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Acute effects of short and long duration dynamic stretching protocols on muscle strength

Efeitos agudos de protocolos de alongamento dinâmico de curto e de longa duração sobre a força muscular

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Abstract

Objective: Compare the acute effects of dynamic stretching protocols on the isokinetic performance of the quadriceps and hamstring muscles at two velocities in adult males. **Methodology**: Included the participation of 14 males (21 ± 2.6 years; 178 ± 0.4 cm; 73.2 ± 20.9 kg) were assessed using an isokinetic dynamometer before and after following a short or long-duration dynamic stretching protocol or a control protocol. The results were assessed by a two-way ANOVA and a Scheffé's *post hoc* test at a 5% significance level. **Results**: No difference was found in the variables assessed at 180°/s after LDDS. At 60°/s, LDDS reduced the power of the knee flexors. The control protocol reduced the power of the knee flexors and increased the power of the extensors. At 60°/s, the work of the knee flexors exhibited a reduction after LDDS. The control protocol resulted in a reduction in the work of the flexors. The peak torque angle exhibited a reduction in the extensors and flexors after LDDS and SDDS. **Conclusion**: Dynamic stretching did not cause any change in the peak torque, which points to its possible use in activities involving velocity and muscle strength. The executing dynamic stretching before physical activities such as running and high-intensity sports might be beneficial by promoting increases in heart rate and in body temperature.

Keywords: Muscle stretching exercises. Muscle strength. Dynamometer for muscle strength.

Resumo

Objetivo*: Comparar os efeitos agudos de protocolos de alongamento dinâmico no desempenho isocinético do quadríceps e isquiotibiais em duas velocidades diferentes em homens adultos.* ***Metodologia****: Participaram 14 sujeitos (21 ± 2,6 anos, 178 ± 0,4 cm; 73,2 ± 20,9 kg) avaliados através de um dinamômetro isocinético, antes e depois de seguir os protocolos de alongamento dinâmico de longa e curta duração e protocolo controle. Os resultados foram avaliados por uma análise de variância de duas fatores e teste post hoc de Scheffé ao nível de significância de 5%.* ***Resultados****: Não houve diferença nas variáveis avaliadas em 180º/s após ADLD. A 60º/s, ADLD reduziu a força dos flexores do joelho na concêntrica e as fases excêntrica do movimento. O protocolo de controle reduziu a força dos flexores do joelho e aumentou a força dos extensores. A 60º/s, o trabalho dos flexores do joelho apresentou redução após ADLD. O protocolo controle reduziu trabalho dos flexores. O ângulo de pico de torque apresentou uma redução nos extensores e flexores após ADLD e ADCD.* ***Conclusão****: O alongamento dinâmico não causou alteração no pico de torque, o que favorece uso em atividades que envolvam velocidade e força muscular . O alongamento antes de atividades físicas como corrida e esportes de alta intensidade pode ser benéfico por promover aumento da frequência cardíaca e da temperatura corporal.*

Palavras-chave*: Exercício de alongamento muscular. Força muscular. Dinamômetro para força muscular.*

Introduction

Athletes usually perform a specific warm-up routine as preparation. Authors such as (1, 2, 3, 4, 5, 6) among others, recommend warming up for athletes to prepare mentally and physically for training or competition. Dynamic stretching seems to be an efficient strategy for specific muscle warm-up preceding sports, as it is a functional technique that prepares the body for physical activity (7). This benefit occurs because the movements performed reproduce the ones executed during the corresponding sport or physical activity rather than engaging a particular muscle, as other stretching techniques do. In addition, the primary aims of dynamic stretching are: to modify the level of strength of the muscles involved in the movement, to promote the stretch reflex, to favor the contraction of the stretched muscles, to increase the body temperature, and to reduce the stiffness of muscles and joints (8, 9).

Some studies, such as the one by (10), found significant increases in muscle power following dynamic stretching. In the studies conducted by (11) and (12), dynamic stretching contributed to increases in muscle strength. Conversely, (8) and (13) did not find any changes in muscle strength following dynamic stretching.

According to (10), the improvement in muscle performance following dynamic stretching might be associated with two factors: an increase in the muscle temperature and the occurrence of post-activation potentiation (PAP). PAP involves the phosphorylation of myosin regulatory light chains, which improves the actin-myosin interaction. This interaction is caused by the voluntary contraction of the muscle antagonist to the targeted stretched muscle (14) described PAP as a set of sequential muscle contractions occurring over a very short period of time and thus characterized it as post-tetanic potentiation. According to (11), PAP reduces the time to peak torque and increases the rate of muscle torque development. Other authors, such as (12), agree with (10) and (11) and attribute the improvement of the muscle performance to at least one of the following physiological factors: increased motor unit activation, increased muscle temperature, or PAP. However, other studies, such as the one by (13), did not find significant changes in the torque or peak torque upon conducting an isokinetic assessment. (8) also found no change in the muscle performance as indicated by the results on the isometric peak torque obtained using an isometric dynamometer.

The studies that applied dynamic stretching protocols exhibited methodological design variation in the number of series, the number of exercises, the sample profile, and the protocol length (8, 10, 11, 12, 13). Therefore, one might question whether the reported acute effects of dynamic stretching on muscle strength are a function of the protocol.

Based on the results of these previous studies, one of the hypotheses formulated in this study is that the dynamic stretching of short duration will cause significant increase in peak torque, angle of peak torque and total work during isokinetic evaluation at an angular velocity of 60°/s and, the other hypothesis is that dynamic stretching of short duration will not cause significant increases in peak torque, angle of peak torque and total work during isokinetic evaluation at an angular velocity of 180°/s.

As a consequence, there is no consensus on the acute effects of dynamic stretching on muscle strength. For that reason, the present study tested two protocols for dynamic stretching that differed in duration at two angular velocities to contribute to the understanding of the acute effects of the duration of dynamic stretching on the isokinetic performance of the knee extensors and flexors.

Materials and methods

Experimental approach to the problem

All the procedures were performed at the Center for Isokinetic Dynamometry of the Physical Therapy Teaching Clinic (Centro de Dinamometria Isocinética da Clínica Escola de Fisioterapia – PUCPR – Campus Curitiba, Brazil) and divided into two phases. Phase one comprised one stage that was performed on one day and consisted of the recruitment and selection of volunteers, the signing of the informed consent forms, and the execution of clinical interviews. Phase two comprised three stages: acquaintance with the isokinetic dynamometer and assessment, application of the stretching protocol, and isokinetic reassessment (Figure 1).

All the volunteers participated in the two phases, which demanded attendance at the PUCPR physical therapy clinic on 11 non-consecutive days for 48-hour intervals (13) and the participation in experimental sessions for protocol application and data collection.

In phase two, the volunteers' quadriceps and hamstring muscles were assessed using an isokinetic dynamometer at two different angular velocities, 60°/s and 180°/s. The volunteers' positioning in the isokinetic dynamometer followed (15, 16, 17), and the variables analyzed were: peak torque (Nm), peak torque angle (°), total work (Joules), and average power (Watts).

Subjects

The sample comprised 14 volunteers with an average age of 21 ± 2.6 (years old), an average height of 178 ± 0.4 (cm), an average body mass of 73.2 ± 20.9 (kg), and an average body mass index of 23 ± 6.1 (kg/m^2) who were students of Physical Education at Pontifical Catholic University of Paraná and Technological University of Paraná. The volunteers comprised one single experimental group and were subjected to short- and long-duration stretching, as well as to a control protocol. Volunteers who answered "no" to all questions in the Physical Activity Readiness Questionnaire – PAR-Q (18) and exhibited at least 70% of the normal muscle length amplitude (19) were included in the study. Individuals who reported or exhibited any type of musculoskeletal dysfunction in the past three months, such as ligament injury, muscle strain, or bone fractures in the lower limbs, were excluded.

All the volunteers signed an informed consent form. The study was approved by the Human Research Ethics Committee of PUCPR, ruling no. 48572.

Procedures

Completed one phase, on phase two, day one, an experimental session was conducted, which comprised a general warm-up on a bicycle ergometer for five minutes (3, 20, 21). Next, the volunteers were subjected to a protocol for acquaintance with the isokinetic dynamometer (13, 15, 16, 17).

On phase two, day 2, the second experimental session was conducted, which included the same warm-up routine on the bicycle ergometer as in day one. Next, the volunteers were subjected to isokinetic assessment of concentric and eccentric knee flexion and extension at 60°/s with two-minute intervals for recovery (22). Then, they performed the short-duration dynamic stretching protocol (SDDS), which lasted for two minutes and twenty seconds. After the conclusion of the SDDS protocol, the isokinetic reassessment was performed.

On phase two, days three and four, the third experimental session was conducted, which comprised systemic warming up on a bicycle ergometer, followed by isokinetic assessment of concentric and eccentric knee flexion and extension at 60°/s. Two minutes later, the participants executed the long-duration stretching protocol (LDDS), which lasted for three minutes and thirty seconds. After the conclusion of the LDDS protocol, the isokinetic reassessment was performed. The third session was conducted on two non-consecutive days (with a 48 hour interval).

On phase two, day five, the fourth experimental session was conducted, which comprised systemic warming up on a bicycle ergometer, followed by isokinetic assessment of concentric and eccentric knee flexion and extension at 60°/s (15). The control (CTRL) protocol was executed two minutes later. For the CNTRL protocol, the volunteers performed no stretching but instead sat on a chair for a period of time equivalent to the average amount of time of the SDDS and LDDS protocols, three minutes and fifteen seconds. After the conclusion of the CTRL protocol, the isokinetic reassessment was performed.

On phase two, days six, seven, eight, nine, 10, and 11, the same stretching protocols as on days two, three, four, and five were performed. However, isokinetic assessment and reassessment were performed at an angular velocity of 180°/s on the quadriceps and hamstring muscles and relative to the concentric phase of movement only (13).

The stretching protocols described below are among the most widely used by athletes before physical activities, predominantly requiring strength, velocity, and resistance (12).

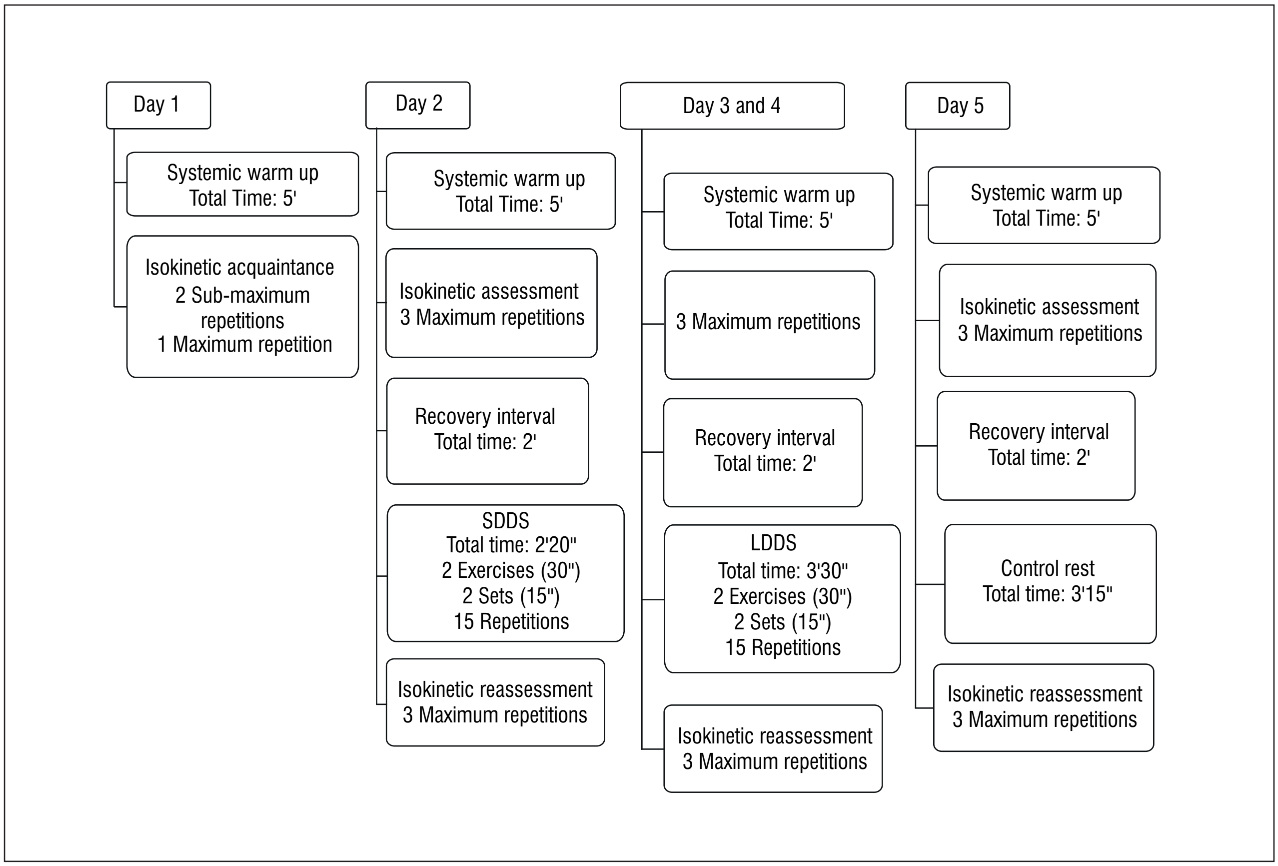

Figure 1 - Flowchart of the second phase of the study
Source: Research data.

Stretching protocols

SDDS protocol

The volunteers performed two dynamic stretching exercises, one targeting the hamstrings and the other targeting the quadriceps muscle group. Two series comprising 15 repetitions of each exercise were performed, the first five repetitions being slow (one per second) and the last 10 being as fast as possible (12). A pace tracker (Yankz PaceTat) was used to indicate the slower rhythm, while the faster one was established by each individual volunteer. A 15 second interval separated the series corresponding to the same stretching exercise, whereas a 30 second interval was used in the shift to the second exercise (quadriceps to hamstring), for a total time of approximately two minutes and 20 seconds.

The dynamic stretching exercises and their order were as follows:

1) In the bipedal position, the volunteers flexed the hip corresponding to the dominant side to approximately 90° with the knee in extension so that the thigh was pulled towards the trunk. The volunteers were required to keep the abdominal muscles contracted throughout the exercise. Figure 2A depicts the posture adopted by subjects during this exercise;
2) In the bipedal position, the volunteers flexed the knee corresponding to the dominant side to approximately 90° until the heel came as close to the buttocks as possible. The volunteers were required to keep the abdominal muscles contracted throughout the exercise. Figure 2B depicts the posture adopted by subjects during this exercise.

LDDS protocol

The exercises included in the LDDS protocol were the same as those in the SDDS protocol, and thus the volunteers performed two types of dynamic stretching exercises, one targeting the hamstring and the other targeting the quadriceps muscle group. Each exercise comprised three series with 15 repetitions each, the first five being slower and the last 10 being as fast as possible. A pace tracker (Yankz PaceTat) was used to maintain the slower rhythm (60 beeps/minute), while the faster rhythm was established by each individual volunteer. A 15 second interval separated the series corresponding to the same (quadriceps) stretching exercise, whereas a 30 second interval was used in the shift to the second (quadriceps to hamstring) exercise for a total time of approximately three minutes and 30 seconds.

The dependent variables analyzed were: peak torque (Nm), peak torque angle (°), total work (Joules), and average power (Watts).

The independent variables analyzed were angular velocity (60°/s and 180°/s), stretching (SDDS and LDDS) and control (CTRL) protocols, and time points before and after the protocols.

Statistics analyses

The normality of the data were assessed by the Shapiro-Wilk test. The numerical values underwent logarithmic transformation to make non-normal distributions become normal distributions, thus allowing for comparisons of the variables before and after the application of the stretching (SDDS and LDDS) and control protocols using a test for parametric samples.

The comparison of the investigated variables between the stretching (SDDS and LDDS) and control protocols before and after application was performed separately for each tested isokinetic velocity (60°/s and 180°/s), for both dynamic contraction phases (concentric and eccentric), and for both muscular groups (quadriceps and hamstring). This analysis was done using ANOVA repeated measures (protocols SDDS, LDDS, and CTRL) with one factor (timepoints: before and after) to identify significant differences between the investigated isokinetic variables. Whenever a difference was found, the Scheffé post-hoc test was used to identify the variables involved.

Statistical analysis was performed using SPSS 14 software, the significance level was 0.05. A statistical power of about 70% was achieved with the sample size of the study.

Results

The results of the isokinetic variables before and after the execution of the stretching and control protocols are described in Tables 1, 2, and 3, including the mean and standard deviation, as well as in Table 4, in which the p value (significance) is indicated.

Significant differences were not found in the peak torque, the total work, the average power, or the peak torque angle of the knee extensors or flexors in either the concentric or the eccentric phases of movement at an angular velocity of 180°/s.

Discussion

The present study investigated the acute effects of SDDS and LDDS and a control protocol on the isokinetic performance of the knee flexors and extensors at two different angular velocities, 60°/s and 180°/s.

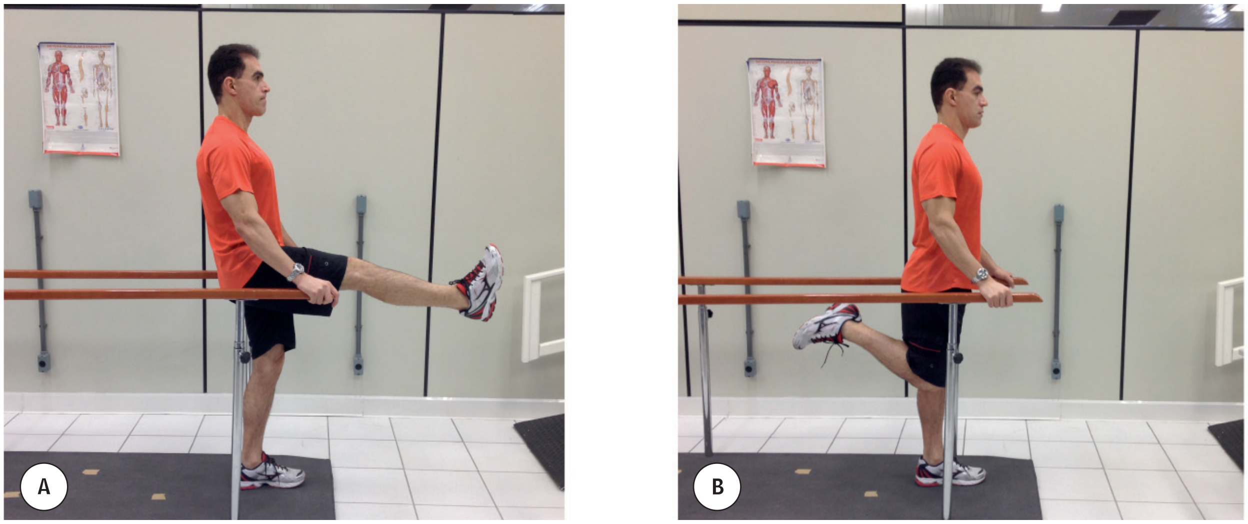

Figure 2 - Posture adopted by subjects during the stretching exercises targeting the hamstrings (A) and quadriceps (B) muscle groups

Source: Research data.

Table 1 - Results corresponding to knee extensors at 60º/s

Protocol	Variables	Concentric		Eccentric	
		Before	After	Before	After
SDDS	Peak torque (Nm)	213.6 ± 28.1	208.3 ± 26.6	305.3 ± 57.1	308.1 ± 46.7
	Total work (J)	249.9 ± 33.5	247.5 ± 37.4	337 ± 72	355 ± 58.5
	Power (W)	142.1 ± 20.4	141.4 ± 21.8	187.2 ± 40.6	198.2 ± 33.9
	PT angle (degrees)	61.9 ± 6.7	60.1 ± 7.2	64.4 ± 6.8	64.1 ± 4.8
LDDS	Peak torque (Nm)	203.8 ± 33.8	206.9 ± 27	306.6 ± 48.7	312.5 ± 35.8
	Total work (J)	238.4 ± 32.7	244.1 ± 27.5	342.3 ± 55.3	340 ± 39.2
	Power (W)	136.6 ± 18.2	140 ± 16.6	188.4 ± 32.3	189 ± 21.9
	PT angle (degrees)	63.6 ± 7.9	63.5 ± 5.5	67.6 ± 7.9	63.1 ± 7.9
CTRL	Peak torque (Nm)	206.6 ± 32.4	210.8 ± 40.9	316.3 ± 49.4	323.3 ± 61.6
	Total work (J)	239.9 ± 38	255.7 ± 57	343 ± 55.6	343.8 ± 71.5
	Power (W)	137.9 ± 22.5	141.6 ± 27.3	188.6 ± 32.1	196.6 ± 36.2
	PT angle (degrees)	66.9 ± 9.2	64.6 ± 10.1	71 ± 6.7	70.1 ± 7.2

Note: PT = peak torque. Values expressed as mean ± standard deviation. Mean and standard deviation corresponding to knee extensors - 60º/s.

Source: Research data.

Table 2 - Results corresponding to knee flexors at 60º/s

(To be continued)

Protocol	Variables	Concentric		Eccentric	
		Before	After	Before	After
SDDS	Peak torque (Nm)	150.6 ± 27.5	151.1 ± 27.9	185.8 ± 43.1	193.5 ± 45.9

Table 2 - Results corresponding to knee flexors at 60º/s

(Conclusion)

Protocol	Variables	Concentric		Eccentric	
		Before	After	Before	After
SDDS	Total work (J)	188.6 ± 35.3	184.6 ± 32.7	238.6 ± 58.7	234.4 ± 58
	Power (W)	107.6 ± 21.8	105.7 ± 19.1	134.4 ± 34.1	132.1 ± 32.3
	PT angle (degrees)	26.9 ± 6.8	25.4 ± 5.5	20.6 ± 9.2	14.9 ± 7.4
LDDS	Peak torque (Nm)	148.6 ± 29.1	141.3 ± 27.6	187 ± 47.2	181.6 ± 45.4
	Total work (J)	192.6 ± 45.4	173.5 ± 34.3	243.1 ± 59.1	226.4 ± 56
	Power (W)	106.2 ± 19.8	100.4 ± 20.7	135.4 ± 33.3	125.9 ± 31.4
	PT angle (degrees)	21.8 ± 6.9	21 ± 6	23.6 ± 13.6	18.3 ± 11.4
CTRL	Peak torque (Nm)	143 ± 28.7	142.2 ± 32.5	188.9 ± 49.4	181.8 ± 51
	Total work (J)	182.4 ± 37.6	178.7 ± 37.4	246.6 ± 65.8	229.2 ± 63.6
	Power (W)	104.3 ± 21.8	102.9 ± 22.3	138.8 ± 37.1	128.7 ± 35.1
	PT angle (degrees)	21.8 ± 5.1	24.6 ± 6.3	20.3 ± 9.4	19.2 ± 12.2

Note: PT = peak torque. Values expressed as mean ± standard deviation. Mean and standard deviation corresponding to knee flexors - 60º/s.
Source: Research data.

Table 3 - Results corresponding to knee flexors and extensors at 180º/s

Protocol	Variables	Concentric		Eccentric	
		Before	After	Before	After
SDDS	Peak torque (Nm)	158.1 ± 23.9	158.6 ± 29.3	114.7 ± 21.4	117.7 ± 21.1
	Total work (J)	180.8 ± 28.3	181.4 ± 31	143.6 ± 26.5	145.1 ± 26.1
	Power (W)	271.1 ± 43.3	271.7 ± 47.5	210.7 ± 39.6	213.1 ± 45
	PT angle (degrees)	58.5 ± 6.4	59.9 ± 5	34.8 ± 5.2	33.6 ± 5.9
LDDS	Peak torque (Nm)	157.6 ± 22.1	157.4 ± 26.4	116.6 ± 21.8	118.8 ± 20.1
	Total work (J)	180.8 ± 26.5	179.4 ± 31.5	146.1 ± 25.3	147.1 ± 25
	Power (W)	276.6 ± 43.5	270.9 ± 52.1	219 ± 42.2	221.9 ± 41
	PT angle (degrees)	59.2 ± 5.1	59.7 ± 5.9	34.5 ± 6.1	33.2 ± 7.7
CTRL	Peak torque (Nm)	156.6 ± 28.4	153.2 ± 31.3	117.7 ± 22	119.7 ± 21.5
	Total work (J)	179.6 ± 31.3	177.1 ± 36.7	144.9 ± 26.8	148.4 ± 25.6
	Power (W)	272.1 ± 56.2	268.7 ± 59.3	212.2 ± 46.1	219.1 ± 44.5
	PT angle (degrees)	59.1 ± 6	60.2 ± 5	33.6 ± 6.9	33.5 ± 6.6

Note: PT = peak torque. Values expressed as mean ± standard deviation. Mean and standard deviation - 180º/s.
Source: Research data.

Table 4 - Summary of the results of the statistical analysis

	Variável	Protocol		Time-point		Protocol vs time-point	
		Conc	Ecc	Conc	Ecc	Conc	Ecc
Extensors	Peak torque 60º/s	0.874	0.271	0.782	0.166	0.291	0.961
	Total work 60º/s	0.888	0.995	0.149	0.374	0.23	0.346
	Average power 60º/s	0.925	0.968	0.262	0.019*	0.469	0.364
	Peak torque angle 60º/s	0.306	0.032*	0.215	0.05*	0.58	0.138
	Peak torque 180º/s	0.9	-	0.106	-	0.528	-
	Total work 180º/s	0.946	-	0.367	-	0.702	-
	Average power 180º/s	0.959	-	0.215	-	0.608	-
	Peak torque angle 180º/s	0.306	-	0.215	-	0.58	-
Flexors	Peak torque 60º/s	0.71	0.95	0.083	0.41	0.139	0.066
	Total work 60º/s	0.889	0.997	0.003*	0*	0.57	0.214
	Average power 60º/s	0.889	0.98	0.016*	0*	0.209	0.116
	Peak torque angle 60º/s	0.06	0.793	0.658	0.013*	0.323	0.643
	Peak torque 180º/s	0.943	-	0.1	-	0.888	-
	Total work 180º/s	0.952	-	0.154	-	0.787	-
	Average power 180º/s	0.835	-	0.172	-	0.718	-
	Peak torque angle 180º/s	0.06	-	0.658	-	0.323	-

Note: * statistically significant difference. p-values Two-Away ANOVA.
Source: Research data.

The results of the isokinetic assessment at an angular velocity 60°/s are included in the discussion of the stretching and control protocols below.

The SDDS protocol induced a significant reduction in the peak torque angle during the eccentric phase of the knee flexor movement in the assessment at 60°/s. This result indicates that greater strength was achieved during muscle stretching compared to the period before stretching. According to (23), the reduction in the peak torque angle, even after acquaintance with the isokinetic dynamometer, might be associated with the volunteers' learning of the eccentric movement in the isokinetic dynamometer, as this activity occurred in the post-stretching assessment, i.e., the second assessment performed in the day. This hypothesis is strengthened by the fact that SDDS was the first protocol performed and that the same stretching procedure did not induce any significant difference in the peak torque, total work, or average power in the concentric and eccentric phases of movement of the knee extensors and flexors. However, the reduction in the peak torque angle might also have occurred due to changes in the elastic properties of the knee flexors as an effect of SDDS itself. As observed by (24), dynamic stretching induces an increase in the body temperature and consequently promotes an increase in the metabolic reactions and the nerve conduction speed. This finding was also reported by (25), who followed increases in electromyographic (EMG) activity measured during vertical jumping following dynamic stretching.

The lack of significant differences in the peak torque, total work, and average power might be accounted for by physiological mechanisms. One such mechanism might be associated with the action of the Golgi tendon organ – GTO (8, 13). According to

(26), once the GTO detects an increase in the muscle tendon tension caused by the successive quick movements undergone in dynamic stretching, it does not allow the maximal strength and thus reduces the risk of injury in the agonist muscle. That interruption in the action of the agonist muscle resulted in inefficient stretching of the antagonist muscle, which is precisely the goal of dynamic stretching. That action of the GTO might have also contributed to the lack of action of another physiological mechanism, the PAP, which according to (27) and (14) is one of the mechanisms that improves muscle performance. However, the type of training and/or the distribution of the muscle fibers might influence the ability to trigger PAP, as (28) observed.

Nevertheless, if the GTO did exert an action in SDDS, it was discrete because no significant reduction was found. Such a discrete action might be related to the short duration of dynamic stretching, as two series with 15 repetitions were performed with rest intervals between them totaling two minutes and 20 seconds.

Contrary to the results of the present study, (12) found a significant increase in the peak torque at an angular velocity of 60°/s, which they attributed to PAP, increased muscle temperature, or increased motor unit activation. It is worth noting that the participants in (12) study were female elite athletes who performed two series with 15 repetitions of each of four dynamic stretching exercises, while in our study male non-athletes performed just two dynamic stretching exercises. Therefore, although the numbers of series and repetitions were the same in both studies, the discrepancy in the results might be due to the differences in the number of stretching exercises and in the sample profile (11). Therefore, future studies should include techniques to identify and measure muscle temperature together with the isokinetic assessment during the performance of the dynamic stretching protocols. In addition, an EMG device should be used to record the muscle electrical activity and to establish the presence of the factors mentioned by the authors that were cited above (GTO and PAP).

In another study, whose results also diverged from the ones in the present study, (11) assessed the muscle power of the knee extensors and flexors after dynamic stretching in healthy males and found significant increases, which they attributed to PAP. It is worth noting that these authors used a device to assess dynamic constant external resistance muscle contraction (which calculates the power from the velocity and duration of the knee extension movement), while we used an isokinetic dynamometer. The equipment used for the assessment and the number of stretching exercises might account for the discrepancy in the results, as the numbers of series and repetitions were the same in both studies. To elucidate the effects of dynamic stretching, investigators should use the same instruments for assessment. Therefore, it is suggested that future studies use isokinetic dynamometers to establish the effect(s) of dynamic stretching on muscle strength.

The LDDS protocol results were similar to those of the SDDS protocol. There was no change in the peak torque after the LDDS protocol was performed, while the peak torque angle exhibited a significant reduction in the eccentric phase of the knee extensors movement. That reduction might be related to the effects of stretching on the contractile and elastic properties of muscles, as according to (29), dynamic stretching might reduce the stiffness of muscles and joints, thus modifying the length-to-tension ratio and consequently creating ideal conditions in the muscle-tendon unit for the development of tension. However, as a function of the five-day interval between the isokinetic assessments corresponding to the SDDS and LDDS protocols, the reduction in the peak torque angle might be attributed to the volunteers' learning of the eccentric movement in the isokinetic dynamometer. These arguments are strengthened by the fact that no significant difference was found in the peak torque angle following the CTRL protocol, which was performed after the dynamic stretching protocols.

Unlike the SDDS protocol, the LDDS protocol induced significant differences in the average power and total work in the concentric and eccentric phases of the knee flexors movement. One might suppose that the reductions in the average power and the total work after LDDS are related to the protocol duration (three minutes and 30 seconds) and the reduced mechanical stress to which the knee flexors are exposed in daily activities compared to the extensors. This reduced stress might be associated with their low strength (8). In addition, the reductions in the average power and total work might also be due to the normal deficit of the knee flexors relative to the extensors, which varies from 50 to 70% (18, 23). The knee flexors are normally weaker than the extensors. All those phenomena might have occurred, as no significant difference was found in the average power or total work relative to the knee extensors following either the SDDS or the LDDS protocol. The peak torque did not change after the LDDS or the SDDS protocol.

However, a significant increase in the average power was found in the eccentric phase of the knee extensors movement after the application of the CTRL protocol. That increase might not only be due to the effect of training (learning the movement technique) afforded by the isokinetic assessment performed before the period of rest but also to the normal deficit of the knee flexors relative to the extensors, as the former exhibited a significant reduction in the average power during the isokinetic assessment. In addition, the lack of stretching might have increased the tendon stiffness, thus contributing to the improved average power (30).

Compared to the CTRL protocol, the total work significantly decreased during the eccentric phase of the knee flexors movement. In mathematical terms, work is directly proportional to the torque achieved, and it is the result of the behavior of force all along the force-displacement curve; the reduction seems to be related to the order in which the protocols were performed. According to (31), this relationship occurs because a period of up to 72 hours is needed for the maximal performance of the targeted muscle to be achieved, while the intervals established in the present study lasted only 48 hours. As a result, muscle fatigue might have occurred, as the CTRL protocol was the last protocol applied, during the course of the isokinetic assessments.

The results obtained in the isokinetic assessment at an angular velocity of 180°/s following the application of the SDDS, LDDS, and CTRL protocols did not show any significant difference in the peak torque, total work, average power, or peak torque angle in either the concentric or the eccentric phase of movement of either knee flexors or extensors. The lack of an effect of the dynamic stretching (SDDS and LDDS) and control protocols on those isokinetic variables might be the result of the force-to-velocity ratio mentioned by (22). According to those authors, those two variables bear an inverse correlation, i.e., during movement at high velocity, the force required tends to be lower compared to that required by movement at a lower velocity. In addition, the lack of significant changes in the variables investigated at an angular velocity of 180°/s might be related to the “size principle” described by (3), according to which movements performed at high velocity produce low tension and thus recruit motor neurons with low thresholds of excitability. Conversely, lower velocities generate greater tension and thus recruit motor neurons with high excitability thresholds. An EMG assessment might confirm the relevance of that principle. Therefore, it is recommended that future studies include EMG records to establish the level of muscle activation during movement.

To summarize, SDDS and LDDS did not induce significant changes in the peak torque, although significant changes were found in the average power, total work, and peak torque angle of the knee flexors and extensors. Therefore, dynamic stretching did not hinder the ability to reach maximal strength.

Conclusion

To conclude, we believe that the results of the present study might be helpful for future research on the effects of dynamic stretching on the performance in sports, as dynamic stretching did not result in a significant reduction in the peak torque, average power, or total work.

This study has demonstrated that executing dynamic stretching does not promote deficits on muscular strength. Therefore, this kind of stretching should be safely performed physical activities such as walking, low-intensity running, recreational games, and high-intensity sports.

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