Original Article

Acute static stretching with different volumes improves hamstring flexibility but not reactive strength index and leg stiffness in well-trained judo athletes

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ABSTRACT

Purpose: The aim of this study was to compare the effects of different volumes of static stretching exercises (SS) on the reactive strength index (RSI), leg stiffness (K_{leg}), and hamstring flexibility in well-trained judo athletes. Method: In total, 17 international level judo athletes (11 women and 6 men; age, 20.47 ± 1.59 years; experience in judo, 11.35 ± 1.84 years) were recruited for this study. The athletes completed three different SS sessions named low (LV–SS: 3.5 min), moderate (MV–SS: 7 min), and high volumes (HV–SS: 10.5 min), 72 h apart, in a randomized crossover study. Before and after each SS exercise session, hamstring flexibility, RSI and K_{leg} were evaluated by a sit-and-reach test and a Myotest accelerometric system, respectively. Results: Different volumes of SS exercises improved hamstring flexibility ($p < .05$); however, no one exercise was superior in improving hamstring flexibility than the other ($p > .05$). Different volumes of SS exercises neither improved nor reduced RSI and K_{leg} ($p > .05$). Conclusion: Judo athletes can use LV–SS, MV–SS, or HV-SS for hamstring flexibility enhancement, and SS exercises can be used as a part of a warm-up session prior to judo training or competition.
Keywords: Hamstring flexibility; Combat sport; Stiffness; Stretching exercises; Stretch-shortening cycle.

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INTRODUCTION

Warming-up before a physical activity is a universally accepted practice for athletes to physically and mentally prepare for optimum performance. Furthermore, warm-up exercises are believed to improve range of motion (ROM) and enhance performance (Ayala et al., 2015; Young and Behm, 2002).

A warm-up generally consists of two main components (Konrad et al., 2017; Behm et al., 2015; Behm and Chaouachi, 2011): a) submaximal exercise, including running and cycling; and b) stretching exercises such as static (SS), ballistic (BS), dynamic (DS), and proprioceptive neuromuscular facilitation (PNF). SS is generally preferred by athletes prior to athletic events because it is considered an effective method to increase joint range of motion (ROM) and is thought to improve performance and reduce the incidence of activity-related injuries (Chaabene et al., 2019; Behm et al., 2016; Behm and Chaouachi, 2011). However, some researchers have argued that SS might lead to a decrease in muscular performance when used prior to athletic events (Kruse et al., 2015; Taniguchi et al., 2015; Haddad et al., 2014; Tsolakis et al., 2012). Although the exact mechanism of the negative effect of SS on muscular performance is unknown, mechanical alterations, such as those in muscle tendon unit stiffness, and neural alterations, such as changes in reflex sensitivity and decreased motor unit activation, might be responsible for a reduction in muscle performance after SS (Haddad et al., 2014; Kay and Blazevich, 2012; Tsolakis and Bogdanis, 2012).

The aforementioned negative effects of SS can change depending on factors such as stretching intensity, volume, duration, stretch position, rest interval, and stretching method (Katura et al., 2017; Avloniti et al., 2016; Behm and Chaouachi, 2011; Molacek et al., 2010). Behm and Chaouachi (2011) and Robbins and Scheuermann (2008) concluded that when the total duration of SS performed on a single muscle group exceeds 90 s, muscular performance impairment is highly possible; these findings are corroborated by the studies of Behm and Chaouachi (2011) and Robbins and Scheuermann (2008). Furthermore, Andrejic et al. (2012) reported that both 5.5 min and 10.5 min of SS lead to impairment of muscular power as evaluated by the standing long jump, vertical jump, and 4*15 m standing start running tests in young male basketball players. According to Pekünlü et al. (2016), both 6 min and 12 min SS led to a significant reduction in countermovement jump (CMJ) performance to a similar extent in well-trained female combat athletes. Moreover, Zakas et al. (2006) reported that the dominant leg peak torque of the extensor muscles of the knee decreased after 5 min and 8 min SS in young semi-professional soccer players.

RSI and K_{leg} are the two most important tools for monitoring muscle performance, including stretch shortening cycle (SSC) movements such as jumping, sprinting, and throwing (McMahon et al., 2012; Lloyd et al., 2009; Flanagan et al., 2008). RSI is described as an individual's ability to change quickly from an eccentric to concentric contraction, and can be considered as a measure of "explosiveness" (Flanagan et al., 2008), while K_{leg} describes the relationship between a given force and the magnitude of deformation of an object or body (McMahon et al., 2012; Butler et al.,2003).

Although RSI and K_{leg} are important in monitoring muscle performance, there is no clear conclusion on the effects of different volumes of SS on RSI and K_{leg}, and previous studies have reported contradictory results (Konrad et al., 2017; Miyamoto et al., 2017; Stafilidis & Tilp, 2015; Taniguchi et al., 2015; Pasqua et al., 2014; Akagi and Takahashi, 2013; Mizuno et al., 2013; Kallerud and Gleeson, 2013; Werstein and Lund, 2012; Hobara et al., 2011; Hoge et al., 2010; Ryan et al., 2008; Reid and McNair, 2004). While some of the previous studies reported no change, or an increase in RSI and K_{leg} after SS (Henriquez-Olguin et al., 2015; Stafilidis and Tilp, 2015; Werstein & Lund, 2012; Hobara et al., 2011; Hoge et al., 2010; Tsolakis et al., 2010), others reported that RSI and K_{leg} were negatively affected by SS (Konrad et al., 2017; Miyamoto et al., 2017;

Taniguchi et al., 2015; Pasqua et al., 2014; Akagi and Takahashi, 2013; Mizuno et al., 2013; Kallerud and Gleeson, 2013; Ryan et al., 2008; Reid and McNair, 2004). These contradictory results might be due to sex and physical fitness level of the subjects, the SS program (intensity, volume), and the devices used for measuring RSI and K_{leg} (Miyamoto et al., 2017; Pasqua et al., 2014; Akagi and Takahashi, 2013; Werstein and Lund, 2012; Hobara et al., 2011; Reid and McNair, 2004). Indeed, the device used for measurement (accelerometric system, force plate, elastography, different mathematical models) is considered to be the most important factor to affect the results (Taniguchi et al., 2015; Werstein and Lund, 2012; Tsolakis et al., 2010; Lloyd et al., 2009; Reid and McNair, 2004).

To the best of our knowledge, this is the first study to use an accelerometric system to determine the RSI and K_{leg} of subjects jumping in an SSC movement. The purpose of this study was to investigate the effects of different volumes of SS on hamstring flexibility, RSI, K_{leg}, jump height (JH), and ground contact time (GCT) in well-trained judo athletes. We hypothesized that (1) HV-SS would result in a greater reduction in RSI, K_{leg}, JH, and GCT performance than LV-SS and MV-SS; and (2) HV-SS would result in a greater improvement of hamstring flexibility compared to LV-SS and MV-SS.

MATERIAL AND METHODS

Study design

DAY 1: LV– SS (3.5 min)	DAY 2: MV– SS (7 min)	DAY 3: HV– SS (10.5 min)
*Warm-up 5 min running at 7 km/h and 1% slope	*Warm-up 5 min running at 7 km/h and 1% slope	*Warm-up 5 min running at 7 km/h and 1% slope
3 min rest	*3 min rest*	*3 min rest*
	PRE-TESTS	
*S&R test: 2 trials with 3 min rest	*S&R test: 2 trials with 3 min rest	*S&R test: 2 trials with 3 min rest
3 min rest	*3 min rest*	*3 min rest*
*Jump-plyometric test: 2 trials with 3 min rest	*Jump-plyometric test: 2 trials with 3 min rest	*Jump-plyometric test: 2 trials with 3 min rest
2 min rest	*2 min rest*	*2 min rest*
Stretching exercises with low volume (3.5 min)	*Stretching exercises with moderate volume (7 min)*	*Stretching exercises with high volume (10.5 min)*
3 min rest	*3 min rest*	*3 min rest*
	POST TESTS	
*S&R test: 2 trials with 3 min rest	*S&R test: 2 trials with 3 min rest	*S&R test: 2 trials with 3 min rest
3 min rest	*3 min rest*	*3 min rest*
*Jump-plyometric test: 2 trials with 3 min rest	*Jump-plyometric test: 2 trials with 3 min rest	*Jump-plyometric test: 2 trials with 3 min rest

LV–SS: Static stretching with low volume, MV–SS: Static stretching with moderate volume, HV–SS: Static stretching with high volume, S&R: Sit and reach test.

Figure 1. Experimental design.

This study had a randomized crossover study design. Each athlete completed three different treatments and testing sessions with a 72 h interval. Each session commenced with a warm-up that consisted of 5 min of running at a speed of 7 km/h and a slope of 1% on a motor driven treadmill. After a 2 min rest, the athletes performed a sit and reach (S&R) test and a reactive jump test to obtain the RSI, K_{leg}, JH, and GCT as a pre-test. The S&R test and jump-plyometric test (also known as a reactivity test) were performed twice with a 3 min rest in between, and the best result was used for statistical analysis. After the pre-test session, the athletes were assigned to a stretching session, LV-SS, MV-SS, or HV-SS, in a randomized manner. The athletes took a 3 min rest between stretching sessions and post-test. In the post-test session, the athletes completed the S&R test and reactivity test as in the pre-test. The research design is presented in Figure 1.

Subjects

In total, 17 international level judo athletes (11 women and 6 men) participated in this study. The descriptive features of the athletes are presented in Table 1. The study was conducted in accordance with the principles of the Declaration of Helsinki, and the study protocol was approved by the Trakya University Ethics Committee [2018/295]. Athletes provided written consent prior to participation. The inclusion criteria were as follows: Age 18 years or above, a minimum of 5 years of experience in judo, international level athlete, under 100 kg body mass, out of the body mass reduction period, and no history of lower body injury in the past 6 months. Individuals using ergogenic supplements, such as creatine, amino acids, and protein powder, were excluded. The athletes were instructed not to consume too much coffee (limited to 1 cup) prior to the tests, and not to engage in high-intensity physical activity 24 hours prior to the tests.

Table 1. Descriptive features of the athletes.

Variable	M ± SD (n = 17)
Age (year)	20.47 ± 1.59
Height (cm)	166.58 ± 8.78
Body mass (kg)	67.41 ± 9.33
Experience in judo (years)	11.35 ± 1.84
Total training duration (hours/week)	16.47 ± 7.91

M: Mean, SD: Standard deviation.

Stretching exercises

Four different stretching exercises were performed during each SS session: The bilateral straddle stretch, unilateral sartorius stretch, unilateral standing quadriceps stretch, and unilateral gastrocnemius stretch exercises. All SS exercises were selected from the subjects' regular training program and from a study by Chatzopoulos et al. (2014). In the LV–SS session, unilateral exercises were performed 3×10 s (each extremity), and for bilateral exercises 3×10 s (total stretch time: 3.5 min). In the MV–SS session, unilateral exercises were performed 3×20 s (each extremity), and bilateral exercises were performed 3×20 s (total stretch time: 7 min). In the HV-SS session, unilateral exercises were performed 3×30 s (each extremity), and bilateral exercises were performed 3×30 sec (total stretch time: 10.5 min). Each stretch was held at the point of mild discomfort (POD), and the duration of stretching (10 s to 30 s) fell within the recommendations set forth by the American College of Sports Medicine guidelines to testing and prescriptions (Kruse et al., 2015).

Body mass and height measurement

The body mass and height of the athletes were measured using a digital scale (Seca, 769, Turkey). Body mass and height were measured while the subjects were barefoot and wearing short tights and short sleeve shirts.

Sit and reach (S&R) tests

Lower back and hamstring flexibility were assessed using an S&R testing box (Tartı Med, Turkey). The athletes placed their feet 30 cm apart while making contact with a standard box in the seated position. The athletes then leaned forward slowly to reach as far as possible, while keeping their hands adjacent to one another (Peacock et al., 2015).

Jump-plyometric test

The reactive strength index (RSI), K_{leg}, GCT, and JH were determined via the Myotest Pro system (Myotest SA, Switzerland), which has been previously deemed valid for assessing these parameters (Choukou et al., 2014). The Myotest Pro system offers several performance tests, such as half squat, jump-plyometric test, countermovement jump, and squat jump, to assess an athlete's performance. We used the jump-plyometric test to assess the K_{leg}, RSI, JH, and CT, as in the study by Laffaye et al. (2016). After measuring the body mass of the subjects, the device was attached to the belt and fixed vertically. The subjects were asked to hop in place five times, as high as possible while reducing GCT. The instructions given were: "When the acoustic signal sounds, hop in place five times, with minimal knee flexion and maximal JH. After the last jump, the subject returns to a vertical standing posture and wait for the final acoustic signal" (Laffaye et al.,2016). After the final signal, the jump-plyometric test was completed, and RSI, K_{leg}, GCT, and JH were automatically calculated by the device. This procedure was repeated twice, with a 3-min rest in between. The best scores obtained from the two treatments were taken forward for statistical analysis.

Data analysis

Data from the current study were analysed using SPSS® Windows Statistical Program Version 23.0 (IBM® Corp., 2016, Armonk, NY). The effects of interaction between factors on variables were examined by one-way variance analysis for repeated measurements (ANOVA; 3 × 2, Group × Time). Time (pre-test - post-test) was determined as the factor among the participants, and group (LV-SS, MV-SS, and HV-SS) was determined as the factor between the participants. Normality assumption of the related data was checked using the Shapiro-Wilk test. Sphericity was evaluated by Mauchly's test of sphericity. The Friedman test was used to compare the mean differences between the groups belonging to the independent variables that were not normally distributed, and the Wilcoxon signed rank test was used in pairwise comparisons. In order to test whether there was any progress between the pre-post-test values of the groups, the independent samples t-Test or Mann-Whitney U test was used. Descriptive statistics were reported either by mean ± standard deviation or median (25%–75% percentiles). The statistical significance level was set at $p \leq .05$ for all analyses. The effect sizes of the related analyses were also demonstrated.

RESULTS

There were statistical differences in the S&R test between the pre- and post-tests after LV–SS, MV–SS, and HV–SS ($p < .05$) (Table 2). However, according to paired comparison results, no one stretching exercises with different volume was superior in terms of improving hamstring flexibility ($p < .05$) (Table 3). Although there was a statistical difference in JH between pre- and post-test after MV–SS in favour of the post-test ($p < .05$), when the mean difference scores of the pre-test-post-test values (shown as Δ in Table 2) were compared to each other, no statistically significant difference was observed between any pairwise comparisons ($p > .05$) (Table 2 and 3). No statistically significant differences were found for RSI, GCT, or K_{leg} in any test results ($p > .05$) (Table 2 and 3).

Table 2. Comparison of absolute mean differences between pre and post-test.

Variable	LV-SS pre test-post test M ± SD (n = 17)	p	ES	MV-SS pre test-post test M ± SD (n = 17)	p	ES	HV-MM pre test-post test M ± SD (n = 17)	p	ES
S&R test (cm)	Pre 15.26 ± 6.57 Post 16.79 ± 6.11 Δ1 = 1.53 ± 2.62	.028*	2.16[d]	Pre 15.97 ± 5.87 Post 17.59 ± 5.82 Δ2 = 1.62 ± 1.41	< .01*	3.00[d]	Pre 16.91 ± 5.19 Post 18.35 ± 5.44 Δ3 = 1.44 ± 2.02	.010*	1.25[d]
RSI (mm/ms)	Pre 3.20 ± 0.44 Post 3.23 ± 0.55 Δ1 = 0.04 [-0.056 0.60]	.535	0.11[r]	Pre 3.23 ± 0.62 Post 3.29 ± 0.52 Δ2 = 0.04 [-0.51 0.57]	.570	0.10[r]	Pre 3.28 ± 0.43 Post 3.31 ± 0.64 Δ3 = 0.09 [-0.63 0.76]	.776	0.50[r]
JH (cm)	Pre 29.76 ± 6.67 Post 39.62 ± 37.69 Δ1 = 0.10 [-6.80 5.80]	.943	0.01[r]	Pre 29.90 ± 5.71 Post 31.55 ± 5.70 Δ2 = 1.20 [-2.60 5.10]	.017*	0.41[r]	Pre 30.97 ± 5.59 Post 32.30 ± 7.02 Δ3 = 0.10 [-3.70 10.10]	.209	0.22[r]
GCT (ms)	Pre 152.0 ± 20.93 Post 154.0 ± 23.36 Δ1 = -1.00 [-16.00 27.00]	.906	0.02[r]	Pre 149.9 ± 26.25 Post 155.3 ± 24.66 Δ2 = 5.00 [-32.00 58.00]	.264	0.20[r]	Pre 149.7 ± 24.26 Post 152.5 ± 25.34 Δ3 = 0.00 [-20.00 57.00]	.900	0.20[r]
Kleg (N/m)	Pre 49.55 ± 34.22 Post 39.82 ± 13.33 Δ1 = -1.60 [-155.60 10.10]	.554	0.10[r]	Pre 41.05 ±13.00 Post 39.34 ± 13.69 Δ2 = -4.10 [-14.50 17.50]	.332	0.17[r]	Pre 41.00 ± 12.22 Post 42.68 ± 11.75 Δ3 = 2.30 [-5.70 11.80]	.344	0.16[r]

*LV–SS: 3.5 min of SS; MV–SS: 7 min of SS; HV–SS: 10.5 min of SS; S&R: Sit and reach test; RSI: Reactive strength index; JH: Jump height; GCT: Ground contact time; Kleg: Leg stiffness; Δ Absolute difference between pre and post-test. ES: Unbiassed effect size (repeated measures ANOVA for Cohen's d; Mann Whitney-U Test for Hedge's r); (Cohen's effect size d; 0.2 = small, 0.5 = medium, 0.8 = large effect size); Hedge effect size r ; 0.1 = small, 0.3 = medium, 0.5 = large effect size); Z: Z value in Wilcoxon). *p < .05.*

Table 3. Paired comparison for differences between pre- and post-test.

Variable	M ± SD	p	ES
	ΔLV–SS - ΔMV-SS = -0.09 ± 3.50	.918	0.06^{d}
S&R Test (cm)	ΔLV–SS - ΔHV-SS = 0.09 ± 3.28	.913	0.08^{d}
	ΔMV–SS - ΔHV-SS = 0.18 ± 1.71	.677	0.18^{d}
	ΔLV–SS - ΔMV-SS = 0.15 [-0.98 0.75]	.776	0.05^{r}
RSI (mm/ms)	ΔLV–SS - ΔHV-SS = -0.07 [-1.16 0.95]	.687	0.07^{r}
	ΔLV–SS - ΔHV-SS = 0.05 [-0.78 0.86]	.831	0.04^{r}
	ΔLV–SS - ΔMV-SS = 1.70 [-4.40 8.00]	.407	0.14^{r}
JH (cm)	ΔLV–SS - ΔHV-SS = 0.00 [-6.40 12.10]	.776	0.05^{r}
	ΔMV–SS - ΔHV-SS = -0.60 [-8.50 10.40]	.687	0.07^{r}
	ΔLV–SS - ΔMV-SS = 4.00 [-27.00 32.00]	.463	0.13^{r}
GCT (ms)	ΔLV–SS - ΔHV-SS = 0.00 [-31.00 60.00]	.887	0.02^{r}
	ΔMV–SS - ΔHV-SS = -8.00 [-63.00 34.00]	.653	0.08^{r}
	ΔLV–SS - ΔMV-SS = 1.10 [-19.60 50.30]	.723	0.06^{r}
Kleg (N/m)	ΔLV–SS - ΔHV-SS = 2.20 [-8.90 162.70]	.449	0.13^{r}
	ΔMV–SS - ΔHV-SS = 3.40 [-22.40 19.70]	.149	0.25^{r}

LV–SS: 3.5 min of SS; MV–SS: 7 min of SS; HV–SS: 10.5 min of SS; S&R: sit and reach test; RSI: Reactive strength index; JH: Jump height; GCT: Ground contact time; Kleg: Leg stiffness; Δ Absolute difference between pre- and post-test; ES: Unbiased effect size (repeated measures ANOVA for Cohen's d; Friedman test for Hedge's r); (Cohen's effect size d; 0.2 = small, 0.5 = medium, 0.8 = large effect size); Hedge effect size r; 0.1 = small, 0.3 = medium, 0.5 = large effect size); p < .05.

DISCUSSION

The purpose of this study was to investigate different volumes of SS on hamstring flexibility, RSI, K_{leg}, JH, and GCT in well-trained judo athletes. The hypotheses were: 1) HV–SS would result in a greater reduction in RSI, K_{leg}, JH, and GCT performance than LV–SS and MV–SS; and 2) HV–SS would result in a greater improvement in hamstring flexibility compared to LV–SS and MV–SS. The main findings of this study were: a) After all the static stretching exercises with different volumes, hamstring flexibility was significantly improved without any change in subsequent RSI, Kl_{eg}, JH, or GCT performance, b) LV–SS, MV–SS, or HV–SS had similar impacts on hamstring flexibility; c) none of the stretching exercises with different volumes lead to any change in LV–SS, MV–SS, or HV–SS, positively or negatively. According to the results of the present study, the hypotheses of the study remained unverified.

Flexibility is an important physiological component of physical fitness (Odunaya et al., 2005), and SS exercises improve flexibility and range of motion (ROM) in various joints (Logan et al., 2018; Cini et al., 2017; Bremner et al., 2015; Tsolakis and Bogdanis, 2012; Odunaya et al., 2005; DePino et al., 2000). Increasing ROM and/or flexibility after SS is explained by decreased passive stiffness of the muscle tendon-unit stiffness (MTS) and increased stretch tolerance (Hatano et al., 2019; Donti et al., 2014). However, some studies reported that SS with different volumes did not improve flexibility or ROM (Heisey et al., 2016; Donti et al., 2014; Hoge et al., 2010; Tsolakis et al., 2010). These conflicting results on the effects of SS on flexibility or ROM may be caused by gender differences, fitness characteristics of the subjects, and stretching duration and intensity (Heisey et al., 2016; Apostolopoulos et al., 2015; Donti et al., 2014; Hoge et al., 2010; Tsolakis et al., 2010). Unick et al. (2005) proposed that well-trained athletes may be less susceptible to stretch-induced decrements in explosive performance compared to untrained individuals.

Despite the fact that K_{leg} is an important factor for achieving a better performance during sports activities, the influence of SS prior to exercises on K_{leg} remains unclear. Hobara et al. (2011) reported that 3 min of SS for plantar flexors had no significant effect on K_{leg} during bilateral hopping. Hoge et al. (2010) also reported that nine 135 s sessions of SS were unlikely to have affected the viscoelastic properties of the muscles. The lack of a reduction in leg stiffness can be explained by an adaptation of leg stiffness during two-legged hopping, which could be a compensatory mechanism to maintain a comfortable level of stiffness (Hobara et al., 2011).

Several researchers have argued that SS with different volumes leads to a decrease in MTS (Taniguchi et al., 2015; Pasqua et al., 2014; Akagi and Takahashi, 2013; Mizuno and Umemura, 2013; Ryan et al., 2008). Indeed, Ryan et al. (2008) reported that SS of 2–8 min resulted in significant decreases in MTS. The factors leading to an SS induced reduction in MTS are attributed to the following: a) viscoelastic changes in musculotendinous unit (MTU), b) increased tendon compliance, c) increased fascicle length, d) alterations in intramuscular connective tissues, e) increased displacement of muscle, and f) reduced neural activity, motor unit recruitment, and reflex sensitivity (Kataura et. al, 2016; Donti et al., 2014; Mizuno and Umemura, 2013; Tsolakis and Bogdanis, 2012; Hobara et al., 2011; Hoge et al., 2010; Ryan et al., 2008). According to Hobara et al. (2011), these conflicting results may be attributed to discrepancies in the type of testing movement (resting or hopping), selected muscle, stretch intensity (maximal or submaximal), stretch protocol (intermittent or continuous), stretch duration, or any combination of the above. Some researchers have argued that SS intensity might be the most important factor leading to a decrease in MTS (Kataura et al., 2016; Apostolopoulos et al., 2015; Donti et al., 2014; Hobara et al., 2011). Kataura et al. (2016) reported lower hamstring stiffness after SS exercises applied at a 120% POD than after an 80% POD. Moreover, Young et al. (2006) reported that 2 min of SS at 90% intensity had no significant effect on muscle performance, despite 2 and 4 min of SS at 100% intensity causing an impairment to fast SSC muscle performance due to neural factors and a reduction in MTS. In the current study, SS exercises were applied at the POD as we aimed to cause any SS-induced injury.

RSI has been described as a simple tool to monitor stress on the MTU and to quantify plyometric or SSC performance (Werstein et al., 2012; Flanagan et al., 2008). While Pasqua et al. (2014) reported that JH, GCT, and RSI were negatively influenced by a 10 min SS exercise, Tsolakis et al. (2010) argued that 6 min SS exercises had no significant effects on squat jump (SJ) height, RSI, and GCT performance of well-trained fencers, either positively or negatively. Werstein and Lund (2012) also reported that SS exercises had neither a positive nor negative effect on RSI performance in female Division I soccer players. The results of our study revealed that none of the 3.5 min, 7 min, and 10.5 min SS exercises significantly affected GCT and JH. This was expected since our results also revealed that SS exercises had no significant impact on RSI. It is known that RSI is dependent on JH and GCT (Flanagan et al., 2008); if SS exercises had any effects on GCT and/or JH, RSI would have also been affected by SS exercises with different volumes used in this study.

This study has some limitations: a) The athletes were instructed to stretch to mild comfort, and the subjectivity of this perception may have resulted in an effective stretch by some of the athletes; b) we did not use any tool to monitor the intensity of SS exercises, such as *Visual* Analog Scale (VAS) or Borg CR 10 Scale; c) we did not use statistical power to determine the sample size of the study, but instead tried to recruit all well-trained judo athletes from the city.

CONCLUSIONS

The results of the study revealed that well-trained judo athletes can use different volumes of SS exercises to improve hamstring flexibility without any subsequent reduction in muscular performance, such as RSI, K_{leg}, JH, and GCT, as evaluated by an accelerometer during hopping tasks. Because SS exercises no detrimental effects on RSI, K_{leg}, GCT, or JH, judo athletes can use SS exercises as part of their warm-up routine. However, trainers or athletes should pay attention to the training level of the athletes, as well as stretching intensity and SS exercises, since different exercises or intensities might lead to different results. Further research is required to determine the effects of other volumes and intensities of SS that were not examined in this study in enhancing hamstring flexibility, RSI, and Kl_{eg}.

AUTHOR CONTRIBUTIONS

Study design: İmren Kurtdere, Cem Kurt. Data collection: İmren Kurtdere, Cem Kurt. Methodology: İmren Kurtdere, Cem Kurt. Fund collection: İmren Kurtdere, Cem Kurt. Statistical analyses: İlbilge Özsu Nebioğlu. Writing-original draft preparation: Cem Kurt, İlbilge Özsu Nebioğlu. Writing-review and editing: Cem Kurt, İlbilge Özsu Nebioğlu.

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No potential conflict of interest was reported by the authors.

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