INFLUENCE OF FOAM ROLLING ON ELBOW PROPRIOCEPTION, STRENGTH,
AND FUNCTIONAL MOTOR PERFORMANCE

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EFFECTS OF FOAM ROLLING ON ELBOW PROPRIORCEPTION, STRENGTH, AND FUNCTIONAL MOTOR PERFORMANCE

ABSTRACT

Context: Foam rolling has recently been used frequently to increase flexibility. However, its effects on proprioception, strength and motor performance are not well known. In addition, very few studies have examined the effects of foam rolling in the upper extremity.

Objective: To investigate the effects of foam rolling on elbow proprioception, strength, and functional motor performance in healthy individuals.

Design: Randomized controlled study.

Setting: Exercise laboratory of X Department, X University.

Patients or Other Participants: Sixty healthy participants (mean age=22.83±4.07 years).

Intervention(s): We randomly assigned participants into two groups: the foam rolling group (FRG) (4 weeks of foam rolling for the biceps brachii muscle) and control group (CG) (no foam rolling).

Main Outcome Measure(s): We evaluated proprioception (joint position sense [JPS] and force matching), biceps brachii muscle strength, and functional motor performance (modified pull-up test [MPUT], closed kinetic chain upper extremity stability test [CKCUEST], and push-up test) at the baseline, and at the end of the 4th week and 8th week.

Results: JPS at 45° elbow flexion, muscle strength, CKCUEST, and push-up test results improved after foam rolling and improvement was maintained at the follow-up (p<0.017). While the changes in groups for the results of proprioception and CKCUEST were similar among the three time points (p>0.05), there were significant improvements for the muscle strength from baseline to the second evaluation, and from baseline to the follow-up (p<0.001) in the FRG compared to the CG (p=0.004). The FRG was superior to the CG in the
improvement of push-up test results among the three time points (p=0.040, p=0.001, p<0.001). Other data did not change (p>0.05).

**Conclusion:** Foam rolling is effective in improving elbow JPS in small flexion angles, biceps brachii strength, and some parameters of upper extremity functional motor performance. These effects are maintained 4 weeks after application.

**Keywords:** Position sense, force sense, musculoskeletal injury, upper extremity, prevention

**Contribution of each author to the manuscript:**
1) Substantial contributions to conception and design, acquisition of data, and analysis and interpretation of data: AAA,
2) Drafting the article and revising it critically for important intellectual content: AAA and BBB,
3) Final approval of the version to be published: AAA and BBB.

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**Key Points:**
1. 4 weeks of foam rolling to biceps brachii improved its muscle strength, elbow JPS measured at a relatively small joint angle, and some parameters of upper extremity functional motor performance.
2. Positive effects of 4 weeks of foam rolling continue for one more month.
3. Foam rolling to biceps brachii is not recommended to improve elbow force sense and JPS measured at larger angles.
INTRODUCTION

Proprioception, which is a prerequisite for optimal muscular control, coordination, and stabilization, is vital for a full movement repertoire that includes activities of daily living (ADL) (such as walking, reaching, and lifting objects) as well as challenging athletic skills (such as jumping, shooting, and throwing). Muscle strength, which is essential for general health and physical fitness, also facilitates participation in ADL, physical activity, leisure activities, and sporting performance. Strength, proprioception, and neuromuscular control are combined in functional motor performance, which involves movements whose reflections are directly seen in ADL and sports. After an injury, proprioception decreases due to deafferentation caused by damage to mechanoreceptors, which disrupts the neuromuscular response required for joint stabilization in the regulation of function, and thus, decreases stability. This could ultimately lead to further microtrauma and re-injury. In this context, strength and neuromuscular control are critical to improve performance, and to prevent injury and re-injury in the upper extremity. The recovery of decreased strength and neuromuscular control after injury is also a prerequisite for returning to sports.

The proprioception and neuromuscular control of the shoulder and elbow are necessary for accurate positioning of the hand and proper function of the upper extremity during ADL and sporting activities. While a growing number of research studies focus on proprioception and neuromuscular control of the shoulder region, focusing on the elbow in this scope is surprisingly still in its infancy. Focusing on the elbow joint is of great importance for the following reasons: The elbow joint contributes to stabilization and the fulfillment of fine manipulative tasks, and to achieving high performance in sports. During multi-joint activity, coordination among joints compensates for errors, thereby improving performance. Erroneous deviations of proximal limb segments can be offset by distal joints, and this compensatory behavior can be organized on the basis of proprioception.
Moreover, higher errors seem to occur in elbow proprioception when compared to shoulder proprioception during some sporting activities such as overhead throw. It is also reported that deterioration in the proprioceptive input at the elbow results in a greater disturbance to endpoint positioning of the arm movements, than deterioration in the proprioceptive input at the shoulder does. Besides, sporting activities often lead to injuries that impair elbow proprioception. It appears crucial to develop effective interventions to improve elbow proprioception and neuromuscular control.

Foam rolling is an affordable, easy, and time-efficient technique that has been commonly used as an exercise and massage tool in recent years. It is reported that foam rolling increases flexibility, joint and fascia mobility. Results of a few studies that reported the effects of the technique on strength/endurance, proprioception, and performance are in part contradictory. Some studies investigating the effects of foam rolling on proprioception, strength/endurance or performance reported no effect or a decrease, while others have found evidence to support improvements in proprioception, strength/endurance or performance following foam rolling. However, none of these studies are on the upper extremity. The cylindrical structure of the material used in foam rolling, its texture, and the application of the technique with a certain pressure with body weight, may affect proprioception by stimulating the receptors. This may contribute to strength and functional stability/motor performance if the afferent pathways can be rearranged and the co-activation of some force couples can be facilitated. Conversely, it may be expected that the application will not improve or worsen strength due to its possible relaxation effect.

There is no study on the effects of foam rolling on functional motor performance and its use in the elbow region. Furthermore, acute effects of the technique have generally been investigated. High-quality and well-designed randomized controlled studies are warranted to
investigate the effects of the technique with a longer application period and appropriate follow-ups.\textsuperscript{14} Determining whether foam rolling is an effective intervention to improve elbow proprioception, strength, and upper extremity performance would be useful for guiding the healthcare team in implementing effective interventions to improve upper extremity performance and prevent musculoskeletal injuries.

The purpose of this study was to evaluate the effects of foam rolling for the elbow at the end of the four-week intervention and at a one-month follow-up on proprioception, strength, and functional motor performance.

**MATERIALS AND METHODS**

**Research Design**

Between September 2017-December 2018, 60 healthy university students participated in this randomized controlled study conducted at X University, X Department. The Ethics Committee of X University (Number: XXX) approved this study, and participants gave their written informed consent. Participants were randomly divided into the Foam Rolling Group (FRG) or Control Group (CG) (n\textsubscript{FRG}=n\textsubscript{CG}=30) (Figure 1) by a computerized random number generator (Random.org; Randomness and Integrity Services Ltd, Dublin, Ireland; https://www.random.org).

**Participants**

Volunteers were included if they were ≥18 years of age, did not have elbow pain up until 6 months before recruitment, and did not regularly perform upper extremity sports in the previous 6 months. Exclusion criteria were open wound, acne, or similar skin problems that may prevent the application of foam rolling, experience of foam rolling or myofascial relaxation exercises, a history of previous or current upper extremity injuries, upper extremity fracture or surgery, or a systemic musculoskeletal disease, osteoporosis, diabetes mellitus and peripheral neuropathy, vertigo, cardiovascular disease, and pregnancy.
As there were no relevant studies, we included 30 individuals in each group to ensure parametric conditions instead of performing an a priori power analysis.

**Procedures**

Foam rolling and evaluations were performed on the dominant side. 120-sec rest periods were given between the evaluations. Evaluations were done before administration, at the end of 4 weeks, and 1 month after the second evaluation (at the end of 8 weeks). Any learning effect was excluded by performing a familiarization session for all tests.

**Outcome Measures**

**Proprioception:**

Joint position sense (JPS)

The participants sat on the chair with their back supported and their hip flexed approximately 90°. The forearm was placed on the arm of the chair, covered with a foam pad, in a semi-prone position with the elbow fully extended at the starting position. The participant bent his/her elbow to the target angle (45°, 60°, and 75° elbow flexion in a random order [JPS_45°, JPS_60°, JPS_75°, respectively]) measured by a digital inclinometer (Baseline, NY, USA), and maintained this position for 5 sec to learn this angle. Afterward, he/she returned to the initial position and rested for 5 sec. (Figure 2). Participants repeated this protocol three times with eyes open (EO) and eyes closed (EC). In the actual test, we applied the EC protocol three times. Based on the test-retest in 10 patients, our test-retest reliability was determined to be ICC (3,k)=0.78 (JPS_45°), 0.94 (JPS_60°), and 0.78 (JPS_75°).

**Force Matching**

Force sense was assessed using force reproduction by limb matching that involves the use of a reference force, determined as a percentage of a maximal voluntary isometric contraction, and attempting to replicate that force. The hand-held dynamometer (HHD) is a
small, portable, low-cost, and easy-to-use device that was reported to be valid and reliable in
isolated strength testing of various muscles.\textsuperscript{21} As there are limited studies of reliable force-
reproduction measures in the elbow region, we used a force matching test protocol that
appears to be compatible with HHD.\textsuperscript{13} We measured force matching for elbow flexion. The
participant sat in a chair with 90° elbow and 90° shoulder flexion, the forearm in supination,
and the elbow rested on the table. First, we measured the maximum voluntary contraction
(MVC) for elbow flexors 3 times using a hand-held dynamometer (HHD) (MicroFET\textsuperscript{®}3;
Hoggan Inc, UT, USA) and averaged the results. Next, we calculated 30\% of the MVC and,
after a 45-sec rest, taught the participant the amount of target contraction three times with EO
and EC. Then, we asked the participants to match the same force with EC (Figure 3).\textsuperscript{22} Our
test-retest reliability was ICC (3,k)=0.83.

We recorded the deviation (absolute error) from the target and averaged the 3 test
results in all proprioception evaluations.

\textbf{Muscle Strength:}

We measured the biceps brachii muscle strength with the HHD. The participants laid in
a supine position with a neutral shoulder, elbow in 90° flexion, and forearm in supination. We
placed the HDD proximal to the styloid process and asked the participant to perform a
gradually increasing MVC in 2 sec and then maintain it for 5 sec. The participant provided
muscle contraction until his/her effort matched the examiner. We averaged the 3 test results.
We allowed a rest period of 1 min between tests.\textsuperscript{23} Our test-retest reliability was ICC
(3,k)=0.97.
**Functional motor performance:**

Before the tests, the participants performed warm-up from submaximal to maximal levels. For a high-intensity effort, we verbally encouraged the participants throughout the evaluations. We allowed a 1-min rest between tests.

**Closed Kinetic Chain Upper Extremity Stabilization Test (CKCUEST)**

We marked two lines (two strips of athletic tape with a width of 3.8 cm) parallel to each other at a distance of 90 cm on a floor as measured with a standard cloth tape measure. The starting position for the test was one hand on each piece of tape while the body was in a push-up position. The participant had to move both hands back and forth from each line as many times as possible in 15 s, men in the push-up position, and women in the modified push-up position (kneeling) (Figure 4). We averaged the 3 test results. We allowed a 45-sec rest period between repetitions. In addition to the average number of lines touched, the score and power were calculated using the following equation: score=average of the number of lines touched/height, power=[(68% weight*the average number of lines touched) / 15]. Our test-retest reliability was ICC (3,k)=0.91.

**Modified Pull-up Test (MPUT)**

We positioned the participants on their back and adjusted the metal frame above their heads to be just above the shoulder level. Men performed the pull-up test with the support from their heels, while women were supported with a step just below the knees. To perform the test at full range, the participants started the test by holding the metal frame with the arms in full extension, pulling it parallel to the floor, and finally lowering their bodies with their elbows fully extended. During the test, we instructed the participants to limit the movement of the head and trunk, and to maintain smoothness as much as possible (Figure 5). The participants performed the test with as many pulls as possible within 15 sec during the three
maximum tests, and we averaged the scores. We allowed a 45-sec rest between repetitions.\textsuperscript{24} We calculated a test-retest reliability of ICC (3,k)=0.93.

**Push-up Test**

Males performed the test in the standard position (on the hands and feet), and females in the modified position (on the hands and knees). While the participant was in the prone position with the trunk straight and hands open at shoulder width, he/she performed push-ups. Participants began the test with the elbows fully extended. As the body descended to the ground, the participants bent their elbows until the humerus was parallel to the surface. Throughout the test, we instructed the subjects to keep the head and trunk position straight. They performed a submaximal warm-up before three maximal tests. They performed the maximal tests after they had performed a 15-sec trial and had a 45-sec rest period. The number of push-ups the participants completed in the 15-sec bout was recorded. We averaged the results.\textsuperscript{24} Our test-retest reliability was ICC (3,k)=0.75.

**Foam Rolling Protocol**

The FRG performed the protocol for 1 session/day, 3 days/week, for 4 weeks with the physiotherapist. We instructed the participants not to do any other exercise or receive any other treatments until the end of the study, and we monitored their compliance during the weekly sessions.

During the application, the participant sat on the floor with the side of the trunk close to a rectangular step. We placed a standard 15.3 cm foam rolling material on the step, and the participant placed the biceps brachii muscle with body weight on the foam rolling material with the shoulder at 90° abduction and the elbow at full extension (Figure 6). We preferred the biceps brachii muscle because it would be more distinct and easily distinguishable than the other muscles. The participants performed a total of 2 sets (60 sec each) of foam rolling in the form of 10 back-and-forth movements in 1 minute. We used a metronome to control the
speed. We allowed a 30-sec rest between sets. To ensure adequate pressure during the application, we provided verbal encouragement for the participants to place as much of their bodyweight as possible onto the foam roller, pushing into discomfort but not pain. Before the application, we conducted a trial session for teaching purposes.26

**CG Protocol**

We handed out an information brochure to the CG about proprioception, strength, function, and foam rolling. We asked them not to do regular sports during the study and to continue ADL as usual. We monitored their compliance monthly.

**Statistical Analysis**

We used the “Statistical Package for Social Sciences (SPSS v22.0)” for all data analyses. We used the Shapiro-Wilk test to determine the normal distribution of continuous data. We used the Mann-Whitney U test to compare height, body weight, BMI, and age, and the $\chi^2$ test to compare the gender and dominant extremity distribution of the two groups. Among the three evaluations, Friedman analysis of variance was used to examine the changes in proprioception, strength, and performance data. Then, to identify the time interval in which a meaningful difference occurred based on the level of significance of the data, Wilcoxon analysis and Bonferroni correction were performed ($p<0.0167$). We used the Mann-Whitney U Test to compare changes between these three time intervals between the groups. We set the significance level as $p <0.05$. In the post hoc power analyses, we accepted $\geq 0.80$ as sufficient to show significant differences.

**RESULTS**

Participants’ mean age was 22.83±4.07 years, and their mean BMI was 22.44±3.39 kg/cm². All participants attended all sessions without any side effects.
Baseline main outcome measurements and participant characteristics were similar among groups (p>0.05), except age (p=0.01) (Table 1). Table 2, Table 3, and Table 4 present outcome measurement results. Supplementary Table 1, Supplementary Table 2, and Supplementary Table 3 present the effect sizes and post-hoc power results.

**Proprioception:**

**JPS**

JPS_45° of the FRG was more accurate after 4 weeks of intervention compared to the first assessment values (p=0.01). The values of the CG did not change (p=0.72). When the changes in the groups over time were compared, there were no differences between the groups after 4 weeks (p_{JPS,45°}=0.06) and after 8 weeks (p_{JPS,45°}=0.33). Other JPS data did not change significantly over time in either group (p_{JPS,60°}=0.38 for FRG, p_{JPS,60°}=0.71 for CG) (p_{JPS,75°}=0.60 for FRG, p_{JPS,75°}=0.38 for CG) (Table 2).

**Force matching**

There was no significant change in force matching data over time in either group (p=0.65 for FRG, p=0.51 for CG) (Table 2).

**Muscle Strength:**

In the second (p_{2nd-1st}=0.002) and third (p_{3rd-1st}=0.001) assessments, muscle strength increased in the FRG compared to the first assessment values. The CG’s values did not change (p=0.85). When the changes over time within groups were compared, the changes between the first and second (p_{2nd-1st}=0.004) assessments and between the first and third assessments (p_{3rd-1st}=0.001) were different. However, the changes between the second and the third assessment results were not different between the groups (p=0.98) (Table 3).

**Functional motor performance:**

**CKCUEST**
In the FRG, after both 4 weeks ($p_{\text{average}_{2nd-1st}}=0.001$, $p_{\text{score}_{2nd-1st}}<0.001$, $p_{\text{power}_{2nd-1st}}=0.001$) and 8 weeks ($p_{\text{average}_{3rd-1st}}=0.001$, $p_{\text{score}_{3rd-1st}}=0.001$, $p_{\text{power}_{3rd-1st}}=0.002$) of application, CKCUEST results improved compared to the pre-intervention results ($p_{\text{average}}<0.001$, $p_{\text{score}}=0.001$, $p_{\text{power}}=0.001$). When we compared the changes in the groups over time, there was no difference between measurement times ($p_{\text{average}_{2nd-1st}}=0.12$, $p_{\text{average}_{3rd-2nd}}=0.46$, $p_{\text{average}_{3rd-1st}}=0.34$; $p_{\text{score}_{2nd-1st}}=0.13$, $p_{\text{score}_{3rd-2nd}}=0.42$, $p_{\text{score}_{3rd-1st}}=0.34$; $p_{\text{power}_{2nd-1st}}=0.11$, $p_{\text{power}_{3rd-2nd}}=0.68$, $p_{\text{power}_{3rd-1st}}=0.32$). The CG’s values did not change ($p_{\text{average}}=0.55$, $p_{\text{score}}=0.055$, $p_{\text{power}}=0.055$).

**MPUT**

There was no significant change in the MPUT data over time in either group ($p=0.07$ for FRG, $p=0.80$ for CG).

**Push-up Test**

In the FRG, push-up results improved after 4 weeks ($p_{2nd-1st}=0.003$) and 8 weeks ($p_{3rd-1st}=0.001$) of intervention compared to pre-intervention, but there was no change in the CG values ($p=0.057$). When we compared the changes in the groups over time, we observed that the FRG results significantly improved compared to the CG results at all time intervals ($p_{2nd-1st}=0.04$, $p_{3rd-2nd}=0.001$, $p_{3rd-1st}<0.001$)(Table 4).

**DISCUSSION**

JPS at 45° elbow flexion, muscle strength, CKCUEST, and push-up test results improved after 4 weeks of foam rolling and improvement was maintained for one more month. There were significant improvements in muscle strength from baseline to the second evaluation, and from baseline to the follow-up in the FRG compared to the CG. The FRG was superior to the CG in the improvement of push-up test results among the three time points.
There are several potential mechanical, neurophysiological, and psychological mechanisms for the beneficial effects of foam rolling including improved proprioceptive feedback\textsuperscript{13, 15}, muscle firing rate and fiber recruitment\textsuperscript{15, 18}, circulation\textsuperscript{13, 14, 27}, mobility\textsuperscript{17}, autonomic nervous system (ANS) activation\textsuperscript{28}, and perceptions of well-being\textsuperscript{29}.

Foam rolling improved JPS\textsubscript{45°}. At the end of the 8th week, the results deteriorated slightly compared to the values obtained after the 4 weeks of application and improved compared to the baseline values, but these changes were not statistically significant. Therefore, we can say that the values obtained after application were maintained for one more month. However, this result should be interpreted with caution because of its similarity with the baseline value. While JPS did not change in the CG and the improvement in JPS\textsubscript{45°} in the FRG was greater than in the CG, we may have failed to show a significant difference between groups, attributable to our insufficient statistical power (post-hoc power=0.21-0.54).

The improvements we found in JPS\textsubscript{45°} may be due to the following mechanisms: During rolling, pressure-related elongation in the muscle may activate the muscle spindle and Golgi tendon organs (GTO) and the mechanoreceptors in the fascia, so that the muscle will give more proprioceptive feedback to the central nervous system\textsuperscript{13, 15}. The relatively normal JPS values\textsuperscript{4}, and the more accurate baseline values for JPS\textsubscript{60°} and JPS\textsubscript{75°} compared to JPS\textsubscript{45°} could be the reasons for the lack of improvement in these JPS values.

Foam rolling did not change force matching. Force sense arises from the sense of tension peripherally (afferent feedback from the muscle) and the sense of effort centrally. The main factor in the prediction of the target force appears to be the sense of effort\textsuperscript{30}. It appears that foam rolling does not have a significant central effect. David et al. also found improvement in knee JPS but not in force sense after foam rolling. They suggested that most of the time spent during foam rolling application is for the muscle belly, which stimulates the muscle spindles more, and less time is spent for the tendons, which stimulates the GTO less.
Therefore, they associated their findings with the fact that the force sense testing acts on the GTO, while the JPS test acts on the GTO and muscle spindles.\textsuperscript{15} This could also explain our results.

The biceps brachii strength increased after 4 weeks of foam rolling, and this improvement was maintained for one more month. Increased neural stimulation via foam rolling may increase the firing rate and patterning of muscle fiber recruitment.\textsuperscript{15, 18} The technique might have caused elongation of the shortened sarcomeres with ischemic compression and a better contribution to the contraction of the muscle.\textsuperscript{31} Moreover, reactive hyperemia due to pressure may lead to better oxygen uptake, and a decrease in the production of nociceptive and inflammatory substances, which may result in less damage to muscle fibers, and as a result, better power production might have occurred.\textsuperscript{13, 32}

The pressure applied during foam rolling may lead to an increase in blood supply and to tissue biochemical changes similar to those of other massage techniques. These changes can be listed as: Increased circulating neutrophil levels\textsuperscript{33}, much smaller increases in post-exercise plasma creatine kinase\textsuperscript{33}, activation of sensors for the transcription of cytochrome c oxidase subunit VIIb (COX7B) and NADH Dehydrogenase 1 (ND1), indicating generation of new mitochondria\textsuperscript{34}, and much fewer active immune cytokines reflecting less cellular stress and inflammation.\textsuperscript{34} With the formation of new mitochondrial cells, the muscle tissue can be oxygenated more, and muscle strength may increase.\textsuperscript{18}

Another possible mechanism could be ANS activation with stimulation of interstitial Type III and IV receptors that respond to light touch, and Ruffini terminations in the fascia that respond to deep continuous pressure. Stimulation of these receptors can reduce sympathetic tone, increase gamma motor neuron activity, and promote the relaxation of intra-fascial smooth muscle cells.\textsuperscript{28} The ANS can also change vasodilatation state and fascial
viscosity. Optimum relaxation in muscle and fascia might have had a positive effect on the muscle length-tension relationship.\textsuperscript{13, 14, 35}

Strength gains were maintained one month after the application. The following may have been effective for this result: The stimulation of the proprioceptors in myofascia may have resulted in neural and myofascial adaptation. Fascia is thought to have a memory due to the mechanoreceptor and nociceptor structures it contains. Neural inputs to the brain can be changed along with myofascial memory changes obtained by applications that use contact and pressure, such as foam rolling. In addition, the collagen in the fascia is deposited along the direction of stretching at the molecular and macroscopic levels. Mechanical loads affect collagen alignment and deposition. Furthermore, the extracellular matrix can also be effective in this memory. Muscle appears to have a memory due to the central motor learning ability and DNA-containing nuclei within the muscle. These all point to a myofascial memory and, moreover, a myofascial awareness.\textsuperscript{36} In future studies, how long this effect persists should be investigated with a longer follow-up.

In the results of the studies that investigated the effects of foam rolling on performance,\textsuperscript{18, 29,37,38} especially immediate results are inconsistent. We found that CKCUEST and push-up test results improved after 4 weeks of foam rolling and that this improvement was maintained for one more month. As discussed in the section on strength, neural and myofascial adaptation and myofascial memory/awareness can be the explanations for the maintaining of the positive results.

Foam rolling can influence performance by creating a warm-up effect that can be attributed to circulatory changes and fascial relaxation.\textsuperscript{14} Changes in tissue perfusion, an increase in plasma nitric oxide levels, a decrease in arterial stiffness, and an improvement in vascular endothelial function\textsuperscript{27} may lead to changes in afferent muscle fibers and ANS activation. As performance mainly depends on muscle strength and neuromuscular control, \textsuperscript{14}
improved strength and proprioception may explain the improvement in performance tests based on dynamic stabilization. Foam rolling did not improve or deteriorate the MPUT results. Through the increased dynamic neuromuscular stabilization with intense mechanoreceptor stimulation by foam rolling,\textsuperscript{1,5} our performance tests performed in a weight-bearing position and requiring more joint stability may have better reflected the effects of the application.\textsuperscript{23} Lastly, there may also have been an increase in performance due to a possible increase in mobility\textsuperscript{17,37} or a psychological environment conducive to enhancing performance by reduced fatigue perception via stimulation of parasympathetic activity\textsuperscript{14,17,29}.

**Limitations**

The first limitation of this study is the lack of blinding of the investigator who performed the measurements, as it was a thesis study. Therefore, we took strict precautions to avoid bias. The author was not allowed to read the results on the measurement device throughout the tests. A trained assistant, blinded to the group assignments, read and recorded the results. To prevent bias in functional performance tests, the researcher did not see the first evaluation results while recording the following evaluation results. The other author, who was unaware of the group assignment of the participants, performed the data analyses.

Another limitation could be the lack of standardization of the pressure during foam rolling. Although we provided verbal encouragement for the participants to obtain adequate pressure onto the foam roller, we recommend ensuring standardization of the pressure with objective methods during application for future studies.

**CONCLUSION**

Foam rolling to biceps brachii is a safe method for improving its muscle strength, elbow JPS measured at 45°, and some parameters of upper extremity functional motor performance. After the 4-week training, improvements continued for one more month. Foam rolling had no
effect on force matching or JPS measured at larger angles. In future studies, the long-term
effects of the technique and related mechanisms, its effectiveness in the athletic population,
and various elbow pathologies should be investigated.
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LEGENDS TO FIGURES

1. **Figure 1:** CONSORT (Consolidated Standards of Reporting Trials) flow diagram of the study.

2. **Figure 2:** Measurement of the Joint Position Sense

3. **Figure 3:** Measurement of the Force Matching

4. **Figure 4:** Closed Kinetic Chain Upper Extremity Stability Test (Positioning of the Women-on the Left and Positioning of the Men-on the Right)

5. **Figure 5:** Modified Pull-Up Test (Positioning of the Women-on the Left and Positioning of the Men-on the Right)

6. **Figure 6:** Foam Rolling Application
Table 1. Participants’ Characteristics

| Characteristic              | FRG (n=30)          | CG (n=30)          | p value  |
|-----------------------------|---------------------|-------------------|----------|
| Age (years) a               | 21.70 (18.00 – 27.00) | 23.97 (18.00 – 47.00) | 0.019 § * |
| Height (cm) b               | 171.93±8.33         | 168.63±7.85       | 0.071 §  |
| Weight (kg) b               | 68.93±13.46         | 62.43±11.06       | 0.080 §  |
| BMI (kg/m²) b               | 23.16±3.67          | 21.72±2.98        | 0.171 §  |
| Sex c (Male/Female)         | 18/12               | 11/19             | 0.071 †  |
| Dominant Extremity c (Right/Left) | (30/0)         | (29/1)            | 0.313 †  |

a Values are presented as median (minimum – maximum). b Values are presented as mean ± standard deviation. c Values are distribution as number of the participants in each group. BMI: Body Mass Index. †: χ² test, §: Mann Whitney U test. FRG: Foam Rolling Group, CG: Control Group. * p<0.05
| Outcome Measure | Group   | 1st     | 2nd     | 3rd     | Δ 2nd-1st | Δ 3rd-2nd | Δ 3rd-1st | Time p † | Binary Comparison of Measurement Times (p)†† |
|-----------------|---------|---------|---------|---------|-----------|-----------|-----------|---------|---------------------------------------------|
|                 | 45°     |         |         |         |           |           |           |         |                                             |
| JPS(*)          | FRG     | 4.86 ± 3.24 | 3.04 ± 1.87 | 3.82 ± 2.01 | -1.82 ± 3.72 | 0.77 ± 2.67 | -1.04 ± 3.05 | 0.010* | 2>1*** (0.01) 1=3 (0.09) 2=3 (0.14)     |
|                 | CG      | 4.93 ± 3.06 | 4.81 ± 2.76 | 4.59 ± 2.87 | -0.12 ± 3.49 | -0.31 ± 2.80 | -0.33 ± 3.27 | 0.723  | NA                                          |
|                 | 60°     |         |         |         |           |           |           |         |                                             |
|                 | FRG     | 4.07 ± 1.93 | 4.56 ± 2.61 | 3.59 ± 1.51 | 0.48 ± 3.17 | -0.26 ± 2.82 | -0.47 ± 2.40 | 0.387  | NA                                          |
|                 | CG      | 4.86 ± 3.58 | 4.19 ± 2.74 | 4.43 ± 2.59 | 0.66 ± 3.46 | 0.23 ± 3.49 | -0.42 ± 4.25 | 0.712  | NA                                          |
|                 | 75° a   |         |         |         |           |           |           |         |                                             |
|                 | FRG     | 3.00 (0.66-10.33) | 3.49 (0.66-7.66) | 3.00 (0.66-8.00) | 0.00 [-7.00-2.33] | -0.83 [-4.67-4.33] | 0.00 [-8.33-5.67] | 0.607  | NA                                          |
|                 | CG      | 3.66 (0.66-11.33) | 3.00 (1.33-8.66) | 2.49 (0.66-3.33) | -0.33 [-5.67-5.33] | -0.33 [-5.67-3.67] | -0.83 [-6.67-5.33] | 0.387  | NA                                          |
| Force match a   | p §     |         |         |         |           |           |           |         |                                             |
|                 | 45°     | 0.069   | 0.108   | 0.332   | 0.322     | 0.482     | NA        | NA      |                                             |
|                 | 60°     | 0.290   | 0.234   | 0.450   | 0.450     | 0.519     | NA        | NA      |                                             |
|                 | 75°     | 0.544   | 0.906   | 0.819   | 0.819     | NA        | NA        | NA      |                                             |
| BB              |         |         |         |         |           |           |           |         |                                             |
|                 | FRG     | 0.30 (0.06-0.70) | 0.03 (0.25-1.13) | 0.30 (0.06-0.76) | 0.000 [-0.50-0.67] | -0.11 [-0.70-0.57] | -0.01 [-0.57-0.57] | 0.655  | NA                                          |
|                 | CG      | 0.31 (0.06-0.96) | 0.316 (0.10-0.76) | 0.28 (0.10-0.83) | -0.03 [-0.60-0.60] | -0.08 [-0.43-0.43] | -0.01 [-0.50-0.30] | 0.519  | NA                                          |

1st: Baseline, 2nd: After four weeks, 3rd: At the end of 8 week. Δ: Change between two measurements. Values are presented as mean ± standard deviation unless otherwise indicated. a Values are presented as median (min-max). FRG: Foam Rolling Group, CG: Control Group. BB: Biceps Brachii, JPS: Joint Position Sense, †: Change in time (The Friedman Analysis of Variance), ††: Wilcoxon Signed-rank Test, §: Change in time between groups (Mann Whitney-U Test). NA: Not applicable. Statistically significant difference: * p<0.05, ** p<0.0167.
Table 3. Muscle strength results among groups

| Outcome Measure | Group | 1st | 2nd | 3rd | Δ 2nd-1st | Δ 3rd-2nd | Δ 3rd-1st | Time p† | Binary Comparison of Measurement Times (p)†† |
|-----------------|-------|-----|-----|-----|-----------|-----------|----------|--------|----------------------------------|
| Muscle strength (kg) |       |     |     |     |           |           |          |        |        |
|                  | FRG   | 19.95 ± 4.30 | 21.33 ± 5.42 | 21.21 ± 4.70 | 1.29 ± 2.15 | -0.02 ± 2.17 | 1.26 ± 1.91 | <0.001* | 2>1 † **(0.002) 3>1 † **(0.001) 2=3 (0.98) |
|                  | CG    | 18.58 ± 4.47 | 18.27 ± 3.54 | 18.29 ± 3.97 | -0.31 ± 1.99 | 0.02 ± 1.56 | -0.27 ± 1.42 | 0.851 | NA |
| p §              |       | 0.004** | 0.994 | 0.001** | NA | NA |

1st: Baseline, 2nd: After four weeks, 3rd: At the end of 8 week. Δ: Change between two measurements. Values are presented as mean ± standard deviation. FRG: Foam Rolling Group, CG: Control Group. BB: Biceps Brachii, †: Change in time (The Friedman Analysis of Variance). ††: Wilcoxon Signed-rank Test, §: Change in time between groups (Mann Whitney-U Test). NA: Not applicable. Statistically significant difference: * p<0.05, ** p<0.0167.
| Outcome Measure | Group | 1<sup>st</sup> | 2<sup>nd</sup> | 3<sup>rd</sup> | Δ 2<sup>nd</sup>- 1<sup>st</sup> | Δ 3<sup>rd</sup>- 2<sup>nd</sup> | Δ 3<sup>rd</sup>- 1<sup>st</sup> | Time | Binary Comparison of Measurement Times (p)†† |
|-----------------|-------|-------------|-------------|-------------|----------------|----------------|----------------|------|----------------------------------|
| **MPUT**        |       |             |             |             |                |                |                |      |                                  |
| FRG             | 8.78 ± 2.36 | 9.18 ± 2.43 | 9.61 ± 2.66 | 0.42 ± 1.53 | 0.42 ± 1.48 | 0.82 ± 1.57 | 0.077 | NA                               |
| CG              | 8.46 ± 2.05 | 8.31 ± 2.22 | 8.65 ± 2.69 | -0.15 ± 1.99| 0.34 ± 1.64 | 0.18 ± 2.09 | 0.805 | NA                               |
| **Push up**<sup>a</sup> |       |             |             |             |                |                |                |      |                                  |
| FRG             | 12.00 (7.00-17.00) | 13.16 (7.00-22.00) | 13.50 (7.66-21.00) | 1.66 [-3.33] - [10.00] | 1.10 [-1.00] - [4.00] | -0.66 [-2.67] - [8.00] | 0.005<sup>*</sup> | 2>1 † **(0.003) 3>1 † **(0.001) 2=3 (0.084) |
| CG              | 11.00 (6.33-17.33) | 12.16 (7.00-16.66) | 10.99 (5.33-16.33) | 0.16 [-7.67] - [4.67] | 0.66 [-4.33] - [3.00] | 1.83 [-5.33] - [2.33] | 0.057 | NA                               |
| **Functional motor performance**<sup>b</sup> |       |             |             |             |                |                |                |      |                                  |
| p §              |       |             |             |             |                |                |                |      |                                  |
| Average         | 19.52±4.59 | 21.82±5.06 | 21.77±4.82 | -2.29±3.08 | -0.44±2.35 | 2.25±3.46 | <0.001<sup>*</sup> | 2>1 † **(0.001) 3>1 † **(0.001) 2=3 (0.72) |
| Score           | 0.28±0.07  | 0.32±0.08  | 0.24±0.07  | 0.03±0.04  | -0.001±0.035 | 0.03±0.05 | 0.001<sup>*</sup> | 2>1 † **(0.000) 3>1 † **(0.001) 2=3 (0.74) |
| Power           | 59.69±12.83 | 66.57±12.09 | 66.45±12.43 | 6.88±9.80 | -0.12±7.70 | 6.75±11.64 | 0.001<sup>*</sup> | 2>1 † **(0.001) 3>1 † **(0.002) 2=3 (0.79) |
| Average         | 20.69±3.25 | 21.59±3.11 | 22.22±4.59 | 0.95±2.84 | 0.56±2.00 | 1.52±3.46 | 0.550 | NA                               |
| Score           | 0.31±0.06  | 0.32±0.06  | 0.33±0.07  | 0.01±0.04  | 0.009±0.030 | 0.02±0.05 | 0.055 | NA                               |
| Power           | 59.37±15.17 | 61.82±15.84 | 63.32±16.66 | 2.45±8.38 | 1.49±5.59 | 3.95±6.66 | 0.055 | NA                               |

1<sup>st</sup>: Baseline, 2<sup>nd</sup>: After four weeks, 3<sup>rd</sup>: At the end of 8 week. Δ: Change between two measurements. Values are presented as mean ± standard deviation unless otherwise indicated. <sup>a</sup> Values are presented as median (min-max). FRG: Foam Rolling Group, CG: Control Group. CKCUEST: Closed Kinetic Chain Upper Extremity Stability Test, MPUT: Modified pull-up test. <sup>b</sup> MPUT outcome: the number of pull-ups, Push up test outcome: the number of push-ups, CKCUEST outcome: average number of lines touched, score (inch<sup>-1</sup>) and power (kg). †: Change in time (The
Friedman Analysis of Variance), ††: Wilcoxon Signed-rank Test, §: Change in time between groups (Mann Whitney-U Test). NA: Not applicable. Statistically significant difference: * p<0.05, ** p<0.0167.
Supplementary Table 1. Effect size and post-hoc power results for proprioception

| Outcome Measure | Effect size   | Post-hoc power |
|-----------------|---------------|----------------|
|                 | FRG           |                |
|                 | 2nd - 1st    | 0.64           | 0.99           |
|                 | 3rd - 1st    | 0.36           | 0.86           |
|                 | 3rd - 2nd    | 0.39           | 0.90           |
|                 | 2nd - 1st    | 0.04           | 0.06           |
|                 | 3rd - 1st    | 0.11           | 0.11           |
|                 | 3rd - 2nd    | 0.07           | 0.08           |
|                 | Δ2nd - 1st   | 0.47           | 0.54           |
|                 | Δ3rd - 1st   | 0.36           | 0.38           |
|                 | Δ3rd - 2nd   | 0.22           | 0.21           |
|                 | CG           | 20th           |                |
|                 | 2nd - 1st    | 0.20           | 0.64           |
|                 | 3rd - 1st    | 0.27           | 0.84           |
|                 | 3rd - 2nd    | 0.42           | 0.99           |
|                 | 2nd - 1st    | 0.21           | 0.19           |
|                 | 3rd - 1st    | 0.13           | 0.12           |
|                 | 3rd - 2nd    | 0.09           | 0.09           |
|                 | Δ2nd - 1st   | 0.34           | 0.58           |
|                 | Δ3rd - 1st   | 0.37           | 0.58           |
|                 | Δ3rd - 2nd   | 0.01           | 0.58           |
|                 | 2nd - 1st    | 0.05           | 0.12           |
|                 | 3rd - 1st    | 0.21           | 0.65           |
|                 | 3rd - 2nd    | 0.20           | 0.62           |
|                 | 2nd - 1st    | 0.17           | 0.15           |
|                 | 3rd - 1st    | 0.39           | 0.43           |
|                 | 3rd - 2nd    | 0.25           | 0.24           |
|                 | Δ2nd - 1st   | 0.09           | 0.10           |
|                 | Δ3rd - 1st   | 0.14           | 0.13           |
|                 | Δ3rd - 2nd   | 0.04           | 0.07           |
|                 | 2nd - 1st    | 0.14           | 0.39           |
|                 | 3rd - 1st    | 0.11           | 0.29           |
|                 | 3rd - 2nd    | 0.24           | 0.75           |
|                 | 2nd - 1st    | 0.04           | 0.07           |
|                 | 3rd - 1st    | 0.24           | 0.22           |
|                 | 3rd - 2nd    | 0.22           | 0.21           |
|                 | Δ2nd - 1st   | 0.16           | 0.15           |
|                 | Δ3rd - 1st   | 0.13           | 0.12           |
|                 | Δ3rd - 2nd   | 0.03           | 0.06           |

1st: Baseline, 2nd: After four weeks, 3rd: At the end of 8 weeks. Δ: Change between two measurements. FRG: Foam Rolling Group, CG: Control Group. BB: Biceps Brachii, JPS: Joint Position Sense. *: Indicates a statically significant result.
Supplementary Table 2. Effect size and post-hoc power results for muscle strength

| Outcome Measure | Effect size | Post-hoc power |
|-----------------|-------------|----------------|
| **Muscle strength (kg)** |             |                |
| **BB** |             |                |
| **FRG** |             |                |
| $2^{nd}$-$1^{st}$ | 0.25 | 0.61 |
| $3^{rd}$-$1^{st}$ | 0.28 | 0.67 |
| $3^{rd}$-$2^{nd}$ | 0.01 | 0.05 |
| **CG** |             |                |
| $2^{nd}$-$1^{st}$ | 0.07 | 0.08 |
| $3^{rd}$-$1^{st}$ | 0.06 | 0.08 |
| $3^{rd}$-$2^{nd}$ | 0.01 | 0.05 |
| **Change in time between groups** |             |                |
| $\Delta 2^{nd}$-$1^{st}$ | 0.77 | 0.89 |
| $\Delta 3^{rd}$-$2^{nd}$ | 0.02 | 0.05 |
| $\Delta 3^{rd}$-$1^{st}$ | 0.76 | 0.88 |

1<sup>st</sup>: Baseline, 2<sup>nd</sup>: After four weeks, 3<sup>rd</sup>: At the end of 8 weeks. $\Delta$: Change between two measurements. FRG: Foam Rolling Group, CG: Control Group. BB: Biceps Brachii, *: Indicates a statically significant result.
Supplementary Table 3. Effect size and post-hoc power results for functional motor performance

| Outcome Measure |  | Effect size | Post-hoc power |
|-----------------|----------------|-------------|----------------|
| **MPUT**        | **Binary comparison of measurement times** |  |  |
| **FRG**         | 2nd-1st        | 0.16        | 0.49           |
|                 | 3rd-1st        | 0.32        | 0.93           |
|                 | 3rd-2nd        | 0.16        | 0.49           |
| **CG**          | 2nd-1st        | 0.07        | 0.08           |
|                 | 3rd-1st        | 0.07        | 0.08           |
|                 | 3rd-2nd        | 0.06        | 0.07           |
| **Change in time between groups** |  |  |  |
| **FRG**         | 2nd-1st        | 0.31        | 0.31           |
|                 | 3rd-2nd        | 0.04        | 0.07           |
|                 | 3rd-1st        | 0.34        | 0.35           |
| **Push up**     | **Binary comparison of measurement times** |  |  |
| **FRG**         | 2nd-1st        | 0.63        | 0.99           |
|                 | 3rd-2nd        | 0.15        | 0.31           |
|                 | 2nd-1st        | 0.07        | 0.08           |
| **CG**          | 3rd-1st        | 0.29        | 0.28           |
|                 | 3rd-2nd        | 0.34        | 0.36           |
| **Change in time between groups** |  |  |  |
| **FRG**         | 2nd-1st        | 0.53        | 0.64           |
|                 | 3rd-2nd        | 0.89        | 0.95           |
|                 | 3rd-1st        | 1.20        | 0.99           |
| **CKCUEST**     | **Binary comparison of measurement times** |  |  |
| **FRG**         | 2nd-1st        | 0.47        | 0.97           |
|                 | 3rd-1st        | 0.47        | 0.97           |
|                 | 3rd-2nd        | 0.01        | 0.05           |
|                 | 2nd-1st        | 0.25        | 0.24           |
| **CG**          | 3rd-1st        | 0.38        | 0.41           |
|                 | 3rd-2nd        | 0.13        | 0.12           |
| **Mean**        | **Score**      |  |  |
| **FRG**         | 2nd-1st        | 0.52        | 0.98           |
|                 | 3rd-1st        | 0.57        | 0.99           |
|                 | 3rd-2nd        | 0.01        | 0.06           |
| **CG**          | 2nd-1st        | 0.18        | 0.16           |
|                 | 3rd-1st        | 0.32        | 0.33           |
|                 | 3rd-2nd        | 0.15        | 0.14           |
| **Power**       | **Score**      |  |  |
| **FRG**         | 2nd-1st        | 0.53        | 0.98           |
|                 | 3rd-1st        | 0.53        | 0.99           |
|                 | 3rd-2nd        | 0.01        | 0.05           |
| **CG**          | 2nd-1st        | 0.15        | 0.14           |
|                 | 3rd-1st        | 0.24        | 0.23           |
|                 | 3rd-2nd        | 0.09        | 0.09           |
| **Change in time between groups** |  |  |  |
| **Mean**        | 2nd-1st        | 0.45        | 0.56           |
| **Score**       | 3rd-2nd        | 0.23        | 0.30           |
| **Power**       | 3rd-1st        | 0.19        | 0.25           |

1st: Baseline, 2nd: After four weeks, 3rd: At the end of 8 weeks. Δ: Change between two measurements. FRG: Foam Rolling Group, CG: Control Group. CKCUEST: Closed Kinetic Chain Upper Extremity Stability Test, MFUT: Modified pull-up test. *: Indicates a statically significant result.
Figure 1: CONSORT (Consolidated Standards of Reporting Trials) flow diagram of the study.

Assessed for eligibility (n=68)
Excluded (n=8)
- People under 18 years of age (n=0)
- Pain in the elbow during the last 6 months (n=0)
- Not to be able to participate in all interventions and evaluations (n=3)
- Acne and similar skin problems that may prevent the application of foam rolling (n=0)
- Previous experience with foam rolling (n=0)
- Having a systemic musculoskeletal disease (n=0)
- Upper extremity injury, history of fracture and surgery (n=0)
- Diagnosis of diabetes mellitus and peripheral neuropathy (n=2)
- Having a cardiovascular disease (n=0)
- Diagnosis of osteoporosis (n=0)
- Having vertigo (n=3)

Randomized (n=60)

Allocated to Foam Rolling Group
Received allocated intervention (n=30)

Allocated to Control Group
Received allocated intervention (n=30)

Follow-up
Lost to follow-up (n=0)
Discontinued (n=0)

Lost to follow-up (n=0)
Discontinued (n=0)

Analysis
Analyzed (n=30)

Analyzed (n=30)
Figure 2. Measurement of the Joint Position Sense

Figure 3. Measurement of the Force Matching
Figure 4. Closed Kinetic Chain Upper Extremity Stability Test (Positioning of the Women-on the Left and Positioning of the Men-on the Right)

Figure 5. Modified Pull-Up Test (Positioning of the Women-on the Left and Positioning of the Men-on the Right)
Figure 6. Foam Rolling Application