
Effects of Static Stretching on Squat Performance in Division I Female Athletes

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ABSTRACT

International Journal of Exercise Science 9(3): 359-367, 2016. Static stretching was once recognized as a method of preparation for physical activity that would inhibit performance and increase risk of injury. However, a growing body of research suggests that static stretching may not have an inhibitory effect. Regardless, the data have not examined gender differences or the fatigue index (FI) and flexibility effects of static stretching on the back squat over multiple sets. Therefore, the purpose of this study was to examine the relationship between a static-stretch condition (SC) and control condition (CC) on flexibility and the FI of Division I female athletes during 4 sets of the back squat. Eighteen subjects (mean \pm SD; age 20 ± 1 yrs; height 164.5 ± 14.6 cm; mass 74.1 ± 26.8 kg; waist circumference 73.2 ± 5.4 cm) participated in 3 testing days over the course of 3 weeks. Each subject's 1RM back squat was assessed during the first day of testing and verified during the second. On the third testing day, subjects assigned to the SC held 3 lower-body stretches twice for 30 second intervals and those assigned to the CC rested during the corresponding 7 minutes and 50 second time period. The subjects also performed a fatiguing squat protocol consisting of 4 sets of maximum repetitions on the third day of testing. A significant ($p=0.04$) interaction was noted for flexibility. No significant interaction ($p=0.41$) was observed between the FI of the CC ($41.8 \pm 24.1\%$) or the SC ($27.6 \pm 45.2\%$). These results indicate that static stretching does not have a significant effect on multiple sets of the back squat. Therefore, coaches may allow their athletes to engage in static stretching prior to resistance exercise ad libitum.

KEY WORDS: Resistance exercise, fatigue index, strength, sit-and-reach

INTRODUCTION

It is crucial to consider how physiological changes that occur as a result of static stretching prior to resistance exercise relate to lifting performance. Static stretching, defined as holding a stretched position at the end of the limb's range of motion for a period of 15 to 60 seconds, may have an impact on performance when the muscle spindle changes in length as a result (2). The

change in muscle length could improve performance by decreasing muscular stiffness or hinder performance by altering motor unit activation, inducing muscle damage and increasing the rate of fatigue (3). In addition to changes in skeletal muscle properties, researchers suggest that even short-duration static stretching decreases blood glucose (21), which in turn may increase the rate the fatigue during resistance exercise. Thus, more data are

required to have a better understanding of how static stretching affects performance.

While some research has indicated no change in lifting performance due to static stretching, multiple studies have observed a decreased number of repetitions due to fatigue after static stretching (2, 16, 19). These studies demonstrate that static stretching prior to an acute bout of resistance exercise may have a negative effect on lifting performance. In each of these studies examining the effects of static stretching on acute resistance exercise, the responses were not gender specific or focused on male subjects only. To our knowledge no study has investigated the effects of static stretching in resistance-trained female subjects.

Many of the studies that have measured the effects of static stretching on a submaximal workload have done so using single sets (6, 8, 16, 19). Because resistance exercise often utilizes 2-6 sets of submaximal workload in order for maximum muscle growth and the promotion of strength, it is important to understand the effects of static stretching on multiple sets as well (18). The total volume performed during the acute bout of resistance exercise should also be evaluated. Total volume includes the number of repetitions performed and the weight moved and is a vital variable for long-term adaptations (9, 10, 13, 17). The back squat is a fundamental and essential exercise that is used to augment performance in a myriad of sports and activities (15). However, while previous reports have utilized lower-body exercises that activate the quadriceps, hamstrings and hip extensors, such as the leg press, none have used free-weight exercises such as the back squat.

It is unclear if resistance exercise performance in highly competitive female athletes is inhibited by preparatory static stretching. Therefore, the purpose of the present study was to evaluate the effects of static stretching on flexibility, the total volume, the total number of repetitions, and the fatigue index (FI) utilizing 4 sets on the back squat in female Division 1 athletes. We hypothesized that static stretching may decrease total volume, total number of repetitions and the FI in female athletes when performing multiple sets on the back squat.

METHODS

Participants

Eighteen (n=9 SC, n=9 CC) female athletes participated in the study. The inclusion criteria required subjects to be NCAA Division I student-athletes with self-reported normal menstruation and no limitations due to injury or illness that would prevent successful completion of experimental protocols. As Division I athletes, the subjects performed resistance training at least 3 days a week and maintained practice of their prospective sports for at least 15 hours per week prior to and during participation in the study. All subjects were Kent State University varsity athletes and were recruited from volleyball (n=1), soccer (n=1), field hockey (n=4), softball (n=2), and track and field teams (n=10). Those who represented the track and field team specialized in a wide range of competitive events including throws, horizontal jump, sprints, relay, and distance. Subjects signed an informed consent document approved by the Institutional Review Board at Kent State University.

Protocol

Since our subjects were classified primarily as in-season, we chose a simple two-group experimental design. This experimental design was used to avoid any injuries or fatigue that may be associated with a within-subjects design which in turn may have adversely affected their collegiate sport. Subjects participated in preliminary testing and were randomly assigned to either a static-stretching condition (SC) or a control condition (CC) in a counterbalanced fashion. Subjects participated in 3 testing sessions over the course of 3 weeks (Figure 1). Following an orientation consisting of consent form review and explanation of procedures on the first day of testing, the subject's anthropometrics and maximal strength were assessed using a 1-repetition maximum (1RM) back squat. The subject's 1RM back squat was verified at the second session. At the third session, the subjects were randomly assigned to complete either the SC or CC. Those assigned to the SC completed 7 minutes and 50 seconds of static stretching in 30 second increments and 10 second rest periods in between each set. Those assigned to the CC sat in a chair and read the student newspaper during the corresponding 7 minutes and 50 seconds. Flexibility testing occurred immediately before and after the SC and CC using the modified sit-and-reach box (Acuflex I; Novel Products, Inc., Rockton, IL) to determine the effect of the respective condition. After completing the randomly assigned condition (SC or CC) and the flexibility testing, subjects completed a fatiguing squat protocol consisting of 4 sets of maximum repetitions of the back squat at 80% of their 1RM back squat. This fatiguing squat protocol was only performed during the final visit. With data on weight lifted and

number of repetitions completed, the FI was calculated and analyzed across groups. Subjects completed each testing session at the same time of day (± 1 hour).

Each subject participated in anthropometric testing and a 1RM back squat assessment on the first day of testing and a 1RM back squat verification on the second day of testing before being randomly assigned at the third session to either the SC or CC. Testing sessions were separated by at least 7 days of rest, but no more than 10 days. Subjects were asked to arrive at the laboratory hydrated and to have a small snack 1 hour before testing. They were also asked to refrain from consuming caffeinated beverages 24 hours prior to testing, and participating in strenuous exercise 24 hours prior to testing. Subjects were allowed to drink water ad libitum during testing.

Age, height, weight, and waist circumference were recorded immediately prior to 1RM back squat testing during the second session. Height was measured using a height-measuring rod (Charder, HM210D, Taichung City, Taiwan) and weight was assessed with a digital weight scale (My Weigh, Élite™ Scale, Vancouver, BC, Canada) after the subject removed her shoes. Waist circumference was measured with a measuring tape on the skin at the narrowest point between the xiphoid process and the umbilicus (11).

Assessment of the 1RM back squat followed guidelines set forth by the National Strength and Conditioning Association (1). In short, testing began with two minutes of a warm-up consisting of 8 repetitions of back squats with free weights at 50% of the subject's predicted maximum. After this was

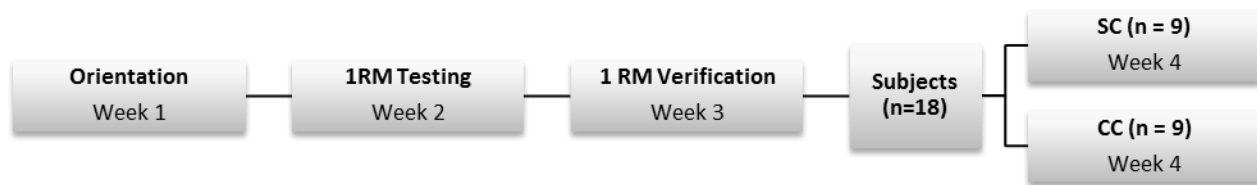


Figure 1. Experimental design. CC=Control condition; SC=Static-stretching condition.

completed, each subject was progressed to a weight that could be moved 1 time through a full range of motion. All 1RM back squats were completed in no more than five attempts separated by 2-minute rest periods. In order to ensure athlete safety and consistent results, 1RM back squat data were only recorded if the subject was able to complete the lift using proper lifting technique. The back squat was considered a successful lift when the subject achieved a parallel femur after a controlled descent with an erect spine, feet shoulder width apart, and toes pointed slightly outwards (1). Proper breathing was encouraged throughout the lift. Data from the subject's greatest successfully lifted load was recorded as the 1RM back squat. The 1RM back squat verification that took place during the third session followed the same protocol. The greatest 1RM back squat from the 2 days of testing was used to determine the load for the fatiguing squat protocol.

Flexibility testing using the sit-and-reach box took place before and after completion of the experimental protocols (SC or CC) in order to assess change in flexibility. To summarize, the subjects sat on the ground with feet flat against the sit-and-reach box and reached to their full range of motion towards the toes while exhaling. The

investigator maintained pressure with one hand on the subject's knees throughout testing in order to ensure full leg extension. Two flexibility measurements were taken. The first was taken before the condition of SC or CC and the second was taken afterwards. Both measurements were calculated by taking the greatest of 3 attempts on the sit-and-reach box. Change in flexibility was determined using the greatest of the three measurements taken before and after the SC or CC conditions.

The SC targeted the gluteal muscles, quadriceps, and hamstrings and is based on the protocol used by Barroso et al. (2). In the first stretch which targeted the gluteal muscles, the subject lay in a supine position with one knee fully extended. The subject then used her hands to flex the opposite knee towards her chest. In the second stretch which targeted the quadriceps, the subject lay on her side with the leg closest to the floor extended and with the arm of same side supporting the head. The subject then used her free hand to pull the opposite heel towards the buttocks. The subject's knees remained together and the hips formed a straight line. The third stretch targeted the hamstring which involved the subject lying supine with one leg fully extended on the ground while the other fully extended leg was pulled towards the chest at the knee.

For each stretch, the point of muscular discomfort of the subject dictated the maximum extent of the stretch. The subject performed each stretch on first the right and then the left side for a period of 30 seconds each, followed by a 10-second rest interval. The entire protocol was then repeated. Total time of stretching was 7 minutes and 50 seconds. The subjects in the CC rested in a chair for 7 minutes and 50 seconds during the corresponding time reading or doing puzzles in a local newspaper in order to limit mental imagery.

Upon arrival at the laboratory, the subjects participated in a 10-minute supine rest and then a 5-minute warm-up on an Airdyne AD4 Upright Exercise Bike (Schwinn Bicycle Company, Chicago, Il.). The subjects then performed sit-and-reach testing before and after each condition according to their assigned group. After the second sit-and-reach test, subjects participated in a warm-up consisting of a 3-minute bout of exercise on the stationary bike and 4-6 repetitions of the back squat at 50% of their 1RM back squat. After completion of the second warm-up, the subjects rested for 3 minutes before testing began with the first of four sets of the 80% 1RM back squats. Each subject was instructed to complete as many repetitions as possible at 80% 1RM back squat before muscle failure or demonstration of poor form as noted by the research technician. Three minutes of rest were given between each set. The fatiguing squat protocol was only performed once by the subjects on the final day of participation. The FI, which is the decline in an athlete's force or power output across time, was obtained by first determining the total force exerted during set 1-4 (19). Total force exerted during each set was established by

taking the product of load lifted and number of repetitions completed. After computing total force exerted for each set, the FI was evaluated using the following equation (20):

$$FI = [(TF (\text{Set } 1) - TF (\text{Set } 4)) / (TF (\text{Set } 1))] * 100\%$$

where: FI= fatigue index and TF = total force (load lifted × number of repetitions performed). In addition, repetitions were counted for each of the 4 sets in order to determine total volume.

Statistical Analysis

A one-way analysis of variance (ANOVA) was used to compare the two groups at baseline. An independent samples t-test was used to assess differences between groups at the baseline sit-and-reach. A two-way ANOVA was used to assess condition (SC, CC) across time (before, after) and interactions on the sit-and-reach. If the interaction was deemed significant, paired t-tests were used for post-hoc analysis. Separate one-way ANOVAs were used to compare the load volume, number of repetitions, total volume and the FI between groups. Analysis of the Effect Size was performed with the partial Eta squared (η^2_p). All analyses were completed using IBM SPSS (Armonk, NY) version 21. Statistical significance was set at an alpha of $p \leq 0.05$. All data reported are mean \pm standard deviation (SD). Based on pilot data we calculated an effect size of 1.3, which estimated 9 subjects per group to achieve a power of 80%.

RESULTS

The two groups were similar for demographics (Table 1). There was no significant ($p=0.3$) difference between the

two groups before the intervention for the sit-and-reach. There was a significant ($F_{1,16}=5.01$, $p=0.04$; $\eta_p^2=0.24$) group-by-time interaction for the sit-and-reach (Figure 2). The SC had a 4.68% increase in flexibility while the CC had a 0.88% increase. There were no significant differences for the total volume lifted ($F_{1,16}=1.3$, $p=0.27$), the total number of repetitions ($F_{1,16}=2.9$, $p=0.12$), or the FI ($F_{1,16}=0.70$, $p=0.42$) (Table 2).

Table 1. Subject characteristics (N=18)

	SC (n=9)	CC (n=9)
Age (years)	20 ± 1	20 ± 1
Height (cm)	169.3 ± 5.9	160.1 ± 19.9
Weight (kg)	64.4 ± 6.5	68.9 ± 16.6
Waist Circumference (cm)	73.0 ± 3.8	73.4 ± 7.0
1RM Back Squat (kg)	92 ± 14	105 ± 20

Data are mean ± SD

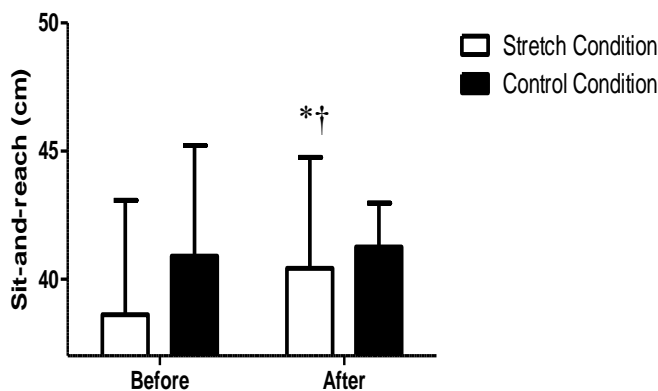


Figure 2. Differences in flexibility using the sit-and-reach test before and after the stretch condition and control condition in Division I female athletes (N=18). * $p<0.05$, significantly different than before the stretch condition; † $p<0.05$, significantly different than the control condition.

Table 2. Effects of condition on performance assessments (N=18).

Assessments	Stretch Condition	Control Condition	Significance
Total Volume Lifted, kg	2083 ± 700	2461 ± 705	P = 0.145
Repetitions	25 ± 11	33 ± 7	P = 0.321
Fatigue Index, %	27.6 ± 45.2	41.8 ± 24.1	P = 0.41

Data are mean ± SD

DISCUSSION

The purpose of the present study was to determine the fatigue index and flexibility effect of the SC on the back squat FI in Division 1 female athletes. The most significant findings were that the SC caused no significant change in the volume lifted, the number of repetitions, or the FI in Division I female athletes despite increases in flexibility.

Our results are supported by findings reported by Beedle, Rytter, Healy, and Ward (3). Their study concluded that static stretching of the quadriceps and hamstring, when held three times at full range of motion for 15 seconds, has no effect on the free-weight, leg press 1RM in college-aged men and women (n=51). However, this study did not look at the effect of static stretching over multiple sets of the leg press and used shorter stretch intervals. The importance of stretch interval length was confirmed by the later work of Kay and Blazeovich (12) which was used in the present study. Their study suggested that any stretch sustained for less than 30 seconds may have no effect on maximal strength performance and noted that the detrimental

effects of static stretching may apply exclusively to the stretches held for durations greater than 60 seconds (12). Therefore, it is clear that the optimal window for peak performance may require a static stretch lasting longer than 30 seconds, but no more than 60 seconds.

Although there was no statistically significant difference in volume, repetitions, or the FI between the SC and CC, physiological significance is possible. Beedle et al. (3) suggest that static stretching may enhance lifting performance due to how the amount of muscle stiffness varies in direct proportion to the amount of energy required for contraction. Alternatively, that same study also recognized that overstretching, understood as the possible danger of static stretching before lifting, may damage the muscle spindle and reduce motor unit activation as a result of changes in neuromuscular feedback responses (3). In addition, work by Fowles et al. suggests that motor unit activation may be attenuated up to 1 hour after stretching, which may increase the rate of fatigue (5). While skeletal muscle properties appear to be altered with static stretching, so does glucose uptake and utilization. It has been suggested that static stretching may influence glucose uptake via increased activation of adenosine monophosphate kinase mediated glucose transporter (GLUT-4) pathway (4), however this is not conclusive. Therefore, it is reasonable to conclude that the inhibitory effects of overstretching may have counteracted the benefits of increased flexibility. In addition, if there is increased glucose uptake and utilization due to static stretching prior to the acute resistance exercise then the onset of fatigue would occur earlier.

Interestingly, while there was no statistical significance difference in the number of repetitions between groups in the present study, those in the SC had fewer repetitions than those that underwent the CC. Despite our lack of statistical difference which coincides with the current evidence indicating no change in lifting performance due to static stretching (8, 12, 18), a decreased number of repetitions due to fatigue after static stretching during multiple sets of lower-body resistance exercises have been reported (2, 16, 19). A study conducted by Barroso et al. (2) using trained men indicated that static stretching, when performed in 30 second intervals, significantly reduced the number of repetitions on the leg press (-20.8%) performed on a resistance machine set at 80% of the 1RM and the total volume (-20.4%) over 3 sets. Nelson et al. (16) also suggests that static stretching inhibits muscle strength endurance. In their study, the male (n=11) and female (n=11) subjects showed declines in endurance during knee-flexion exercises when performed at 40%, 50%, and 60% of their body weight after static stretching performed in 30 second intervals by 9%, 28%, and 24%, respectively. Sá et al. (2015) reported that following a standard warmup, consisting of 30% of the 12RM, and ballistic stretching using 9 untrained male subjects were able to produce more repetitions compared to static stretching over 4 different exercises. Ballistic stretching differs from static stretching in that it involves using the momentum of the body in a bounce-like motion to extend a particular body part to its full range of motion (18). Exercise included the leg press, leg extension, leg flexion and plantar flexion. In order to compare the findings of Sá et al. to the present study more specifically,

examination of the leg press only demonstrated more repetitions for the standard warmup when compared to the ballistic stretching or static stretching. The results of these studies, when compared with our findings, point towards the possibility that static stretching prior to resistance exercise performed on resistance machines inhibits performance to a greater extent than it would prior to free-weight lifting. This could be because of the fact that free-weight lifting also relies on the stabilization muscles that were not targeted during stretching. However, work using multiple sets and free-weights, in this case the bench press, has demonstrated no difference between sets when completed after a session of intense static stretching, ballistic stretching or no stretching (7).

This study is not without limitations. For one, our participants were well-trained female athletes from a variety of sports. While different sports have different levels of required flexibility, the CC demonstrated no statistical change. Another limitation may be that we did not control for menstrual cycle fluctuations. However, it has been suggested that estrogen may not influence flexibility (14), and may not affect muscle performance (22) but this is not conclusive (23).

The results of this study suggest that static stretching prior to lower-body resistance exercise will have no effect on performance in female Division I athletes. This is in contrast to other reports that have suggested a negative effect of static stretching on performance. In the present study, despite an increase in muscle flexibility, no statistical significant differences in volume, repetitions, or fatigue were observed

between the SC and CC. This may have been influenced by the use of highly trained athletes in the present study, which in turn may limit the ability to generalize the data to different populations. It is important for future studies to continue to investigate the effects of static stretching on lifting performance using multiple set regimes but also to consider addressing the effects of dynamic stretching on back squat performance in highly trained individuals.

Athletes use static stretching as means to warm-up prior to engaging in resistance exercise. It is clear that two bouts of 30 second stretches may increase flexibility without altering the amount of weight, or volume, lifted. Because increased flexibility during resistance exercise may allow for an increased range of motion, through which an athlete is capable of moving a weight, it may benefit athletes to recognize that they have the freedom to decide whether or not to perform static stretching without undue concern of it having a negative impact on performance. Thus, coaches may encourage static stretching prior to resistance exercise entirely at their discretion as the results seem to be negligible.

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