Immediate Effect of "Duration of Static Stretching" on Strength and Power of Shortened Triceps Surae Muscle

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Abstract

Introduction: Muscle shortness is the cause of many musculoskeletal pain syndromes. Although stretching exercise reduces muscle shortness, the immediate effect of stretching on muscular strength and power needs further investigation. In this study, the immediate effect of "static stretching duration" on the isokinetic strength and power of shortened triceps Surae muscle (STSM) was investigated. **Methods:** It was a quasi-experimental study. In the descriptive part of research, the range of motion of the active dorsiflexion of 57 male students was measured. With the criterion of active dorsiflexion range of motion less than 20 degrees, 12 people (20.8±1.5 years, 177.7±4.7 cm, 74.4±12.9 kg) were selected for the experimental part of the research, which included 4 sessions. In the first session, the strength and power of the subjects was measured as a pre-test by an isokinetic dynamometer. In the next three sessions, in every session, one of the three static stretching protocols of 30, 120, and 360 seconds was randomly applied to STSM of each subject and Immediately after the stretch, strength and power were measured as the post-test. Data analysis was performed by dependent t-test and alpha level was set at 0.05. **Results:** Our findings showed that, compared to the pretest, the power was significantly increased by all three stretch protocols of 30 (P = 0.04), 120 (P = 0.03) and 360 seconds (P = 0.03). However, for muscular strength, 120 (P = 0.03) and 360 second (P = 0.03) stretch protocols led to significant increase, but 30 second stretch did not significantly increase it (P = 0.13). **Conclusion:** The present study showed that different durations of static stretching on STSM do not immediately reduce muscular strength and power compared to before stretching. Accordingly, it seems that in the warm-up phase of sport training, performing any of these stretching protocols is applicable.

Keywords: Triceps Surae muscle, Static stretch, Strength, Power

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Introduction

Shortness of the triceps surae muscle has a relatively high prevalence. For example, the reported prevalence rate is 20% in Iranian girls under 17 and 62% in Danish individuals under 17. Shortness of this muscle has been cited as one of the causes of several musculoskeletal pain syndromes and injuries. Specifically, the shortness of this muscle, by decreasing the ankle dorsiflexion range of motion, is mentioned as one of the potential causes of lateral ankle sprain. Furthermore, the shortness of this muscle is often a hidden reason behind low back pain. Performing activities such as jumping and landing requires an ankle dorsiflexion angle of 20 to 30 degrees. When a muscle remains in a shortened position for an extended period or is subjected to overuse, it may become shortened. Locally, muscular shortness results in a reduced joint range of motion, altered joint alignment, and a change in the length-tension relationship. Moreover, due to the chain-like nature of the human kinetic system, muscular shortness initiates chain reactions along the kinetic chain, leading to changes in posture and movement patterns. These changes predispose individuals to the development of Movement Impairment Syndromes.

Methods such as local vibration, ultrasound, and static stretching for correcting muscular shortness are employed. Among researchers, there is disagreement regarding the appropriate duration of a single set of static stretching for correcting muscular shortness. One group of researchers believes that 30 seconds is the optimal duration for a single static stretch set. Another group of researchers is of the opinion that stretching with longer sets, even up to one hour, has a greater impact on correcting muscular shortness. Static stretching is based on biomechanical and neurophysiological factors. Biomechanical factors refer to the induction of viscoelastic and plastic changes in the non-contractile elements of the muscle, which leads to an increase in the resting length and extensibility of the muscle-tendon unit. Neurophysiological factors refer to autogenic inhibition. In autogenic inhibition, after a few seconds of stretching, the inhibitory impulses from the Golgi tendon organs overcome the excitatory impulses from the muscle spindles, leading to muscle inhibition and relaxation. There is a disagreement among researchers regarding the necessary duration for the onset of autogenic inhibition.

In the past, stretching exercises, with the aim of improving athletic performance through increased flexibility, were a mandatory part of the warm-up routine in every training session. However, the immediate enhancement of athletic performance following static stretching has now been questioned. Some studies have reported that static stretching acutely reduces the ability of the muscle to produce tension and torque, resulting in decreased strength, power, and a decline in performance. Other studies have reported the opposite. The changes observed in the muscle immediately following stretching, in terms of altered strength and power, can be attributed to two factors: neural and biomechanical. Neural factors include all the inhibitory mechanisms resulting from stretching, such as the fatigue response, the Hoffman reflex, autogenic inhibition, inhibitory feedback from joint mechanoreceptors, and the inhibition of corticospinal neural pathways. These mechanisms inhibit the muscle due to stretching by inhibiting the muscle spindle or the alpha motor neuron. Biomechanical factors refer to the acute changes induced in the muscle's passive stiffness and length-tension relationship as a result of stretching. These changes lead to a reduced capacity for force production after stretching.

Today, the view of the majority of researchers is that in muscles with normal length, static stretching for durations less than 60 seconds does not immediately reduce strength and power following the stretch, but stretching for more than 60 seconds does cause a reduction in strength and power. Therefore, in muscles with normal length, the threshold time for an immediate decline in strength and power following static stretching is 60 seconds. The question then arises: Is the threshold time for an immediate decline in strength and power following stretching in a shortened muscle also 60 seconds, or does the muscular shortness alter this threshold time? Therefore, the present study evaluated the immediate effect of static stretching with durations of 30 seconds (< 60 seconds), 120 seconds, and 360 seconds (> 60 seconds) on the strength and power of the shortened muscle. The chosen muscle was the triceps surae muscle.

Methods

The present research was a quasi-experimental study. The subjects acted as their own control group during the first round of testing (pre-test) and as the experimental group during the subsequent three rounds of testing in which the independent variable (stretching protocols) was applied. The sampling process for this study involved two stages. A random cluster sampling method was used in the descriptive stage, and a purposive sampling method was used in the experimental stage. The statistical population included all male university students who had registered for the specialized physical education course at the University of Isfahan. At the time of the research, there were 30 classes for this course. In the first stage of sampling, two of these classes were selected using the random cluster sampling method. In the second stage of sampling, after obtaining informed consent from all individuals in the two selected classes (57 people), 12 subjects who exhibited shortness of the

Figure 1: Active dorsiflexion range of motion measurement

triceps surae muscle (STSM) in their dominant leg were selected as participants.
Inclusion criteria were an active dorsiflexion range of motion of less than 20 degrees and a willingness and ability to perform the exercises. Exclusion criteria included the subject's unwillingness to continue cooperation, failure to adhere to the training schedule, and absence from the testing and training sessions.

Table 1: Sequence of Stretching Protocols for Subjects

Groups	Intervention Session 1	Intervention Session 2	Intervention Session 3
1	30 seconds	120 seconds	360 seconds
2	360 seconds	120 seconds	30 seconds
3	30 seconds	360 seconds	120 seconds
4	120 seconds	30 seconds	360 seconds
5	360 seconds	30 seconds	120 seconds
6	120 seconds	360 seconds	30 seconds

Protocol and Procedure

The research was conducted in four sessions at the Corrective Exercises Laboratory of the Faculty of Sport Sciences, University of Isfahan. Each session lasted approximately 30 minutes per subject. The rest interval between two consecutive sessions was set at one week to prevent the training effects from interfering with each other. The first session was dedicated to the pre-test, and none of the stretching protocols were performed. In this session, height and weight were first measured. Subsequently, the strength and power of the short triceps surae muscle of the dominant leg of each subject were measured using an isokinetic dynamometer (Biodex System 3, manufactured in the USA), which served as the pre-test data.
In the three subsequent sessions, each subject performed one of the three static stretching protocols (30, 120, and 360 seconds). Immediately following the stretch, strength and power were measured as the post-test. Since performing both a pre-test and post-test in a single session with only a 20-minute interval (the duration of the stretching protocol application) would introduce a Testing Effect (fatigue, learning, etc.), which is a threat to internal validity, no pre-test was conducted in these three sessions. Instead, the data from the first session was used as the pre-test data for comparison.

To ensure the stretches were precisely administered and required constant supervision by the researcher, the stretching was performed one-on-one rather thanin a group setting. To randomize the order and sequence of the three stretching protocols for each subj ect, the participants were divided into six separate groups of two people, and the stretching protocol was applied to each subject in each session according to Table 1.

Assessment of Triceps Surae Muscle Length

The length of the triceps surae muscle was assessed by measuring the active ankle dorsiflexion range of motion using a universal goniometer (Figure 1). This measurement was performed by an expert evaluator. In this procedure, the volunteer was placed in a supine position with the knees fully extended, and the subtalar joint was placed in a neutral position. The goniometer axis was positioned below the lateral malleolus, the stationary arm was aligned with the fibula, and the moving arm was aligned with the fifth metatarsal bone. The volunteer was then asked to perform active ankle dorsiflexion. The measurement of the moving arm's displacement was recorded as the active dorsiflexion range of motion.

Assessment of Strength and Power

The measurement of strength and power was performed by a specialized operator using an isokinetic dynamometer (Biodex System 3, manufactured in the USA) (Figure 2). A blinding procedure was implemented during this measurement; the machine operator was unaware of the study hypotheses and the specific stretching protocols applied. The mechanical setup of the device, including the seat height, the distance from the seat to the pedal, and the backrest angle, was adjusted for each subject to ensure the head and neck were in a neutral position, the spine was in full contact with the backrest, the torso was at an angle of approximately 70 to 80 degrees relative to the horizontal surface, the subject's thigh was at an angle of 20 to 30 degrees relative to the horizontal, and the lower leg was positioned horizontally.

An angular velocity of 60 degree / second was selected. Each subject was then instructed to perform three consecutive plantarflexion-dorsiflexion movements with maximum effort. Following each test, the strength was reported as maximum applied torque and the power was reported as average power.

Figure 2: Plantar flexion strength test

Stretching Protocol

The training program consisted of three static stretching protocols; 30, 120, and 360 seconds, applied to the shortened triceps surae muscle of the dominant leg (Table 2). The stretching movement performed was identical across all three protocols (Figure 3). In this movement, the triceps surae muscle of the dominant leg was subjected to a stretch. The individual was positioned on an inclined surface such that the sole of the dominant foot was on the inclined surface, and the non-dominant foot was positioned above the inclined surface. In the dominant leg, the hip joint was in a neutral position, the knee joint was in full extension, and the ankle joint was in dorsiflexion. In the non-dominant leg, the hip and knee joints were in flexion. The head, neck, and torso were also maintained in a neutral position.

Figure 3: Triceps surae Stretch

Since stretching exercise should not be associated with pain, the intensity of the stretch was regulated based on the Parameter of Perceived Pressure. A score of 100 was considered the pain threshold. A score of 90 was defined as "maximum perceived pressure without pain," and a score of 60 was considered "moderate perceived pressure." Scores of 70 and 80 were assigned to the two intermediary sensations between these two levels of perceived pressure. Each subject was trained to rate the intensity of the stretch using one of the scores: 70, 80, or 90. Considering that a longer duration for a single set of stretching requires a lower intensity to be applied, the stretch intensities for the 30, 120, and 360 second protocols were set at scores of 90, 80, and 70, respectively. For each subject, the slope of the foot-placement surface was adjusted by changing the number of supports beneath the base until the desired perceived stretch intensity was achieved.

Statistical Analysis

All statistical analyses were performed using SPSS statistical software, Version 18, with the level of significance set at $P < 0.05$. Data description was performed using means and standard deviations, and the normality of the data distribution was assessed using the Shapiro-Wilk Test. In this research, a pre-test was conducted in the first session, and three types of training interventions were applied in the subsequent three sessions, with the tests repeated immediately after each intervention as post-tests. Thus, each subject served as their own control, creating an opportunity to compare the post-test score of each intervention with the pre-test score. Therefore, the analyses were conducted using the Dependent T-Test.

Results

The results concerning the sociodemographic characteristics of the volunteers are presented in Table 3.
Table 4 presents the data for the isokinetic concentric peak strength of the shortened triceps surae muscle at pre-test and immediately following the different stretching protocols. Figure 1 displays this data on a bar chart. Table 5 shows the information regarding the comparison of this data between the various stretching protocols and the pre-test.
As observed, immediately following the 30-second stretching protocol, muscle strength did not significantly increase compared to the pre-test ($P = 0.127$). However, immediately following the 120-second ($P = 0.028$) and 360-second ($P = 0.034$) stretching protocols, muscle strength significantly increased compared to the pre-test. The Effect Size (ES) for the 30 s, 120 s, and 360 s protocols compared to the pre-test was 0.13, 0.25, and 0.24, respectively. Comparing the strength data after the stretch protocols, the change in strength was not significant between the paired protocols: 30 s and 120 s ($P = 0.143$), 30 s and 360 s ($P = 0.234$), and 120 s and 360 s ($P = 0.925$). The Effect Sizes for these protocol pairs were 0.08, 0.07, and -0.01, respectively.

Table 2: Identical Static Stretching Programs with Different Time Protocols

Protocol	Duration of Each Stretch Set	Number of Sets	Duration of Each Rest	Total Stretching Time	Stretch Intensity (Perceived Pressure Score)
30 seconds	30 seconds	24	10 seconds	12 minutes	90
120 seconds	120 seconds	6	40 seconds	12 minutes	80
360 seconds	360 seconds	2	120 seconds	12 minutes	70

Table 3: Sociodemographic Characteristics of the Subjects

Variable	Mean ± Standard Deviation	Significance Level (P)
Age (years)	20.83 ± 1.20	0.078
Height (cm)	177.75 ± 4.73	0.673
Weight (kg)	74.42 ± 12.89	0.348
Body Mass Index (kg/m)	23.48 ± 3.46	0.655
Active Dorsiflexion Range of Motion (degrees)	12.25 ± 3.31	0.734

Table 4: Sociodemographic Characteristics of the Subjects

Significance Level (P)	Strength (Newton-meter)	Test Session
0.132	33.10 ± 17.85	Pre-test
0.688	38.12 ± 53.41	Post-stretch (30 s)
0.885	41.12 ± 48.94	Post-stretch (120 s)
0.490	41.16 ± 18.10	Post-stretch (360 s)

Table 6 presents the data for the average power of the shortened triceps surae muscle at pre-test and immediately following the various stretching protocols. Figure 2 displays this data on a bar chart. Table 7 shows the information regarding the comparison of this data between the various stretching protocols and the pre-test.

As observed, immediately following the application of all three stretching protocols—30 s (P = 0.038), 120 s (P = 0.034), and 360 s (P = 0.030)—muscle power significantly increased compared to the pre-test. The Effect Size (ES) for the 30s, 120s, and 360s protocols was 0.27, 0.39, and 0.31, respectively. Comparing the power data after the stretch protocols, the change in power was not significant between the paired protocols: 30 s and 120 s (P = 0.303), 30 s and 360 s (P = 0.427), and 120 s and 360 s (P = 0.934). The Effect Sizes for these protocol pairs were 0.10, 0.03, and -0.06, respectively.

Table 5: Comparison of Peak Strength of Shortened Triceps Surae Muscle Between Various Stretching Protocols and Pre-test using Dependent t-Test

Effect Size (ES)	Significance Level (P)	t-value	Compared Pairs
0.13	0.127	1.67	Pre-test - 30 s Stretch
0.25	0.028	2.52	Pre-test - 120 s Stretch
0.24	0.034	2.42	Pre-test - 360 s Stretch

0.08	0.143	1.59	30 s Stretch - 120 s Stretch
0.07	0.234	1.27	30 s Stretch - 360 s Stretch
-0.01	0.925	0.096	120 s Stretch - 360 s Stretch

Table 6: Results of the Average Power Test for Shortened Triceps Surae Muscle

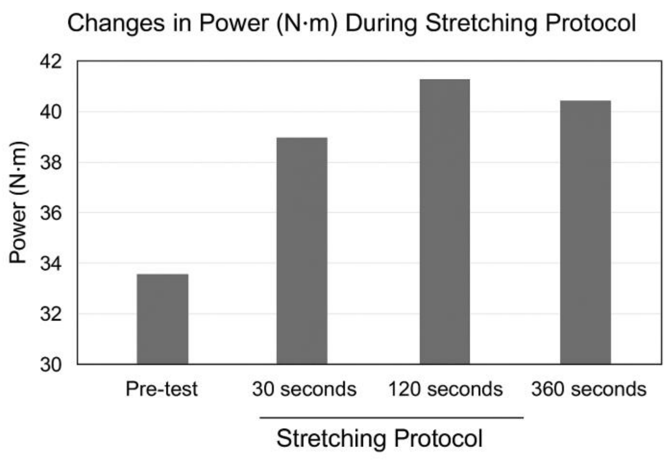

Figure 4: Bar chart of peak triceps surae muscle power in the pre-test and after different stretching protocols

Discussion

In the present study, the immediate effect of 30, 120, and 360 seconds of static stretching on the isokinetic concentric peak strength and average power of the shortened triceps surae muscle was tested. The findings showed that, compared to the pre-test, all three types of stretching caused an increase in the strength and power of the shortened muscle immediately after the stretch. The increase in strength was not significant for the 30-second stretch but significant for the 120- and 360-second stretches. The increase in power was significant for the 30-, 120-, and 360-second stretches. Overall, compared to before stretching, none of the 30-, 120-, and 360-second static stretching protocols led to a reduction in the strength and power of the shortened muscle immediately after the stretch.

The immediate effect of stretching on the strength and power of a shortened muscle can be attributed to both neural and biomechanical factors. Neutrally, the inhibition of the muscle spindle or the alpha motor neuron due to stretching usually causes a decline in muscle strength and power after stretching. In a

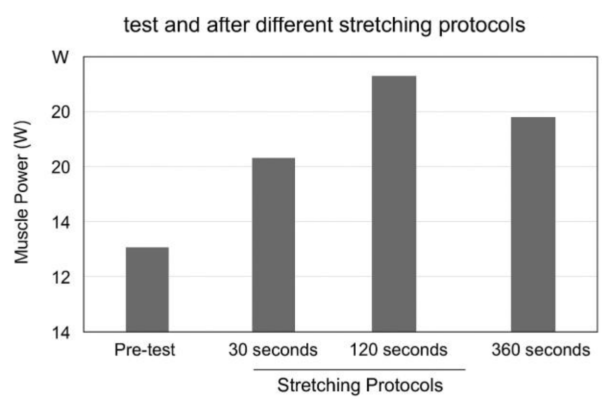

Figure 5: Bar chart of peak triceps surae muscle power in the pre-test and after different stretching protocols

shortened muscle compared to a muscle of normal length, active resting tone is increased and the excitation threshold is decreased. Therefore, the time required for the inhibition of the muscle spindle or the alpha motor neuron due to stretching is likely longer. Consequently, the required stretching duration for muscle inhibition is prolonged. This duration is approximately 60 seconds in a muscle of normal length. In the current study, even after 360 seconds of stretching, the strength and power of the shortened muscle did not decrease. This suggests that in a shortened muscle, the stretching duration required for muscle inhibition is likely greater than 360 seconds.

Biomechanically, a decrease in passive stiffness or a change in the length-tension relationship due to stretching typically causes a decline in muscle strength and power after stretching. A shortened muscle has greater passive stiffness compared to a muscle of normal length, and likely requires longer stretching times for its stiffness to decrease. In terms of the length-tension relationship, muscular shortness leads to a reduced resting length of the muscle fiber and a suboptimal overlap between actin and myosin filaments, resulting in a non-optimal length-tension relationship. When a shortened muscle is subjected to prolonged stretching, the phenomenon of creep increases the resting length of the muscle fibers, bringing them closer to their natural resting length. Consequently, the length-tension relationship approaches its optimal state, and strength and power increase.

The results of the present study showed that the 30-second stretch did not cause a decline in strength and power immediately after the stretch. Several studies have reported that strength and power do not decline immediately after static stretching of less than 60 seconds, which is consistent with our findings. They explained that short-duration stretching (60 \seconds) does not induce autogenic inhibition or inhibition of the corticospinal neural pathway. They also mentioned that short-duration stretching does not reduce the stiffness of the muscle-tendon unit. Several other studies reported that short-duration stretching causes a reduction in strength and power immediately after the stretch, via inhibitory feedback from joint receptors or by causing autogenic inhibition, which is inconsistent with our study. These inconsistent studies were conducted on muscles of normal length. The shortness of the muscle selected in the present study may be a reason for this inconsistency. It is likely that muscular shortness, by causing the aforementioned neural changes, prevents the decline in strength and power after stretching.

The results of the present study showed that the 120 and 360 second stretches did not cause a decline in strength and power immediately after the stretch. Several studies have reported that strength and power decline immediately after static stretching of more than 60 seconds, which is inconsistent with our study. Some of these studies were conducted at durations of 120, 135, 180, and 300 seconds. They justified this finding by stating that long-duration static stretching (> 60 seconds) causes inhibition of the muscle spindle or inhibition of the corticospinal pathways. They also stated that stretching longer than 120 seconds or longer than 180 seconds causes a reduction in passive stiffness and a decline in force production. These studies were performed on muscles of normal length. The muscular shortness in the present study may be a reason for this inconsistency. It is likely that muscular shortness, by causing the aforementioned neural and biomechanical changes, prevents the decline in strength and power after stretching.

A limitation of this research was the use of a goniometer to determine the active dorsiflexion range of motion for assessing muscular shortness. The goniometer is a mechanical tool. It is suggested that more precise methods or instruments, such as digital inclinometers, be used for a more accurate assessment of muscular shortness in future research. This study evaluated the immediate effect of stretching on the strength and power of the shortened muscle. It is suggested that the long-term effect of these three stretching protocols on the strength and power of the shortened muscle be investigated in future research.

Conclusion

Since none of the three 30, 120, and 360 second stretching protocols immediately caused a reduction in the strength and power of the shortened triceps surae muscle, their performance during the warm-up phase before exercise or athletic performance is permissible. Furthermore, based on the Effect Size index in Tables 5 and 7, these three stretching protocols caused a significant immediate increase in strength and power compared to before stretching. Therefore, it is recommended that these protocols be used to improve the strength and power of a shortened muscle.

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Ethical consideration
Ethical considerations in terms of honesty and integrity in texts and sources have been observed.

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Conflict of interest
None.

Authors' contributions
All authors contributed equally to the preparation of this article.

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