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THE ACUTE EFFECT OF STRETCHING ON FORCE AND POWER

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Abstract
The sample of ten young healthy subjects, male, age 20, 21 (students of the Faculty of Sports, University of Banja Luka, Bosnia and Herzegovina), were examined for the effect of dynamic and static stretching on exercise of force and power of quadriceps and hamstring muscle of the dominant leg knee joint. Using the isokinetic dynamometer, both muscle groups were diagnosed with variables: maximum torque (force), relative torque, explosive force and relative power. Measurements were carried out under conditions of slow (60°/s) and fast speed (240°/s) contractions. The same measurement protocols were implemented in three experimental situations: without the initial stretching (WS), after the dynamic stretching (D) and after the static stretching (S). Results of statistical analysis show that both types of expansion lead to an increase of force and power of hamstring and quadriceps *(quadriceps 60°/s: WS - 2,67 Nm/kg, D - 3,06 Nm/kg , S -3,05 Nm/kg; hamstring 60°/s: WS -2,25 Nm/kg , D -2,41 Nm/kg , S- 2,41 Nm/kg; quadriceps 240°/s: WS- 1,42 Nm/kg , D- 1,70 Nm/kg , S- 1,64 Nm/kg; hamstring 240°/s: WS -1,51 Nm/kg , D- 1, 85 Nm/kg , S - 1, 71 Nm/kg)*. Looking at the results, both group of muscle (quadriceps and hamstring) produced greater explosive force at a speed of 60°/s after the static stretching. (*Quadriceps: WS- 158,99 Nm, D- 188,13 Nm, S- 188,72 Nm; hamstring: WS- 149,53 Nm, D-156,67 Nm, S-164,00 Nm)*. Both group of muscle produced greater explosive force at the speed of 240°/s after the dynamic stretching *(quadriceps: WS-106,75 Nm ,D- 131, 50 Nm, S- 126,30 Nm; hamstring : WS- 114,41 Nm, D-139,02 Nm, S-129,43 Nm)*. This indicates that static and dynamic stretching have positive acute effects when applied before the activities in which the rate of contraction is small and external resistance is large, while only dynamic stretching has a positive effect when it precedes the activities of higher muscle contraction speed. Regardless of the elongation model applied, quadriceps is the dominant muscle group during the slow contractions (60°/s), while at high speeds, the role of hamstring significantly increases.

Key words: **isokinetic contractions, quadriceps, hamstring**

Introduction

A large number of athletes use stretching exercises as a part of the warm-up routine before physical activity to improve performance and prepare for competition or training. Recent research shows that acute stretching has negative effects as well, and that can lead to a decrease in muscle power (Behm, et al., 2004; Evetovich et al., 2003), muscular endurance (Franco et al., 2008; Nelson et al., 2005), vertical jump, (Church et al., 2001; Cornwell et al., 2001; Young et al., 2003) and sprint speed (Nelson et al., 2005). Exploring the effects of static and dynamic stretching on the extensors and flexors in the knee joint, Yamaguchi et al. (2005) found that static stretching before a training method had negative effects on the expression of power, speed and agility, and that dynamic stretching had a positive impact on increasing the force of muscle and joint stability. Other researchers also point at the acute adverse effects of static stretching points (Kokkonen et al.,1998; Young et al., 2002; Behm et al., 2001; Šimić et al., 2013) , however, they also assumed the possible positive effects of dynamic stretching. Examining the impact of stretching on running speed, some argue that static stretching has a negative impact on acceleration (Fletcher et al., 2004), while Nelson et al. (2005) demonstrated that such influence does not exist. In addition to the type of stretching, the effects of the duration of the stretching exercises have also been studied. In an experiment, Ogura et al. (2007) compared the two static stretching exercises of m. quadriceps femoris for the duration of 30 and 60 seconds and came to the conclusion that a shorter extension did not affect the ability of muscle while stretching for 60 seconds caused a significant reduction in power. At this point, the researchers only agree with one thing, that long-term regular use of systematic static stretching after training contributes to increasing the range of motion and reducing the risk of injury to the lower extremities at high stresses (Knapik et al., 2001; Witvrouw et al., 2003; Jamtvedt et al., 2010). This work attempted once again to examine the effect of acute static and dynamic stretching prior to the exertion of force and muscle power.

The problem of reaching a definite conclusion about the acute effects of static and dynamic stretching also lies in the different conditions in which the testing of muscular force is conducted. Most measurements are carried out in isometric conditions, despite the fact that the muscle strain in real movements primarily takes place in a dynamic mode. Overcoming these differences between laboratory measurement conditions and objective exertion of muscular force in real conditions of stress, largely ensure measurement in isokinetic conditions. The isokinetic dynamometer offers a more precise identification of the maximum muscle capacity as well as registration of the relationship between different muscle groups, especially the relationship between agonist and antagonist during the execution of real movement. The aim of this study was to use isokinetic diagnostics, as the most reliable methods of measuring muscle performance today, once again to study the effects of different models of stretching applied in the acute phase of warming, compared to the expression of force variables of the knee joint extensor and flexor muscles (m. quadriceps femoris and hamstring).

Methods

Sample of examines

This research was done as cross study with a group composed of 10 healthy young males aged between 20-21 years old. The group was very homogeneous in terms of anthropometric and motor characteristics, and was formed by students of the Faculty of Physical Education and Sport, University of Banja Luka, Bosnia and Herzegovina.

Measurements

The subjects underwent isokinetic testing on a Con-Trex isokinetic machine which registered the following variables of force and power of extensors and flexors of the knee joint (quadriceps and hamstring):

- Maximum torque -force (Nm),
- Relative torque - torque force expressed in relation to body weight (Nm/kg),
- Explosive force – maximum torque realized 0.2 seconds after the start of movement (Nm),
- Relative power - expressed relative to body mass (W/kg).

Con-trex isokinetic multi joint module is rotatory testing , training and therapeutic system to test and train all major joints of the upper and lower limbs in the open kinetic chain. Testing muscular force in isokinetic conditions is carried out at a given fixed rate of contraction, with optimum adaptation of the muscle to resistance, fatigue and pain. The pressure is always optimal because the angular velocity of the joint is constant. It is controlled and maintained during stress, which eliminates fluctuations in linear speed of the muscles used during exercise. In addition to diagnostics, isokinetic is also used in the training purposes because it provides a relatively unchanged external resistance throughout the range of motion. At the beginning of isokinetic movements, angular speed increases until reaching the desired speed. During the initial phase, i.e. reaching the desired speed, external resistance is negligible. After reaching the set speed, there is no additional acceleration, but the movement takes place with a continuous speed throughout the range of motion in the joint. The isokinetic dynamometer eliminates the effects of gravity and provides constant external resistance which makes active muscles exert greater power in each phase of movement. During isokinetic joint stress, the load is small, and the resistance can not be greater than the force used, which minimizes the possibility of injury.

Representative biomechanical size, reflecting the power of movement performed during isometric testing is the maximum torque formed around the axis of rotation of the joint. The main component of the total PTO torque is produced by the active muscles, while the contribution of other structures (membranes, articulated sleeve and ligaments) is minimal, making the moment registered by an isokinetic dynamometer theoretically equated with muscle torque. It is this fact that speaks loudly in favor of greater objectivity of muscular force isokinetic testing in relation to the isometric tests in which the angle of the joint, the position of exercisers and body weight can significantly affect the variability of results.

Respondents performed flexion and extension movements at different speeds, 60°/s and 240°/s, first in the form of slow, then fast contraction. The same protocol of diagnostics in variables of force and power was conducted three times under different circumstances, in relation to whether muscle stretching was applied and which procedures was used for stretching right before the isokinetic test. The first measurement was conducted without prior stretching, while the next two protocols were implemented immediately after the administration of various stretching programs. The first program consisted of dynamic stretching exercises, and the second was conducting static stretching exercises. A week long pause was taken between each test, in order to eliminate the effects of fatigue and excitation of these motor units. In the period between the testing, subjects performed their regular daily activities and were not subjected to any systematic training.

Without stretching

After warming up by running at a moderate pace for 5 minutes, respondents approached the isokinetic apparatus and during the next two minutes, were properly positioned in relation to the dynamometer apparatus. The test consisted of two parts. In the first part, we applied the slow contraction movements of flexion-extension at 60°/s. These stresses correspond to the maximum power zone, given that these produced the highest value of force. Each subject performed a series of four consecutive slow contractions. This was followed by a break of one minute. The second part of the test was carried out immediately after the break and was used to apply the same flexion-extension contraction movements, but at a speed of 240°/s. These stresses correspond to the speed power zone. Each subject performed a series of 14 consecutive rapid contractions. All variables of force and power were automatically registered by the software of the isokinetic apparatus.

Dynamic and static stretching program

The stretching program was carried out immediately before the isometric test. After the five minute moderate warm up, performed by running, the subjects preformed a program of uniform elongations which consisted of 4 exercises, of which two were for stretching the quadriceps (first from a starting position of standing on one leg, the other leg stretching by pulling the foot to a position of maximum flexion and the second one was to step forward), and two for stretching the hamstring (from the initial position of standing, raising a bent leg towards your chest and from the initial position of standing upright, alternating lifting the feet high). The same exercises were used in both stretching protocols (dynamic and static), but in the first protocol muscles were stretched using the dynamic mode (short interval swings), while in the second test used endurance in static positions after reaching the maximum amplitude. Each individual exercise was repeated four times for the duration of 20 seconds. The pause between repetitions was 10 seconds and pause between exercises was 10 seconds. The total duration of the entire protocol of the stretching exercises was 5 minutes. After the exercise, the subjects took a short break of two minutes to prepare themselves for the approaching isokinetic test.

Statistical analysis

For analysis and data processing obtained in this research program package SPSS for Windows, version 21.0 was used, while during interpretation professional literature was consulted. The significance of the differences between the average values of the variables of force and power, resulting in three different time points, was tested by analysis of variance (repeated measures model). For the analysis of variability sources a post hoc analysis was used (Tukey test). Level of safety was determined on the level of 95%, with risk of mistake of 5%.

Results

Comparing the average values calculated for the variables of force and power, it was found that most of them increased after the application of the static and dynamic stretching exercises. The set of variables that were monitored during isokinetic testing of hamstring and quadriceps at a rate of contraction of **60°/s**, significant differences were only absent in the variable Relative power of the hamstring : *Rel. power hamstr: WS-1,65 W/kg, D - 1,75W/kg, S- 1,76W/kg (Table 1).*

*Table 1. Average values of the variables of force and power of Quadriceps and Hamstring diagnosed with an isokinetic dynamometer after various stretching models at the speed of contraction of **60 °/s**.*

Gr.	*Variables*	*Without stretching*	*Dynamic stretching*	*Static stretching*	*F*	*Sig.*
Quadriceps	*Max. torque (Nm)*	221.02	250.64	249.97	34.95*	.00
	Rel. torque (Nm/kg)	2.67	3.06	3.05	34.63*	.00
	Explosive force (Nm)	158.99	188.13	188.72	17.86*	.00
	Relative power (W/kg)	1.74	1.95	1.90	7.86*	.01
Hamstring	Max. torque (Nm)	180.44	199.54	196.79	11.45*	.00
	Rel. torque (Nm/kg)	2.25	2.41	2.41	6.58*	.02
	Explosive force (Nm)	149.53	156.67	164.00	8.70*	.01
	Relative power (W/kg)	1.65	1.75	1.76	3.64	.07

At the contraction speed of **240**°/s, all of the tested differences were significant: *Max. torque quadr. WS-127,15 Nm ,D-154,73 Nm ,S-151,95 Nm; Rel. torque quadr.:WS-1,42 Nm/kg, D-1,70 Nm/kg, S-1,64 Nm/kg; Expl. force quadr.:WS-106,75 Nm, D-131,50 Nm, S-126,30 Nm; Rel. power quadr: WS-2,55 W/kg, D-3,08 W/kg, S-2,95 W/kg; Max.torque hamstr.:WS-131,21 Nm, D-164,87 Nm, S-151,29 Nm; Rel.torque hamstr.:WS-1,51 Nm/kg, D-1,85 Nm/kg, S-1,71 Nm/kg; Expl.force hamstr:WS-114,41 Nm, D-139,02 Nm, S-129,43 Nm; Rel. power hamstr: WS- 2,99 W/kg, D-3,73 W/kg, S-3,42 W/kg (Table 2).*

*Table 2. Average values of the variables of force and power of Quadriceps and Hamstring diagnosed with an isokinetic dynamometer after various models stretching at the speed of contraction of **240** °/s.*

Gr.	***Variables***	***Without stretching***	***Dynamic stretching***	***Static stretching***	***F***	***Sig.***
Quadriceps	*Max. torque (Nm)*	127.15	154.73	151.95	50.17*	.00
	Rel. torque (Nm/kg)	1.42	1.70	1.64	38.17*	.00
	Explosive torque (Nm)	106.75	131.50	126.30	109.35*	.00
	Relative power (W/kg)	2.55	3.08	2.95	28.31*	.00
Hamstring	*Max. torque (Nm)*	131.21	164.87	151.29	8.68*	.01
	Rel. torque (Nm/kg)	1.51	1.85	1.71	11.21*	.00
	Explosive torque (Nm)	114.41	139.02	129.43	6.76*	.01
	Relative power (W/kg)	2.99	3.73	3.42	7.64*	.01

Explosive force after static stretching for both group of muscle at a speed of 60°/s : *Expl.force quadr.: WS-158,99 Nm, D- 188,13 Nm, S- 188,72 Nm; Expl. force hamstr.: WS- 149,53 Nm, D-156,67 Nm, S-164,00 Nm).* Explosive force after the dynamic stretching for both group of muscle at the speed of 240°/s: *Expl. force quadr.: WS-106,75 Nm ,D- 131, 50 Nm, S- 126,30 Nm; Expl. force hamstr. : WS- 114,41 Nm, D-139,02 Nm, S-129,43 Nm (Table 1 , Table 2)*

Although the main source of variability in all the variables of force and power in Tables 1 and 2 was caused by significantly lower force values detected in the first test, when the stretching is omitted. In this study, it was important to determine the relationship between the variables of force obtained after the application of the two stretching models (dynamic and static). Results of the Post Hoc analysis (Tukey test) showed that the different effects of dynamic and static stretching were observed only for hamstring and in conditions of rapid contraction, 240°/s (Table 3). Statistically significant differences were found for the following variables: *Max. torque hamstr. (Sig. =, 016), Rel. torque hamstr. (Sig. =, 004), Expl. force hamstr. (Sig. = 025) and the Rel. power hamstr. (Sig. = 011) .*

Table 3. Results of Post Hoc analysis (Tukey test)- dynamic stretching produced significantly higher values of the variables of hamstring at the speed of contraction of 240 °/s.

Variables		*Max.torque hamstr.*	*Relat.torque hamstr.*	*Explosive force hamstr.*	*Relative power hamstr.*
		Sig.	*Sig.*	*Sig.*	*Sig.*
Dynamic stretching	**Without stretching**	.002	.003	.004	.003
	Static stretching	.016	.004	.025	.011

The most noticeable difference between the effects of different models of stress is valid for the variable Maximum torque (force) of quadriceps and hamstring which are stated by torque values in terms of slow contraction (60°/s): *Max.torque quadr.: WS- 221,02 Nm, D- 250,64 Nm, S- 249,97 Nm; Max.torque hamstr.: WS-180,44 Nm, D - 199,54 Nm, S-196,79 Nm*, and rapid contractions (240°/s): *Max. torque quadr.: WS- 127,15 Nm, D- 154,73 Nm , S-151, 95 Nm; Max. torque hamstr: WS -131,21Nm, D- 164,87Nm, S-151,29 (Figure 1 and Figure 2).*

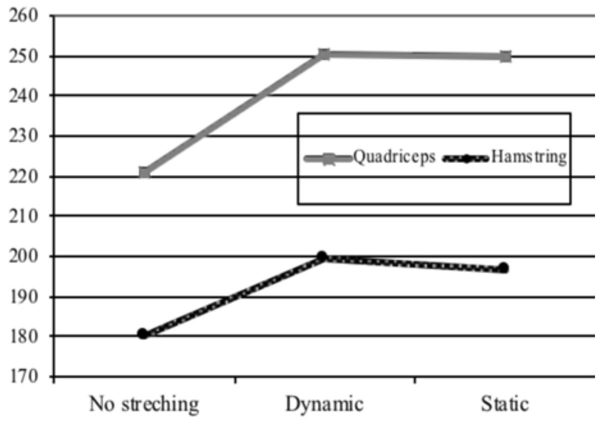

Figure 1. Maximum torque (Nm) of Quadriceps and Hamstring of the knee joint diagnosed by an isokinetic dynamometer at a rate of contraction of 60 °/s.

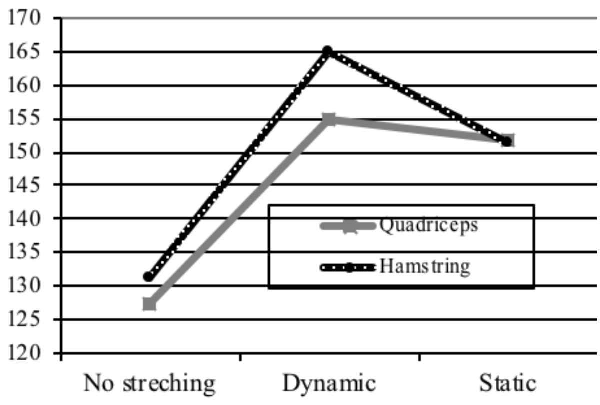

Figure 2. Maximum torque (Nm) of Quadriceps and Hamstring of the knee joint diagnosed by an isokinetic dynamometer at a rate of contraction of 240 °/s.

Discussion

Based on these results, we can conclude that at a speed of 60°/s, for most variables, there exists a statistically significant difference after both types of stretching (dynamic and static) compared to the initial testing prior to which there was no stretching applied.

Looking at the results of quadriceps and hamstring explosive force it can be concluded that both groups of muscles ,at a speed of contraction of 60°/s, produced greater explosive force after the static stretching. This means that static stretching exercises when applied before the activities in which the rate of contraction is small (60°/s) and the external resistance is large, positively effect the expression of explosive force of thigh muscles. Both groups of muscles (quadriceps and hamstring), at a speed of 240°/s, produce greater explosive force after the dynamic stretching program, indicating that the dynamic extension has a positive effect on the expression of thigh muscle explosive force when it precedes the activities of higher muscle contraction speed which eliminates minor external resistance. Regardless of the elongation model applied, quadriceps is the dominant muscle group during the slow contractions (60°/s), while at high speeds, the role of hamstring significantly increases.

These data figures digress a little from the conclusions of previous studies. For example, Moss (2002) and Shrier (2004) recommend avoiding static stretching prior to high intensity and explosive activities. Moss (2002) emphasizes that static stretching prior to high intensity activities can prevent the effect, i.e. cause loss of power and force due to a decrease in muscle activation and contractile properties at the cellular level. Some authors (Ayala et al., 2013) indicate that both dynamic and static stretching have no influence on the force and unilateral relationship, therefore both types of stretching have no effect on reducing the risk of injury. In general, the warm-up protocols used to include mainly just static stretching exercise. The negative effects of static stretching have been proven in many studies, but it should be noted that there are numerous studies that point out that there is no adverse effect associated with static stretching. Lately, static stretching has been mainly depicted in a negative connotation, at the same time, dynamic stretching is considered desirable in the warm-up phase of the organism. Werstein et al. (2012) observed the influence of dynamic and static stretching on the expression of isokinetic force and concluded that dynamic stretching results in a significant increase in power compared to static stretching. Some more recent studies suggest that dynamic stretching affects the increase of: maximum force of the quadriceps (Aguilar et al. 2012), feet extensors and flexors power (Sekir et al., 2010) and explosive force (Vanderka, 2008; Vetter, 2007).

However, evidence to suggest the benefits of one type of stretching over another is generally inconsistent because the mentioned works deal with two different populations (recreation enthusiasts and professional athletes); the length of the applied stretch in the protocols is different; the types of tests are different, therefore one still can not argue that there is only one type of stretching applicable.
The main goal of any warm-up protocol is to improve the abilities of the athletes for activity that follows and reduce the possibility of injuries to a minimum. Warm-up protocols should include activities that are tailored to the movements that are specific to a particular sport. Sports that require a high level of static flexibility should include static stretching of the low level stretching in the warm up phase, while sports that are dominated by the movements of large amplitude movements should include in their protocol the dynamic stretching movements that mimic movements applicable in sport.

If we observe the results of the explosive force of the quadriceps and hamstrings at 60 °/s, it can be concluded that the quadriceps is the dominant group because it produces the explosive force in relation to the hamstring. However, in an endurance test (240 °/s) the hamstring shows much more explosive force. It can be concluded that the explosiveness of quadriceps is expressed in a test of force, and when it comes to durability, the hamstring takes the lead role and becomes the dominant muscle group. Davies (1987), based on the results of research, claims to have the highest torque in the initial stages of testing endurance produced by the quadriceps, while at the end of the endurance tests, the maximum torque was produced by the hamstring. According to Davies, fast muscle fibers at faster contractions produce greater torque, with a much smaller decline in force over a range of speeds, in comparison to the slow muscle fibers. The result is as expected, due to the hamstring muscles being the dominant group at higher speeds because they have a large portion of the fast muscle fibers and are designed for rapid movement. All three hamstring muscles (m. semimembranosus, m. semitendinosus and m. biceps femoris caput longum) are, in fact, double-pitched (in the hip joint, acting as an extensors, and in the knee joint as flexors), and their ability to develop force is greater than front lodge muscle where the three heads of the quadriceps muscle (m. vastus lateralis, m. vastus medialis and m. vastus intermedius) act only in the knee joint. M. rectus femoris is the only component of the quadriceps comparable to the antagonist hamstring and is activated just before the end of the motion range of knee extensions. The hamstring has the ability to produce more force over a longer period and at higher speeds and decrease in hamstring power is significantly lower than in the quadriceps that fatigues faster. For more a reliable explanation of the stretching effects in terms of real sports stress, it is necessary to further perfect the training tools for monitoring variables of force and power in free movement.

Conclusion

The results of this study points to the justification of applying stretching exercises in order to create better conditions for the exercise of force and power. Unlike some previous studies that pointed to the negative effects of static stretching on some motor skills in which power plays a significant role, here both of the models of stretching (dynamic and static) had positive impacts on almost all variables of force and power manifested in isokinetic conditions of stress. Since the effects of gravity in these conditions were largely eliminated and the muscles acted in isolation, the importance of stretching can be explained primarily by an increased excitation of motor units involved in the isokinetic movements. While in slow motion, in which force is dominant, both types of stretching had nearly the same impact on the power and force (both extensors and flexors in knee), in the fast movements, which are predominantly associated with explosive force, the dynamic stretching turned out to be significantly more efficient and exclusively at flexors (hamstring). Since exercising in isokinetic conditions is mostly applied in rehabilitation, based on the results of this research, stretching can be recommended as a reliable way to better prepare the muscles during therapeutic exercise.

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