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Original article

Acute effects of two different stretching techniques on isokinetic strength and power

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A B S T R A C T

Objectives: To examine and compare the acute effects of short duration static and dynamic lower-limb stretching routines on the knee flexor and extensor peak torque and mean power during maximal concentric and eccentric muscle actions.
Method: Forty-nine active adults completed the following intervention protocols on separate days: non-stretching, static stretching and dynamic stretching. After the stretching or control intervention, concentric and eccentric isokinetic peak torque and mean power of the leg extensors and flexors were measured in prone position. Measures were compared via a fully-within-groups factorial ANOVA.
Results: Neither static nor dynamic stretching has influence on isokinetic peak torque and mean power when they were compared with the control condition. Paired comparison also showed that the isokinetic strength and power results reported by dynamic stretching session were slightly higher than those found during the static stretching session.
Conclusions: Short pre-exercise static and dynamic lower-limb stretching routines did not elicit stretching-induce reductions or improvements in knee flexor and knee extensor isokinetic concentric and eccentric strength. In addition, the findings of the current study support the claim that dynamic stretching may be preferable to static stretching as part of a warm-up designed to prepare for physical activity.

Efecto agudo de 2 técnicas de estiramiento diferentes sobre la fuerza y potencia isocinética

Palabras clave:
Calentamiento
Fuerza muscular
Pico de fuerza
Potencia
Isocinético

R E S U M E N

Objetivos: Examinar y comparar los efectos agudos de una rutina de estiramientos estáticos o dinámicos de corta duración sobre el pico de fuerza máximo y potencia media de la flexión y extensión concéntrica y excéntrica de la rodilla.
Método: Cuarenta y nueve adultos activos completaron los siguientes protocolos de intervención en días separados: no-estiramiento, estiramiento estático y estiramiento dinámico. Después de la intervención de control o estiramiento, el pico de fuerza máximo y la potencia media de la flexión y extensión concéntrica y excéntrica de la rodilla fueron medidos en posición prono. Las medidas fueron comparadas a través de un análisis factorial ANOVA intergrupo.

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Resultados: Ni el protocolo de estiramientos estático ni el dinámico tuvieron influencia sobre el pico de fuerza máximo y potencia media isocinética cuando fueron comparados con la condición de control. Las comparaciones por pares también mostraron que los resultados de fuerza y potencia isocinética durante la sesión de estiramientos dinámicos fueron ligeramente mayores que los encontrados durante la sesión de estiramientos estáticos.
Conclusiones: Una rutina de corta duración de estiramientos estáticos o dinámicos del tren inferior no produjo alteraciones en la fuerza isocinética concéntrica y excéntrica de la flexión y extensión de rodilla. Además, los hallazgos del presente estudio apoyan la idea de que el estiramiento dinámico podría ser preferible antes que el estiramiento estático como parte del calentamiento previo a una actuación física.

Efeito agudo de 2 diferentes técnicas de alongamento sobre a força e potência isocinética

Palavras-chave:
Aquecimento
Força muscular
Pico de força
Potência
Isocinética

R E S U M O

Objetivos: Examinar e comparar os efeitos agudos de uma rotina de alongamentos estáticos e dinâmicos de curta duração sobre o pico de força máxima e potência média da flexão e extensão concêntrica e excêntrica do joelho.
Método: Quarenta e nove adultos ativos completaram os seguintes protocolos de intervenção em dias distintos: sem alongamento, alongamento estático e alongamento dinâmico. Depois da intervenção de alongamento ou controle, o pico de força máxima e a potência média da flexão, extensão concêntrica e excêntrica do joelho foram medidos em posição pronada. As medidas foram comparadas através de uma análise fatorial ANOVA intergrupo.
Resultados: Tanto o protocolo de alongamento estático quanto o protocolo de alongamento dinâmico tiveram influência sobre o pico de força máxima e potência média isocinética quando comparados com a condição controle. As comparações por pares também mostraram que os resultados de força e potência isocinética durante a sessão de alongamento dinâmico foram ligeiramente maiores que os encontrados durante a sessão de alongamento estático.
Conclusão: Uma rotina de curta duração de alongamentos estáticos ou dinâmicos de membros inferiores não produziram alterações na força isocinética concêntrica e excêntrica da flexão e extensão do joelho. Além disso, os achados do presente estudo corroboram com a ideia de que alongamento dinâmico poderia ser preferível ao invés do alongamento estático, como parte do aquecimento antes da atividade física.

Introduction

Stretching activities before exercise are believed to prepare the musculo-skeletal system for physical activity and sport events by improving joint range of motion, thus promoting improved performance and reducing the relative risk of injury.[1] Consequently, athletes, coaches and sport practitioners regularly include stretching exercises in both training programs and in pre-event warm-up activities.[2]

However, recent evidence has questioned the traditional hypothesis that supported the practice of pre-exercise stretching as a measure to increase sport performance.[3,4] In this sense, it has been shown that a bout of static stretching may temporarily reduce strength performance, in relation to force and power production, when it is performed prior to events.[3,4] It was shown that pre-exercise static stretching might acutely compromise a muscle's ability to produce strength either isometrically[5,6] or isokinetically[7-11](mainly under concentric actions) for the knee joint measured throughout a single-joint isokinetic testing protocol. Explanations for this so-called stretching-induced strength deficit include: (a) alterations in the mechanical components of skeletal muscle contraction[7,8]; (b) decreases in muscle activation[5,12,13]; or (c) a combination of both mechanical and neural factors.[7] In contrast, some evidence exists indicating that dynamic stretching exercises may induce improvement in isometric and isokinetic strength and power performance.[11,14,15] Although the exact mechanisms by which dynamic stretching may improve strength performance are not well known, previous studies have suggested that a dynamic stretching exercise might exert positive effects on muscular performance by an elevation of muscular temperature,[16] or post-activation potentiation[14,15]caused by voluntary contractions of the antagonist of the target muscle.

These effects have implications for athletes involved in activities that require maximal strength and power production, such as rugby and football, and have led some researchers to recommend that pre-exercise static stretching should be omitted or replaced by dynamic stretching during warm-ups prior to strenuous exercise and/or sport events. However, when the body of literature regarding the acute effects of pre-exercise stretching on strength and power production is carefully scrutinized, some important limitations are noted, which may question the applicability of the last recommendation in the physical training context. For instance, most of the studies that have investigated the acute effects of static stretching on strength and power have designed protocols which use overall stretch durations on a single muscle group (quadriceps, gastrocnemius and hamstrings mainly), ranging from 90 s to 60 min.[5,12-17] These single muscle group and long stretching protocols are not representative of typical warm-ups used by athletes and recreationally active people to prepare for exercise or competition.[18] Furthermore, very few studies have carried out direct comparisons between stretching protocols with consistent stretch doses (overall and single stretching duration) and different stretch techniques (i.e. static vs dynamic stretching) on concentric and/or eccentric maximal isokinetic strength and power output to elucidate the optimal pre-participation protocol for sport activities.[11,19] Additionally, although there are studies indicating improved muscle strength performance following dynamic stretching,[14,15] it is not known how dynamic stretching affects strength and power during isokinetic quadriceps and hamstring actions in concentric and eccentric modes.

Therefore, the main purpose of the current study was to examine and compare the acute effects of short duration static and dynamic lower-limb stretching routines with consistent stretching parameters (duration, intensity, number of exercises, repetitions) on the knee flexor and extensor peak torque and mean power during maximal concentric and eccentric muscle actions in recreationally athletes.

Method

Participants

Twenty-five men (age = 21.3 ± 2.5 years; stature = 176.3 ± 8.4 cm; body mass = 74.4 ± 10.8 kg) and 24 women (age = 20.4 ± 1.8 years; stature = 164.7 ± 7.6 cm; body mass = 62.9 ± 8.6 kg) who were recreationally active adults (engaging in 2–5 h of moderate physical activity 3–5 days per week) completed the current study.

The exclusion criteria were: (a) histories of orthopedic problems, such as episodes of hamstrings and quadriceps injuries, fractures, surgery or pain in the spine or hamstring and quadriceps muscles over the past six months; (b) missing a testing session during the data collection phase; and (c) not have delayed onset muscle soreness (DOMS) through each testing session. Women participants could not be in the ovulation phase of their menstrual cycle during testing to reduce the effects of hormonal status on muscle-tendon unit stiffness and knee joint laxity.[20] The participants were verbally informed about the characteristics of the methods to be utilized as well as the purpose and risks of the present study, and written informed consent was obtained from all participants. Furthermore, the study was approved by the University of Gloucestershire Research Ethics Committee (United Kingdom).

Experimental design

A crossover study design, in which participants executed all experimental conditions, was used to investigate the purposes of the current study. Use of a pre- and post-test design, in which participants performed a pre and post-stretch isokinetic assessment was not adopted because in a pilot study participants reported that the testing procedure was too long and subsequently they felt less able to undertake the post-stretch assessment and hence, bias the results. In addition, some participants reported musculoskeletal fatigue during the post-stretch assessment. Therefore, to ensure the optimal preparedness state of each participant throughout the testing procedure, the current study used a crossover design.

Participants visited the laboratory on four occasions with 72–96 h rest interval between testing sessions. The first visit was a practice/habituation session to the isokinetic testing procedure and stretching exercises, and the following three visits were the experimental sessions. During each experimental session, participants began by completing a 5 min standardized warm-up (cycling at 90 W for men and 60 W for women at 60–70 rpm). The stretching (static or dynamic) or non-stretching (control) intervention was performed immediately after the standardized warm-up. The order of stretching (static and dynamic) and non-stretching conditions was randomized. After the stretching and non-stretching conditions, the participants performed a specific isokinetic warm-up consisting on 4 sub-maximal (self-perceived 50% effort) and 2 maximal eccentric knee flexion actions.

The rationale of using this warm up structure (standardized warm-up + stretching or non-stretching + specific warm-up) was to replicate the typical warm-up structure that is usually performed by athletes and recreationally active participants.[4]

The knee flexor and extensor peak torque and mean power assessment of the dominant leg (determined through interview and defined as leg preference when kicking a ball) was carried out 2–3 min (post-test) after the stretching protocol was completed. In the non-stretching session, the knee flexor and extensor peak torque and mean power assessment was carried out after the standardized warm-up (Fig. 1). The rationale for assessing only the dominant leg was based on the fact that previous studies have not reported leg-related differences in relation to muscle-tendon unit properties, when the same amount of stretching is applied.[21]

Stretching protocols

In each stretching session, participants performed five unassisted stretching exercises designed to stretch the major muscle groups used during running (gluteus, psoas, adductors, hamstrings and quadriceps) and reflect the stretching typically performed by athletes and recreationally active people (Fig. 2).

The static and dynamic stretching sessions differed only in the stretch technique used; whereas the other stretching load characteristics (duration, intensity, repetition and exercise positions) were identical. The stretching exercises were performed twice in a randomized order under the direct supervision and guidance of the investigators. Each stretching exercise was completed on the right and left limb before another exercise was performed. No-rest interval was allowed between limbs, although a 20 s rest period was allowed between stretch repetitions and exercises (once the leg was returned to a neutral position). The intensity of stretching was self-determined but set to the threshold of mild discomfort, not pain, as acknowledged by the participant.

During the static stretching session, participants were asked to hold each stretch position for 30 s. During the dynamic stretching session, participants were instructed to perform 15 continuous controlled dynamic movements from the neutral stance to the end of the range of movement. A rate of one stretch cycle every 2 s was set and the movements were at a controlled speed throughout the range of movements. In addition, during dynamic stretching, participants were instructed that the end position should be the same as the end position during static stretching.

Isokinetic testing

A Biodex System-3 Isokinetic dynamometer (Biodex Corp., Shirley, NY, USA) and its respective manufacture software were used to determine peak torque and mean power during knee extension and flexion isokinetic movements.

Participants were secured in a prone position on the dynamometer with the hip passively flexed at 10–20° and the head maintained erect[22] (Fig. 3). The axis of rotation of the dynamometer lever arm was aligned with the lateral epicondyle of the knee. The force pad was placed approximately 3 cm superior to the medial malleolus with the foot in a relaxed position. Adjustable strapping across the pelvic, posterior thigh proximal to the knee and foot localized the action of the musculature involved. The range of movement was set from 90° knee flexion (starting position) to 0° (0° was determined as maximal voluntary knee extension for each participant).

The isokinetic examination was separated into two parts. The first part of the examination was the assessment of the knee extensor followed by the knee flexor muscles with a concentric/concentric (CON/CON) testing method. The second part of the

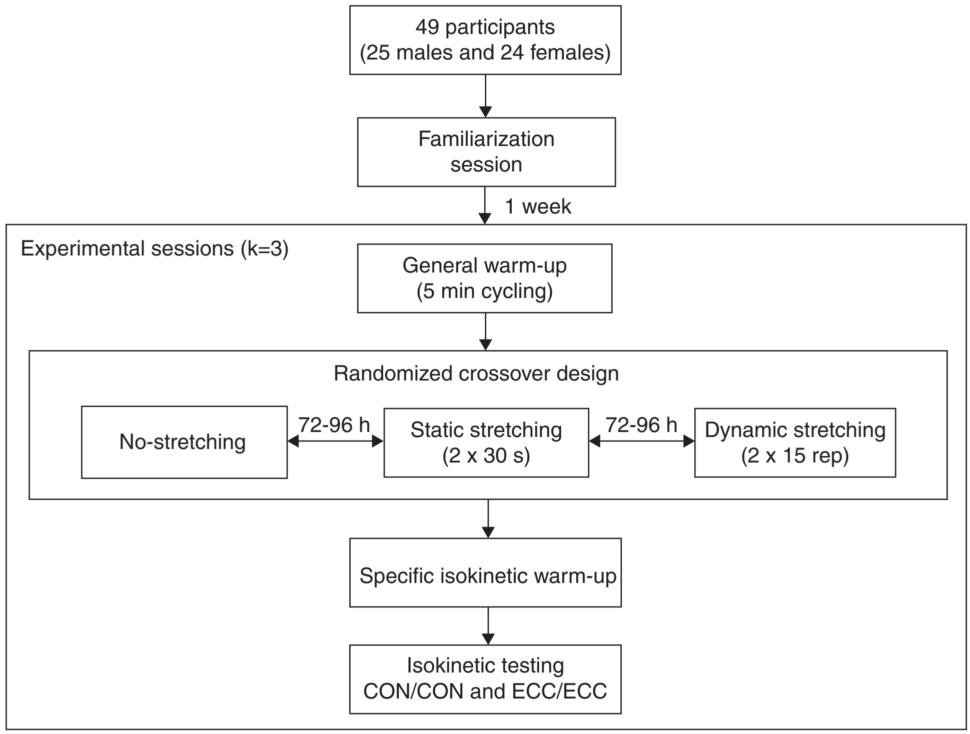

Fig. 1. Flow of participants through experimental sessions of the study.

examination was the assessment of the knee extensor followed by the knee flexor muscles with an eccentric/eccentric (ECC/ECC) testing method. In both testing methods, two cycles of knee flexions and extensions were performed at three pre-set constant angular speeds in the following order: 60, 180 and 240 °/s (slow to fast). When a variation greater than 5% was found in the peak torque scores between cycles at the same speed, an extra cycle was performed and the two most related cycles were used for the subsequent statistical analyses. The 60 and 180 °/s angular speeds were chosen to be consistent with previous studies.[7,8,10,23] The 240 °/s angular speed was chosen as the fastest velocity because in a pilot study with 10 participants of similar age and training status, they subjectively indicated that 240 °/s was the maximum CON/CON and ECC/ECC cycles speed that they were able to perform comfortably during the test and because the constant velocity period is very short at velocities faster than 240 °/s. Pilot work also showed that participants could not maintain the required torque output throughout the range of motion in the reactive eccentric mode, subsequently causing stalling of the lever arm. Therefore, the passive eccentric mode was chosen so that the full range of movement would be completed for every action.

The two testing method (CON/CON and ECC/ECC) were separate by a 5 min rest interval and a rest of 30 s was allowed between action cycles. The number of maximal muscle actions and the rest-period durations were chosen to minimize musculoskeletal fatigue, which is unlikely to occur with only two reciprocal muscle actions at three speeds and a 30 s rest between reciprocal muscle actions and speeds and 5 min rest between testing modes. Both for CON/CON and ECC/ECC cycles, participants were encouraged to push/resist as hard and as fast as possible and to complete the full range of motion.

Measures

For both isokinetic parameters of peak torque and mean power, the average of the two trials at each speed through the testing sessions was used for subsequent statistical analysis. In addition, Sole et al.[24] reported better reproducibility when they used the mean value from 3 trials rather than the single highest value from the 3 repetitions for concentric and eccentric peak torque. In each trial, peak torque was reported as the maximum torque value and power was reported as time-averaged integrated area under the

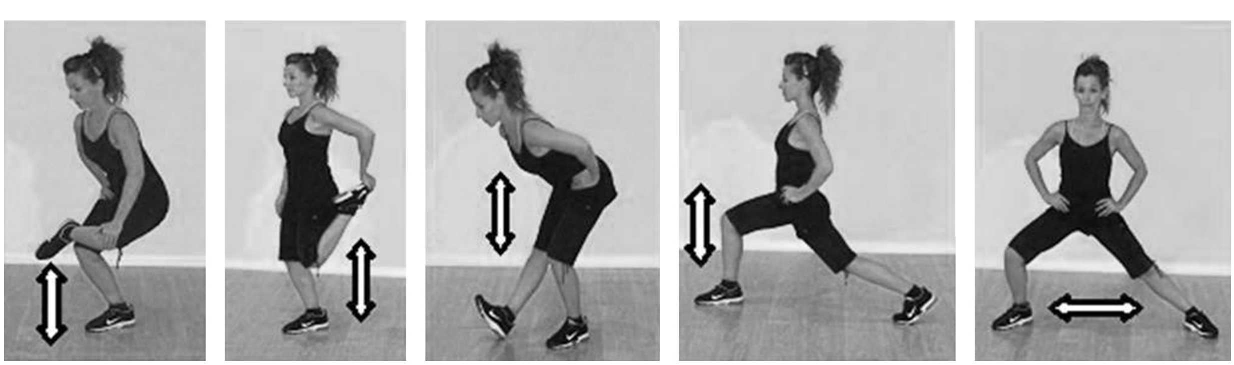

Fig. 2. Stretching exercises (left to right: gluteus, quadriceps, hamstrings, psoas, and adductors).

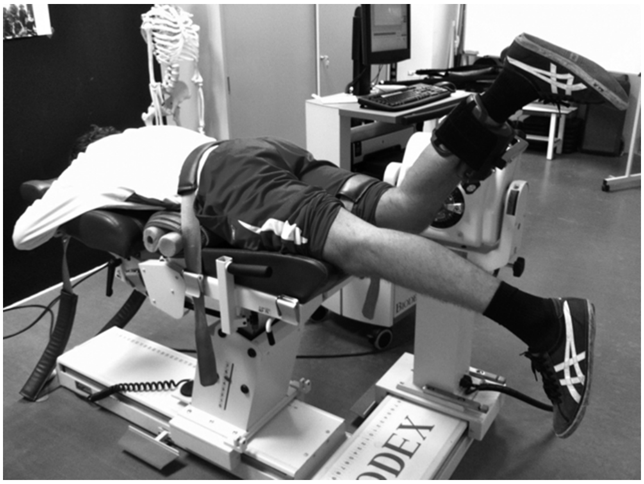

Fig. 3. Isokinetic testing position.

angle-torque relationship. The speed throughout each repetition was analyzed and it was also verified that, at the greater angular velocity, peak torque and power was developed during the constant speed period. The constant speed periods during concentric muscle actions were approximately the 82, 50 and 42% of the full knee flexion and extension ROM for the speeds 60, 180 and 240 °/s respectively. For the eccentric muscle action, the constant speed periods were 79, 48 and 40% of the full knee flexion and extension ROM at 60, 180 and 240 °/s respectively (data obtained from 20 participants).

Statistical analysis

Before any statistical analyses were performed, the distribution of raw data sets was checked using the Kolmogorov–Smirnov test. Descriptive statistics including means, standard error of the means and 95% confidence intervals were calculated for each measure.

Recent research studies have consistently reported no sex-related differences in relation to the same stretching treatment on isokinetic peak torque values[7,10,12] so men's and women's data were not analyzed separately. Descriptive statistics including means and standard deviations were calculated for each measure.

Mean effects of stretching (static and dynamic) and their 90% confidence limits were estimated using a spreadsheet designed by Hopkins[19] via the unequal-variances t statistic computed for change scores between paired sessions (control vs static; control vs dynamic; static vs dynamic) for each variable. Alpha was $p < 0.05$. Each participant's change score was expressed as a percentage of baseline score via analysis of log-transformed values, to reduce bias arising from nonuniformity of error. Errors of measurement and individual responses expressed as coefficients of variation were also estimated. In addition, the analysis determines the chances that the true effects are substantial or trivial when a value for the smallest worthwhile change is entered.

Coefficients of variation (CV) determined the smallest substantial/worthwhile change for each of the variables. To the authors' knowledge, no studies have analyzed the absolute reliability of the knee flexor and extensor peak torque and mean power during maximal concentric and eccentric muscle actions with the participants adopting a prone position, so we chose 0.20 standardized units (that is a fraction of the between-subjects standard deviation at baseline) as the smallest worthwhile change.[25] The default of 0.20 gives chances that the true effect is at least small.[25]

The qualitative descriptors proposed by Hopkins[25] were used to interpret the probabilities that the true affects are harmful, trivial or beneficial: <1%, almost certainly not; 1–4%, very unlikely; 5–24%, unlikely or probably not; 25–74%, possibly or may be; 75–94%, likely or probably; 95–99%, very likely; >99%, almost certainly.

Effect sizes, which are standardized values that permit the determination of the magnitude of differences between groups or experimental conditions,[26] were also calculated for each of the variables using the method previously described by Cohen.[26] Cohen[26] assigned descriptors to the effect sizes (d) such that an effect size of 0.4 or less represented a small magnitude of change while 0.41–0.7 and greater than 0.7 represented moderate and large magnitudes of change, respectively.

Results

Tables 1 and 2 present the mean and standard deviation for peak torque and power in each experimental session ($k = 3$) for knee extension and knee flexion in both concentric and eccentric muscle actions respectively.

As presented in Tables 3 and 4, there were no a clear main effects ($p > 0.05$; trivial effect with a probability of 75–95%; $d < 0.4$) on concentric and eccentric knee flexion and extension peak torque and power between paired treatments. However, there were possible positive effects ($d > 0.15$; positive effect with a probability of 75–95%;) of dynamic stretching on some peak torque and power variables (see Tables 3 and 4) when they were compared with the static stretching treatment.

Discussion

The primary findings of the present study indicate that short and contextualized lower limb static and dynamic stretching routines have no a stretching-induce strength and power deficit or improvement effects on concentric and eccentric knee flexion and extension isokinetic movements at three different speeds (60, 180 and 240 °/s) in recreationally athletes.

Our findings are not consistent with several recent studies,[11,12,17-27] although not all,[23,28,29] that has indicated that a bout of static stretching may cause transient decreases in isolated muscle strength. A possible explanation for these conflicting results could be attributed to the different static stretch durations used in these studies. Generally, in those studies that have reported static stretching-induced strength and power deficits, a single muscle group was statically stretched for between 90 s and 60 min.[5,12-17] Contrarily, our study in conjunction with some studies that have shown no static stretching-induced strength and power deficits have used a lower overall stretch duration ranging from 30 to 90 s.[23,28,29] Therefore, it would appear that there is a dose-dependent threshold of static stretching necessary to reflect any statistically detectable change in isokinetic strength and power. This hypothesis has been recently confirmed by some studies which have examined and carried out direct comparisons between the acute effects of stretching routines with different overall stretch doses and consistent stretching parameters (technique intensity, exercise positions and muscle stretched).[23,28,30-32] For example, Zakas et al.[23] after examining the effects of two different overall durations (45 s and 300 s) of acute static stretching on isokinetic peak torque production in pubescent soccer players reported that stretching caused a significant decrease in strength performance (5–12%) when the stretch duration was 300 s, while a stretch duration per isolate muscle of 45 s did not alter the mechanism of force production. In addition, Murphy et al.[30] found that a bout of 6×6 s of static stretching for the hamstring was enough to improve hip flexion ROM for 30 minutes without cause impairments on jump height and reaction time. Consequently, overall static stretch duration per isolate muscle group $\leq$60–90 s

Table 1
Peak torque and mean power output among experimental sessions ($k = 3$) during concentric and eccentric knee extension muscle actions.[a]

	Concentric mode			Eccentric mode		
	60°/s	180°/s	240°/s	60°/s	180°/s	240°/s
No-stretching session (control)						
Peak torque (Nm)	120.7 ± 33.7	96.7 ± 34.7	92.6 ± 29.2	169.5 ± 66.5	148.0 ± 38.7	144.4 ± 49.7
Power (W)	60.4 ± 18.5	99.2 ± 35.8	99.2 ± 35.8	81.00 ± 32.1	140.0 ± 40.9	172.5 ± 48.7
Static stretching session						
Peak torque (Nm)	122.4 ± 36.7	95.1 ± 30.1	88.4 ± 29.0	154.9 ± 67.8	142.4 ± 40.5	143.2 ± 58.4
Power (W)	63.4 ± 18.5	95.8 ± 32.3	101.3 ± 36.6	78.0 ± 28.0	133.1 ± 42.1	174.5 ± 52.0
Dynamic stretching session						
Peak torque (Nm)	128.4 ± 41.7	98.7 ± 29.9	91.5 ± 31.5	165.1 ± 64.5	160.5 ± 63.1	147.6 ± 53.0
Power (W)	64.5 ± 21.9	100.3 ± 33.0	99.9 ± 38.0	79.3 ± 35.6	141.5 ± 41.0	172.1 ± 53.6

[a] All values are mean ± standard deviation.

Table 2
Peak torque and mean power output among experimental sessions ($k = 3$) during concentric and eccentric knee flexion muscle actions.[a]

	Concentric mode			Eccentric mode		
	60°/s	180°/s	240°/s	60°/s	180°/s	240°/s
No-stretching session (control)						
Peak torque (Nm)	74.7 ± 24.7	68.1 ± 23.2	64.0 ± 22.8	82.6 ± 27.7	83.1 ± 26.2	80.6 ± 25.8
Power (W)	45.5 ± 13.7	78.3 ± 23.8	81.2 ± 28.9	48.3 ± 18.6	80.1 ± 38.8	92.4 ± 33.6
Static stretching session						
Peak torque (Nm)	72.8 ± 24.1	65.7 ± 21.7	57.8 ± 20.8	83.5 ± 25.5	79.6 ± 23.3	78.5 ± 23.7
Power (W)	44.5 ± 14.2	77.7 ± 24.9	76.0 ± 26.5	50.1 ± 16.6	76.6 ± 41.9	89.5 ± 32.7
Dynamic stretching session						
Peak torque (Nm)	75.0 ± 22.6	69.6 ± 21.3	60.9 ± 22.9	84.7 ± 28.6	81.8 ± 23.9	77.6 ± 26.9
Power (W)	46.4 ± 13.9	80.3 ± 23.4	83.6 ± 26.7	49.8 ± 17.4	82.3 ± 39.0	90.3 ± 34.5

[a] All values are mean ± standard deviation.

may have no stretching-induced alterations in strength and power during concentric and eccentric isokinetic muscle actions.

The results of the current study also suggest that there were no significant differences in isokinetic strength and power performance after dynamic stretching compared with control condition. These findings are not consistent with previous studies that have reported increased strength and/or power after a bout of dynamic stretching.[11,33,34] A possible explanation for the discrepancy between the results of the current study, that showed no dynamic stretching-induced improvements on isokinetic strength and power; in contrast with the results reported by previous studies may be due to the different stretch duration used. For example, Sekir et al.[11] designed a dynamic stretching protocol with an overall stretch duration per muscle (quadriceps and hamstrings) of 60 s (4 × 15 dynamic movements) and Manoel et al.[34] carried out 3 repetitions of 30 s dynamic stretches, while the current study stretched the major muscle groups of the lower limb (psoas, quadriceps, hamstrings, gluteus and adductors) using a overall stretch duration of 30 s per muscle group (2 × 15 dynamic movements). Perhaps, as occur with static stretching, the dynamic stretching-induced enhancement of muscular performance phenomenon may be governed by a dose–response relationship, where the shorter volumes (<30 s) do not affect muscle performance and longer duration may facilitate performance (>60–90 s).[4] However, future studies are necessary to test this hypothesis.

Another important issue regarding the pre-exercise stretching routine design is the stretch technique used. When static and dynamic stretching treatments were compared, the results of the current study showed that dynamic stretching reported slightly higher scores than static stretching ($d > 0.15$; percentage change ranged form 1.2 to 14.7) for most of the strength and power variables. Therefore, this finding supports the recent claims that suggest that dynamic stretching is preferable to static stretching as part of a warm-up designed to prepare for physical activity due to the possible enhancement of muscular performance[11,33–37]; and the similar acute increases in static flexibility as static stretching.[38,39]

Another important clinical question is whether the effects of stretching of knee flexor and extensor muscle groups, which are closely related to the actual demands of sport on strength performance, elicit a similar response, in order to make evidence-based recommendations. The results of the current study and the findings reported by Sekir et al.[11] have demonstrated that knee flexor and extensor muscles respond in the same way to static and dynamic stretching.

Two different methodological aspects of the current study should be highlighted because they might make the results more valid than previous studies. The first aspect is the design of the stretching protocol used. The current study used a multiple-muscle stretching protocol (in which participants stretched the major lower-limb muscles) instead of the widely used single-muscle protocol (in which participants stretched only the muscle studied).[15-27] The rationale for using a multiple-muscle stretching protocol was because an acute bout of static stretching may reduce muscle activation via peripheral (autogenic inhibition of the Golgi tendon reflex, mechanoreceptor and nociceptor afferent inhibition) and central nervous system (supraspinal fatigue) mechanisms.[5,8,12] In this sense, Avela et al.[5] and Cramer et al.[8] found that an acute bout of static stretching caused a decrease in muscle activation not only in the stretched muscle but also in the un-stretched contralateral muscle (via central nervous system mechanism). However, the degree of contribution of each mechanism (peripheral and central) on the reduction in muscle activation is still unclear. Therefore, effects of stretching before exercise and sport events should be investigated using multiple-muscle stretching protocols that reflect the stretching stimuli that athletes and recreationally active people usually apply both to the peripheral and central nervous system during a typical warm-up

Table 3
Concentric (CON) and eccentric (ECC) knee flexion peak torque (PT) and power (PW) percentage changes (mean, 90% confidence limit), effect size (*d*) and likelihood (%) of being positive/trivial/negative among treatment sessions (paired comparisons). Practical assessments of the effects are also shown.[a]

	Static vs control		Dynamic vs control		Dynamic vs static	
	Change (%) +/Trivial/– (inference)	Effect size	Change (%) +/Trivial/– (inference)	Effect size	Change (%) +/Trivial/– (inference)	Effect size
PT_{CON60}	−3.1 (−8.5 to 2.7) 1/76/23 (likely trivial)	−0.09	0.9 (−3.5 to 5.5) 6/92/2 (likely trivial)	0.03	4.8 (−1.3 to 11.2) 45/54/0 (possible positive)	0.14
PT_{CON180}	−2.8 (−8.4 to 3.2) 0/87/13 (likely trivial)	−0.08	1.5 (−3.9 to 7.2 5/94/1 (likely trivial)	0.04	5.5 (−0.5 to 11.9) 32/68/0 (possible positive)	0.15
PT_{CON240}	−9.4 (−15.7 to −2.7) 0/26/74 (possible negative)	−0.27	−3.8 (−9.6 to 2.2 0/81/19 (likely trivial)	−0.11	6.4 (−1.7 to 15.1) 41/58/0 (possible positive)	0.17
PW_{CON60}	−4.5 (−10.0 to 1.3) 1/64/55 (possible trivial)	−0.14	1.4 (−4.2 to 7.4) 21/74/5 (possible trivial)	0.04	6.7 (0.1 to 13.7) 72/28/0 (possible positive)	0.19
PW_{CON180}	−0.1 (−5.9 to 6.0) 3/93/4 (likely trivial)	0.01	0.6 (−3.8 to 5.1) 2/98/0 (very likely trivial)	0.02	1.2 (−6.2 to 9.1) 11/84/4 (likely trivial)	0.04
PW_{CON240}	−6.2 (−14.5 to 3.0) 1/58/42 (possible negative)	−0.17	−0.5 (−5.8 to 5.1) 1/97/2 (very likely trivial)	0.02	7.1 (−3.3 to 11.1) 45/53/2 (possible positive)	0.18
PT_{ECC60}	−0.8 (−4.9 to 3.5) 0/99/1 (very likely trivial)	−0.02	2.6 (−1.6 to 6.9) 5/95/0 (very likely trivial)	0.07	4.0 (0.1 to 8.2) 11/84/0 (likely trivial)	0.11
PT_{ECC180}	−4.7 (−9.7 to 0.6) 0/70/30 (possible trivial)	−0.15	−0.4 (−4.3 to 3.8) 0/99/1 (very likely trivial)	−0.01	5.3 (−0.3 to 11.1) 35/65/0 (possible positive)	0.16
PT_{ECC240}	−3.0 (−7.6 to 1.9) 0/88/12 (likely trivial)	−0.09	−1.4 (−5.6 to 3.0) 0/97/3 (very likely trivial)	−0.04	1.8 (−3.5 to 7.5) 8/92/1 (likely trivial)	0.06
PW_{ECC60}	3.8 (−2.7 to 10.6) 14/86/0 (likely trivial)	0.09	4.1 (−2.1 to 10.6) 14/86/0 (likely trivial)	0.1	2.6 (−3.1 to 8.6) 6/94/0 (likely trivial)	0.06
PW_{ECC180}	−4.2 (−11.3 to 3.6) 1/76/23 (likely trivial)	−0.12	3.2 (−2.6 to 9.3) 15/85/0 (likely trivial)	0.09	8.8 (0.6 to 17.6) 64/36/0 possible positive)	0.24
PW_{ECC240}	−4.0 (−10.3 to 2.8) 0/79/21 (likely trivial)	−0.11	−0.3 (−6.1 to 5.9) 2/96/3 (very likely trivial)	−0.01	2.8 (−4.0 to 10.1) 13/86/1 (likely trivial)	0.08

[a] If chance of benefit and harm both >5%, true effect was assessed as unclear (could be beneficial or harmful). Otherwise, chances of benefit or harm were assessed as follows: <1%, almost certainly not; 1–5%, very unlikely; >5–25%, unlikely; >25–75%, possible; >75–95%, likely; >95–99%, very likely; >99%, almost certain.

Table 4
Concentric (CON) and eccentric (ECC) knee extension peak torque (PT) and power (PW) percentage changes (mean, 90% confidence limit), effect size (*d*) and likelihood (%) of being positive/trivial/negative among treatment sessions (paired comparisons). Practical assessments of the effects are also shown.[a]

	Static vs control			Dynamic vs control			Dynamic vs static		
	Change (%)	Effect size	+/Trivial/− (inference)	Change (%)	Effect size	+/Trivial/− (inference)	Change (%)	Effect size	+/Trivial/− (inference)
PT_{CON60}	0.2 (−5.6 to 6.3)	0.01	9/84/7 (likely trivial)	4.2 (−1.5 to 10.2)	0.14	39/61/0 (possible positive)	4.3 (−4.2 to 13.5)	0.14	43/53/4 (possible positive)
PT_{CON180}	0.9 (−8.3 to 7.2)	−0.03	5/85/10 (likely trivial)	0.5 (−6.7 to 8.4)	0.02	8/87/5 (likely trivial)	3.8 (−3.0 to 11.0)	0.11	21/78/1 (likely trivial)
PT_{CON240}	−7.8 (−14.4 to −0.8)	−0.25	0/36/64 (possible negative)	−0.8 (−5.6 to 4.2)	−0.03	1/96/3 (very likely trivial)	7.3 (−0.9 to 16.2)	0.22	54/45/0 (possible positive)
PW_{CON60}	0.6 (−5.6 to 7.1)	0.02	14/71/9 (likely trivial)	1.7 (−4.7 to 8.5)	0.05	22/72/6 (possible trivial)	1.6 (−6.7 to 10.6)	0.05	28/61/11 (possible trivial)
PW_{CON180}	−2.9 (−9.8 to 4.5)	−0.08	1/82/17 (likely trivial)	−0.7 (−7.8 to 6.9)	−0.02	4/89/7 (likely trivial)	6.1 (−1.5 to 14.3)	0.16	38/62/0 (possible positive
PW_{CON240}	−3.3 (−11.2 to 5.3)	−0.10	2/74/23 (likely trivial)	−2.4 (−8.5 to 4.2)	−0.07	1/87/12 (likely trivial)	2.0 (−7.6 to 12.5)	0.06	19/74/7 (possible trivial)
PT_{ECC60}	−5.9 (−12.5 to 1.1)	−0.16	0/56/44 (possible negative)	−3.5 (−9.4 to 2.8)	−0.09	0/79/20 (likely trivial)	5.1 (−2.3 to 13.1)	0.13	34/65/1 (possible positive)
PT_{ECC180}	−4.5 (−12.6 to 4.3)	−0.13	1/70/29 (possible trivial)	9.0 (−4.0 to 23.7)	0.25	59/38/2 (possible positive)	14.7 (0.6 to 30.9)	0.40	81/18/1 (likely positive)
PT_{ECC240}	−5.4 (−17.7 to 8.8)	−0.12	4/67/29 (possible trivial)	−1.9 (−9.5 to 6.4)	−0.04	1/92/7 (likely trivial)	−2.5 (−9.1 to 4.5)	−0.06	0/94/6 (likely trivial)
PW_{ECC60}	−3.2 (−9.9 to 4.0)	−0.08	1/84/15 (likely trivial)	−3.1 (−9.8 to 4.0)	−0.08	0/85/15 (likely trivial)	2.4 (−5.8 to 11.4)	0.06	15/83/2 (likely trivial)
PW_{ECC180}	−6.0 (−14.4 to 3.3)	−0.17	1/55/44 (possible negative)	2.0 (−5.8 to 10.5)	0.06	15/82/3 (likely trivial)	9.4 (2.1 to 17.3)	0.25	68/32/0 (possible positive)
PW_{ECC240}	3.8 (−4.9 to 13.4)	0.10	16/82/2 (likely trivial)	−0.6 (−9.3 to 11.6)	0.02	5/85/11 (likely trivial)	−1.6 (−8.6 to 5.9)	−0.04	3/87/10 (likely trivial)

[a] If chance of benefit and harm both >5%, true effect was assessed as unclear (could be beneficial or harmful). Otherwise, chances of benefit or harm were assessed as follows: <1%, almost certainly not; 1–4%, very unlikely; 5–24%, unlikely; 25–74%, possible; 75–94%, likely; 95–99%, very likely; >99%, almost certain.

to make evidence-based recommendations. The second methodological aspect that should be underlined is related to the isokinetic testing position used. Studies that have investigated the effects of stretching on isokinetic strength, with the goal of making recommendations to design warm-up protocols that allow athletes improving performance and reducing the risk of lower limb musculoskeletal injury, have typically reported data obtained from participants tested in a seated position. However, rarely are field and court sport athletes active with those kinematics (e.g., the hip flexed at 80–110°).[40,41] Most lower limb injuries occur while athletes engage in some running activity where the hip angle is reported to typically be approximately 10–20° to the vertical with foot plant occurring directly inferior to the torso and not with a hip flexion angle of 80–110°.[41] Thus, it could be argued that isokinetic screening where the hip angle is more similar to when executing real-world sporting tasks would be more ecologically valid than using other traditional methods.[22,40] Based on the last statement, the current study selected a prone position with hip flexed 10–20°, which replicates the hip position and knee flexor and extensor muscle length-tension relationships that occur during running/sprinting.[22,40] Although the standing position appears to be the most ecologic valid testing position, it was not used because of technical issues (the bench of the dynamometer could not adapted to this position). However, it is possible that if the same hip flexion is used in both standing and prone positions, the stretch-tension relationship of the knee flexors and extensors will not likely differ and the relative contribution of the active contractile components of the muscles to overall force production would not change. Future studies are necessary to test this hypothesis.

Although the current study is the first that has designed and examined the acute effects of a short and sport contextualized static and dynamic pre-exercise lower limb stretching routine with consistent stretch parameters on several isokinetic concentric and eccentric strength parameters (peak torque and power) in a large sample size of recreationally athletes, some limitations should be noted. The first limitation is that this study did not directly evaluate changes in the range of motion or changes in resistance and tolerance to stretch due to the experimental stretching treatments. Therefore it is not known whether the stretching interventions were actually effective in increasing flexibility or in decreasing muscle stiffness, although previous studies from our laboratory that have used identical stretching doses have reported increases in flexibility.[38] Another potential limitation of the current study is the population used. Although this investigation used 49 participants, much higher than previous studies, the participants were homogenous based on age and physical status, which could limit the external validity of the results.

Therefore, the results of the present study indicate that short pre-exercise static and dynamic lower-limb stretching routines do not elicit stretching-induce deficits or improvements on knee flexor and knee extensor isokinetic concentric and eccentric strength and power. However, there is some evidence from our findings, in conjunction with similar previous studies, that dynamic stretching is preferable to static stretching as part of a warm-up designed to prepare for physical activity due to the possible enhancement of muscular performance.

Conflicts of interest

The authors have no conflicts of interest to declare.

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