injuries of the glenohumeral joint and did not practice flexibility training regularly. Participants were informed about all the procedures before the start of the familiarization session. Before they were included in the study, each participant gave written informed consent.

Procedure

Shear wave elastography (SWE)

SWE was performed with an ultrasound scanner (Aixplorer V12.3, Supersonic Imaging, Aix-en Provence, France), coupled with a linear transducer array (SuperLinear 15 - 4, 4 - 15 MHz, Vermont, Tours, France). The measurements were performed in SWE mode (musculoskeletal preset, penetration mode, smoothing level 5, persistence off, scale 0 - 450 kPa). For the marking of the measurement position on the skin half way between the sternomanubrial joint and the beginning of the axillary fold (de Oliveira et al., 2020), the participant stood upright with relaxed arms. For the measurement, the participant was seated next to the custom-made testing device, the shoulder joint at 45° abduction, with elbow flexion of 90° and shoulder flexion of 31° ± 7.5° (mean ± sd). The hand rested on the load cell (VPG Force Sensors, Model 1022, Tedea – Huntleigh, Netanya, Israel), which was positioned at shoulder height in front of the participant (Figure 1B). For better orientation and reliability during the SWE measurements, a B-mode picture of the first attempt (i.e., the first trial of the pre-measurement) gave visual support. A hand-held technique (Lacourpaille et al., 2012) was used to measure the PMa muscle stiffness in a relaxed state. The ultrasound probe was aligned in plane with the fascicles and between the PMa muscle aponeuroses, and the region of interest (ROI) was defined as large as possible. The sEMG signal was controlled throughout the measurement duration to ensure a relaxed muscle state during acquisition. Pre and post, three videos, of 15 s each, were recorded at the marked skin position.

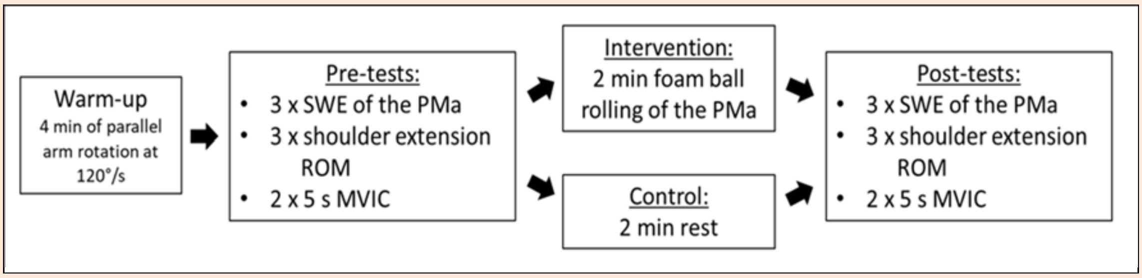

Figure 2. Schematic representation of the study design. SWE = shear wave elastography, PMa = pectoralis major muscle, ROM = range of motion; MVIC = maximal voluntary isometric contraction.

The mean of five consecutive frames within each video with the lowest SD within the ROI was determined (averaged values, analyzed with MATLAB R2017b, MathWorks, Natick, USA; Morales-Artacho et al., 2017). Subsequently, the shear modulus of the PMa for analysis was calculated as the mean between the two closest values of the three videos (Morales-Artacho et al., 2017).

Shoulder extension range of motion (ROM)

To determine the shoulder extension ROM, a 3D-motion capture system (Qualisys, Gothenburg, Sweden) was used. The participant's arms and trunk were marked according the Qualisys "Cast upper body marker set", extended with 16 markers (1-cm diameter) of the "CGM upper body marker set". The participant was seated next to the testing device (45° shoulder abduction). Moreover, to avoid changes in elbow flexion angle during movement, the elbow angle was fixed at 90° with a custom-made fixation (Figure 1C). To avoid any evasive movement of the body, the participant's trunk was fixed to the backrest with a strap. The starting position was a neutral shoulder joint position (= 0° extension), and the participant was asked to slowly move their arm along the fixed board, as far behind the body as possible, while keeping the shoulder low. The movement was repeated three times, with 15-s breaks in between. The sEMG of the PMa was recorded throughout each trial, and if any activation occurred, the attempt was repeated. To extract the angles of the shoulder joint, the recorded markers were mapped into a model consisting of a torso and the upper arm using Visual3D Professional x64 (C-Motion, Inc. Germantown, Virginia, USA). The joint angles in all three planes of motion were then calculated based on the positions of the torso and the upper arm relative to each other. The trial with the greatest shoulder extension ROM was taken for further analysis.

Maximal voluntary isometric contraction (MVIC) peak torque

MVIC peak torque testing was performed in the same position as described for the SWE. To prevent the participant from co-activating other parts of the body during the MVIC, the participant was asked to let their legs hang loosely while sitting on the chair (Figure 1A). Consequently, the participant was asked to push as hard as possible against the force sensor with the palm of their hand for 5 s, performed twice. In all attempts, the participant was verbally encouraged and the tests were performed with 1-min rest between each trial, to avoid fatigue. For the further analysis, the mean of the two highest MVIC peak values was taken.

Surface electromyography (sEMG)

During all the measurements (SWE, ROM, MVIC), the muscle activation was measured using sEMG (myon 320, myon AG, Zurich, Switzerland) with a sampling rate of 2000 Hz. Surface electrodes (Blue Sensor N, Ambu, A/S, Ballerup, Denmark) were placed on the prepared skin on the most medial part of the PMa (pars clavicularis) of the testing side with a distance of 2 cm between the electrodes. If necessary, the sEMG signals of the MVIC measurements were high-pass filtered (10 Hz, Butterworth) and the root mean square (RMS, 50ms window) was determined. A trial was repeated if any muscle activation was visually detected in the raw sEMG data while monitored online during the ROM or SWE trials.

Foam ball rolling intervention (FB-PMa-rolling)

Each participant of the FB-PMa-rolling group was asked to perform 2 min of continuous FBR of the PMa muscle. Therefore, the participant stood with their face close to the wall. Each participant was asked to roll the foam ball (Ball 12, Blackroll AG, Bottighofen, Schweiz) with a diameter of 12 cm between the upper end of the sternum (distal of the sternoclavicular joint) and the beginning of the axillary fold with a pressure at the onset of discomfort (Figure 3). The rolling frequency was set at 2 s per direction to maximize potential ROM increases (Behm et al., 2020). A metronome provided auditory signals to maintain the requested rolling pace. The participant was asked to keep the rolling intensity (i.e., until the point of discomfort) constant during the intervention. Each participant of the control group rested for 2 min, without any activity, in a standing position.

Figure 3. Schematic representation of the two turn positions during the rolling intervention. A = most medial position at the upper end of the sternum (distal of the sternoclavicular joint). B = most lateral position at the beginning of the axillary fold.

Statistical analysis

SPSS (version 28, SPSS Inc., Chicago, Illinois) was used for the statistical analysis. All parameters were tested for a normal distribution using the Shapiro-Wilk test, and for the baseline variety using a t-test or Wilcoxon test. The intra- and inter-day reliability for SWE was assessed with intraclass correlation coefficient (ICC). For the normally distributed data, a mixed factorial ANOVA (within factor: time (pre vs. post) and between factor: group (intervention vs. control)) was performed. Following significant interaction effects in the ANOVA, paired t-tests were performed to test for changes within the groups. If the data were not normally distributed, Wilcoxon tests were performed instead. If a Wilcoxon test revealed a significant effect, a Mann-Whitney U-test was applied between the delta values (pre to post) of the two groups to test for differences between the groups. Additionally, the partial eta-square (η^2) was calculated. The alpha level was set to 0.05.

Results

Baseline measurements

The baseline measurements of both groups showed no differences for shoulder extension ROM ($p = 0.88$), MVIC

Table 1. Mean ± standard deviation pre and post values of the measured parameters.

	Intervention group (FB-PMa-rolling)		Control group (CG)	
	Pre	post	pre	post
Shoulder extension ROM (°)	68.4 ± 6.2	69. 5 ± 6.1	68.5 ± 7.6	68.4 ± 7.0
MVIC peak torque (N)	331.9 ± 126.4	320.2* ± 114.3	329.4 ± 109.1	309.6* ± 119.3
Shear modulus (kPa)	7.7 ± 2.5	7.9 ± 3.0	7.2 ± 2.4	7.5 ± 3.3

ROM = range of motion, MVIC = maximal voluntary isometric contraction, PMa = pectoralis major, CG = control group, * = significantly different from pre value.

peak torque (p = 0.63), or SWE values (p = 0.79). The absolute values of the pre and post data are listed in Table 1.

Shear modulus measurement reliability and values

The SWE intra-day ICC values for the PMa were 0.99 (confidence interval (CI): 0.98 - 0.99, coefficient of variation (CV): 0.03), while the inter-day ICC values for the PMa were 0.89 (CI: 0.42 - 0.98; CV: 0.11). The Wilcoxon tests revealed no significant effect in the shear modulus of the PMa between the pre and post data in both groups (FB-PMa-rolling: p = 0.86; control: p = 0.7).

Shoulder extension ROM values

The repeated measures ANOVA revealed no significant time (p = 0.3; F = 1.12; $\eta^2 = 0.03$) or interaction effect (p = 0.24; F = 1.44; $\eta^2 = 0.04$) for the shoulder extension ROM measurements.

MVIC peak torque values

For the MVIC measurements, the repeated measures ANOVA revealed a significant time effect (p = 0.01; F = 7.03; $\eta^2 = 0.16$; intervention group = -3%; control group = -8%), but no significant interaction effect (p = 0.49; F = 0.48; $\eta^2 = 0.013$).

Discussion

Two minutes of FR with a foam ball had no acute effects on shoulder extension ROM or muscle stiffness. Physical performance (i.e., MVIC) decreased following this intervention, but also after a 2-min resting phase in the control group.

Although not significant, there was an increase in shoulder extension ROM of 1.1° following the 2-min FBR intervention. Prior studies reported a significant increase in joint ROM immediately after FR of the muscle tissue of the lower limbs (MacDonald et al., 2013; Harper et al., 2019; Nakamura et al., 2021), which was still increased 30 min post-exercise (Monteiro et al., 2018; Kasahara et al., 2022). Similarly, it has been reported that stretching of the lower limbs increases ROM (Behm et al., 2016; Konrad et al., 2019; Konrad and Tilp, 2020). We hypothesize that the observed non-significant lower ROM changes in our study might be due to the anatomical arrangement of the shoulder structures. Our intervention was aimed at targeting the clavicular part of the PMa, which was due to practical reasons as we included both sexes in our study. The PMa inserts on the medial part of the clavicula and goes to the Crista tuberculi majoris of the humerus (Schünke et al., 2008). A further structure treated with the rolling intervention was the fascia pectoralis, which lies superficial to the PMa and has insertions at the first rib, the sternum, and the clavicula (Schünke et al., 2008). It is further connected to the fascia cervicalis and the abdominal muscles (Schünke et al., 2008). It could be argued that the pectoralis minor muscle, which goes from the third, fourth, and fifth rib to the processus coracoideus and the fascia clavipectoralis, which surrounds the pectoralis minor muscle and has insertions at the clavicula, processus coracoideus, and the first rib, should have been additionally treated to induce significant increases in ROM (Schünke et al., 2008). However, in the present study, this would not have been possible for the female participants due to the uncomfortable and painful situation for the soft part of the breast. The length and functioning of, specifically, the pectoralis minor muscle and its surrounding connective structures are thought to be associated with scapular kinematics and positioning as well as an increase in glenohumeral ROM (Le Gal et al., 2018; Umehara et al., 2018). We hypothesize that, due to the differences in anatomical origins and insertions of these myofascial structures, the ROM changes might have been higher if the pectoralis minor muscle and the corresponding structures had been additionally targeted. It is clear that, due to their commonalities in innervation, function (respiratory muscle and shoulder girdle movement), and position, the PMa and pectoralis minor muscle cannot be considered and treated completely separately. This is why some studies do not differentiate between stretching or self-massage targeting the PMa or pectoralis minor muscle (De Groef et al., 2017; Le Gal et al., 2018; Kanhachon and Boonprakob, 2021). Therefore, we recommend that future studies should either choose a male sample only to target the pectoralis minor with an FB. Alternatively, a stretching stimulus which is feasible for both female and male participants might lead to the expected increase in ROM.

Neither shoulder extension ROM nor PMa stiffness changed after FB-PMa rolling intervention. This is in contrast to results obtained by Umehara et al. (2018), who reported that both shoulder ROM and pectoralis minor stiffness changed after a stretching intervention. We hypothesize that the duration of the intervention with 2 min in total might have been too short to induce stiffness changes. Behm et al. (2020) recommended in their FR prescription for the lower extremities 1 - 3 sets of 30 - 120 s FR at a frequency of 2 - 4 s per direction to maximize ROM increase. In the present study, the chosen intervention of continuous FR with an FB for 2 min with a frequency of 2 s per direction fits the prescription, but the FB applies pressure only on a small area of the complex structures, and therefore might have only a local effect. A greater area of applied pressure might be necessary to induce functional changes, which would not have been possible for female participants.

Interestingly, the muscle performance decreased in both the intervention group as well as in the control group (i.e., significant time effect). As we tested a group of recreational sports persons, we did not expect the warm-up and pre-test shoulder tests (i.e., MVIC) to be fatiguing. A closer look at the type of sports the participants usually perform showed that the group was relatively heterogenous and that our participants mainly performed lower limb-centered sports. This could have led to different muscle fiber type distributions between the participants at baseline or altered the training loads during the study. Therefore, this specific MVIC shoulder test, which is rarely performed in daily routine and requires activity of muscles which are seldomly trained in isolation, might have induced muscle fatigue. For example, it is well known that, in throwing sports, especially in overhead sports such as tennis or baseball, an internal rotation ROM deficit is present, which goes along with structural changes and an increased risk of injury (Hodgins *et al.*, 2017; Le Gal *et al.*, 2018; Nojiri *et al.*, 2019; Laudner and Thorson, 2020; Pozzi *et al.*, 2020). As this might have been present in some of our participants, we performed a subgroup analysis and clustered the participants according to their main sport (CrossFit, soccer, overhead sports, endurance sports), but we did not find any differences between the groups. However, when splitting the two main groups (intervention vs. control) into subgroups, the number of participants per subgroup became quite small, so these subgroup analyses need to be treated with caution. Unfortunately, the small sample size did not allow for a sex-specific subgroup analysis, which we recommend for further studies on this topic.

We are aware that our study has several limitations, which might have influenced the results. Considering the anatomical origins and connected areas, in addition to the pectoralis minor muscle and fascia clavipectoralis, we could have also considered the position of the upper cervical spine during the test, as the fascia pectoralis is connected to the fascia cervicalis superficialis, which originates at the protuberantia occipitalis externa, the linea nuchae superior, and the mandibular in the cervical region (Schünke *et al.*, 2008). In addition, the thoracal spine influences the shoulder girdle movement and shoulder position alterations (Kim et al., 2018; Cardoso *et al.*, 2021). Although thoracic movement was restricted in our study, possible alterations might have influenced shoulder movement. Furthermore, the tests of shoulder extension for ROM and flexion for strength used in the current study were selected to obtain values in the sagittal plane of motion and to exclude rotations or evasive movements. This decision was made because the pectoralis major muscle consists of two parts (clavicular and sternal head) that function differently and have different injury incidence or elongation during stretching (Umehara *et al.*, 2021). The clavicular portion, which we measured with SWE in the current study, is responsible for humeral flexion, whereas the sternal and abdominal portion produces horizontal adduction and internal rotation. In order to test the extensibility and also the strength capacity of the clavicular portion, rotations were omitted, although an extended test battery with tests also testing the sternal and abdominal portion would have allowed a more comprehensive conclusion. Although FB-PMa-rolling interventions might not be relevant for injury prevention in sports in the first place, treatment of shoulder ROM deficits or posture alterations should be kept in mind. The pectoralis minor muscle seems to be the more contributing factor, but PMa treatment routines are also recommended for baseball players due to significant differences in PMa muscle length and scapular parameters between the throwing and non-throwing shoulder (Hodgins *et al.*, 2017).

Conclusion

We conclude that a 2-min FBR intervention of the upper part of the pectoralis muscle (pars clavicularis) does not affect muscle stiffness, ROM, or physical performance (i.e., MVIC peak torque), which is in contrast to FR interventions of single muscles of the lower limbs. We recommend that future studies should emphasize testing acute and long-term FR interventions of several muscles of the upper limbs with a variety of intervention durations and intensities, and should compare the effects with those of the lower limbs.

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Key points

- This was the first study to explore the acute effects of a foam ball rolling exercise of the pectoralis major (pars clavicularis) muscle on range of motion, maximum isometric contraction, and muscle stiffness.
- A 2-min foam rolling exercise of the pectoralis major (pars clavicularis) muscle with a foam rolling ball has no acute effects on shoulder extension ROM or muscle stiffness.
- Strength measures (i.e., MVIC peak torque) showed a time effect in the mixed factorial ANOVA, indicating a decrease in physical performance in both groups.

AUTHOR BIOGRAPHY

Marina M. REINER
Employment
Institute of Human Movement Science, Sports and Health, University of Graz, Austria
Degree
MSc
Research interests
Muscle-tendon unit, training science, biomechanics
E-mail: marina.reiner@uni-graz.at

Anna GABRIEL
Employment
Department of Sport and Health Science, Technical University of Munich, Munich, Germany
Degree
MSc
Research interests
Physical therapy, orthopedics, myofascial chains, assessment in therapy
E-mail: anna-gabriel@tum.de

Markus TILP
Employment
Institute of Human Movement Science, Sports and Health, University of Graz, Austria
Degree
PhD
Research interests
Biomechanics, training science, muscle-tendon unit, sports game analysis
E-mail: markus.tilp@uni-graz.at

Andreas KONRAD
Employment
Institute of Human Movement Science, Sports and Health, University of Graz, Austria
Degree
PD, PhD, MSc
Research interests
Biomechanics, muscle performance, training science, muscle-tendon unit, soccer science
E-mail: andreas.konrad@uni-graz.at

✉ **Ass. Prof. Dr. Andreas Konrad**
Institute of Human Movement Science, Sport and Health, University of Graz Mozartgasse 14, A – 8010 Graz, Austria