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Research article

Effects of Static and Dynamic Stretching on the Isokinetic Peak Torques and Electromyographic Activities of the Antagonist Muscles

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Abstract
The aim of this study was to investigate if static and dynamic stretching exercises of the knee muscles (quadriceps and hamstring muscles) have any effects on concentric and eccentric isokinetic peak torques and electromyographic amplitudes (EMG) of the antagonist muscles. Twenty healthy male athletes (age between 18-30 years) voluntarily participated in this study. All of the subjects visited the laboratory to complete the following intervention in a randomized order on 5 separate days; (a) non-stretching (control), (b) static stretching of the quadriceps muscles, (c) static stretching of the hamstring muscles, (d) dynamic stretching of the quadriceps muscles, and (e) dynamic stretching of the hamstring muscles. Static stretching exercises either for the quadriceps or the hamstring muscles were carried out at the standing and sitting positions. Subjects performed four successive repetitions of each stretching exercises for 30 seconds in both stretching positions. Similar to static stretching exercises two different stretching modes were designed for dynamic stretching exercises. Concentric and eccentric isokinetic peak torque for the non-stretched antagonist quadriceps or hamstring muscles at angular velocities of 60°/sec and 240°/sec and their concurrent electromyographic (EMG) activities were measured before and immediately after the intervention. Isokinetic peak torques of the non-stretched agonist hamstring and quadriceps muscles did not represent any significant ($p > 0.05$) differences following static and dynamic stretching of the antagonist quadriceps and hamstring muscles, respectively. Similarly, the EMG activities of the agonist muscles exhibited no significant alterations ($p > 0.05$) following both stretching exercises of the antagonist muscles. According to the results of the present study it is possible to state that antagonist stretching exercises either in the static or dynamic modes do not affect the isokinetic peak torques and the EMG activities of the non-stretched agonist quadriceps or hamstring muscles.

Key words: Antagonist muscle, stretching, EMG, strength.

Introduction

There are various types of stretching exercises used according to individual preference of athletes or trainers. Ballistic, proprioceptive neuromuscular facilitation (PNF), static and dynamic stretching are the most used stretching techniques (Hedrick, 2000). Since its easy and safe application, static stretching is the first ranked and broadly preferred stretching method among athletes (Alter, 1997; Hedrick, 2000). Recently, a number of comprehensive review articles have indicated that prolonged static stretching can compromise isometric and isokinetic force output (Behm and Chaouachi, 2011; Behm et al., 2016; Kay and Blazevich, 2012; Simic et al., 2013), whereas dynamic stretching may have either no adverse effect or improve subsequent muscle strength performance (Sekir et al., 2010; Yamaguchi et al., 2007; Yamaguchi and Ishii, 2005), although the overall increases were of small to moderate magnitude (Behm and Chaouachi, 2011; Behm et al., 2016). When the studies were scrutinized, it is obvious that the strength measurements were performed only in the stretched muscles (Behm and Chaouachi, 2011; Behm et al., 2016; Kay and Blazevich, 2012; Simic et al., 2013). However, it is known that during sport activities antagonist muscle co-activations are common to prevent overloading to a joint (Aagaard et al., 1998). Stated in other words, the final external force is directly proportional to the force generated from the agonist muscles and indirectly proportional to the force generated from the antagonist muscles (Baratta et al., 1988; Draganich et al., 1989). On the basis of the evidence that static stretching decreases and dynamic stretching increases muscle strength performance, it can be hypothesized that alterations of muscle strength in the antagonist muscles, either increase with dynamic or decrease with static stretching exercises, could have impacts on the agonist muscles by decreasing or increasing their strength, respectively. Few studies have investigated the effects of antagonist muscle stretching on performance of the agonist muscles (Sandberg et al., 2012; Wakefield and Cottrell, 2015). Sandberg et al. (2012) aimed to investigate the effects of static stretching of antagonist musculature on multiple strength and power measures. They showed that static stretching of the hip flexors and ankle dorsiflexors may enhance vertical jump height and power during countermovement vertical jump, and static stretching of the hamstrings may generate greater isokinetic quadriceps torque production during high angular velocities (300°/sec), with no differences during slower angular velocities (60°/sec). Wakefield and Cottrell (2015) investigated the effects static stretching of hip flexor muscles on vertical jump height. The authors concluded that vertical jump height decreased by 1.74% following static stretching of the agonist muscles (hip extensors) and increased by 1.74% following static stretching of the antagonist muscles (hip flexors). Even though the effects of antagonist static stretching on jump performance provided from the literature, no study to date has investigated the effects of static and dynamic stretching of the antagonist muscles on strength performance of the agonist muscles.

Therefore, the aim of this study was to investigate if static and dynamic stretching exercises of the knee muscles (quadriceps and hamstring muscles) have any

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effects on concentric and eccentric isokinetic peak torques and electromyographic amplitudes (EMG) of the non-stretched antagonist muscles.

Methods

Subjects

Twenty healthy male recreational athletes (24.8 ± 2.8 years; 1.77 ± 0.06 m; 72.7 ± 7.8 kg) voluntarily participated in this study. All subjects were recreational athletes, participating in regular sports activities like, running, soccer, basketball or tennis one time per week. The test procedure was conducted in the dominant leg of the subjects, which was the right leg in 14 and left leg in 6 subjects. The dominant leg was determined according to the declaration of the subjects which leg they are using naturally to kick a ball. Any subject with a current or recent ankle-, knee-, hip-, or low-back-related injury, complaining of swelling, pain or functional limitations in these joints, or having an obvious range of motion limitation in the knee were excluded from the study. Afterwards, the subjects read and signed the informed consent form about the test procedures, and any possible risks and discomfort that might ensue that was approved by the University's Institutional Ethical Board for Protection of Human Subjects (Approval number: 2009-3/76).

Experimental procedure

Before the procedures, each subject was asked to be present in the laboratory to give him information about the stretching exercises and strength measurements. Thereafter in the same day, they participated to a familiarization trial to practice isokinetic knee extensor and flexor strength measurements in concentric and eccentric modes at the selected two angular velocities (60°/sec and 240°/sec). When the subjects attended the laboratory on the next time, they carried out the following intervention protocol in a randomized order on 5 separate days; (a) non-stretching (control), (b) static stretching of the quadriceps muscles, (c) static stretching of the hamstring muscles, (d) dynamic stretching of the quadriceps muscles, and (e) dynamic stretching of the hamstring muscles. Since static stretching exercises either for the quadriceps or the hamstring muscles were carried out in the standing and sitting positions two different stretching modes were designed for dynamic stretching exercises. Concentric and eccentric isokinetic peak torque for the non-stretched antagonist quadriceps or hamstring muscles at angular velocities of 60°/sec and 240°/sec and their concurrent electromyographic (EMG) activities recorded with a portable 8-channel EMG device were measured before the intervention protocol (pre) and immediately after (post). Each subject performed a warm-up on a stationary cycle ergometer for 5 minutes at 50W to enable the subjects be ready before the first isokinetic test procedure. Furthermore, since the duration of static and dynamic stretching exercise took 7 ± 1 minutes, the subjects rested for 7 minutes between the strength measurements in the non-stretching (control) intervention.

Static stretching exercises

The hamstring or quadriceps muscles of the dominant lower extremity were stretched with two unassisted methods. Each unassisted static stretching exercise was performed four times for 30 seconds to the level of mild discomfort, but not pain, as acknowledged by the subject. The rest interval between the four repetitions and between the two unassisted stretching routines was 20 and 30 seconds, respectively. Accordingly, the total static stretching time interval for the hamstring or quadriceps muscle was 7 ± 1 minutes. A detailed description of the same hamstring (Figure 1) or quadriceps (Figure 2) static stretching exercises in the sitting and standing positions used in this study has been published previously by Sekir et al. (2010).

Figure 1. Static stretching for the hamstring muscle in standing and sitting position.

Figure 2. Static stretching for the quadriceps muscle in standing and sitting position.

Dynamic stretching exercises

To be similar with the static stretching exercises, two different stretching methods both for the hamstring and quadriceps muscles were composed for the dynamic stretching routines. The subjects were instructed to contract the opposite muscle of the target muscle (either hamstring or quadriceps) intentionally in the standing upright position and extended or flexed the hip or knee joints once every 2 seconds so that the target muscle was stretched. Before the dynamic stretching exercise, each subject was informed which muscle group they should be contract. Every stretching exercise was repeated four times, slowly at first, and then 15 times as quickly and powerfully as possible without bouncing. The rest interval between the four repetitions and between the two stretching routines was 20 and 30 seconds, respectively. Accordingly, the total dynamic stretching time interval for the hamstring or quadriceps muscle was 7 ± 1 minutes. A detailed description of the same hamstring (Figure 3) or quadriceps (Figure 4) dynamic stretching exercises in two different stretching methods used in this study has been published previously by Sekir et al. (2010).

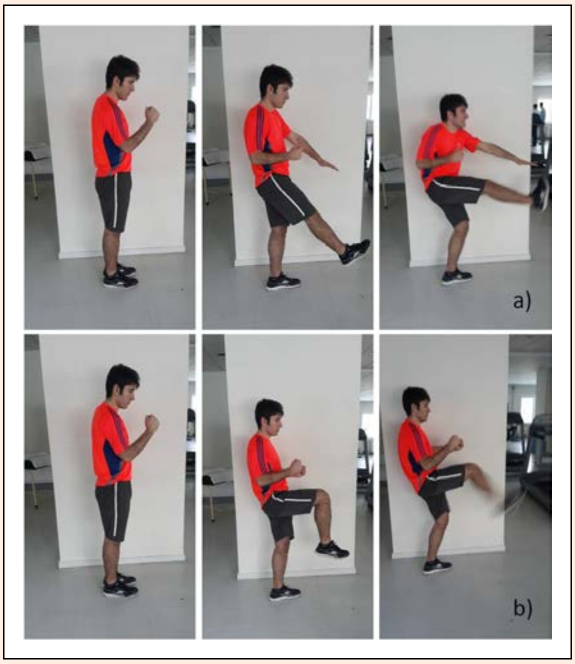

Figure 3. **The two different dynamic stretching methods for the hamstring muscle.**

Isokinetic testing

The Cybex NORM isokinetic system (Lumex Inc., Ronkonkoma, New York, USA) was used for the concentric and eccentric peak torque (PT) measurements of the non-stretched quadriceps or hamstring muscles. A detailed description of the same isokinetic strength measurement protocol used in his study, including instrumentation, calibration, subject preparation, familiarization, and testing procedure, has been published previously by Sekir et al. (2010). Briefly, the concentric and eccentric PT measurements for the non-stretched antagonist hamstring or quadriceps muscle were carried out separately; concentric measurements were performed firstly. At the beginning of the test condition, subjects were allowed three submaximal contractions of the hamstring or quadriceps muscle group to familiarize themselves with the test conditions. Following the three submaximal trials, they were given four maximal contractions at the angular velocities of 60 and 240°/sec. Same angular velocities were used in the eccentric strength measurements as in the concentric measurements. To prevent the build-up of fatigue one and three minutes of rest, respectively, was allowed between each of the test velocities and between the concentric and eccentric measurements. The best PT of the four maximal repetitions for each test condition was collected and used for data analysis.

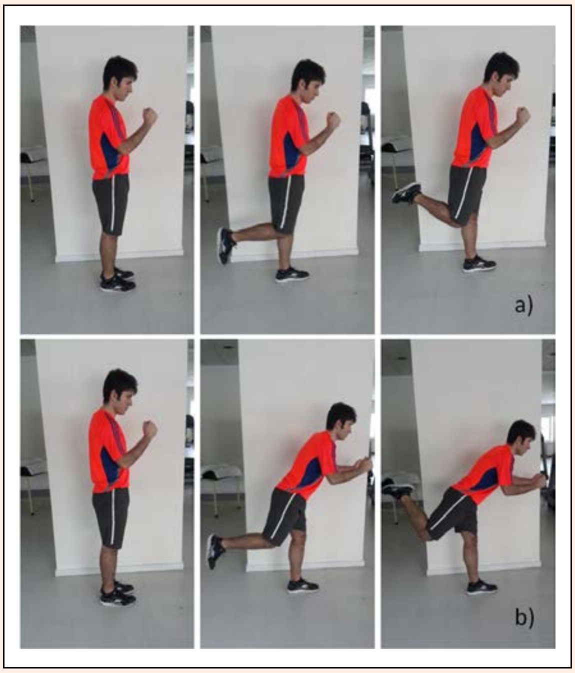

Figure 4. **The two different dynamic stretching methods for the quadriceps muscle.**

EMG measurements

The electromyographic (EMG) activity was recorded from the leg flexor [biceps femoris (BF) and semitendinosus (ST)] and extensor (vastus lateralis and rectus femoris) muscles with a portable 8-channel Muscle TesterTM device (ME6000, Mega Electronics, Kuopio, Finland). Bipolar pregelled Ag/AgCl surface electrodes (Covidien-KendallTM electrodes with a 0.8 cm silver-silver chloride disks; CovidienIlc, Mansfield, USA) were used to record the EMG from these muscles. A detailed description about the same EMG measurement protocol as in this study, including skin preparation, electrode placement over the muscles of the vastus lateralis, rectus femoris, BF, and ST, signal amplification, storage in the microcomputer, and sampling of the analog EMG signal was published previously by Sekir et al. (2010). Consequently, the raw EMG amplitude values (mV) from the transmitted data to a personal computer were calculated automatically by means of ME6000 software (MegaWin v3.1, Mega Electronics) for a period that corresponded to a 90° range of motion from approximately full leg extension to 90° of flexion or from 90° of flexion to full leg extension at the knee. The stored raw EMG data were expressed as absolute root-mean-square amplitude values (mV) by the software. The values calculated from the EMG signals were synchronized to the isokinetic data using the onset of the EMG signal as the onset of concentric and eccentric torque production; therefore, the representative isokinetic values corresponded to EMG values.

Normalization

The EMG amplitude was normalized against the MVC trial that yielded the highest PT value and was carried out before the stretching and first isokinetic testing intervention. MVCs were attained during the isometric contractions on the isokinetic dynamometer at 60° of knee flexion for leg extensors (vastus lateralis and rectus femoris) and 30° of knee flexion for leg flexors (BF and ST). The mean muscular activity for the four concerned muscle group was expressed separately as the percentage (%MVC) of the amplitude values obtained during the middle 2-s epoch of the 5-s MVC trial. In this way, normalization of the EMG amplitude values allowed for comparisons between muscles, limbs, and velocities (Soderberg and Knutson, 2000).

Statistical analysis

Statistical analysis was performed using SPSS version 16.0 (SPSS, SPSS Inc, Chicago, Illinois, USA) software. Mean, standard error of mean, and 95% confidence intervals were used to describe all variables. All tests were two-tailed and the level of significance was set at $p < 0.05$. A power analysis was performed based on the reported values of the study. According to the analysis, group sample sizes of *n*1 = 19 achieved 91% power to detect a mean difference = 5.0 and standard deviations of groups = 5.3 with a significance level (alpha) of 0.05. Repeated-measures 3 (stretch type) x 2 (time) analysis of variance (ANOVA) model was used for comparisons of changes in strength and normalized EMG parameters (%MVC) in both stretching conditions (static and dynamic stretching) and the non-stretching control condition for each muscle. When an appropriate and significant interaction was indicated, follow-up analyses included paired-samples *t*-tests to examine the difference between pre-and post-intervention within the three stretching conditions. In addition, a one-way ANOVA model was used to see whether there was a probability for a significant difference among the three groups' pre-test mean scores.

Results

Strength

The mean PT values, including concentric and eccentric strength, of the hamstring muscle following stretching intervention of the antagonist quadriceps muscle, and of the quadriceps muscle following stretching intervention of the antagonist hamstring muscle are presented in Tables 1 and 2, respectively. According to the 3 x 2 ANOVA model, there were no significant main effects or group x time interactions between the groups for all the measured strength parameters ($p > 0.05$).

EMG

Tables 3 and 4 represent the mean values for the normalized EMG amplitudes in the three groups during concentric and eccentric test modes at both velocities (60 and 240°/sec) for the hamstring muscle (BF and ST) following antagonist quadriceps stretching intervention and for the quadriceps muscle (rectus femoris and vastus lateralis) following antagonist hamstring stretching intervention, respectively. After executing the 3 x 2 ANOVA model, the normalized EMG amplitude values for the hamstring muscle after antagonist quadriceps stretching intervention and for the quadriceps muscle after antagonist hamstring stretching intervention did not show any significant main effects or group x time interactions ($p > 0.05$).

Discussion

Studies present in the literature about stretching have mostly investigated muscle strength variability only in the stretched muscles. At the same time, there are recent studies investigating crossover effects of stretching as

Table 1. Peak muscle strength of the hamstring before and after stretching of the contrary quadriceps muscle in the three groups [mean ± SEM (95% CI)].

	Static		Dynamic		Control		*P* value
	Before	After	Before	After	Before	After	(group x time)
Con60 (Nm)	156 ± 6 (142-169)	158 ± 7 (144-172)	156 ± 6 (143-168)	153 ± 5 (142-175)	160 ± 6 (148-171)	155 ± 5 (143-166)	>0.05
Con240 (Nm)	99 ± 4 (91-108)	98 ± 4 (91-107)	97 ± 4 (90-105)	96 ± 5 (86-106)	94 ± 4 (86-103)	93 ± 5 (83-102)	>0.05
Ecc60 (Nm)	198 ± 8 (182-214)	196 ± 8 (180-213)	195 ± 10 (174-215)	188 ± 8 (172-204)	197 ± 8 (180-214)	189 ± 8 (172-206)	>0.05
Ecc240 (Nm)	178 ± 6 (166-191)	172 ± 7 (158-187)	166 ± 5 (156-177)	169 ± 7 (154-183)	178 ± 8 (161-196)	177 ± 8 (160-194)	>0.05

Con: Concentric; Ecc: Eccentric; 60: 60°/sec angular velocity; 240: 240°/sec angular velocity; Nm: Newton-meter.

Table 2. Peak muscle strength of the quadriceps before and after stretching of the contrary hamstring muscle in the three groups [mean ± SEM (95% CI)].

	Static		Dynamic		Control		*P* value
	Before	After	Before	After	Before	After	(group x time)
Con60 (Nm)	219 ± 7 (204-234)	226 ± 7 (211-241)	228 ± 9 (210-247)	231 ± 9 (211-250)	227 ± 9 (208-247)	227 ± 9 (207-246)	>0.05
Con240 (Nm)	113 ± 4 (105-122)	117 ± 4 (108-126)	118 ± 5 (108-128)	118 ± 6 (106-129)	116 ± 4 (108-125)	117 ± 4 (108-125)	>0.05
Ecc60 (Nm)	286 ± 9 (267-305)	289 ± 11 (265-312)	299 ± 10 (279-319)	304 ± 10 (283-325)	292 ± 11 (270-314)	287 ± 13 (261-313)	>0.05
Ecc240 (Nm)	259 ± 7 (244-274)	259 ± 10 (239-279)	266 ± 8 (250-282)	274 ± 9 (256-292)	264 ± 13 (236-291)	260 ± 10 (240-280)	>0.05

Con: Concentric; Ecc: Eccentric; 60: 60°/sec angular velocity; 240: 240°/sec angular velocity; Nm: Newton-meter.

Table 3. Normalized EMG amplitude values from the biceps femoris and semitendinosus muscles before and after stretching of the contrary quadriceps muscle in the three groups during the isokinetic leg flexion and extension movements in concentric and eccentric modes [mean ± SEM (95% CI)].

	Static		Dynamic		Control		*P* value
	Before	After	Before	After	Before	After	(group x time)
ConST60 (%MVC)	76 ± 6 (63-88)	75 ± 6 (63-87)	73 ± 6 (61-85)	71 ± 6 (58-83)	88 ± 6 (74-101)	80 ± 4 (71-89)	>0.05
ConBF60 (%MVC)	75 ± 5 (64-85)	73 ± 5 (63-83)	77 ± 6 (64-90)	77 ± 7 (64-91)	76 ± 5 (65-87)	71 ± 4 (62-79)	>0.05
ConST240 (%MVC)	63 ± 6 (50-75)	60 ± 5 (49-71)	54 ± 6 (41-67)	56 ± 5 (46-66)	66 ± 5 (56-76)	66 ± 5 (56-75)	>0.05
ConBF240 (%MVC)	67 ± 6 (55-80)	66 ± 5 (56-76)	71 ± 7 (58-85)	70 ± 7 (56-84)	68 ± 6 (55-81)	66 ± 6 (53-79)	>0.05
EccST60 (%MVC)	74 ± 6 (60-87)	78 ± 7 (64-91)	69 ± 6 (57-80)	67 ± 5 (55-78)	71 ± 4 (62-80)	73 ± 5 (62-84)	>0.05
EccBF60 (%MVC)	66 ± 3 (59-73)	67 ± 3 (61-74)	68 ± 4 (59-77)	69 ± 5 (59-78)	69 ± 5 (59-78)	69 ± 4 (60-78)	>0.05
EccST240 (%MVC)	64 ± 6 (51-77)	63 ± 6 (50-77)	57 ± 6 (45-68)	52 ± 5 (41-63)	60 ± 4 (51-68)	62 ± 4 (53-71)	>0.05
EccBF240 (%MVC)	57 ± 3 (50-64)	54 ± 4 (46-62)	58 ± 4 (49-66)	60 ± 5 (48-71)	57 ± 6 (45-69)	62 ± 5 (51-73)	>0.05

Con: Concentric; Ecc: Eccentric; ST: Semitendinosus; BF: Biceps femoris; MVC: Maximal voluntary contraction.

Table 4. Normalized EMG amplitude values from the rectus femoris and vastus lateralis muscles before and after stretching of the contrary hamstring muscle in the three groups during the isokinetic leg extension and flexion movements in concentric and eccentric modes [mean ± SEM (95% CI)].

	Static		Dynamic		Control		*P* value
	Before	After	Before	After	Before	After	(group x time)
ConRF60 (%MVC)	76 ± 4 (68-85)	76 ± 4 (69-84)	81 ± 4 (73-90)	84 ± 6 (72-95)	88 ± 5 (77-98)	83 ± 4 (75-92)	>0.05
ConVL60 (%MVC)	76 ± 4 (68-83)	77 ± 4 (69-85)	77 ± 4 (69-86)	77 ± 4 (69-86)	83 ± 5 (72-93)	79 ± 4 (71-86)	>0.05
ConRF240 (%MVC)	67 ± 3 (61-74)	68 ± 4 (60-75)	68 ± 4 (60-75)	66 ± 4 (58-74)	74 ± 5 (64-83)	73 ± 5 (62-84)	>0.05
ConVL240 (%MVC)	72 ± 4 (64-80)	69 ± 5 (59-79)	77 ± 5 (67-87)	73 ± 5 (63-82)	76 ± 6 (63-89)	71 ± 5 (60-82)	>0.05
EccRF60 (%MVC)	60 ± 3 (53-66)	58 ± 3 (52-64)	58 ± 5 (48-68)	61 ± 4 (52-69)	62 ± 3 (55-69)	65 ± 4 (57-72)	>0.05
EccVL60 (%MVC)	61 ± 5 (52-71)	60 ± 4 (52-69)	61 ± 4 (54-69)	65 ± 4 (56-74)	66 ± 6 (54-78)	65 ± 5 (54-75)	>0.05
EccRF240 (%MVC)	55 ± 4 (47-64)	52 ± 3 (45-58)	53 ± 4 (45-62)	54 ± 4 (46-62)	54 ± 4 (47-62)	55 ± 4 (47-63)	>0.05
EccVL240 (%MVC)	53 ± 6 (42-65)	52 ± 5 (42-61)	55 ± 4 (46-64)	53 ± 5 (43-63)	52 ± 6 (38-65)	55 ± 7 (40-69)	>0.05

Con: Concentric; Ecc: Eccentric; RF: Rectus femoris; VL: Vastus lateralis; MVC: Maximal voluntary contraction.

well (Behm et al., 2016; Chaouachi et al., 2015; Jarbas da Silva et al., 2015; Lima et al., 2014; Marchetti et al., 2014). For instance, these studies focused mainly on the crossover effects of (a) upper body stretching on lower body ROM (Behm et al., 2016), jump performance (Marchetti et al., 2014) and strength (Behm et al., 2016), (b) lower body stretching on upper body ROM (Behm et al., 2016) and strength (Behm et al., 2016), and (c) ipsilateral stretching on contralateral ROM (Chaouachi et al., 2015; Jarbas da Silva et al., 2015; Lima et al., 2014), single-leg bounce drop jump performance (Jarbas da Silva et al., 2015), balance (Lima et al., 2014), muscular activity (Lima et al., 2014) and strength (Chaouachi et al., 2015). Beside these crossover effects, there is limited evidence demonstrating strength responses of the ipsilateral non-stretched antagonist muscles. The main purpose of our study was to display changes in strength of the agonist muscles following stretching of the antagonist muscles, either statically or dynamically. In brief, the results of the present study revealed that static and dynamic stretching exercises of the antagonist muscles do not have any effects on isokinetic muscle strength and EMG activity of the non-stretched agonist muscles.

The antagonist muscles of the agonists, crossing the same joint, are activated coordinately during dynamic movements to hold a position. This phenomenon is defined as muscle co-activation (Bazzucchi et al., 2006; Busse et al., 2006; Xiong et al., 2015). It was suggested that co-activation of the antagonist muscles is necessary to provide movement accuracy and energy efficiency (Higginson et al., 2006). On the basis of this co-activation effect of the muscles, it was stated that antagonist static stretching may induce increases in non-stretched agonist muscle activation and elastic energy storage, and decreases of antagonist co-activation (Paz et al., 2012; Roy et al., 1990; Sandberg et al., 2012). It was also proposed that co-activation of the antagonist muscles would impair the resultant muscle torque of the agonists (Bazzucchi et al., 2006). Accordingly, based on the results of the recent review articles that investigated the effects of static stretching and suggested negative effects in muscle torque with prolonged static stretching (Behm and Chaouachi, 2011; Behm et al., 2016; Kay and Blazevich, 2012; Simic et al., 2013) a possible increase in strength in the agonist muscles following antagonist static stretching could be assumed. Similarly, when the review articles about dynamic stretching is taken in consideration, which displayed trivial to small magnitude increases in muscle strength following dynamic stretching (Behm and Chaouachi, 2011; Behm et al., 2016), a decrease in strength in the opposing muscles of the dynamically stretched muscles would be expected. However, few studies up to date have investigated this hypothesis (Miranda et al., 2015; Paz et al., 2012; Sandberg et al., 2012; Wakefield and Cottrell, 2015). All of the authors incorporated static stretching routines in their studies. This is the first published study, to our knowledge that utilizes dynamic stretching to the antagonist muscles and examines the effects of strength performance in the non-stretched agonist muscles.

The limited numbers of studies in the literature about antagonist stretching have examined the effects of antagonist static stretching on strength (Sandberg et al., 2012), vertical jump performance (Sandberg et al., 2012; Wakefield and Cottrell, 2015) and muscle activation (Miranda et al., 2015; Paz et al., 2012). Sandberg et al. (2012) aimed to investigate the effects of static stretching of antagonist muscles involved during vertical jump performance on various strength and power measures. They elicited significant but small effect size, 9.3% greater knee extension torque during fast angular velocities (300°/sec) but not with slow velocities (60°/sec), with no change in agonist EMG activity following static stretching of the hamstring muscles (3 x 30 second). The antagonist static stretching of the hip flexors and ankle dorsiflexors (3 x 30 second each) also increased vertical jump height by 1.2 cm. Even these results, the authors expressed that practitioners may experiment with static stretching the antagonist muscles to improve performance in high-velocity activities. In partially agreement with this ~~only~~ study investigating torque changes following antagonist stretching, the current study did also not show any torque and EMG differences at slow (60°/sec) and any EMG differences at high (240°/sec) angular velocities both in the knee extensors following static and dynamic stretching of the knee flexors, and in the knee flexors following static and dynamic stretching of the knee extensors. The effects of antagonist static (Miranda et al., 2015) and proprioceptive neuromuscular facilitation (PNF) (Paz et al., 2012) stretching (pectoralis major muscle) on agonist muscle activity (latissimus dorsi and biceps brachii) were investigated. Whereas the same amount of antagonist static stretching produced significant increases in the agonist muscles (Miranda et al., 2015), no significant differences were observed following antagonist PNF stretching (Paz et al., 2012) during seated row resistance exercise test. Nevertheless, the EMG activity of the stretched antagonist muscles (pectoralis major) represented no significant reductions. Miranda et al. (2015) suggested that other mechanical and metabolic mechanisms such as alterations in the acute sensitivity of muscle specific proprioceptors, fatigue and elastic storage rather than a reduction in antagonist co-activation induced by antagonist passive stretching would be associated with the increase in activity of the agonist muscles. The study by Wakefield and Cottrell (2015) demonstrated increases in vertical jump height by 1.74% and improvements in hip extensor ROM by 6.54% following static stretching of the antagonist hip flexor muscles (rectus femoris, iliacus, and iliopsoas; 3 x 30 second). The authors concluded that antagonist muscle stretching induces agonist muscle activation, but the changes in vertical jump height were not correlated with passive hip flexor compliance.

The non-significant EMG activity changes in the agonist muscles following antagonist stretching found in the current study supports the idea that antagonist static or dynamic stretching has no effects on agonist muscle performance. There are two primary hypotheses proposed to explain the mechanisms by which static or dynamic stretching affects strength performance. These are the neuromuscular factors such as the changes in motor neuron pool excitability (Cramer et al., 2005; Herda et al., 2008; Sekir et al., 2010) and the mechanical factors involving the viscoelastic properties of the musculotendinous unit (Cramer et al., 2004; Cramer et al., 2005; Nelson et al., 2001). Cramer et al. (2005) concluded that the altered strength producing capabilities of a muscle as a result of stretching may be due to changes in muscle activation. The strength decrements following static stretching were also supported with EMG activity decreases in the stretched muscles by the study from Herda et al. (2008). Similar to these studies, Sekir et al. (2010) showed also EMG activity decrements concurrent to decreases in strength after static stretching, and EMG activity increments concurrent to increases in strength after dynamic stretching. As a result, regarding the neuromuscular factor, given that we have also measured the EMG activities in the agonist muscles, it can be hypothesized that antagonist stretching does not have any effects on non-stretched agonist muscle activities.

The results of the current study did not represent any change in agonist muscle strength after performing antagonist static or dynamic stretching. Because the aim of our study was to see the effects in the non-stretched antagonist muscles we did not focus on the stretched muscles. Therefore, it is not possible to present any change in the stretched muscles that might be exist. Besides, we think that the amount of stretching either for static or dynamic method is sufficient to produce any possible effects on performance of the stretched muscles. Static stretching routine for one muscle group (leg extensor or flexor) was performed in standing or sitting positions, each for 4 sets of 30 seconds. Similarly, dynamic stretching routine for one muscle group (leg extensor or flexor) was performed also with two different methods, each for 4 sets of 30 seconds. Accordingly, the active static or dynamic stretching time for the leg extensor or flexor muscles was 240 seconds. Decrements in torque production after static stretching and increments in torque production after dynamic stretching of the agonists have been reported in narrative (Behm and Chaouachi, 2011), systematic (Behm et al., 2016; Kay and Blazevich, 2012), and meta-analytical (Simic et al., 2013) review articles, which encompassed several studies. The total active stretching duration for each muscle varied from 30 to 480 seconds in these studies. These reviews reported a clear dose-response effect of stretching as a common result. For instance, the systematic review by Kay and Blazevich (2012) indicated evidence that static stretching of short duration (<45 second) has no detrimental effect, whereas a significant reduction likely occurred with stretches >60 second. Behm et al. (2016), in their largest systematic review to date, represented also greater performance deficits with >60 second (-4.6%) than with <60 second (-1.1%) static stretching. Behm and Chaouachi (2011) reported a dose-response effect for dynamic stretching in which greater overall peak force and power improvements were observed when >90 second (7.3%) vs. <90 second (0.5%). The meta-analytical review by Simic et al. (2013) observed a trend toward enhancing the negative acute effect of static stretching on maximal muscle strength with longer stretch duration. In particular, pooled estimates for stretching lasting <45 second, 46-90 second, and >90 second were -3.2%, -5.6%, and -6.1%, respectively. Therefore, it is possible to state that the stretch duration performed in the current study would be enough to bring out eventual changes in strength in the muscles.

Conclusion

According to the results of the present study it is possible to state that antagonist stretching exercises either in the static or dynamic modes do not affect the isokinetic peak torques and the EMG activities of the non-stretched agonist quadriceps or hamstring muscles. Further research should focus on the effects of antagonist stretching using other techniques like PNF or ballistic stretching and/or different volumes of stretching on the isokinetic peak torques and electromyographic activities of the non-strectched agonist muscles. Furthermore, these effects should be also examined in women or more physically active individuals.

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References

Aagaard, P., Simonsen, E.B., Magnusson, S.P., Larsson, B. and Dyhre-Poulsen, P. (1998) A new concept for isokinetic hamstring: quadriceps muscle strength ratio. American *Journal of Sports Medicine* **26**, 231-237.

Alter, M.J. (1997) Sports Stretch. In: *Sports Stretch.* Ed: Alter, M.J. 2nd edition. Champaign, IL: Human Kinetics. 1-232.

Baratta, R., Solomomow, M., Zhou, B., Letson, D., Chuinard, R. and D'Abrosia, R. (1988) Muscular co-contraction. The role of antagonist musculature in maintaining knee stability. *American Journal of Sports Medicine* **16**, 113-122.

Bazzucchi, I., Sbriccoli, P. and Marzattinocci, G. (2006) Coactivation of the elbow antagonist muscles is not affected by the speed of movement in isokinetic exercise**.** *Muscle & Nerve* **33**, 191-199.

Behm, D.G., Blazevich, A.J., Kay, A.D. and McHugh, M. (2016) Acute effects of muscle stretching on physical performance, range of motion, and injury incidence in healthy active individuals: a systematic review. *Applied Physiology, Nutrition, and Metabolism* **40(1)**, 1-16.

Behm, D.G. and Chaouachi, A. (2011) A review of the acute effects of static and dynamic stretching on performance. *European Journal of Applied Physiology* **111**, 2633-2651.

Behm, D.G., Cavanaugh, T., Quigley, P., Reid, J.C., Nardi, P.S.M. and Marchetti, P.H. (2016) Acute bouts of upper and lower body static and dynamic stretching increase non-local joint range of motion. *European Journal of Applied Physiology* **116**, 241-249.

Busse, M.E., Wiles, C.M. and van Deursen, R.W.M. (2006) Co-activation: its association with weakness and specific neurological pathology. *Journal of Neuroengineering and Rehabilitation* **3**, 26.

Chaouachi, A., Padulo, J., Kasmi, S., Othmen, A.B., Chatra, M. and Behm, D.G. (2015) Unilateral static and dynamic hamstrings stretching increases contralateral hip flexion range of motion. *Clinical Physiology and Functional Imaging* doi: 10.1111/cpf.12263.

Cramer, J.T., Housh, T.J., Johnson, G.O., Miller, J.M., Coburn, J.W. and Beck, T.W. (2004) Acute effects of static stretching on peak torque in women. *Journal of Strength and Conditioning Research* **18**, 236-241.

Cramer, J.T., Housh, T.J., Weir, J.P., Johnson, G.O., Coburn, J.W. and Beck, T.W. (2005) The acute effects of static stretching on peak torque, mean power output, electromyography, and mechanomyography. *European Journal of Applied Physiology* **93**, 530-539.

Draganich, L.F., Jaeger, R.J. and Kralj, A.R. (1989) Coactivation of the hamstrings and the quadriceps during extension of the knee. *The Journal of Bone and Joint Surgery* **71**, 1078-1081.

Hedrick, A. (2000) Dynamic flexibility training. *Strength and Conditioning Journal* **22(5)**, 33-38.

Herda, T.J., Cramer, J.T., Ryan, E.D. and McHugh, M.P. (2008) Acute effects of static versus dynamic stretching on isometric peak torque, electromyography, and mechanomyography of the biceps femoris muscle. *Journal of Strength and Conditioning Research* **22**, 809-817.

Higginson, J.S., Zajac, F.E., Neptune, R.R., Kautz, S.A. and Delp, S.L. (2006) Muscle contributions to support during gait in an individual with post-stroke hemiparesis *Journal of Biomechanics* **39(10)**, 1769-1777.

Jarbas da Silva, J., Behm, D.G., Gomes, W.A., de Oliveira Silva, F.H.D., Soares, E.G., Serpa, E.P., Vilela Junior, G.B., Lopes, C.R. and Marchetti, P.H. (2015) Unilateral plantar flexors static-stretching effects on ipsilateral and contralateral jump measures. *Journal of Sports Science & Medicine* **14**, 315-321.

Kay, A.D. and Blazevich, A.J. (2012) Effect of acute static stretch on maximal muscle performance: a systematic review. *Medicine and Science in Sports and Exercise* **44(1)**, 154-164.

Lima, B.N., Lucareli P.R.G., Gomes, W.A., Silva, J.J., Bley, A.S., Hartigan, E.H. and Marchetti, P.H. (2014) The acute effects of unilateral ankle plantar flexors static-stretching on postural sway and gastrocnemius muscle activity during single-leg balance tasks. *Journal of Sports Science and Medicine* **13**, 564-570.

Marchetti, P.H., de Oliveira Silva, F.H.D., Soares, E.G., Serpa, E.P., Nardi, P.S.M., Vilela, G.B. and Behm, D.G. (2014) Upper limb static-stretching protocol decreases maximal concentric jump performance. *Journal of Sports Science and Medicine* **13**, 945-950.

Miranda, H., Maia, M.D.F., Paz, G.A. and Costa, P.B. (2015) Acute Effects of Antagonist Static Stretching in the Inter-Set Rest Period on Repetition Performance and Muscle Activation. *Research in Sports Medicine* **23**, 37-50.

Nelson, A.G., Allen, J.D., Cornwell, A. and Kokkonen, J. (2001) Inhibition of maximal voluntary isometric torque production by acute stretching is joint-angle specific. *Research Quarterly for Exercise and Sport* **72**, 68-70.

Paz, G.A., Maia, M.F., Lima, V.P., Oliveira, C.G., Bezerra, E., Simao, R. and Miranda, H. (2012) Maximal exercise performance and electromyography responses after antagonist neuromuscular proprioceptive facilitation: A pilot study. *Journal of Exercise Physiology Online* **15(6)**, 60-67.

Roy, M.A., Sylvestre, M., Katch, F.I., and Lagasse, P.P. (1990) Proprioceptive facilitation of muscle tension during unilateral and bilateral knee extension. *International Journal of Sports Medicine* **11**, 289-292.

Sandberg, J.B., Wagner, D.R., Willardson, J.M. and Smith, G.A. (2012) Acute effects of antagonist stretching on jump height, torque, and electromyography of agonist musculature. *Journal of Strength and Conditioning Research* **26(5)**, 1249-1256.

Sekir, U., Arabaci, R., Akova, B. and Kadagan, S.M. (2010) Acute effects of static and dynamic stretching on leg flexor and extensor isokinetic strength in elite women athletes. *Scandinavian Journal of Medicine & Science in Sports* **20**, 268-281.

Simic, L., Sarabon, N. and Markovic, G. (2013) Does pre-exercise static stretching inhibit maximal muscular performance? A meta-analytical review. *Scandinavian Journal of Medicine & Science in Sports* **23**, 131-148.

Soderberg, G.L. and Knutson, L,M. (2000) A guide for use and interpretation of kinesiologic electromyographic data. *Physical Therapy* **80**, 485-498.

Wakefield, C.B. and Cottrell, G.T. (2015) Changes in hip flexor passive compliance do not account for improvement in vertical jump performance after hip flexor static stretching. *Journal of Strength and Conditioning Research* **29(6)**, 1601-1608.

Xiong, Q.L., Wu, X.Y., Xiao, N., Zeng, S.Y., Wan, X.P., Zheng, X.L. and Hou, W.S. (2015) Antagonist muscle co-activation of limbs in human infant crawling: A pilot study. *Conference Proceedings: … Annual International Conference of the IEEE Engineering in Medicine and Biology Society* **2015**, 2115-2118.

Yamaguchi, T., Ishii, K., Yamanaka, M. and Yasuda, K. (2007) Acute effects of dynamic stretching exercise on power output during concentric dynamic constant external resistance leg extension. *Journal of Strength and Conditioning Research* **21**, 1238-1244.

Yamaguchi, T. and Ishii, K. (2005) Effects of static stretching for 30 seconds and dynamic stretching on leg extension power. *Journal of Strength and Conditioning Research* **19**, 677-683.

Key points

- The effects of dynamic stretching of the antagonist muscles on strength performance are unknown.
- We showed that both static and dynamic stretching of the antagonist muscle does not influence strength and EMG activities in the agonist muscles.
- Further research should focus on the effects of antagonist stretching using other techniques like PNF or ballistic stretching and/or different volumes of stretching.

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