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Effects of Dynamic Stretching on Strength, Muscle Imbalance, and Muscle Activation

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Abstract

Purpose: This study aimed to examine the acute effects of dynamic stretching on concentric leg extensor and flexor peak torque, eccentric leg flexor peak torque, and the conventional and functional hamstring–quadriceps (H:Q) ratios.

Methods: Twenty-one women (mean ± SD age = 20.6 ± 2.0 yr, body mass = 64.5 ± >.3 kg, height = 164.7 ± 6.5 cm) performed maximal voluntary isokinetic leg extension, flexion, and eccentric hamstring muscle actions at the angular velocities of $60° \cdot s^{-1}$ and $180° \cdot s^{-1}$ before and after a bout of dynamic hamstring and quadriceps stretching as well as a control condition.

Results: Leg flexion peak torque decreased under both control (mean ± SE for $60° \cdot s^{-1}$ = 75.8 ± 4.0 to 72.4 ± 3.7 N · m, $180° \cdot s^{-1}$ = 62.1 ± 3.2 to 59.1 ± 3.1 N· m) and stretching ($60° \cdot s^{-1}$ = 73.1 ± 3.> to 65.8 ± 3.3 N· m, $180° \cdot s^{-1}$ = 61.2 ± 3.3 to 54.7 ± 2.6 N· m) conditions, whereas eccentric hamstring peak torque decreased only after the stretching ($60° \cdot s^{-1}$ = 87.3 ± 5.1 to 73.3 ± 3.6 N· m, $180° \cdot s^{-1}$ = 89.2 ± 4.4 to 77.0 ± 3.4 N · m) intervention ($P \le 0.05$). Stretching also caused a decrease in conventional H:Q ($60° \cdot s^{-1}$ = 0.58 ± 0.02 to 0.54 ± 0.02, $180° \cdot s^{-1}$ = 0.67 ± 0.02 to 0.61 ± 0.03) and functional H:Q ratios ($60° \cdot s^{-1}$ = 0.69 ± 0.03 to 0.60 ± 0.03, $180° \cdot s^{-1}$ = 1.00 ± 0.06 to 0.60 ± 0.03) ($P \le 0.05$).

Conclusions: Because dynamic stretching reduced concentric and eccentric hamstring strength as well as the conventional and functional H:Q ratios, fitness and allied-health professionals may need to be cautious when recommending dynamic rather than static stretching to maintain muscle force.

Keywords: Stretching Induced, Muscle Strain, Muscle Injury, Knee Injury, Injury Risk, Isokinetic, Muscle Strength

Preathletic event stretching has been recommended with the goal of improving a joint range of motion to achieve optimal performance, decrease stiffness, and possibly decrease injury risk (33,46). Likewise, it has been suggested that stretching before exercise may improve performance (3,36,38). However, recent evidence has indicated that a bout of static stretching may cause transient decreases in dynamic constant external resistance strength (32), maximal concentric isokinetic strength (12,13,22), maximal isometric strength (23), peak twitch force and rate of force development (14), maximal power output (47), balance (4), sprint performance (34), vertical jump performance (7), and other sport-specific measures (24). Collectively, this phenomenon has been termed the stretching induced force deficit. Thus, Behm and Chaouachi (5) suggested that static stretching of any duration should be avoided when even small decreases in performance are undesirable. This recommendation may only apply to static stretching though because several studies have reported that dynamic stretching has no detrimental or positive effects on strength and power output (35), sprint performance (42), vertical jump (7), and other sport-specific tasks (24). Therefore, there is some discrepancy within the literature on the detrimental effects of static versus dynamic stretching such that static stretching may cause a stretching induced force deficit, whereas dynamic stretching may not.

During sprinting, eccentric muscle actions of the hamstring function to decelerate leg extension movement (48) and oppose the action of the quadriceps during the last third of the swing phase (6). Hence, eccentric muscle actions of the hamstrings may be important in preventing knee- and posterior thigh-related injuries during sprinting (39). Because the hamstrings are typically weaker than the quadriceps, this imbalance may increase the risk of injury (39,48). Indeed, hamstring injuries are common in sports involving running and jumping (48). For example, Jönhagen et al. (30) reported injured sprinters typically had weaker eccentric muscle actions than uninjured runners. Sugiura et al. (39) reported that hamstring injuries always occurred in sprinters with preseason weakness in eccentric hamstring muscle actions when compared with the uninjured limb. girls with reduced hamstring strength have a reduced ability to control lower limb alignment, which may to contribute to increased ACL loading and, consequently, increased potential for injury (45). Previous studies have shown static stretching induced decreases in hamstring strength (12,13,25,35), which have been suggested to increase risk of injury (12,13). However, it is unknown whether dynamic stretching elicits similar effects; thus, the present study on dynamic stretching may provide the data needed to make better recommendations to reduce the risk of thigh- or knee-related injuries that may be associated with stretching induced decreases in hamstring strength.

A disproportional hamstring–quadriceps (H:Q) strength ratio may be inversely related to the risk of lower extremity injuries (6,20,21,29,39,48). That is, as the H:Q ratio decreases, the risk of lower extremity injuries may increase. Consequently, the H:Q ratio has been used as a preventative tool to screen for potential hamstring and knee injuries (6,20,21,29,39,48). For example, in a prospective study, Croisier et al. (20) examined professional soccer players' isokinetic strength profiles and reported that the rate of injury during the season was significantly higher in those athletes with strength imbalances. Similarly, Yeung et al. (48) reported that competitive sprinters with a preseason H:Q ratio lower than 0.60 had their risk of hamstring injury increased by 17 times. Accordingly, the general recommendation is that the H:Q ratio should be 0.60 or greater for injury prevention (21), and subsequent strength training can correct low H:Q ratios (28). Incidentally, stretching is also commonly recommended for the prevention and treatment of hamstring strains and knee-related injuries (8). However, if stretching before exercise or athletic performance decreases concentric (12,13,25,35) and eccentric hamstring strength (13,35), then it is possible that stretching may also affect the conventional and functional H:Q ratios. Indeed, recent literature has suggested that little compelling evidence exists to indicate that stretching reduces injury risk (37,40,43).

Whiting and Zernicke (44) have suggested that the hamstrings are particularly susceptible to muscle strains, and hamstring strains may be one of the most common injuries in athletics (>). Moreover, poor flexibility, inadequate strength, and insufficient stretching are among the factors associated with hamstring injuries (2). However, because preexercise stretching can adversely affect hamstring strength (12,13,25,35) and potentially lower the H:Q ratio (11,13), it may, consequently, increase the risk of hamstring- and knee-related injury. As a result, previous studies have suggested that caution must be taken if stretching is conducted before H:Q ratio assessments, especially when H:Q ratios are used as an index for deciding when return to play is appropriate during injury rehabilitation (13). In a recent extensive review, Behm and Chaouachi (5) suggested that dynamic stretching causes either no adverse effects or improves performance, and it is currently becoming more common as part of a warm-up (10). However, there is also evidence to suggest that dynamic stretching decreases hamstring strength (26). In light of the recent debate surrounding the efficacy of dynamic stretching for reducing the risk of injury and improving performance, we hypothesized that dynamic stretching for the hamstrings may increase hamstring strength, increase the H:Q ratio, and subsequently decrease the risk of injury as assessed by the H:Q ratio. To our knowledge, no studies have investigated the effects of an acute bout of dynamic stretching on the conventional and functional H:Q ratios and muscle activity. Therefore, the purpose of this study was to examine the acute effects of dynamic stretching on concentric leg extensor and flexor peak torque, eccentric leg flexor peak torque, and the conventional and functional H:Q ratios during isokinetic muscle actions.

Methods

Subjects.

A convenience sample of 21 women (mean ± SD age = 20.6 ± 2.0 yr, body mass = 64.5 ± >.3 kg, height = 164.7 ± 6.5 cm) volunteered for this study. Before the start of testing, all subjects read and signed an informed consent form and completed a health status questionnaire. Twenty women reported engaging in 1–5.5 h· wk^{-1} of aerobic exercise, 10 reported 1–6.5 h· wk^{-1} of resistance training, and 6 reported 1–3 h · wk^{-1} of recreational sports. Only one participant did not report some form of weekly exercise. In addition, none of the participants reported any current hip-, knee-, or ankle-related injuries. Therefore, these subjects might be best classified as healthy, college-age, recreationally active women. This study was approved by the institutional review board for the protection of human subjects.

Research design.

A repeated-measures design (prestretching vs poststretching) was used to investigate the acute effects of dynamic stretching on concentric leg extensor and flexor PT, eccentric leg flexor PT, the conventional and functional H:Q ratios, and muscle activity. Subjects visited the laboratory on three occasions separated by at least 48 h. The first visit was an orientation and familiarization session, and the subsequent visits were the experimental trials. Familiarization included anthropometric assessments (body mass and height) followed by a practice of the isokinetic tests that would be completed during the experimental trials. In addition, the stretching exercises were performed during the familiarization trial to ensure that each subject could tolerate the stretches. During the experimental trials, participants completed the isokinetic prestretching tests, the stretching intervention or the control condition, and the isokinetic poststretching assessments. The control condition consisted of quiet sitting for 15 min between prestretching and poststretching tests. The average duration of the experimental trials was 49.0 ± 6.1 min (mean ± SD).

Stretching protocol.

The stretching protocol consisted of four sets of four dynamic stretching exercises designed to stretch the anterior and posterior thigh muscles. The exercises were performed with each set lasting 30 s with 15-s rest periods between sets. Two exercises targeted the anterior muscles of the thigh and two targeted the posterior muscles of the thigh. For the first quadriceps stretch, from a standing position, the subject flexed the right knee such that the heel would move toward the buttocks and then the leg was returned back (Fig. 1A; Video, Supplemental Digital Content 1, http://links.lww.com/MSS/A357). For the second quadriceps stretch, the subject flexed the right thigh and leg and extended the right leg backward (Fig. 1B; Video, Supplemental Digital Content 2, http://links.lww.com/MSS/A358). Once completed, the subject brought the leg to the starting position. The first hamstring stretching exercise involved an exaggerated hip extension with the left leg while flexing the trunk at the hip and waist until both hands approached the right foot (Fig. 1C; Video, Supplemental Digital Content 3, http://links.lww.com/MSS/A359). Once completed, the subject returned to the start position and repeated the stretch. The second hamstring stretching exercise was performed while the subject flexed the right thigh while maintaining an extended leg such that the right toes were raised as high as possible. The right thigh was then extended back to the starting position (Fig. 1D; Video, Supplemental Digital Content 4, http://links.lww.com/MSS/A360). No warmup was conducted before the stretching intervention. The average stretching procedure lasted 16.1 ± 2.6 min, and the average time elapsed from the end of the stretching to the start of the post-stretching assessments was 4.9 ± 1.4 min.

Isokinetic testing.
Maximal isokinetic concentric hamstring and quadriceps PT and eccentric hamstring PT of the right leg were assessed in random order using a calibrated Lido Multi-Joint II isokinetic dynamometer (Loredan Biomedical, Inc., West Sacramento, CA) at the randomly ordered velocities of 60° s^{-1} and 180° s^{-1}. H:Q ratios at the velocities of 60° s^{-1} and 180° s^{-1} have both been used to assess injury risk and have been associated with lower-body injury (6,29,48). Subjects were in a seated position with pads securing the right thigh. The input axis of the dynamometer was aligned with the axis of rotation of the right knee. Before the isokinetic assessments, each participant's active range of motion was individually determined as prompted by the Lido software. Three submaximal warm-up repetitions of increasing intensities (i.e., approximately 25%, 50%, and 75% of the subject's perceived maximum) preceded three maximal muscle actions at each velocity. Concentric hamstring and quadriceps PT were assessed consecutively within the same repetition. During the tests, loud verbal encouragement was provided by the investigator such that each subject was instructed to ''kick out'' and ''pull back'' as hard and fast as possible throughout the range of motion. A 1-min rest was allowed between each velocity.

Muscle activity.
Preamplified, bipolar surface EMG electrodes (EL254S; Biopac Systems Inc., Santa Barbara, CA; gain = 350) with a fixed center-to-center interelectrode distance of 20 mm were taped over the vastus lateralis (VL) and biceps femoris (BF) muscles of the right thigh. All electrodes were placed in accordance with the recommendations of Hermens et al. (27). For the VL, the electrodes were placed at the anterior border of the iliotibial band along the muscle's longitudinal axis at 50% of the distance from the greater trochanter to the lateral epicondyle of the femur. For the BF, the electrodes were placed at the midpoint of the distance between the ischial tuberosity and the lateral epicondyle of the tibia. A single pregelled, disposable electrode (Ag-Ag Cl, Quinton Quick Prep, Quinton Instruments Co., Bothell, WA) was placed on the spinous process of the seventh cervical vertebrae to serve as a reference electrode. To reduce interelectrode impedance and to increase the signal-to-noise ratio, local areas of the skin were shaved and cleaned with isopropyl alcohol before placement of the electrodes.

Signal processing.
During each isokinetic assessment, all signals were sampled at 2 kHz and recorded simultaneously with a Biopac data acquisition system (MP150WSW; Biopac Systems Inc.) interfaced with a laptop computer (Inspiron 8200; Dell Inc., Round Rock, TX) using proprietary software (AcqKnowledge version 3.7; Biopac Systems Inc.). The torque and EMG signals were recorded, stored, and processed offline with

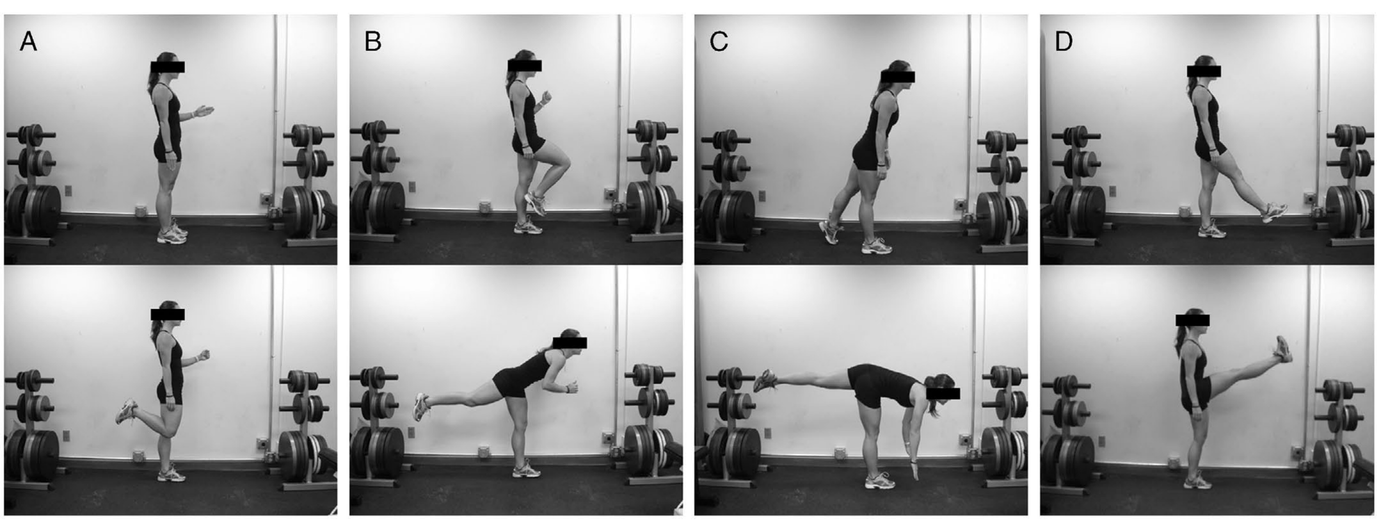

Figure 1: Examples of dynamic stretching exercises aimed for the anterior (A and B) and posterior (C and D) muscles of the thigh.

custom-written software (LabView 8.5; National Instruments, Austin, TX). PT was calculated as the highest 0.05-s average torque value for the repetition that yielded the highest PT value. Conventional H:Q ratios were calculated by dividing each subject's highest concentric hamstring PT by the highest concentric quadriceps PT (11–13). Functional H:Q ratios were calculated by dividing the highest eccentric hamstring PT by the highest concentric quadriceps PT (13).

The raw EMG signals (*K*V) were simultaneously sampled at 2 KHz and expressed as root mean square amplitude values. First, the raw EMG signals were digitally band-pass filtered at 10–500 Hz using a zero phase shift eighth-order Butterworth filter. The EMG amplitude values were then normalized to the highest recorded value that occurred during either the prestretching or poststretching assessments across the two velocities ($60^{\circ}\cdot s^{-1}$, $180^{\circ}\cdot s^{-1}$, and $300^{\circ}\cdot s^{-1}$). The normalized EMG amplitude values were expressed as a percentage of the maximum recorded value (%max) and used in all subsequent statistical analyses.

Statistical analyses.

Eleven separate three-way repeated-measured ANOVA (time [prestretching vs poststretching] x condition [stretching vs control] x velocity [$60^{\circ}\cdot s^{-1}$ vs $180^{\circ}\cdot s^{-1}$]) were used to analyze the concentric hamstring and quadriceps PT, eccentric hamstrings PT, conventional and functional H:Q ratios, and muscle activity during concentric hamstring and quadriceps and eccentric hamstring muscle actions. When appropriate, follow-up analyses were performed using lower-order two-way repeated measures ANOVA and paired sample t-tests. An alpha level of $P \leq 0.05$ was considered statistically significant for all comparisons. Predictive Analytics SoftWare (PASW) version 18.0.0 (SPSS Inc., Chicago, IL) was used for all statistical analyses.

Results

Table 1 displays mean and SD values as well as percent changes where significant differences were observed for concentric hamstring and quadriceps PT, eccentric hamstring PT, and the H:Q conventional and functional ratios before and after the interventions at $60^{\circ}\ s^{-1}$ and $180^{\circ}\ s^{-1}$.

Quadriceps peak torque.

There was no three-way interaction (time x condition x velocity) and no two-way interaction for time x condition, time x velocity, or condition x velocity ($P > 0.05$). In addition, there was no main effect for time or condition ($P > 0.05$). However, there was a main effect for velocity indicating quadriceps PT was higher at $60^{\circ}\cdot s^{-1}$ than $180^{\circ}\ s^{-1}$ ($P < 0.05$).

Hamstring peak torque.

There was no three-way interaction (time x condition x velocity) and no interaction for time x velocity or condition x velocity ($P > 0.05$). However, there was a significant two-way interaction for time x condition ($P < 0.05$). Concentric hamstring PT decreased in both control and stretching conditions at $60^{\circ}\ s^{-1}$ and $180^{\circ}\ s^{-1}$ ($P < 0.05$) with greater decreases in the stretching (10.0%–10.6%) than that in the control (4.5%–4.8%) condition. In addition, there was a main effect for velocity, indicating that PT was higher at $60^{\circ}\ s^{-1}$ than $180^{\circ}\ s^{-1}$ ($P < 0.05$).

For eccentric hamstring PT, there was no three-way interaction (time x condition x velocity) and no two-way interaction for time x velocity or condition x velocity ($P > 0.05$). However, there was a significant two-way interaction for time x condition ($P < 0.05$). Eccentric PT decreased from preintervention to post intervention for the stretching condition at both velocities ($P < 0.05$).

H:Q ratios.

For the conventional H:Q ratio, there was no three-way interaction (time x condition x velocity) and no two-way interaction for time x velocity, time x condition, or condition x velocity, ($P > 0.05$). However, there was a significant main effect for time and for condition ($P < 0.05$). Conventional H:Q ratios decreased from preintervention to postintervention for the stretching condition at both velocities ($P < 0.05$). In addition, there was a main effect for velocity, indicating that conventional ratios were higher at $180^{\circ}\ s^{-1}$ than $60^{\circ}\ s^{-1}$ ($P < 0.05$).

For the functional H:Q ratios, there was no three-way interaction (time x condition x velocity) and no two-way interaction for time x velocity or condition x velocity ($P > 0.05$). However, there was a significant two-way

Table 1. Mean ± SD values of concentric leg extensor and flexor PT, eccentric leg flexor PT, and conventional and functional H:Q ratios assessments.

	Pretest		Posttest		% Change	
	$60^{\circ}\cdot s^{-1}$	$180^{\circ}\cdot s^{-1}$	$60^{\circ}\cdot s^{-1}$	$180^{\circ}\cdot s^{-1}$	$60^{\circ}\cdot s^{-1}$	$180^{\circ}\cdot s^{-1}$
Control condition						
Concentric quadriceps PT (N· m)	132.5 ± 30.9	91.9 ± 19.1	128.9 ± 32.6	93.3 ± 31.9		
Concentric hamstring PT (N· m)	75.8 ± 18.4	62.1 ± 14.7	72.4 ± 16.8*	59.1 ± 14.0*	-4.5%	-4.8%
Eccentric hamstring PT (N· m)	86.0 ± 19.3	89.7 ± 17.5	82.3 ± 15.5	85.5 ± 14.4		
Conventional H:Q ratio	0.58 ± 0.11	0.68 ± 0.11	0.57 ± 0.10	0.67 ± 0.18		
Functional H:Q ratio	0.66 ± 0.15	1.00 ± 0.22	0.66 ± 0.13	1.00 ± 0.34		
Dynamic stretching condition						
Concentric quadriceps PT (N· m)	127.7 ± 34.1	93.1 ± 23.4	125.6 ± 32.0	92.6 ± 22.6		
Concentric hamstring PT (N· m)	73.1 ± 17.7	61.2 ± 14.9	65.8 ± 15.0*	54.7 ± 11.8*	-10.0%	-10.6%
Eccentric hamstring PT (N· m)	87.3 ± 23.4	89.2 ± 20.2	73.3 ± 16.5*	77.0 ± 15.7*	-16.0%	-13.7%
Conventional H:Q ratio	0.58 ± 0.11	0.67 ± 0.11	0.53 ± 0.10*	0.61 ± 0.13*	-6.9%	-9.0%
Functional H:Q ratio	0.69 ± 0.14	1.00 ± 0.27	0.60 ± 0.12*	0.87 ± 0.25*	-13.0%	-13.0%

*Significant decrease from prestretching to poststretching.
PT, peak torque; H:Q, hamstring-to-quadriceps ratio.

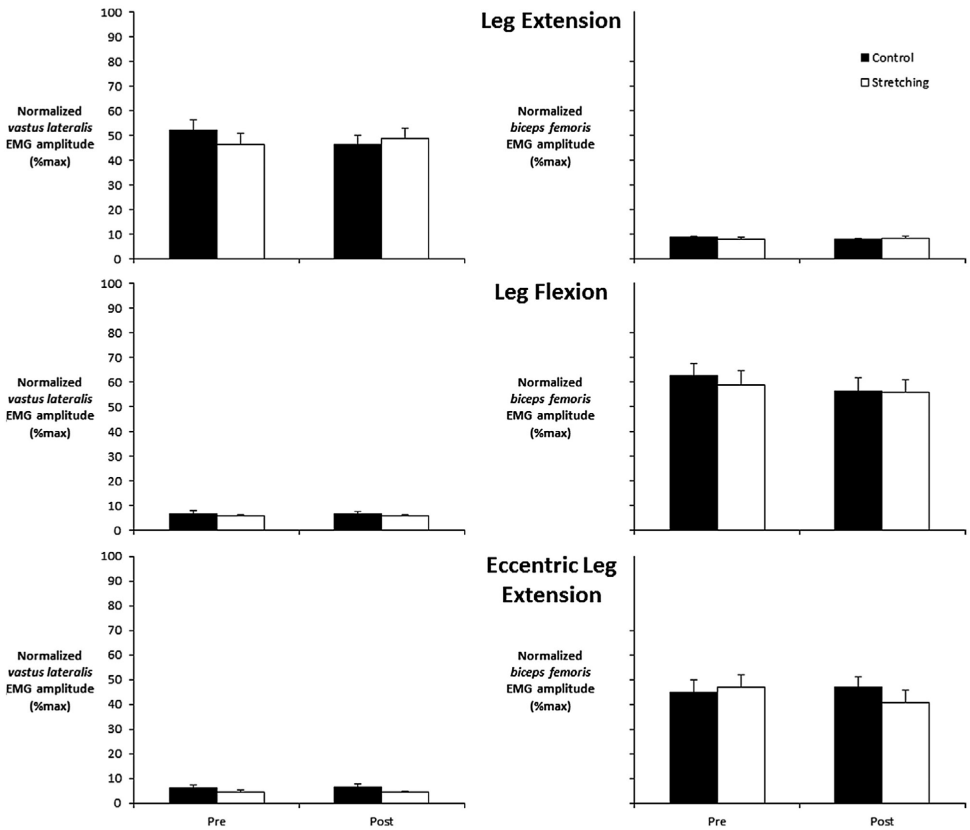

Figure 2: Mean and SE values for normalized EMG amplitude of the vastus lateralis (VL) and biceps femoris (BF) during concentric quadriceps and hamstring muscle actions as well as eccentric hamstring muscle actions at $60^\circ \cdot s^{-1}$ and $180^\circ s^{-1}$.

interaction for time x condition ($P < 0.05$). Functional H:Q ratios decreased from prestretching to poststretching at both velocities ($P < 0.05$). In addition, there was a main effect for velocity indicating conventional ratios were higher at $180^\circ s^{-1}$ than $60^\circ s^{-1}$ ($P < 0.05$).

Muscle activity.

There were no three-way interaction (time x condition x velocity) and no two-way interaction for time x condition, time x velocity, or condition x velocity ($P > 0.05$) for the VL or BF during the concentric quadriceps and hamstring and eccentric hamstring muscle actions. In addition, there was no main effect for time, condition, or velocity ($P > 0.05$), indicating that muscle activity did not change from prestretching to poststretching. Figure 2 presents the mean and SE values for normalized EMG amplitude of the VL and BF during concentric quadriceps and hamstring muscle actions as well as eccentric hamstring muscle actions before and after the stretching at $60^\circ s^{-1}$ and $180^\circ s^{-1}$.

Discussion

The primary results of the present study indicated that dynamic stretching decreased concentric and eccentric hamstring PT as well as the conventional and functional H:Q ratios. Although this study was the first to examine the acute effects of dynamic stretching on the conventional and functional H:Q ratios, our findings were consistent with previous investigations that reported decreases in H:Q ratios and PT after static stretching (11–13). Both conventional and functional H:Q ratios have been used as a preventative tool to screen for potential hamstring- and knee-related injuries (6,20,21,29,39,48). However, caution is warranted when using stretching for rehabilitation and before assessment of musculoskeletal injuries involving the quadriceps, the hamstrings, and/or the knee joint.

Our findings indicated that concentric hamstring PT decreased, whereas concentric quadriceps PT did not change after the stretching and control conditions. Despite the small decreases in PT observed after the control condition, stretching led to decreases in PT of greater magnitude (10.0%–10.6%) than the control (4.5%–4.8%) (Table 1). These findings were consistent with previous studies that have reported decreases in PT after a bout of static stretching (12–14,17,19,22,35) as well dynamic stretching (26). For example, Costa et al. (12, 13) reported 3%–12% decreases in leg flexion strength after hamstring static stretching. Herda et al. (26) suggested that decreases in PT after dynamic stretching were attributed to decreases in passive stiffness and passive resistive torque (26). However, a change in musculotendinous stiffness might not account for the total reduction in voluntary torque production. Future investigations might attempt to move the limb passively through a full range of motion and subtract the passive torque to account for passive torque changes. Nevertheless, alterations in the musculotendinous unit have been suggested as one of the contributing factors, at least in part, for the stretching induced strength deficit along with neural changes related to muscle activation (14,17, 19,22,25). Hence, our findings of decreased strength could be attributed to decreases in musculotendinous stiffness and subsequent increases in electromechanical delay similar to those found with static stretching (14,15). An increase in the electromechanical delay has been associated with decreases in force. It is suggested that an increase in the electromechanical delay occurs as a result of a greater slack in the musculotendinous unit such that more force is dissipated to surrounding tissues rather than direct force transmittal from the contractile component to the bone (14,15). Sekir et al. (35), however, reported increases in concentric and eccentric hamstring and quadriceps PT after dynamic stretching. The discrepancy between the results of the current study and those of Sekir et al. (35) might be attributed to different dynamic stretching protocols. The current study used dynamic stretching that involved controlled repetitions for 30 s, whereas Sekir et al. (35) stretched ''as quickly and powerfully as possible'' (p. 270), which may be more synonymous with a traditional warm-up. In addition, testing took place approximately 5 min after stretching. This time elapsed between stretching and testing might have allowed small changes in torque development to dissipate, whereas a longer delay might have allowed torque levels to attain normality such that perhaps a greater delay between the stretching intervention and strength assessment would not have caused a strength reduction.

Traditionally, the H:Q ratio is calculated by dividing the maximal concentric leg flexor PT by the maximal concentric leg extensor PT, which is regarded as the conventional H:Q ratio that indicates a basic strength comparison between the opposing muscle groups (1). However, during human motion (especially during athletic activities), the hamstrings often function eccentrically to resist, control, and oppose the powerful contraction of the quadriceps during leg extension that takes place while running or kicking (6,48). Thus, it has been suggested that that the ratio between maximal eccentric leg flexion PT and maximal concentric leg extension PT may be more reflective of the functional difference between hamstring and quadriceps strength and is regarded as the functional H:Q ratio (39,48). In fact, it has been postulated that hamstring muscle strains typically occur during the eccentric phase of muscle contraction (29). Hence, the functional H:Q ratio is thought to be more representative of knee joint stabilization during leg extension by the muscles involved (1). The 14%–16% decreases in eccentric hamstring PT observed in the present study were consistent with those of Costa et al. (13), Sekir et al. (35), and Herda et al. (26), who reported 6%–19% decreases in eccentric hamstring PT after static stretching. However, our findings were different from previous studies that have reported no changes in eccentric PT after stretching (16,18). It is possible that the quadriceps (16,18) respond differently to stretching than the hamstrings during eccentric muscle actions, which may be related to greater force producing capabilities of the quadriceps, greater relative muscle cross-sectional area, and/ or its muscle architecture. In addition, the quadriceps muscles have a longer range of motion and are therefore more difficult to target during stretches. Hence, future studies should examine stretches in which the quadriceps are more clearly targeted as well as strength imbalance among different muscle groups.

Several studies have examined the neuromuscular factors underlying the stretching induced force deficit using surface EMG (11,14,22,26). The stretching induced force deficit has been attributed to alterations in the mechanical components of skeletal muscle contraction (14,22,25) and/ or neural factors related to muscle activity (17,19,31,41). Our findings supported those of Costa et al. (11), Herda et al. (25), and Evetovich et al. (22), who reported no stretching induced changes in EMG amplitude during maximal concentric isokinetic leg extension or leg flexion muscle actions. In contrast, Herda et al. (25,26) reported increases and decreases, respectively, in EMG amplitude after dynamic stretching. It is unclear why there are discrepancies among the present study and those of Herda et al. (25,26), but they may be related to different testing protocols because Herda et al. used isometric muscle actions, whereas dynamic, isokinetic muscle actions were used in the present study. Nevertheless, the lack of changes observed in muscle activity in the present study suggested that the acute effects of dynamic stretching may have been related to mechanical rather than neural mechanisms. Alternatively, small changes in muscle activity might not have been detectable using EMG, or may have been masked by changes in amplitude cancellation or synchronization or changes in the transfer of electrical signal through the muscle. Future studies using a more detailed analysis of the mechanisms underlying the stretching induced strength deficit should be undertaken.

In summary, dynamic stretching adversely affected concentric and eccentric hamstring strength in the present study. As a result, conventional and functional H:Q ratios also decreased after dynamic stretching. In addition, H:Q ratios increased as angular velocity increased, which is also consistent with previous reports (11–13,21). These findings may provide clinically useful information regarding the use of dynamic stretching before an H:Q ratio assessment or before sports performance events that are commonly associated with hamstring- and knee-related injuries. Future studies should examine in more detail the time course of the alterations on strength caused by dynamic stretching as well as the addition of a warm-up to more completely determine the practical impact of the current results. On the basis of our findings, caution is warranted when recommending dynamic stretching in lieu of static stretching. Thus, it may be important to limit any stretching that could potentially decrease concentric and/or eccentric hamstring strength, particularly if the stretching can be accomplished at any other time during the day rather than before strength testing or athletic performances. It has been suggested that a stretching routine be conducted separately from the main training regimen or during the post exercise period (5,10). The results of the current and previous studies (11,13,15) have collectively suggested that strength and conditioning coaches, athletic trainers, and physical therapists may want to avoid using static or dynamic stretching as a means of injury risk prevention immediately before athletic activities.

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