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# ACUTE RESIDUAL EFFECTS OF SHORT AND LONG DURATION STATIC STRETCHING ON COUNTER MOVEMENT JUMP PERFORMANCES IN WELL-TRAINED FEMALE COMBAT ATHLETES

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**Abstract:**
Duration of static stretching is the most crucial factor associated with static stretch-induced impairments in explosive muscular performances. The aim of this study was to investigate the acute residual effects of lower body short (S-SS) and long duration static stretching protocols (L-SS) on counter movement jump (CMJ) performances in skilled female combat athletes. Twelve well-trained female combat athletes (training experience: 11.5 ∓ 3.6 years) performed S-SS (6 min of total stretch duration) and L-SS (12 min of total stretch duration) separated by 48 hours in a randomized, balanced order. After each protocol, participants performed, respectively, counter movement jump with arm swing ($CMJ_{AS}$) and with hands on hip ($CMJ_{HH}$) separated by 30-second rest interval at the 15th second and 1st, 5th, 10th, 15th, and 20th minute of the 20-minute recovery period. An insignificant interaction effect was found for Protocol × Time in CMJ heights ($p = 0.722$) indicating that both S-SS and L-SS reduced CMJ heights to a similar extent over the course of 20 min recovery period. S-SS and L-SS led to a mean CMJ height reduction of 6.29% ($p < 0.05$, $d = 0.603$) and 6.74% ($p < 0.05$, $d = 0.610$), respectively. Greater than 50% of participants experienced a reduction in $CMJ_{AS}$ height exceeding minimum detectable change score with 90% confidence at each time point during the recovery period without exception. Use of static stretching protocols ≥ 6

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minutes prior to competitions and/or training sessions may lead to impairment in lower body explosive strength of well-trained female combat athletes that persists at least 20 minutes. This impairment may also indirectly hinder their sport-specific performance since combat sports include a great deal of movement patterns related to lower body explosive strength.

**Keywords:** flexibility, lower body, performance impairment, vertical jump, warm-up

## Introduction

High level of flexibility is a prerequisite for athletic success in combat sports that require relatively large range of motions (ROM) and extreme limb positions (Comas, Valentino, Bridgett, & Hayden, 2014; Costa, Medeiros, & Fukuda, 2011). Especially, flexibility of hip, knee, and shoulder joints is important for the defensive and offensive technical and tactical skills (Comas et al., 2014; Costa et al., 2011). Low flexibility in these joints may impair competition performance in combat sports (Costa et al., 2011).

Static stretching (SS) is the easiest and most commonly used stretching method that is stated to enhance flexibility (Bradley, Olsen, & Portas, 2007; Judge et al., 2013; Robbins & Scheuermann, 2008). Hence, SS exercises are routinely included in training programs and used prior to competitions by combat athletes as a part of warm-up to acutely increase ROM and prepare their muscles for intense muscular efforts such as stretch shortening type explosive movements. However, there are studies indicating that impairment in muscular performances in explosive type activities such as jumping height is possible if performed after SS (Bradley et al., 2007; Cornwell, Nelson, & Sidaway, 2002; Fletcher & Monte-Colombo, 2010; Hough, Ross, & Howatson, 2009; Pinto, Wilhelm, Tricoli, Pinto, & Blazevich, 2014; Tsolakis & Bogdanis, 2012; Unick, Kieffer, Cheesman, & Feeney, 2005; Vetter, 2007; Young & Elliott, 2001). On the other hand, as also stated in the meta-analytical review of (Simic, Sarabon, & Markovic (2013), in many other studies no reduction in vertical jump height was found (Chaouachi et al., 2009; Church, Wiggins, Moode, & Crist, 2001; Curry, Chengkalath, Crouch, Romance, & Manns, 2009; Dalrymple, Davis, Dwyer, & Moir, 2010; Little & Williams, 2006; J. C. Murphy, Mccrory, Nagle, & Robertson, 2010; Power, Behm, Cahill, Carroll, & Young, 2004; Unick et al., 2005; Young & Elliott, 2001). Even some researchers reported enhanched vertical jump performances after short duration static stretching (Holt & Lambourne, 2008; J. R. Murphy, Di Santo, Alkanani, & Behm, 2010). In their review article, Kay & Blazevich (2012) indicated that static stretch-induced impairment in performances requiring maximal strength, explosive strength and speed were reported in 50% of studies including sufficient control and reliability. Based on these conflicting results, the latest recommendations of American College of Sports Medicine (ACSM) include removing flexibility exercises prior to strength and power-related activities as a precaution to avoid possible reductions in these muscular performances. ACSM also express the need for further studies to clarify the conflicting effects of SS on related performances (Swain, American College of Sports Medicine., & American College of Sports Medicine., 2014).

Highly different modes, intensities, frequencies, durations of stretches, and measurement methods used in the studies could be the reasons of the contradictory findings (Kay & Blazevich, 2012; Unick et al., 2005). Although Simic et al (2013) have reported that stretch-induced impairments in muscular performances are independent of gender and training level, these factors are also suggested to be possible reasons of contradictions in some studies (Curry et al., 2009; Dalrymple et al., 2010; Kay & Blazevich, 2012; Unick et al., 2005). However, the most crucial factor associated with static stretch-induced impairments in explosive movements is stated to be the duration of SS (volume) (Behm & Chaouachi, 2011; Kallerud & Gleeson, 2013; Kay & Blazevich, 2012; J. R. Murphy et al., 2010; Simic et al., 2013). ACSM recommends stretching to be held for 10 to 30 seconds for 3-4 times at a point of mild discomfort (Swain et al., 2014).

According to Siatras, Mittas, Mameletzi, & Vamvakoudis (2008) and Torres et al. (2008), there was no detrimental effect of short duration SS on subsequent muscular performances. J. R. Murphy et al. (2010) and Simic et al. (2013) suggest that as the duration of stretching increases impairments in performance increase. (Behm & Chaouachi (2011) have emphasized that when the total duration of SS performed on a single muscle group exceeds 90 s, muscular performance impairment is highly possible. On the other hand, Kallerud & Gleeson (2013) set this time limit as ≥ 60 s and suggested SS of less than 45 s in each muscle is safe in regard to possible detrimental effects on muscular performances.

Training level and gender of participants are suggested to be some other critical factors that should also be considered to determine whether SS has detrimental effects on muscular performances including explosive type movements. Egan, Cramer, Massey, & Marek (2006) suggested that trained athletes might be less susceptible to the stretch-induced performance reductions in explosive muscular efforts than untrained or sedentary individuals. In addition, Unick et al. (2005) and Tsolakis & Bogdanis (2012) stated that acute effects of SS may not inhibit power performance in trained female athletes compared to their male counterparts.

Although there is a great deal of studies that investigated the effects of SS exercises on subsequent explosive muscular performances, there seems to be no evident result. Moreover, there is a limited number of studies conducted on well-trained female athletes (Church et al., 2001; Tsolakis & Bogdanis, 2012; Unick et al., 2005). It is beneficial to learn whether SS, indeed, results in performance reductions in explosive type muscular activities and, if so, how long these performance reductions persist (Holt & Lambourne, 2008; Hough et al., 2009; J. C. Murphy et al., 2010).

This issue is of great importance for power and strength athletes and their trainers to adjust the timing of the implementation of stretching exercises in training sessions or prior to competitions, if the use of stretching exercises is really a prerequisite for the related sport discipline (Unick et al., 2005). Limited number of studies investigated the residual effects of SS on vertical jump performance (Curry et al., 2009; Dalrymple et al., 2010; J. R. Murphy et al., 2010; Power et al., 2004; Unick et al., 2005). Therefore, this study focused particularly on well-trained female combat athletes experienced in stretch-shortening type muscular activities that require relatively large ROM and aimed to investigate the acute residual effects of short (S-SS) and long duration lower body SS protocols (L-SS) on counter movement jump (CMJ) performances. Secondary purpose is to assess the minimum detectable change scores at 90% confidence ($MDC_{90}$) for counter movement jump with arm swing ($CMJ_{AS}$) and with hands on hips ($CMJ_{HH}$).

The hypotheses of the present study were 1) Both L-SS and S-SS would result in reduction in vertical jump performance, 2) L-SS would result in a greater reduction in vertical jump performance compared with S-SS, and 3) inhibitory effect of S-SS on CMJ would disappear more rapidly over the course of the 20-minute recovery period compared with L-SS.

## Material and Method

### Participants

Twelve well-trained female combat athletes (mean ± standard deviation; age: 21.2 ± 2.5 years, height: 1.60 ± 0.06 m, body mass: 57.5 ± 9.8 kg, training experience: 11.5 ± 3.6 years, weekly training volume: 8.79 ± 3.32 hours) competing in judo, karate, tae kwon do, and Muay Thai volunteered to participate in the present study.

Participants had no history of injury and health problems that would prohibit participation in the study. Participants were required to refrain from vigorous physical activity, consumption of alcohol, any food or drinks containing caffeine or any other types of stimulants at least 24 hours prior to the testing session. In addition, they were asked to have their usual night sleep and follow their normal diet (consumption of a light meal at least 3 hours prior to testing). Participants were informed of the purpose, procedures and experimental risks of the study verbally. Then, they read and signed a written informed consent statement. Approval was granted from the medical ethics committee of the medical faculty of the local university in accordance with the Declaration of Helsinki (approval number: 2014/89-12/10).

**Procedures**

This study consisted of 2 sessions separated by 48 hours. All of the tests were performed by the same researcher at strict times between 11:00 to 14:00 each day to avoid the possible effect of circadian rhythm on the study results. A familiarization session was conducted 5–7 days prior to the start of the study. The aim was to familiarize participants to the laboratory conditions, testing equipment, and actual test design. Subsequent two sessions were performed to assess the effects of different SS durations on CMJ performances.

Participants were assigned into S-SS (total time under stretch: 6 min) and L-SS (total time under stretch: 12 min) with a randomized, balanced order. None of the participants were instructed about the expected effects of SS protocols on CMJs. At the beginning of each session, participants cycled for five minutes on a cycle ergometer (834 E, Monark, Vansbro, Sweden) at 70–80 rpm with no load as warm up. After a one-minute passive rest, they performed $CMJ_{AS}$ and $CMJ_{HH}$ separated by 30 s rest interval. This jumping procedure was repeated 3 times with 1 minute intervals and the best jump heights were recorded as the pre-test scores for $CMJ_{AS}$ and $CMJ_{HH}$. CMJ heights were assessed using Myotest Pro System (Myotest Sport Pro, Sweden). Order of vertical jump types was determined randomly prior to the start of the study and all the participants used this order in both sessions. In each vertical jump type, participants rapidly squat down to a self-selected depth and then immediately performed the vertical jump. Strong verbal encouragement was provided to each participant to ensure that each jump was performed with maximal effort. Participants used the same shoe wear in both sessions.

One minute after the pre-test, a stretching protocol (see Figure 1) including four different self-applied passive unilateral SS exercises (Unick et al., 2005) targeting main muscles activated during a vertical jump was started. Hamstring stretch in the protocol was applied unilaterally (modified hurdler) as in the study of (Power et al., 2004). Since combat athletes generally use self-applied stretching exercises in their training, exercises in the current study were also performed similarly. Each stretch was held at "the point of mild discomfort" and lasted for 15 seconds (total of 3 min for each leg) and 30 seconds (total of 6 min for each leg) in the S-SS and L-SS, respectively. These durations and set numbers were chosen to mimic the study of (Unick et al., 2005). In addition, they represent a typical combat athlete's stretching protocol and also fell within the limits of ACSM's recommendations (Swain et al., 2014). Young, Elias, & Power (2006) showed that stretches including 10% less elongation than "the point of mild discomfort" led to less impairment in muscular power compared with a full stretch. Therefore, participants were instructed to increase the intensity of stretching during each stretch if the feeling of "mild discomfort" in the initial stretch position faded away due to acute relaxation of muscles. The aim was to ensure that each stretch was performed to the limits of ROM and there was no inter-individual stretch intensity difference throughout the stretch duration.

During a 20-minute recovery period after the end of each stretching protocol, participants performed $CMJ_{AS}$ and $CMJ_{HH}$ separated by 30 s rest interval at six time points: on the 15th second and on the 1st, 5th, 10th, 15th, and 20th minute of the recovery period. Measurements were performed within a recovery period of 20 minutes since this time period is stated to be a realistic post-stretch time frame for the assessment of stretching effects on performance (Kay & Blazevich, 2012). Participants rested 2 minutes passively after each $CMJ_{HH}$ and in the remaining rest period they walked with a moderate pace to maintain the body temperature and then performed the next two CMJs (rest was passive between 15th second and 1st minute). Since the rest intervals between each successive jumps in our study design were sufficient for full recovery (Simic et al., 2013) and there was no factor that could likely lead to any type of potentiating effect on CMJs, a separate control session was not conducted to assess time effect on the $CMJ_S$ during 20-minute recovery period. Supporting this issue, Unick et al. (2005) demonstrated that there was no time effect on the vertical jump scores across 30-minute time frame.

Schematic representation of the study design and details of stretching protocols were demonstrated in Figure 1.

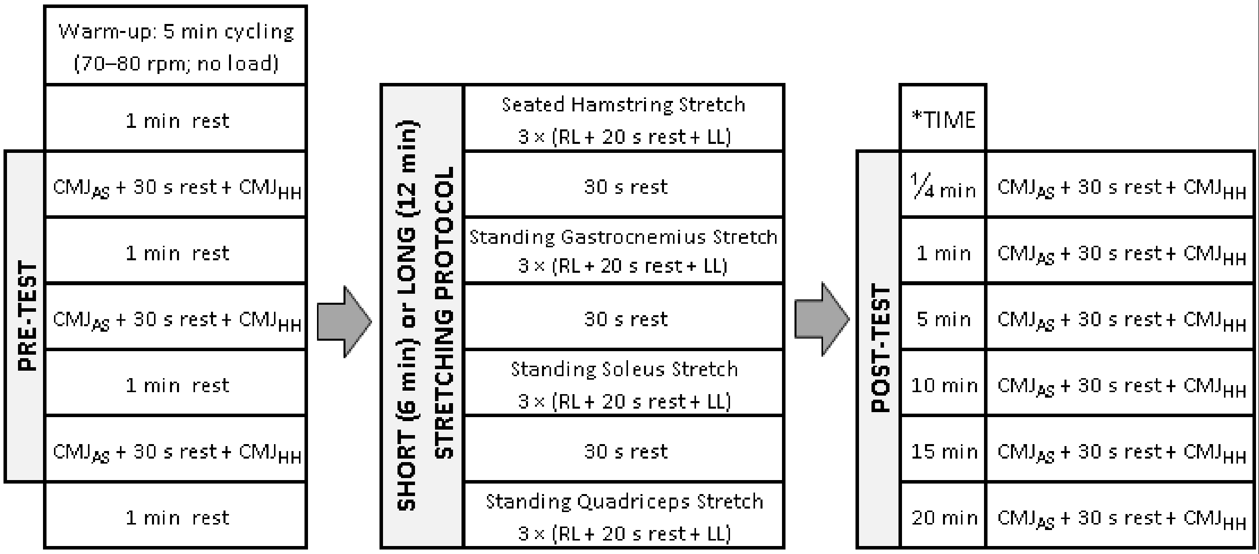


**Figure 1:** Schematic representation of the study design.

Each unilateral stretch lasted for 15 s and 30 s for the short and long duration static stretching protocol, respectively. There is 20 s rest interval between sets of each stretching exercise. All rests are passive. rpm = revolution per minute, $CMJ_{AS}$ = counter movement jump with arm swing, $CMJ_{HH}$ = counter movement jump with hands on hip, RL = stretch for right leg, LL = stretch for left leg,
s = second, min = minute, *TIME = time passed after the stretching protocols

**Statistical Analyses**

Study data were analysed using the SPSS Statistics for Windows version 20 software program (IBM, Armonk, NY; 2011). To assess the normality of related data, the Shapiro-Wilk test was performed and skewness and kurtosis values were checked.

Relative reliability of pre-test vertical jump heights between S-SS and L-SS sessions was assessed using intraclass correlation coefficient (ICC) and its 95% confidence interval (CI). ICC was computed using a two-factor mixed-effects model with absolute agreement. Absolute reliability was assessed using standard error of measurement (SEM) and coefficient of variation (CV) with 95% CI.

Jump Type ($CMJ_{AS}$, $CMJ_{HH}$), Protocol (S-SS, L-SS), and Time (baseline, 15 sec, 1 min, 5 min, 10 min, 15 min, 20 min) were the within participant factors of the current study. Main and interaction effects of factors on CMJ heights were investigated using three-factor repeated-measures design analysis of variance (ANOVA; 2 × 2 × 7, Jump Type × Protocol × Time). Intra-protocol comparisons were performed using one-way repeated-measures ANOVA. If a significant *F*-ratio was found, Fisher's least significant difference post hoc test was used to perform pairwise comparisons. Confidence interval adjustment was not performed for multiple pairwise comparisons to avoid loss of statistical power (Nakagawa, 2004; Perneger, 1998). Unbiased effect sizes of the differences (Hedge's d; $d < 0.2$ trivial, $0.2 \leq d < 0.5$ small, $0.5 \leq d \leq 0.8$ moderate, $d > 0.8$ large effect size) were also reported. One-sample t-test was used for each jump type separately to assess whether mean difference in CMJ height changes between post-L-SS and post-S-SS at each testing time point during 20 min recovery period was different from "0 cm". Statistical significance level was set at $p \leq 0.05$ for all analyses.

When performance changes are observed in individuals, it is of great importance to assess how substantial they are (Hopkins, 2000). Therefore, the percentage of participants who showed reduction in CMJ heights greater than the minimum detectable change at 90% confidence level ($MDC_{90}$) and the percentage who showed reduction greater than the smallest worthwhile change or clinically important difference (SWC) were calculated using baseline CMJ data obtained in two testing sessions. Performance reductions greater than $MDC_{90}$ and SWC were regarded as "real change" and "practically important change", respectively (Greenfield et al., 2014).

$MDC_{90}$ was calculated using the following equation:

$$MDC_{90} = SEM \times 1.65 \times \sqrt{2} \quad [1]$$

where SEM is the standard error of measurement, 1.65 is the z score of 90% confidence level, and $\sqrt{2}$ is the variance of two measurements. SEM was estimated by taking the square root of the mean square error term in repeated measures ANOVA outcomes, since this measure is not affected by the range of measured values (Atkinson & Nevill, 1998). SWC was calculated according to Cohen effect size benchmark (0.2 SD) (Tanner, Gore, & Australian Institute of Sport., 2013).

## Results

Mean baseline $CMJ_{AS}$ and $CMJ_{HH}$ of the study sample were 35.6 ± 3.9 cm, and 31.4 ± 3.4 cm, respectively. Pre-test measures obtained in two sessions were highly reliable (Table 1).

**Table 1:** Reliability results for CMJ based on pairwise comparisons between baseline CMJ heights obtained in different static stretching protocol sessions

| | Paired Protocols | | p | d [95% CIs] | ICC [95% CI] | CV [95% CI] (%) | SEM (cm) |
|---|---|---|---|---|---|---|---|
| | S-SS | L-SS | | | | | |
| $CMJ_{AS}$ (cm) | 35.4 ± 4.0 | 35.8 ± 4.0 | 0.33 | −0.10 [−0.31 – 0.11] | 0.99 [0.96 – 1.00] | 3.09 [2.21 – 5.16] | 1.01 |
| $CMJ_{HH}$ (cm) | 31.2 ± 3.2 | 31.7 ± 3.7 | 0.16 | −0.11 [−0.26 – 0.03] | 0.99 [0.96 – 1.00] | 2.78 [1.99 – 4.63] | 0.658 |

S-SS = short duration static stretching protocol, L-SS = long duration static stretching protocol, $CMJ_{AS}$ = counter movement jump with arm swing, $CMJ_{HH}$ = counter movement jump with hands on hip, ICC = intraclass correlation coefficient, CV = coefficient of variation, SEM = standard error of measurement, CI = confidence interval, d = unbiased effect size of the difference (Hedge's d; $d < 0.2$ trivial; $0.2 \leq d < 0.5$ small; $0.5 \leq d < 0.8$ moderate; $d \geq 0.8$ large effect size)

The three-factor repeated measures ANOVA (2 × 2 × 7, Jump Type × Protocol × Time) revealed a significant main effect for Jump Type indicating that participants obtained greater jump heights in $CMJ_{AS}$ when compared with $CMJ_{HH}$ ($p < 0.001$, $\eta_p^2 = 0.947$, power = 1.00). A significant main effect for Time ($p < 0.001$, $\eta_p^2 = 0.683$, power = 1.00) revealed that participants obtained different CMJ heights at different time points. There was a similar change pattern (an insignificant interaction effect for Protocol × Time) in CMJ heights throughout the 20-minute recovery period after each stretching protocol ($p = 0.722$, $\eta_p^2 = 0.377$, power = 0.127).

CMJ heights remained significantly diminished throughout the recovery period (Table 2-3). S-SS led to a mean $CMJ_{AS}$ and $CMJ_{HH}$ height reductions of 1.96 cm and 2.25 cm with mean effect sizes of 0.509 and 0.697, respectively. These reductions were 2.31 cm and 2.21 cm with mean effect sizes of 0.584 and 0.635 for L-SS. Individual changes in CMJ heights relative to baseline value over the course of the 20 min recovery period were demonstrated in Figure 2-3.

**Table 2:** Differences in jump height between the baseline score and scores obtained on the specified testing time points during the 20 min recovery period after the short duration static stretching protocol

| : | Reductions in $CMJ_{AS}$ | | | | |
|---|---|---|---|---|---|
| | Δ (cm) | 95% CI of Δ | p | d | 95% CI of d |
| Base – 15 s | 1.93 | 0.87– 2.99 | 0.002* | 0.510 | 0.193 – 0.827 |
| Base – 1 min | 1.37 | −0.12 – 2.85 | 0.067 | 0.364 | −0.013 – 0.741 |
| Base – 5 min | 1.76 | 0.85 – 2.67 | 0.001* | 0.438 | 0.163– 0.713 |
| Base – 10 min | 1.91 | 1.01 – 2.80 | <0.001* | 0.507 | 0.228 – 0.787 |
| Base – 15 min | 2.41 | 1.34 – 3.48 | <0.001* | 0.613 | 0.260 – 0.996 |
| Base – 20 min | 2.37 | 1.25 – 3.48 | <0.001* | 0.624 | 0.263 – 0.984 |
| | Reductions in $CMJ_{HH}$ | | | | |
| | Δ (cm) | 95% CI of Δ | p | d | 95% CI of d |
| Base – 15 s | 1.74 | 0.91 – 2.58 | <0.001* | 0.529 | 0.208 – 0.850 |
| Base – 1 min | 1.92 | 0.92 – 2.92 | 0.001* | 0.636 | 0.246 – 1.030 |
| Base – 5 min | 2.48 | 1.30 – 3.65 | <0.001* | 0.876 | 0.383 – 1.370 |
| Base – 10 min | 2.43 | 1.67 – 3.18 | <0.001* | 0.686 | 0.344 – 1.030 |
| Base – 15 min | 2.61 | 1.45 – 3.77 | <0.001* | 0.740 | 0.311 – 1.170 |
| Base – 20 min | 2.34 | 1.65 – 3.04 | <0.001* | 0.712 | 0.356 – 1.070 |

*$p < 0.05$, $CMJ_{AS}$ = counter movement jump with arm swing, $CMJ_{HH}$ = counter movement jump with hands on hip, Δ = reduction, Base = baseline jump height, CI = confidence interval, min = minute, d = unbiased effect size of the difference (Hedge's d; $d < 0.2$ trivial; $0.2 \le d < 0.5$ small; $0.5 \le d \le 0.8$ moderate; $d > 0.8$ large effect)

**Table 3:** Differences in jump height between the baseline score and and scores obtained on the specified testing time points during the 20 min recovery period after the long duration static stretching protocol

| | Reductions in $CMJ_{AS}$ | | | | |
|---|---|---|---|---|---|
| | Δ (cm) | 95% CI of Δ | p | d | 95% CI of d |
| Base – 15 s | 2.29 | 1.05 – 3.54 | 0.002* | 0.597 | 0.215 – 0.979 |
| Base – 1 min | 1.72 | 0.58 – 2.86 | 0.007* | 0.412 | 0.106 – 0.718 |
| Base – 5 min | 2.03 | 0.73 – 3.34 | 0.006* | 0.530 | 0.153 – 0.906 |
| Base – 10 min | 2.66 | 1.66 – 3.66 | <0.001* | 0.698 | 0.330 – 1.070 |
| Base – 15 min | 2.77 | 1.96 – 3.57 | <0.001* | 0.693 | 0.351 – 1.040 |
| Base – 20 min | 2.36 | 1.20 – 3.52 | <0.001* | 0.572 | 0.219 – 0.924 |
| | Reductions in $CMJ_{HH}$ | | | | |
| | Δ (cm) | 95% CI of Δ | p | d | 95% CI of d |
| Base – 15 s | 2.33 | 1.41 – 3.24 | <0.001* | 0.676 | 0.322 – 1.30 |
| Base – 1 min | 1.48 | 0.75 – 2.20 | <0.001* | 0.401 | 0.157 – 0.644 |
| Base – 5 min | 1.74 | 0.79 – 2.69 | 0.002* | 0.473 | 0.165 – 0.781 |
| Base – 10 min | 2.75 | 1.56 – 3.94 | <0.001* | 0.825 | 0.376 – 1.27 |
| Base – 15 min | 2.28 | 1.37 – 3.18 | <0.001* | 0.653 | 0.306 – 1.00 |
| Base – 20 min | 2.68 | 1.66 – 3.71 | <0.001* | 0.780 | 0.371 – 1.19 |

*$p < 0.05$, $CMJ_{AS}$ = counter movement jump with arm swing, $CMJ_{HH}$ = counter movement jump with hands on hip, Δ = reduction, Base = baseline jump height, CI = confidence interval, min = minute, d = unbiased effect size of the difference (Hedge's d; $d < 0.2$ trivial; $0.2 \le d < 0.5$ small; $0.5 \le d \le 0.8$ moderate; $d > 0.8$ large effect)

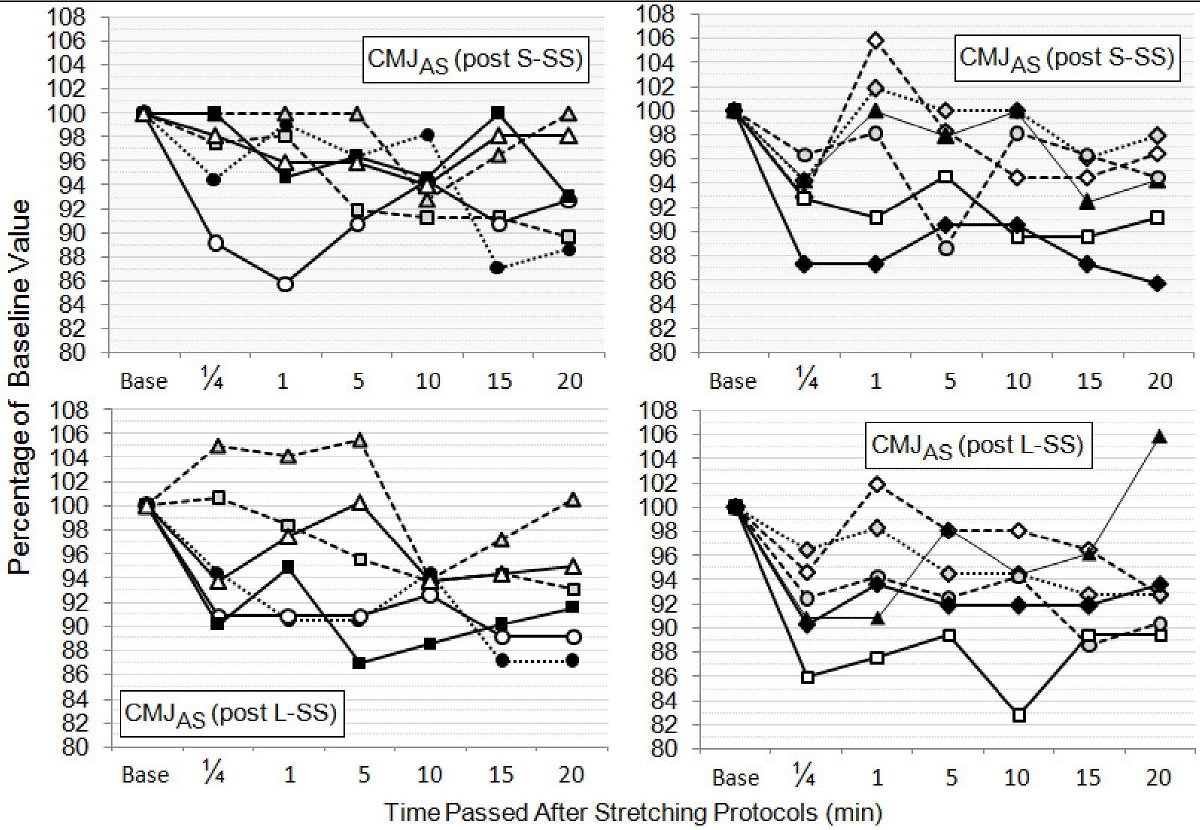


**Figure 2:** Individual CMJAS heights relative to the baseline value over the 20-min recovery period.

Results of the 12 participants were divided into two parts to avoid confusion. Each part shows the results of six participants represented by different symbols. Graphs with gray background show the results of the S-SS protocol. Graphs with no background color show the results of the L-SS protocol. CMJAS = counter movement jump with arm swing, S-SS = short duration static stretching protocol, L-SS = long duration static stretching protocol

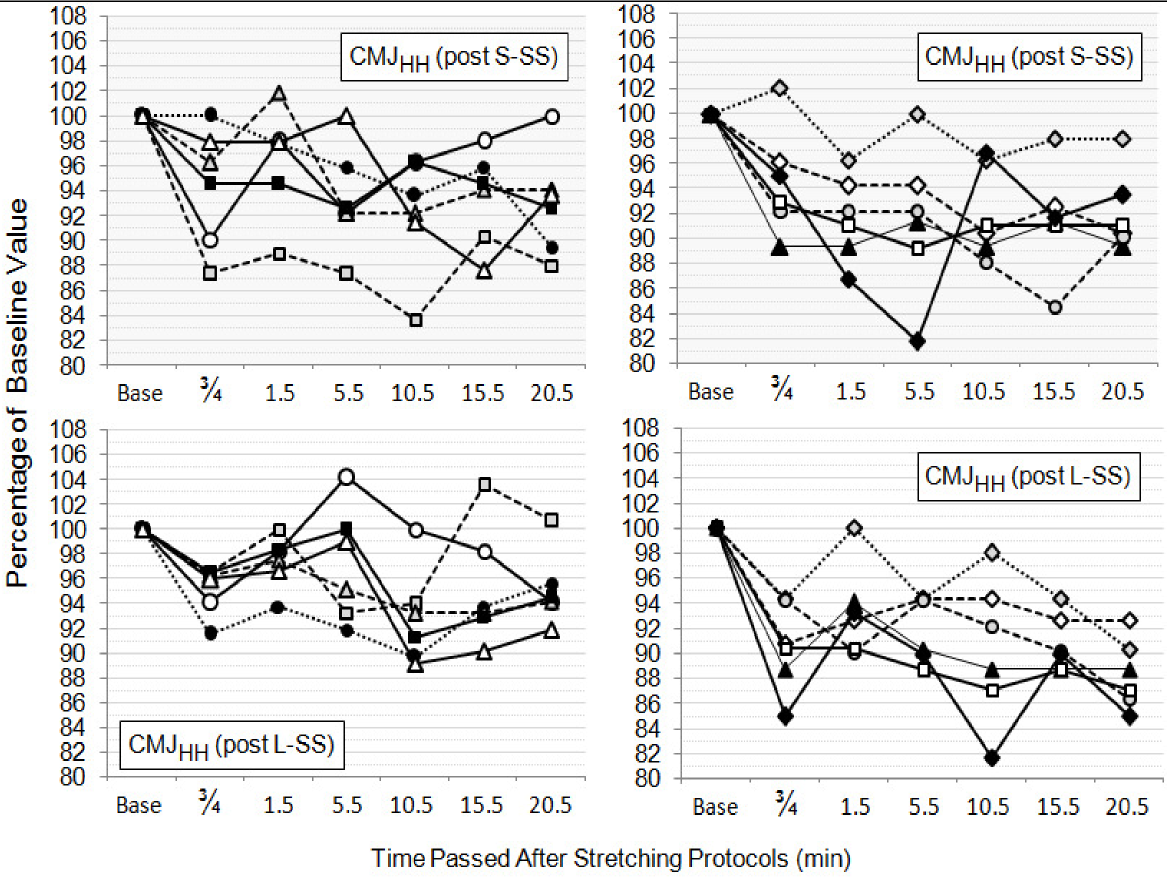


**Figure 3:** Individual CMJHH heights relative to the baseline value over the 20-min recovery period.

Results of the 12 participants were divided into two parts to avoid confusion. Each part shows the results of six participants represented by different symbols. Graphs with gray background show the results of the S-SS protocol. Graphs with no background color show the results of the L-SS protocol. CMJHH = counter movement jump with hands on hip, S-SS = short duration static stretching protocol, L-SS = long duration static stretching protocol

There was no statistically significant difference in jump height changes between L-SS and S-SS at any of the time points over the course of the 20 min recovery period ($p > 0.05$) indicating that both L-SS and S-SS showed similar inhibitory effects on CMJAS and CMJHH (Figure 4).

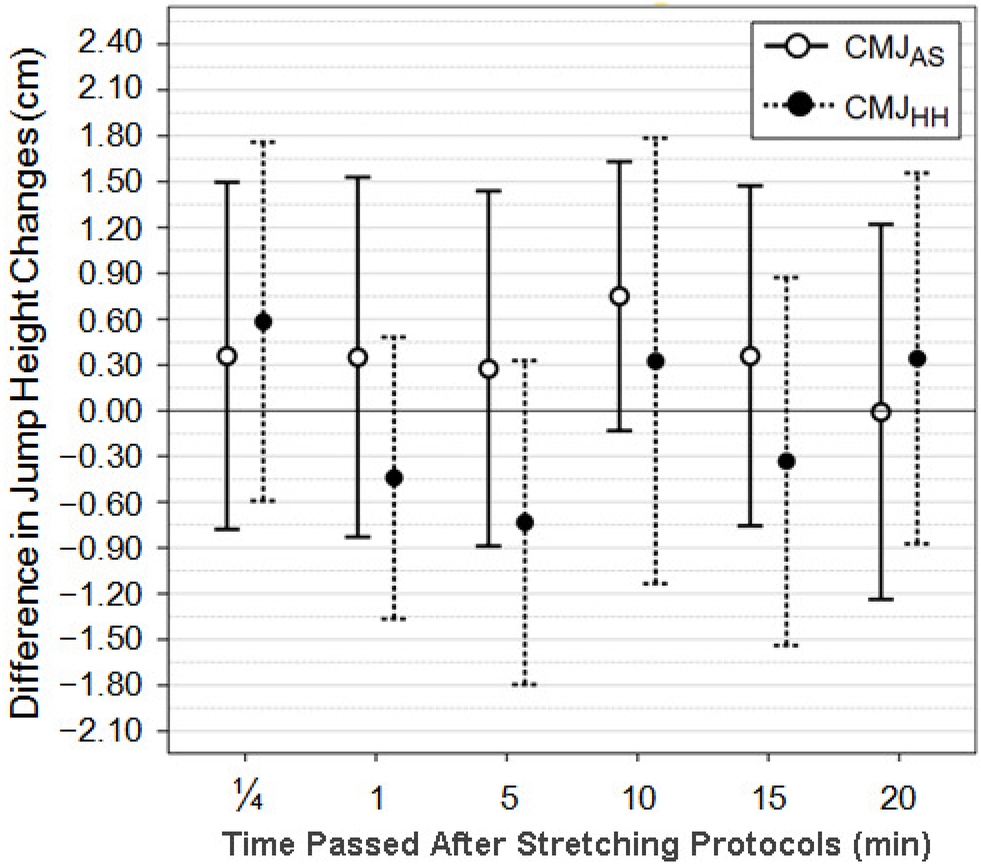


**Figure 4:** Mean difference in vertical jump height changes (Δ) between post-long duration and post-short duration static stretching protocols at each testing time point during the 20-min recovery period.

There were no statistically significant differences in jump height changes at any time point at the level of $p \leq 0.05$. Jump height changes in $CMJ_{AS}$ and $CMJ_{HH}$ are similar at each time point during the recovery period. Error bars indicate 95% confidence interval. $CMJ_{AS}$ = counter movement jump with arm swing, $CMJ_{HH}$ = counter movement jump with hands on the hip.
Δ = (post-test CMJ height – pre-test CMJ height in L-SS) − (post-test CMJ height – pre-test CMJ height in S-SS)

$MDC_{90}$ for $CMJ_{AS}$ and $CMJ_{HH}$ were 2.36 cm and 1.54 cm, respectively. At the least 25% and at the most ≈ 67% of participants experienced a $CMJ_{AS}$ height reduction greater than $MDC_{90}$ after each stretching protocol at each testing time points during the recovery period. According to $CMJ_{HH}$ data, at the least 50% of the participants experienced a jump height reduction greater than $MDC_{90}$ 15 seconds and 1 minute after each stretching protocol. At the 5th, 10th, 15th and 20th minute of the recovery, this percentage score exceeded 75% (Figure 5). The SWC for $CMJ_{AS}$ and $CMJ_{HH}$ were 0.781

cm and 0.675 cm, respectively. The percentage of participants exceeding SWC score over the course of the recovery period was demonstrated in Figure 6.

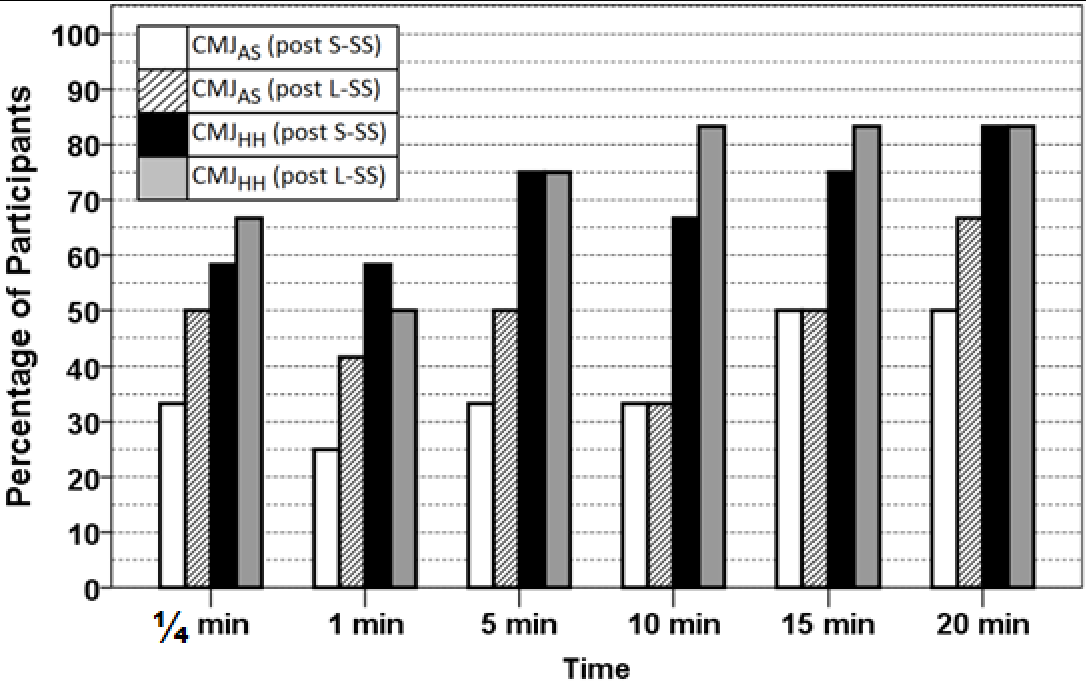


**Figure 5:** Percentage of participants who experienced reductions in vertical jump height greater than the minimum detectable change score with 90% confidence ($MDC_{90}$ = 2.36 cm for $CMJ_{AS}$ and 1.54 cm for $CMJ_{HH}$).

$CMJ_{AS}$ = counter movement jump with arm swing, $CMJ_{HH}$ = counter movement jump with hands on the hip, S-SS = short duration static stretching protocol, L-SS = long duration static stretching protocol

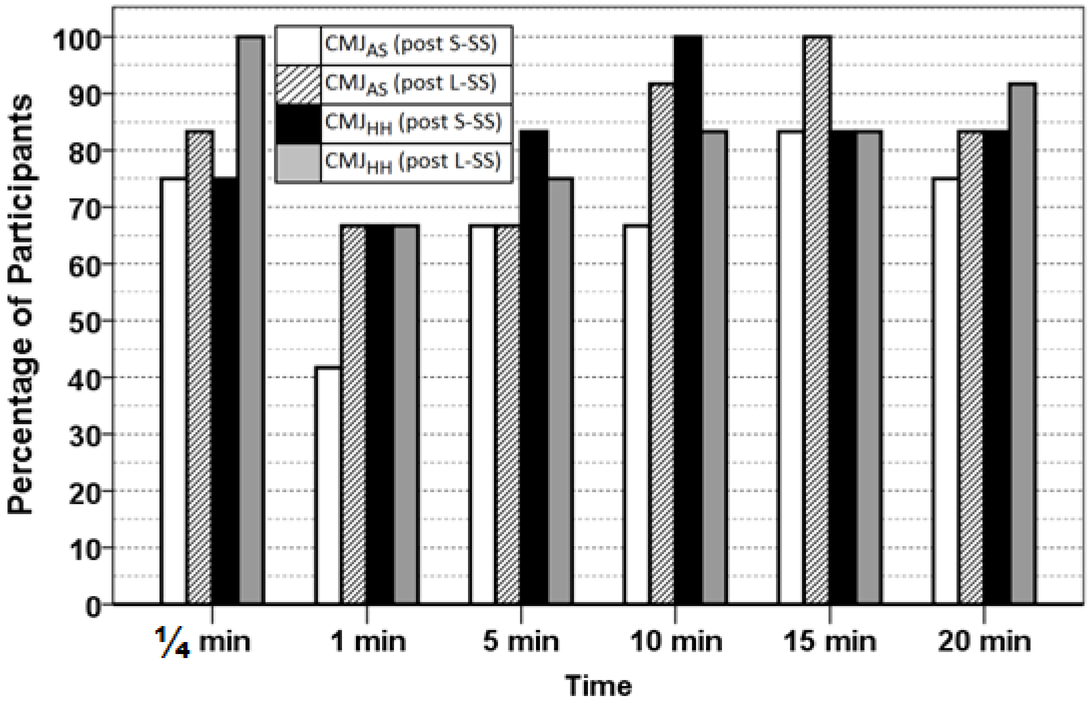


**Figure 6:** Percentage of participants who experienced reductions in vertical jump height greater than the minimum detectable change score with 90% confidence ($MDC_{90}$ = 2.36 cm for $CMJ_{AS}$ and 1.54 cm for $CMJ_{HH}$).

$CMJ_{AS}$ = counter movement jump with arm swing, $CMJ_{HH}$ = counter movement jump with hands on the hip, S-SS = short duration static stretching protocol, L-SS = long duration static stretching protocol

## Discussion

To our knowledge the present study is one of the very limited studies that includes highly reliable data and controlled design (Tsolakis & Bogdanis, 2012; Unick et al., 2005) investigating the acute residual effects of SS of different durations on vertical jump height in well-trained female athletes. The findings of the current study were in support of only one of our study hypotheses that both L-SS and S-SS would result in reduction in CMJ performance. Since effects of SS on muscular performances is task specific (Kay & Blazevich, 2012; Simic et al., 2013), discussion section mostly focused on the results of studies including vertical jump as the dependent variable.

Conflicting results related to the acute effects of SS on CMJ in the literature could be due to highly different stretching program variables (mode, intensity, frequency, duration, and recovery period prior to performance testing) as well as different characteristics of study samples (gender, training status, etc.) (Tsolakis & Bogdanis, 2012; Tsolakis, Douvis, Tsigganos, Zacharogiannis, & Smirniotou, 2010; Unick et al., 2005). This issue makes comparing and interpreting study results challenging (Tsolakis & Bogdanis, 2012). However, duration of SS seems to be the most crucial factor affecting on subsequent athletic performance (Chaouachi et al., 2009; Dalrymple et al., 2010; Gonzalez-Rave, Machado, Navarro-Valdivielso, & Vilas-Boas, 2009; Little & Williams, 2006; J. R. Murphy et al., 2010; Robbins & Scheuermann, 2008; Tsolakis & Bogdanis, 2012), with longer strech duration results in greater impairment in performance (Kallerud & Gleeson, 2013; Kay & Blazevich, 2012; Simic et al., 2013).

Some studies conducted on trained athletes found no detrimental effect of SS on vertical jump performance that contradicted our findings. Dalrymple et al. (2010) and Little & Williams (2006) used shorter duration of SS (≈ 5.5 min and 4 min, respectively) compared with our S-SS and found no performance change in CMJ. In contrast, Tsolakis & Bogdanis (2012) demonstrated a 4.5 min SS-induced impairment in CMJ. Brief intermittent SS protocols (3.6 min and 2.5 min, respectively) in the studies of J. R. Murphy et al.(2010) and Curry et al. (2009) revealed a performance enhancing effect of SS. Brief SS has been suggested to put less stress on muscles that allows performance enhancement via warm-up induced metabolic and neural excitation (J. R. Murphy et al., 2010). However, Tsolakis & Bogdanis (2012) found no performance enhanching effect even after 1.5 min brief SS. In other studies (Fletcher & Monte-Colombo, 2010; Tsolakis et al., 2010; Unick et al., 2005) that used similar stretching durations with the S-SS in our study, SS was found to have no detrimental effect on vertical jump, being inconsistent with our finding. This inconsistency could be resulted from differences in aforementioned SS protocol variables. Chaouachi et al. (2009) conducted a study on highly trained males with a total SS duration of 8 min. Although this duration was longer than our S-SS, no impairment was detected in their study that contradicted our finding. This was quite likely due to the additional 5 min explosive type warm-up activity included in their study design performed after SS and prior to CMJ performance. Any kind of possible stretch-induced jump performance reduction in their study –if indeed there was any– might have been masked by the possible post activation potentiation effect of prior explosive type warm-up activity (Chaouachi et al., 2009; Little & Williams, 2006). In contrary to aforementioned findings, a reduction in vertical jump performance after 5 min SS was demonstrated in the study of Hough et al. (2009) that was in line with our findings.

Time period between SS and jump performance should be considered in the evaluation of possible SS-induced effects on performance measures (Hough et al., 2009; Unick et al., 2005) since these effects are time-sensitive. Therefore, assessing residual effects of SS on athletic performance is of great importance. Curry et al. (2009) conducted a study on untrained females who performed 7.2 minutes of SS. Insignificant reduction was detected in CMJ 5 min post SS, however –interestingly– impairment in CMJ was observed 30 min post SS. This impairment was likely due to decrease in muscle temperature (J. R. Murphy et al., 2010) rather than a possible delayed effect of SS since participants sat down quietly for 25 minutes between the two testing time points. Possible loss of interest or motivation during this inactive period might have been another cause of the impairment. Although muscle temperature was not measured in our study, results were unlikely affected by this variable as our participants walked for three minutes during rest periods to maintain muscle temperature. Dalrymple et al. (2010) investigated the effects of ≈ 5.5 min SS on CMJ across 5 min post SS measured by 1 min intervals. No significant reduction was found in CMJ in none of the testing time points. The researchers claimed that no impairment in CMJ might have been due to structural muscle characteristics of female athletes that made them less susceptible to stretch-induced impairment in CMJ compared with males. Twelve untrained male participants performed 13.5 min SS in the study of Power et al. (2004). Unilateral concentric only jump and drop jump performances were found to be unaffected by SS for 120 min. Testing intervals were much greater in their study compared with ours. Also, jump types were different. Since the characteristics of stretch-shortening cycle differ dramatically between concentric only jump, drop jump, and CMJ, performances during these jumps after SS may be affected differently (Behm & Chaouachi, 2011). Therefore, comparison of their results with those in the current study was quite difficult. However, possible reduction in muscle temperature (J. R. Murphy et al., 2010) during 18 min rest period immediately before the post-test measurement in the control condition and 30 min intervals between testing time points in their study design could be regarded a crucial issue threatening the reliability of their study results.

Our study resembles that of Unick et al. (2005) who found no detrimental effect of SS on CMJ of trained basketball players at 4th, 15th, and 30th minute after SS. Well-trained basketball players are accustomed to high intensity and high volume plyometric drills in trainings and perform a great number of jumps during competitions. Therefore, familiarity of participants with the testing skill (CMJ) and possible chronic training adaptations to jumping activities such as enhanced neuromuscular recovery might have offset the possible negative effects of SS on CMJ performance in these athletes (Dalrymple et al., 2010; Unick et al., 2005). Similar mechanism could also be the cause of no CMJ impairment in female volleyball players after SS in the study of Dalrymple et al. (2010) since volleyball players are also highly familiarized with jumping skills. Besides, most combat sports are performed on relatively soft floors that might make the neuromuscular adaptation to plyometric type activities more difficult to occur compared to activities on hard floors. This might have been another reason why inhibitory effect of SS on CMJ persisted over the course of 20 min in combat athletes in our study.

J. R. Murphy et al. (2010) demonstrated performance enhancing effect of 3.6 min SS protocol on CMJ that persisted for 10 min. The submaximal intensity of SS (80% of maximal discomfort) and low volume of SS used in their study were likely causes of contradiction between their study results and our findings.

There are several studies demonstrating that detrimental effects of SS originated dominantly from neural inhibition rather than changes in mechanical characteristics of stretched muscles such as decreased muscle stiffness or increased musculotendinous compliance that alters force-length relationship (Cornwell et al., 2002; Cramer et al., 2005; Power et al., 2004; Tsolakis & Bogdanis, 2012; Unick et al., 2005). Although no neurophysiological assessment was performed during our study, it is likely that neural inhibition is the dominant mechanism that caused CMJ reduction over 20 min post stretch recovery period in the current study according to literature knowledge.

It has been stated that neuromuscular inhibition is the primary cause of any performance reduction in vertical jump height within 4-minute post-SS. This time period is reported to be sufficient for the recovery of motor neuron excitability (Avela, Kyrolainen, Komi, & Rama, 1999). It was also reported that 5 min recovery is sufficient for any possible negative effects of SS to disappear (Chaouachi et al., 2009; Hough et al., 2009). However, very high intensity SS was used in the current study. This high intensity SS might have caused a long lasting decrease in muscle spindle sensitivity which in turn might have resulted in reduction of motor unit recruitment and CMJ performance (Avela et al., 1999; Fletcher & Monte-Colombo, 2010) that persisted for a relatively long time period (20 min).

No significant difference both in the decrease and recovery of CMJ performance between S-SS and L-SS might have been resulted from a possible threshold for high intensity SS volume in lower body. Accordingly, a lower body SS volume greater than approximately 6 min might have no extra impairment effect on CMJ performance. However, this could only be regarded speculation and needs further investigation.

The conflicting results regarding the effects of acute stretching protocols on CMJ in the literature could also be resulted from the design of the conducted studies (Kay & Blazevich, 2012). The intra-individual variability of the participants should be considered in testing protocols. Reporting the relative and absolute reliability statistics is the easiest way to show that performed studies include no biased results. By this way, it could be identified whether the magnitude of the differences between control condition and intervention(s) are within the limits of data variability (Kay & Blazevich, 2012). However, reliability statistics were not reported in several studies (Church et al., 2001; Curry et al., 2009; Dalrymple et al., 2010; Fletcher & Monte-Colombo, 2010; Hough et al., 2009; J. R. Murphy et al., 2010; Young & Elliott, 2001). In these studies, measurement of baseline vertical jump value was not repeated on each intervention days. Main assumption of these studies was that baseline (resting) vertical jump values in the intervention days (if they had been measured) were exactly the same as that in the control condition. This assumption had no solid scientific foundation since possible systematic errors (intra-individual changes) might have affected on the research results and this issue cannot be disproved as no reliability statistics were available. Results of studies with no reliability statistics should be evaluated with caution since they may include systematic errors. Especially in trained athletes, even very small changes in performance measures were highly beneficial in practice. Therefore, assessing these performance changes reliably is far more important in studies including trained participants. Our study design allowed performing reliability statistics that revealed very high reliability levels (Table 1). This issue indicated that our results were unlikely affected by systematic errors in the pre-test measurements.

Traditional statistical analyses generally use mean scores; therefore, their conclusions are relevant to an "average" athlete. However, in practice, there are very few "average" athletes in the sports field. This issue emphasizes the importance of interpreting the study results on an individual basis. Analyses depending on $MDC_{90}$ scores are important for individuals for practical use. As seen in Figure 3, majority of participants had CMJ height reductions exceeding $MDC_{90}$ limit (real change limit) during $CMJ_{HH}$ that depends dominantly on explosive strength of lower body muscles.

Therefore, stretching protocols in our study that led to apparent explosive strength reductions in most of our female athletes could be regarded as unfavourable warm up routines. Even very small changes in performance levels of elite and/or well-trained athletes are critical in the struggle for the gold medal since these athletes are close to their genetic potentials. Therefore, low level inhibitory effect of SS in our study may also be regarded as a critical individual threat for most of the well-trained female athletes according to our SWC results (Figure 4). When the importance of lower body explosive strength is considered in combat sports, it is reasonable to conclude that these small explosive strength reductions may serve as one of the critical factors that decide the loser between two well-trained athletes of the same calibre.

The current study adds to the limited number studies on well-trained female athletes regarding the residual effects of SS on vertical jump performance. Short and long duration static stretching protocols including at the total of 6 minutes and 12 minutes of lower body stretches, respectively, led to a significant reduction in CMJ performances to a similar extent. CMJ performances remained significantly diminished throughout the 20-minute recovery period. Accordingly, use of static stretching protocols ≥ 6 minutes prior to competitions and/or training sessions may lead to impairment in lower body explosive strength of well-trained female combat athletes that persists at least 20 minutes. This impairment may also indirectly hinder their sport-specific performance since combat sports include a great deal of movement patterns related to lower body explosive strength.

Training modalities that would lead to individual performance enhancement of approximate 2.4 cm and 1.5 cm in $CMJ_{AS}$ and $CMJ_{HH}$, respectively, may be considered as effective training modalities to enhance lower body explosive strength of well-trained female combat athletes provided that our study sample was a good representative of this population.

Future studies should consider investigating effects of SS and its variables on various performance measures of well-trained athletes, as well as physiological mechanisms of SS-induced possible inhibitory effects, to clarify the uncertainty regarding these issues.

The small sample size is the main limitation of the current study. In addition, CMJ performances were not assessed beyond the 20 min recovery period, hence we were not able to detect the exact moment for the disappearance of inhibitory effect of SS in the current study.

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