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Research article

Short durations of static stretching when combined with dynamic stretching do not impair repeated sprints and agility

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Abstract
This study aimed to compare the effect of different static stretching durations followed by dynamic stretching on repeated sprint ability (RSA) and change of direction (COD). Twenty-five participants performed the RSA and COD tests in a randomized order. After a 5 min aerobic warm up, participants performed one of the three static stretching protocols of 30 s, 60 s or 90 s total duration (3 stretches x 10 s, 20 s or 30 s). Three dynamic stretching exercises of 30 s duration were then performed (90 s total). Sit-and-reach flexibility tests were conducted before the aerobic warm up, after the combined static and dynamic stretching, and post-RSA/COD test. The duration of static stretching had a positive effect on flexibility with 36.3% and 85.6% greater sit-and-reach scores with the 60 s and 90 s static stretching conditions respectively than with the 30 s condition ($p \leq 0.001$). However there were no significant differences in RSA and COD performance between the 3 stretching conditions. The lack of change in RSA and COD might be attributed to a counterbalancing of static and dynamic stretching effects. Furthermore, the short duration (≤ 90 s) static stretching may not have provided sufficient stimulus to elicit performance impairments.

Key words: Flexibility, agility, running, stretch duration, stretch intensity.

Introduction

Research has appeared in the last 13 years that showed that sustained static stretching could impair subsequent performance (Behm and Chaouachi, 2011; Behm et al., 2001; 2004; Power et al., 2004). A number of these studies used extensive durations that involved 30-60 minutes (Avela et al., 2004; Fowles et al., 2000) or 15-20 minutes (Bacurau et al., 2009; Cramer et al., 2005; Kokkonen et al., 1998) of static stretching. These durations do not reflect common pre-event stretching practice among recreational or most elite athletes. For example, a series of articles that surveyed North American strength and conditioning coaches from professional sports reported average stretch repetition durations of approximately 12 s (Ebben et al., 2005), 14.5 s (Simenz et al., 2005), 17 s (Ebben et al., 2004) and 18 s (Ebben and Blackard, 2001) for baseball, basketball, hockey and football players respectively. Protocols implementing less extensive durations of static stretching such as 2-10 minutes have also reported impairments in subsequent sprint performance (Beckett et al., 2009; Winchester et al., 2008). However, Young et al. (2006) indicated that two minutes of static stretching had no effect on concentric calf raise and drop jump height. This literature tends to indicate that when the total duration of static stretching is ≥ 90 s (e.g. 3 stretches of 30 s each) there is strong evidence for sprint impairments (Behm and Chaouachi, 2011; Nelson et al., 2005; Sayers et al., 2008). Behm and Chaouachi (2011) in an extensive review indicated that if the total duration of static stretching is less than 90 s, there seems to be more variation in the evidence for impairments.

In contrast, dynamic stretching studies show facilitation of explosive (Manoel et al., 2008; Yamaguchi et al., 2007), sprint (Fletcher and Anness, 2007) and jump (Holt and Lambourne, 2008; Hough et al., 2009; Pearce et al., 2009) performance or no adverse effect (Christensen and Nordstrom, 2008; Samuel et al., 2008; Torres et al., 2008). In the context of dynamic stretching, the literature tends to indicate that shorter durations (< 90 s) of dynamic stretching do not adversely affect performance (Beedle et al., 2008; Samuel et al., 2008; Unick et al., 2005), and longer duration of dynamic stretches may facilitate performances (Hough et al., 2009; Pearce et al., 2009; Yamaguchi et al., 2007).

Studies that combine static and dynamic stretching report conflicting results with both impediments in jump height (Young and Behm, 2003) and sprint performance (Winchester et al., 2009). Conversely there were no significant adverse effects on vertical jump and EMG (Wallmann et al., 2008), sprint, agility and jump performance (Chaouachi et al., 2010) and upper body muscular performance (Torres et al., 2008). Based on this conflicting evidence, it is unclear if there is an appropriate or optimal combination and duration of static and dynamic stretching that can be used prior to performance in order to facilitate range of motion and subsequent performance.

The reason to include static stretching in a warm-up is that there are many dynamic sports where enhanced static flexibility would be expected to affect performance. Some examples would include the ability of a goaltender in ice hockey to maximally abduct his/her legs when in a butterfly position, gymnasts performing and holding a split position, wrestling, martial arts, synchronized swimming, figure skating and others. Since studies have indicated that dynamic stretching is not as effective at increasing flexibility as static stretching (Bandy et al., 1998; Chan et al., 2001; Davis et al., 2005), it may be important to include static stretching in the warm-up for

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specific sport applications. Furthermore, it has been shown by some researchers that performing dynamic stretching after static stretching will reduce or remove the detrimental performance effects induced by static stretching (Chaouachi et al., 2010). There are no previous studies investigating the effects of combining various durations of static stretching and dynamic stretching on repeated-sprint performance (RSA) and change of direction (COD). Several authors have argued that the RSA and COD performances are determinants of sport performance in field and court sports such as soccer (Rampinini et al., 2007; Reilly et al., 2000).

Hence, the purpose of this study was to examine the effect of different durations of static stretching followed by dynamic stretching on functional performance measures such as RSA and COD. It was hypothesized that the longest duration of stretching (90 s of total static stretching) would result in impaired RSA and COD performance in comparison to the lower durations of static stretching. As aforementioned that most athletes perform static stretching before the training and competition, therefore we did not include a group with no static stretching as control.

Methods

Design

All participants participated in the within-participant repeated measures study for which they had to visit the sport science laboratory six times (3 stretching protocols x 2 performance tests) in 3 days with 48 hours recovery (i.e., Tuesday, Thursday, and Saturday). On each day, participants reported to laboratory in morning and afternoon sessions with > 4 hours recovery to perform either the RSA or COD in a randomized order. The two sessions within the single day was separated with > 4 hours in order to allow full recovery of the participants. With each laboratory session, participants were tested for flexibility (sit-and-reach) as illustrated in Figure 1. After an aerobic warm up at ~ 9–10 km·h^{-1} for 5 min, one of the three static stretching protocols differing in duration were performed in a randomized order: 1) 3 static stretching exercises of 10 s each; 2) 3 static stretching exercises of 20 s each; and 3) 3 static stretching exercises of 30 s each. Three dynamic stretching exercises of 30 s duration were then performed (90 s in total) for each condition. The second flexibility test was conducted immediately after the combined static and dynamic stretching. The duration between the cessation of the combined static and dynamic stretching and the start of RSA/COD test was standardized at 2 min. After the RSA or COD test, the third flexibility test was performed. The experiment was conducted in an indoor sport court made with a wooden surface, and environmental conditions were consistent with temperature (31.2 ± 0.2°C), and humidity (49.0 ± 0.8%) measured hourly throughout the study.

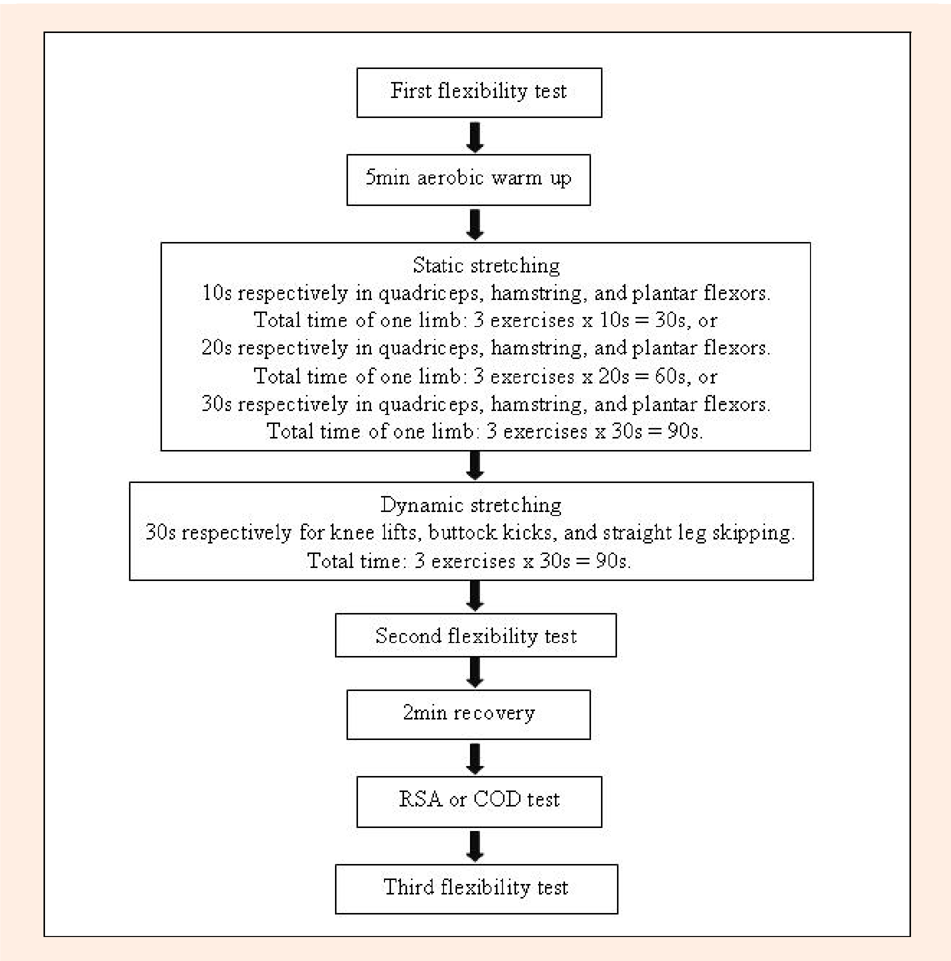

Figure 1. Research design. COD = change of direction; and RSA = repeated sprint ability.

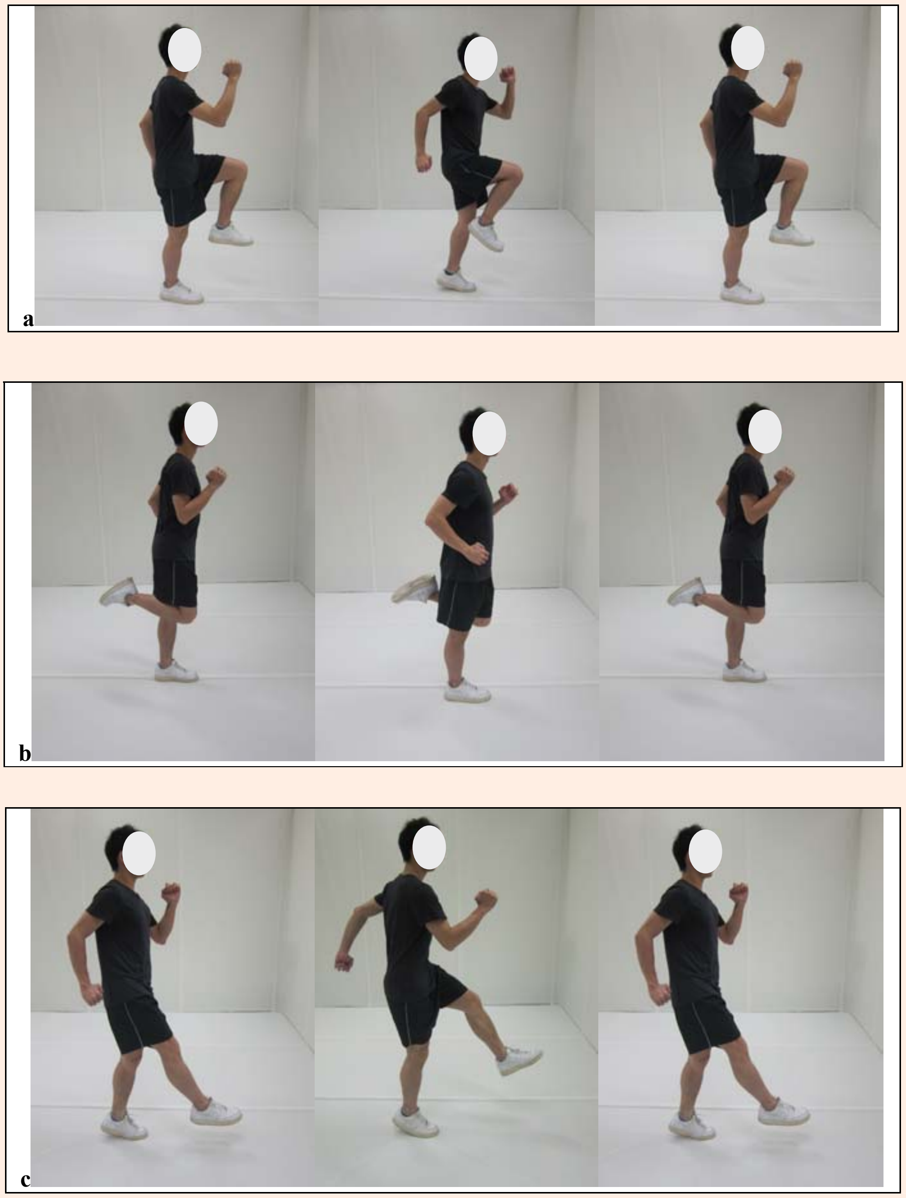

Figure 2. **Movements of (a) high knee lifts, (b) buttock kicks and (c) straight leg skipping.**

Participants

Twenty-five physical education post-graduate male students voluntarily participated in the present study. Their age, height, body mass, and body mass index were 24.6 ± 0.5 years-old, 1.75 ± 0.01 m, 71.1 ± 1.3 kg, and 23.2 ± 0.3 $kg \cdot m^{-2}$ respectively. The participants were physically active on a regular basis (3-5 days per week) and involved a spectrum of competitive and recreational activities. The study was conducted according to the Declaration of Helsinki and the protocol was fully approved by the Clinical Research Ethics Committee before the commencement of the assessments. Written informed consent was received from all participants after a brief but detailed explanation about the benefits, and risks involved with this investigation. Participants were told that they were free to withdraw from the study at any time without penalty. During the study, all participants were instructed to maintain normal daily food and water intake, and no dietary interventions were undertaken. They were also instructed not to participate in vigorous exercises 48 hours before the test.

Flexibility test

The sit-and-reach test was used as a measure of hamstring and lower back flexibility (Canadian Society for Exercise Physiology, 2003). Participants sat on the floor with their legs extended. They were asked to keep their lower backs against the wall. They rested their hands on a measurement box while extending their arms and then reached as far as possible. The measurement was conducted twice, and if the difference was within 2 cm then the best result was used (Canadian Society for Exercise Physiology, 2003). Otherwise a subsequent trial was performed until two consecutive results were within 2 cm. This test was performed immediately before the aerobic warm up, after the combined static and dynamic stretching, and post-RSA/COD test (Figure 1). Repeatability of the flexibility measurement was high with intra-class correlation coefficient (ICC) of 0.84.

Static stretching

Each participant carried out unassisted static stretch exercises (slowly applied a stretch torque to a muscle, maintaining the muscle in a lengthened position) designed to stretch the lower body (Chaouachi et al., 2010). The stretches were held at a point of mild discomfort for the designated duration per muscle group. Participants were told to "stretch to the point of the onset of tension”. Using a similar procedure, Chaouachi et al. (2010) demonstrated the reliability of this subjective intensity stretch with ICC of 0.96 when the stretch was tested for distance reached. At the end of the stretch, the leg was returned to a neutral position, and the participant stretched the other leg. Participants stretched for 10s respectively with the quadriceps, hamstring, and plantar flexors muscles in the condition 1 (total time for one limb was 30s, Figure 1), whereas in condition 2 each stretching time was 20s (total time for one limb was 60s) and in condition 3 each stretching time was 30s (total time for one limb was 90s). The time of stretching was measured by a handheld stopwatch. The investigator was present in all training sessions to provide detailed instructions, continually monitor the stretching activities and the duration of each participant.

Quadriceps stretching exercise: The participant stood upright with one hand against a wall for balance. Then the participant flexed his knee until a significant stretch was experienced. The ipsilateral hand grasped the ankle of the flexed leg, and the foot was raised so that the heel of the dominant foot approached the buttocks (Chaouachi et al., 2008). At the end of the stretch, the leg was returned to a neutral position, and the participant stretched the other leg.

Hamstring stretching exercise: The participants performed the hamstring stretch by standing erect with one foot planted on the floor and the toes pointing forward. The heel of the foot to be stretched was placed on the floor with the ankle dorsiflexed. The participant then flexed forward at the hip, maintaining the spine in a neutral position while reaching forward with the arms. The knee remained fully extended. The participant continued to flex at the hip until a mild point of discomfort was felt in the posterior thigh while maintaining a normal rate of breathing (Chaouachi et al., 2008). At the end of the stretch, the leg was returned to a neutral position, and the participant stretched the other leg.

Plantar flexors stretching exercise: With the leg to be stretched in an extended knee position and the foot planted on the floor approximately 1 meter from the wall, the participant leaned forward against the wall supported by their arms to stretch the plantar flexors (Behm et al., 2004). At the end of the stretch, the leg was returned to a neutral position, and the participant stretched the other leg.

Dynamic stretching

Dynamic activities lasted for a total duration of 90 s (each individual stretch was performed for 30 s, Figure 1) and involved the following movements in the same sequence: high knee lifts, buttock kicks, and straight leg skipping (Dintiman and Ward, 2003). High knee lifts (Figure 2a), buttock kicks (Figure 2b), and straight leg skipping (Figure 2c) were used to dynamically stretch the hip extensors (gluteals and hamstrings), quadriceps and hamstrings, and plantar flexors. The time of stretching was measured by a handheld stopwatch. Participants performed these dynamic stretches on a 15 m long wooden path back and forth with each leg repeated for 41.0 ± 0.4 times (ICC = 0.87), 36.7 ± 0.3 times (ICC = 0.90), and 29.5 ± 0.2 times (ICC = 0.91), respectively for high knee lifts, buttock kicks, and straight leg skipping.

Repeated-sprint Ability (RSA) and Change of Direction (COD) Test

The RSA test involved straight-line sprints (6 x 20 m with 25 s active recovery), whereas the COD (6 x 20 m with 25 s active recovery) test required a change of direction at 100 degrees for every 4 m (Bishop et al., 2001). During the active recovery participants slowly jogged back to the starting line and waited for the next sprint. Sprint time for 20 m was measured by an infra-red timing system (Brower Timing Systems, Salt Lake City, Utah, USA) located at the starting line and the finishing line with 1 m height, and the recovery time was controlled by hand-held stopwatch. The participants stood 0.5 m behind the sensor before they commenced each sprint, starting from a standing position. Each participant was instructed and verbally encouraged to give a maximal effort during all RSA and COD tests.

RSA and COD were analyzed by four methods: (1) the fastest time (FT) among the sprints, (2) average time (AT) among sprints, (3) total time (TT), and (4) percentage decrement score (%Decre) as reported by Glaister (2008). The TT was used as it has been recommended by previous studies of RSA and COD (Beckett et al., 2009; Pyne et al., 2008). The %Decre was selected as it was recently reported as the most valid and reliable method of quantifying fatigue in RSA tests (Glaister et al., 2008).

Statistical analyses

A one-way ANOVA with repeated measures was used to examine the changes in flexibility between various warm up conditions. A two-way ANOVA with repeated measures (3 warm up protocols x 4 parameters in each test) was used to examine the RSA/COD performances with the three different prior warm up protocols. When a significant difference was determined in the above analyses, pair-wise comparisons were made using Bonferroni’s adjustment to control the Type-1 error rate. Relationships between acute changes in flexibility and RSA/COD performances were examined by Pearson moment correlation coefficient. The magnitude of the correlations was determined using the modified scale by Hopkins (2000): trivial: $r < 0.1$; low: 0.1–0.3; moderate: 0.3–0.5; high: 0.5–0.7; very high: 0.7–0.9; nearly perfect > 0.9; and perfect: 1. The significance level was defined as $p \leq 0.05$.

Results

A main effect for condition (combined static and dynamic stretching) demonstrated that the duration of static stretching had a significant ($F = 42.8$, $p \leq 0.001$) positive effect on flexibility with 36.3% and 85.6% greater

Table 1. Change of flexibility (sit-and-reach test) before and after various combined static and dynamic stretching durations and testing. Values are mean (± SEM).

	Condition 1 (10 s)	Condition 2 (20 s)	Condition 3 (30 s)
Changes after warm up (cm) (2nd minus 1st flexibility test)	2.78 (.35) ***	3.79 (.45) ***	5.16 (.46) ***
Change after RSA or COD (3rd minus 2nd flexibility test)	2.43 (.30)	2.35 (.32)	1.82 (.20)

*** Significant differences between all groups at $p \leq 0.001$.

sit-and-reach scores with the 60 s (3 x 20 s) and 90 s (3 x 30 s) static stretching conditions respectively than with the 30 s (3 x 10 s) condition (Table 1). However there were no statistically significant differences in RSA (F = 0.13, p > 0.05, Table 2) and COD (F = 2.02, p > 0.05, Table 3) between the 3 stretching conditions. After the RSA or COD tests, sit-and-reach scores further increased, but there was no significant difference between the 3 stretching conditions (F = 2.14, p > 0.05, Table 1). Furthermore, there were non-significant low correlations between acute changes of flexibility and RSA/COD performances (p > 0.05, Table 4).

Discussion

The most important finding of the present study was the lack of significant difference in RSA and COD performance with 30-90 s of static stretching in combination with 90 s of dynamic stretching. One important goal of stretching during a warm-up prior to activity would be to improve performance. A review by Behm and Chaouachi (In press) summarized the plethora of studies reporting static stretch-induced impairments in subsequent performance. However, they highlighted the greater variability in the findings with shorter durations of stretching. The possibility of a duration-dependent effect is suggested by the greater preponderance of static stretching-induced impairments in studies using longer duration stretching protocols. A number of studies with less than 60 s of total static stretching report no significant decreases in sprint performance (Hayes and Walker, 2007; Vetter, 2007). Studies implementing different durations of stretching within the same study have reported decrements in isokinetic torque (Siatras et al., 2008) and isometric force (Ogura et al., 2007) when using 60 s of static stretching but no effect with less than 30 s of static stretching. However the evidence is not unanimous. Whereas static stretch durations of 90 s have impaired sprint performance (Sayers et al., 2008; Winchester et al., 2008), other studies with only 20 s (Beckett et al., 2009) and 40 s (Chaouachi et al., 2008) of stretching for each muscle group have reported RSA and COD (Beckett et al., 2009) and sprint (Chaouachi et al., 2008) impairments. In the present study, there was no duration dependent effect as there was no significant difference between 30 s, 60 s or 90 s of total static stretching (followed by 90 s dynamic stretching) on RSA and COD performance. However there were other factors that could also have impacted these results such as the possible potentiating factors associated with dynamic stretching (Behm and Chaouach, 2011). Static stretching is typically not performed in isolation and thus the effects of static stretching may be influenced by dynamic stretching.

The various durations of static stretching were combined with 90 s of dynamic stretching in the present study. In contrast to the many static stretching-induced impairment studies, a number of dynamic stretching protocols have reported facilitation of subsequent explosive (Manoel et al., 2008; Yamaguchi et al., 2007) sprint (Little and Williams, 2006) and jump (Holt and Lambourne, 2008; Hough et al., 2009; Pearce et al., 2009) performance. The combination of static stretching and dynamic stretching in the present study may have counterbalanced the possible negative (i.e. static stretching) and positive (i.e. dynamic stretching) effects. Fletcher and Anness (2007) combined static passive stretches with active dynamic stretches and reported significantly slower 50 metre sprint times. Similarly, Young and Behm (2003) combined a variety of protocols that involved a warm-up run, static stretching and jumps. The results indicated that submaximal intensity running and practice jumps had a positive effect whereas static stretching had a negative influence on explosive force and jumping performance. Young and Behm (2003) had participants stretch the quadriceps and plantar flexors for 2 min each to the point of discomfort. The greater intensity and duration of stretch as compared to the present study could have contributed to their deficits. However, Chaouachi et al. (2010) implemented 8 stretching protocols involving static and dynamic stretching that were performed either alone or combined and also altered the intensity of static stretching to either less than or to the point of discomfort. Only 1 of 56 interactions of static and dynamic stretching and intensity of stretching showed a significant difference for sprint time, and there were no other significant differences based on static stretching intensity or the sequencing of static and dynamic stretching.

The present study had participants stretch to a point of mild discomfort. There has been some other evidence in the literature to suggest that less than maximal intensity stretching might not produce stretch-induced deficits (Knudson et al., 2001; Knudson et al., 2004;

Table 2. Effects of combined static and dynamic stretching durations on repeated-sprint ability (RSA) performance. Values are mean (± SEM).

	Condition 1 (10 s)	Condition 2 (20 s)	Condition 3 (30 s)
Fastest time (s)	3.32 (.03)	3.33 (.03)	3.33 (.04)
Average time (s)	3.42 (.04)	3.43 (.04)	3.43 (.04)
Total time (s)	20.49 (.22)	20.58 (.22)	20.56 (.24)
Percentage decrement score (%)	2.87 (.27)	2.98 (.31)	2.95 (.35)

Table 3. Effects of combined static and dynamic stretching durations on change of direction (COD) performance. Values are mean (± SEM).

	Condition 1 (10 s)	Condition 2 (20 s)	Condition 3 (30 s)
Fastest time (s)	6.26 (.09)	6.22 (.10)	6.15 (.12)
Average time (s)	6.41 (.09)	6.41 (.11)	6.31 (.12)
Total time (s)	38.47 (.52)	38.47 (.66)	37.86 (.71)
Percentage decrement score (%)	2.39 (.18)	3.09 (.36)	2.56 (.22)

Young et al., 2006). Young et al. (2006) manipulated the volume of stretching and in one condition had the participants stretch to 90% of point of discomfort. They found that two minutes of static stretching at 90% intensity had no effect on concentric calf raise and drop jump height. Knudson and colleagues published two studies (Knudson et al., 2001; Knudson et al., 2004) where the participants were stretched to a point "just before" discomfort. Neither study showed significant decreases in performance. Behm and Kibele (2007) conversely did find static stretch-induced deficits in jump performance when stretching at the point of discomfort as well as 50 and 75% of the point of discomfort.

Notwithstanding, Fletcher and Anness (2007) reported impaired sprint times with a low duration (3 x 22 s) and intensity (to the point of mild discomfort) of stretching. The Fletcher and Anness study used competitive sprinters whereas the present study used active physical education students. The greater compliance of a stretched muscle (Kokkonen et al., 1998) might be expected to negatively impact elite sprinters (Gleim et al., 1990; Winchester et al., 2008) to a greater degree than physical education students. Increased muscle compliance would allow the energy associated with the stretch to be stored over a longer amortization period within the stretch-shortening cycle (Wilson et al., 1992). Physical education students who are not competitive sprinters would be expected to have longer ground contact times during running which could possibly benefit from a more compliant musculotendinous unit. For example, Wilson et al. (1992) reported 5.4% increases in rebound bench press resistance with increased muscle compliance. A bench press action would have a substantial amortization period or chest contact/rebound time compared to elite runners' foot contact time. Whereas elite runners may benefit from less compliance (Fletcher and Anness, 2007; Gleim et al., 1990; Winchester, 2008) due to their brief ground contact times, physical education students in this study may have had experienced minimal impairments from the possible increase in static stretch-induced compliance.

Hence, the lack of difference between short and long duration static stretching with dynamic stretching may be attributed to a counterbalancing of possible deficits and facilitation associated with static and dynamic stretching respectively. The scope of static stretching-induced impairments may have been moderated by the intensity (point of mild discomfort) of stretching as well as the use of non-elite physical education students (prolonged ground contact times in running).

The lack of facilitation with the combined stretching routine may be attributed to the relatively short duration of the dynamic stretching. Shorter durations (< 90 s) of dynamic stretching have been reported to not adversely affect performance (Beedle et al., 2008; Samuel et al., 2008; Unick et al., 2005) whereas longer durations of dynamic stretches tend to provide greater facilitation (12-15 min: (Pearce et al., 2009), 8 min: (Yamaguchi et al., 2007), 7 min: (Hough et al., 2009)). The 90 s of dynamic stretching in the present study may not have been of sufficient duration to provide facilitation or to overcome possible negative effects of static stretching.

A greater duration of stretching in the present study provided a greater sit-and-reach score. These findings are in accord with other studies that have reported greater ROM with 15 s versus 5 s (Roberts and Wilson, 1999) and 30 s provided greater ROM than 15 s (Bandy and Irion, 1994). Sit-and-reach scores continued to increase following the RSA and COD tests. The greater flexibility following RSA and COD might be attributed to a greater increase in muscle temperature helping to further increase muscle extensibility (Bishop, 2003). In addition, some studies have indicated that dynamic stretching provides similar acute increases in static flexibility as static stretching (Beedle and Mann, 2007; Herman and Smith, 2008). It is important to note that the prior sit-and-reach tests could have also contributed to the increased flexibility scores in the post-warm-up and post-RSA/COD performances.

Conclusion

A combination of different durations of static stretching and dynamic stretching in the present study did not adversely affect or facilitate performance in RSA or COD. There was no duration dependent effect with the 30 s, 60 s or 90 s of static stretching resulting in similar RSA and COD performances. There was a duration dependent effect upon sit-and-reach scores with longer total

Table 4. Correlations between acute changes of flexibility and RSA/COD performances.

		Condition 1 (10 s)	Condition 2 (20 s)	Condition 3 (30 s)	Mean r
RSA	Fastest time (s)	-.17	.18	0.21	0.07
	Average time (s)	-.10	.09	0.25	0.08
	Total time (s)	-.10	.09	0.25	0.08
	Percentage decrement score (%)	.19	-.32	0.12	-0.01
COD	Fastest time (s)	.21	-.03	0.05	0.08
	Average time (s)	.20	-.03	0.07	0.08
	Total time (s)	.20	-.03	0.07	0.08
	Percentage decrement score (%)	-.15	.02	0.23	0.03

durations of combined stretching providing greater flexibility (90 s > 60 s > 30 s). The lack of impairment or facilitation in RSA and COD performances might be attributed to a counterbalancing of possible static stretching-induced impairments with possible dynamic stretch-induced facilitation. On the other hand, the relatively short duration of stretching (≤ 90 s) combined with stretching to the point of mild discomfort may not have elicited performance impairments. Similarly the short duration of dynamic stretching may not have provided sufficient stimulus to elicit performance facilitation.

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Key points

- The duration of combined static and dynamic stretching had a positive effect on flexibility with 36.3% and 85.6% greater sit and reach scores with the 60 s and 90 s static stretching conditions respectively than with the 30 s condition ($p \leq 0.001$).
- No significant differences in RSA and COD between the 3 stretching conditions.
- The lack of change in RSA and COD might be attributed to a counterbalancing of static and dynamic stretching effects.
- The short duration (≤ 90 s) static stretching may not have provided sufficient stimulus to elicit performance impairments.

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