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Research article

Influence of High Intensity 20-Second Static Stretching on the Flexibility and Strength of Hamstrings

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Abstract

The purpose of the present study was to examine the effects of high intensity static stretching for 20 seconds on flexibility and strength in the hamstrings. Seventeen healthy participants (13 men and 4 women) underwent static stretching for 20 seconds at three different intensities based on the point of discomfort (POD, 120% POD, and MaxPOD). To examine the change in flexibility and strength, range of motion (ROM), passive torque, muscle-tendon unit stiffness, peak torque of maximum voluntary isokinetic concentric contraction, and knee angle at peak torque were measured. To evaluate a time course of pain, a numerical rating scale (NRS) was described. ROM (percent change; POD = 113.5 ± 10.4%, 120%POD = 127.6 ± 18.8%, MaxPOD = 135.6 ± 18.5%) ($p < 0.01$) and passive torque (percent change; POD = 124.2 ± 38.9%, 120%POD = 143.4 ± 65.1%, MaxPOD = 171.8 ± 83.6%) ($p < 0.01$) were increased at all intensities. Muscle-tendon unit stiffness was decreased at 120%POD (percent change; 72.4 ± 36.2, $p < 0.01$) and MaxPOD (percent change; 56.6 ± 30.0, $p < 0.01$). Peak torque showed no change at all intensities (percent change; POD = 99.1 ± 14.0%, 120%POD = 95.4 ± 17.4%, MaxPOD = 98.4 ± 20.1%, $p > 0.05$). There were significant correlations between the intensities and relative change of the ROM ($r = 0.57$, $p < 0.01$), passive torque ($r = 0.46$, $p < 0.01$), muscle-tendon unit stiffness ($r = -0.53$, $p < 0.01$) and knee angle at peak torque ($r = 0.50$, $p < 0.01$). NRS increased with the intensity of static stretching (median; POD = 1, 120%POD = 3, Max POD = 8), though the pain disappeared immediately after the stretching (median = 0). In conclusion, static stretching for 20 seconds at high intensity was effective for a decrement in muscle-tendon unit stiffness.

Key words: Stiffness, passive torque, peak torque, pain, short duration, range of motion.

Introduction

Static stretching (SS) is commonly used as a part of a warm-up routine to increase flexibility and prevent sports-related injuries (Takeuchi et al., 2019). To evaluate changes in flexibility, range of motion (ROM), passive torque and muscle-tendon unit stiffness are often measured (Young et al., 2013). Previous review studies have reported that SS increases ROM (Behm et al., 2016; Radford et al., 2006). Alteration of ROM after SS is attributed to changes in muscle-tendon unit stiffness (Konrad et al., 2016; Mizuno, 2017; Morse et al., 2008; Ryan et al., 2009) and tolerance for stretching (Brusco et al., 2019; Magnusson et al., 1996; Nakamura et al., 2013). Muscle-tendon unit stiffness is defined as the value of the slope of the torque-angle curve during passive joint movement (Magnusson et al., 1996). Previous reports have shown that too much stiffness may lead to various lower body injuries including soft-tissue, joint and bone injuries, occurring in non-contact situations (Ekstrand and Gillquist, 1983; Pickering et al., 2017; Watsford et al., 2010). The relationship between relatively high stiffness and the incidence of sports-related injuries is due to a diminished cushioning effect from soft-tissues, resulting in greater stress (Butler et al., 2003; Grimston et al., 1991; Hennig and Lafortune, 1991). Therefore, it is important to reduce muscle-tendon unit stiffness to prevent sports-related injuries.

The effects of SS on ROM and muscle-tendon unit stiffness are affected by the duration of the stretch (Bandy et al., 1997; Matsuo et al., 2013; Ryan et al., 2009). ROM is increased immediately after SS (Boyce and Brosky, 2008; Butler et al., 2016; Fletcher and Monte-Colombo, 2010; Sato et al., 2020), while muscle-tendon unit stiffness is decreased after more than 180 seconds of SS in the hamstrings (Matsuo et al., 2013; Nakamura et al., 2019). Previous studies reported that conditioning coaches use SS for approximately 20 seconds as a part of a warm-up routine (Simenz et al., 2005; Takeuchi et al., 2019). It is reported that SS for 20 seconds in the hamstrings increased ROM, but muscle-tendon unit stiffness did not change (Matsuo et al., 2013). Therefore, it is possible that SS used in a warm-up routine cannot decrease muscle-tendon unit stiffness, with the result that the purpose of the prevention of sports-related injuries cannot be achieved. However, it is very difficult to use SS for more than 180 seconds in a warm-up routine, because the time of sports practice is very limited for many athletes. Therefore, it is necessary to develop a method of SS that can decrease muscle-tendon unit stiffness in 20 seconds.

The intensity of SS is one of the factors that influences the effects of SS (Kataura et al., 2017). Kataura et al. (Kataura et al., 2017) reported that the intensity of SS was negatively correlated with the relative change of passive stiffness of the hamstrings. Therefore, it is possible that high intensity SS for 20 seconds could decrease muscle-tendon unit stiffness. Thus, the purpose of the present study was to examine the effects of high intensity SS for 20 seconds on flexibility (ROM, passive torque, muscle-tendon unit stiffness) and strength (peak torque, knee angle at peak torque) in the hamstrings.

Methods

Participants

Thirteen healthy men (mean ± SD; 21.2 ± 0.4 years, 174.0

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± 0.06 m, 65.2 ± 10.5 kg) and four healthy women (mean ± SD; 21.3 ± 0.5 years, 164.0 ± 0.08 m, 55.3 ± 8.1 kg) were recruited. Participants who regularly performed any flexibility and strength training or who had a history of lower limb pathology were excluded. All participants were informed of the requirements and risks associated with their involvement in this study and signed a written informed consent document. The study was performed in accordance with the Declaration of Helsinki (1964). The Ethics Committee of Kobe International University approved the study (approved No. G2019-094).

Procedure

The participants visited the laboratory three times, with an interval of one week between each visit. They underwent three different intensities of SS in right hamstrings, in random order. Before and after each SS, all measurements except the numerical rating scale (NRS) were taken. NRS was taken during SS, immediately after SS, and 24 hours after SS. All experiments were completed in the same room, in which the temperature was maintained at 25 degrees C.

Sitting position

An isokinetic dynamometer machine (CYBEX NORM, Humac, California, USA) was used in the present study. This study used a sitting position in which the hip joint was flexed, which has been shown to efficiently stretch the hamstrings (Kataura et al., 2017). The participants were seated on a chair with the seat tilted maximally, and a wedge-shaped cushion was inserted between the trunk and the backrest, which set the angle between the seat and the back at approximately 60 degrees. The chest, pelvis, and right thigh were stabilized with straps. The right knee joint was aligned with the axis of the rotation of the isokinetic dynamometer machine. The lever arm attachment was placed just proximal to the malleolus medialis and stabilized with straps. In the present study, reported knee angles were measured using the isokinetic dynamometer machine. A 90-degree angle between the lever arm and floor was defined as 0 degrees of knee flexion/extension.

Range of motion, passive torque, and muscle-tendon unit stiffness

ROM, passive torque and muscle-tendon unit stiffness were calculated by using the isokinetic dynamometer machine in the same fashion as a previous study (Kataura et al., 2017). The knee was passively extended at 5 degrees/second from 0 degrees to the maximally tolerable angle without pain. A previous study reported that the velocity does not cause stretch reflex during passive joint movement (Christopher I Morse, 2011). ROM was defined as the maximal knee extension angle from 0 degrees, and the passive torque was defined as the torque at the maximal knee extension angle. Muscle-tendon unit stiffness was defined as the values of the slope of the regression line that was calculated from the torque-angle relationship using the least-squares method (Magnusson et al., 1996). Muscle-tendon unit stiffness was calculated from the same knee extension angle range before and after SS. The calculated knee extension angle range was defined as the angle from the 50% maximum knee extension angle to the maximum knee extension angle measured before SS. However, if the maximum knee extension angle measured after SS was smaller than that before SS, the muscle-tendon unit stiffness before and after SS was calculated from the 50% maximum knee extension angle to the maximum knee extension angle measured after SS (Kataura et al., 2017). The value of ROM before SS was used for the intensity of SS to normalize to percentages.

Peak torque and knee angle during maximum voluntary isokinetic concentric contraction

The peak torque of knee flexion during maximum voluntary isokinetic concentric contraction at 60 degrees/second was measured. The participants were secured on the isokinetic dynamometer machine in the same fashion as the measurement of ROM. The range of movement was set from 0 degrees to maximum knee extension angle. The participants performed three submaximal warm-up trials on the isokinetic dynamometer machine. After the warm-up trials, the participants performed three maximum voluntary isokinetic concentric contractions. The greatest value of the three repetitions was used for the analyses. The joint angle at the peak torque was provided by the isokinetic dynamometer machine.

Numerical rating scale

The level of pain during SS, immediately after SS, and 24 hours after SS were quantified by an 11-point NRS that ranged from 0 (no pain) to 10 (worst imaginable pain).

Static stretching

The participants were secured on the isokinetic dynamometer machine in the same fashion as the measurement of ROM. SS for 20 seconds was performed at three different intensities based on the point of discomfort (POD) of each participant (POD, 120%POD, MaxPOD). At POD intensity, the angle was set prior to the point of discomfort (POD). At 120%POD intensity, the angle was set to 1.2 times of POD intensity. At MaxPOD intensity, the angle was set at the angle at the maximum point of discomfort. The participants were instructed to relax during each stretch.

Statistical analyses

All variables except NRS were described as mean ± SD in the present study. NRS was described as a median. The statistical power was calculated from the effect size of the muscle-tendon unit stiffness, which was the main outcome of this study, using G*power at a setting of $\alpha = 0.05$ and sample size of 17. The results indicated that the statistical power was 0.99. A two-way repeated-measures analysis of variance was used to examine the effects of intensity of SS (POD vs. 120%POD vs. MaxPOD) and time (pre-SS vs. post-SS). If a significance was detected, post hoc analyses using Bonferroni's test were performed. Partial eta squared values are reported to reflect the magnitude of the differences among each treatment (small = 0.01, medium = 0.06, and large = 0.14) (Cabido et al., 2014; Cohen, 1988). Spearman's rank correlation coefficient was conducted between the intensity of SS and relative change of variables (ROM, passive torque, muscle-tendon unit stiffness, peak torque, and knee angle at peak torque) and NRS. The analyses were performed using SPSS version 25 (SPSS, Inc., Chicago, IL, USA). Differences were considered statistically significant at an alpha level of $p < 0.05$.

Results

Range of motion

For ROM (Table 1), there was significant two-way interaction (intensity × time, $p < 0.01$, partial eta squared = 0.73). Post hoc analysis indicated that ROM significantly increased at all intensities ($p < 0.01$). At post measurement, ROM at MaxPOD intensity was a higher value than that of POD intensity ($p < 0.01$).

Table 1. Alteration of flexibility.

	pre	post	% change
	ROM (degree)		
POD	57.0 ± 14.0	64.0 ± 13.6 **	113.5 ± 10.4
120%POD	57.3 ± 12.0	71.8 ± 12.4 **	127.6 ± 18.8
MaxPOD	57.0 ± 14.2	75.3 ± 12.5 **†	135.6 ± 18.5
	Passive torque (Nm)		
POD	10.9 ± 4.3	13.2 ± 5.9 *	124.2 ± 38.9
120%POD	9.6 ± 4.6	13.7 ± 9.2 *	143.4 ± 65.1
MaxPOD	10.5 ± 5.0	16.6 ± 7.9 **	171.8 ± 83.6
	Muscle-tendon unit stiffness (Nm/degree)		
POD	0.59 ± 0.34	0.66 ± 0.37	111.8 ± 30.6
120%POD	0.63 ± 0.43	0.44 ± 0.33 **†	72.4 ± 36.2
MaxPOD	0.70 ± 0.51	0.34 ± 0.24 **†	56.6 ± 30.0

Values were described as mean ± SD. * $p < 0.05$ vs. pre value at the same intensity. ** $p < 0.01$ vs. pre value at the same intensity. † $p < 0.01$ vs. post value at POD intensity.

Passive torque

For passive torque (Table 1), there was no significant two-way interaction (intensity × time, $p = 0.11$, partial eta squared = 0.13) and no main effect for intensity ($p = 0.46$, partial eta squared = 0.05), but there was a significant main effect for time ($p < 0.01$, partial eta squared = 0.68). Passive torque was increased at all intensities ($p < 0.05$).

Muscle-tendon unit stiffness

For muscle-tendon unit stiffness (Table 1), there was significant two-way interaction (intensity × time, $p < 0.01$, partial eta squared = 0.38). Post hoc analysis indicated that muscle-tendon unit stiffness significantly decreased at 120%POD ($p < 0.01$) and MaxPOD intensities ($p < 0.01$), while there was no change at POD intensity ($p = 0.11$). At post measurement, muscle-tendon unit stiffness at 120%POD ($p < 0.01$) and MaxPOD intensities ($p < 0.01$) was smaller than that of at POD intensity.

Peak torque

For peak torque (Table 2), there was no significant two-way interaction (intensity × time, $p = 0.81$, partial eta squared = 0.01) and no main effect for intensity ($p = 0.17$, partial eta squared = 0.11) and time ($p = 0.35$, partial eta squared = 0.06).

Knee angle at peak torque

For knee angle at peak torque (Table 2), there was significant two-way interaction (intensity × time, $p < 0.01$, partial eta squared = 0.21). Post hoc analysis indicated that the angle significantly increased at 120%POD ($p < 0.05$) and MaxPOD intensities ($p < 0.05$), while there was no change at POD intensity ($p = 0.57$). At post measurement, the angle at MaxPOD intensity was higher than that at POD intensity ($p < 0.01$).

Table 2. Alteration of peak torque and knee angle.

	pre	post	% change
	Peak torque during isokinetic knee flexion (Nm)		
POD	71.5 ± 29.8	71.5 ± 33.6	99.1 ± 14.0
120%POD	63.4 ± 20.0	61.2 ± 26.7	95.4 ± 17.4
MaxPOD	61.9 ± 22.9	59.5 ± 20.3	98.4 ± 20.1
	Angle at peak torque (degree)		
POD	49.4 ± 11.1	48.6 ± 10.9	98.4 ± 14.5
120%POD	48.5 ± 12.3	56.0 ± 19.9 *	114.3 ± 22.3
MaxPOD	48.7 ± 10.8	56.5 ± 17.2 *†	116.4 ± 26.3

Values were described as mean ± SD. * $p < 0.05$ vs. pre value at the same intensity. † $p < 0.01$ vs. post value at POD intensity.

Numerical ranting scale

For the NRS (Table 3), there was a significant two-way interaction (intensity × time, $p < 0.01$, partial eta squared = 0.81). Post hoc analysis indicated that NRS during SS at POD intensity was smaller than that at 120%POD ($p < 0.01$) and MaxPOD intensities ($p < 0.01$), and at 120%POD intensity it was smaller than that at MaxPOD intensity ($p < 0.01$). NRS was decreased at all intensities compared during SS to immediately after SS ($p < 0.01$). At all intensities, NRS showed no change comparing immediately after SS to 24 hours after SS (POD; $p = 0.49$, 120%POD; $p = 1.00$, MaxPOD; $p = 0.06$).

Table 3. Time course of change in NRS.

	During SS	Immediately after SS	24 hours after SS
POD	1 *† (0 - 2)	0 (0 - 0)	0 (0 - 0)
120%POD	3 *†‡ (3 - 5)	0 (0 - 0)	0 (0 - 0)
MaxPOD	8 *†‡§ (8 - 9)	0 (0 - 1)	0 (0 - 0)

Values were described as median (25% - 75%). * $p < 0.01$ vs. value at immediately after SS at the same intensity. † $p < 0.01$ vs. value at 24 hours after SS at the same intensity. ‡ $p < 0.01$ vs. value at during SS at POD intensity. § $p < 0.01$

Correlation between intensity and all variables

There were significant correlations between the intensity and the relative change in ROM ($r = 0.57$, $p < 0.01$), passive torque ($r = 0.46$, $p < 0.01$), muscle-tendon unit stiffness ($r = -0.53$, $p < 0.01$), knee angle at peak torque ($r = 0.50$, $p < 0.01$), and NRS during SS ($r = 0.78$, $p < 0.01$). However, there was no significant correlation between intensity and peak torque of isokinetic knee flexion ($r = -0.07$, $p = 0.63$).

Discussion

At POD intensity, ROM and passive torque were increased, while muscle-tendon unit stiffness was not changed. A previous study reported that ROM was increased immediately after SS (Boyce and Brosky, 2008; Butler et al., 2016; Fletcher and Monte-Colombo, 2010; Sato et al., 2020), though SS for more than 180 seconds is necessary to decrease muscle-tendon unit stiffness in the hamstrings (Matsuo et al., 2013; Nakamura et al., 2019). These data indicated that the results of the present study were consistent with previous studies. Alteration of ROM after SS is attributed to changes in muscle-tendon unit stiffness (Konrad et al., 2016; Mizuno, 2017; Morse et al., 2008; Ryan et al., 2009) and tolerance for stretching (Brusco et al., 2019; Magnusson et al., 1996; Nakamura et al., 2013). In the present study, passive torque was measured as an indicator of change in tolerance (Takeuchi et al., 2018). Therefore, alteration of ROM after SS for 20 seconds at POD intensity was caused by the increment in tolerance for stretching. At both 120%POD and MaxPOD intensities, ROM and passive torque were increased, and muscle-tendon unit stiffness was decreased. These data indicated that alteration of ROM after these intensities of SS was attributed to changes in both muscle-tendon unit stiffness and tolerance for stretching. Furthermore, it is shown that there were significant correlations between the intensity of SS and relative change of ROM, passive torque, and muscle-tendon unit stiffness. Kataura et al. (2017) compared the effects of different intensity SS for 180 seconds and showed that there was a moderate negative correlation between the intensities of SS and the decrease in passive stiffness. Although the detailed mechanism of the effect of SS at high intensity on muscle-tendon unit stiffness is unclear, the intensity of SS relates to the change in muscle-tendon unit stiffness. From these data, SS for 20 seconds at high intensity effectively decreases muscle-tendon unit stiffness.

Change in ROM can be attributed to alteration in musculotendinous visco-elasticity (Kataura et al., 2017; Kay et al., 2016; Magnusson et al., 1997; Matsuo et al., 2013) and reflex activity (Etnyre and Abraham, 1986; Guissard et al., 2001; Guissard and Duchateau, 2004) in addition to alteration in muscle-tendon stiffness and tolerance for stretching. Change in musculotendinous visco-elasticity is measured by using the passive torque over time when the muscle is held in a constant length position (Kataura et al., 2017; Kay et al., 2016; Magnusson et al., 1997; Matsuo et al., 2013). Gajdosik et al. (2006) reported that over 60% of decrement in the passive torque was found within the first 15 seconds of SS. Moreover, Kataura et al. (2017) examined SS at different intensity for 180 seconds in hamstrings, and showed that static passive torque, which was an indicator of musculotendinous visco-elasticity, decreased after the stretching regardless of its intensity. In the present study, passive torque during SS was not measured. However, in accordance with the previous studies, it is possible that alteration in musculotendinous visco-elasticity could be one of the factors in the change in ROM in the present study. Previous studies reported that SS inhibits H-flex throughout the time when the muscle is kept at the static end position of a stretch (Guissard et al., 2001; Hwang, 2002; Masugi et al., 2017). H-reflex decreases immediately as static stretching is applied and in proportion to the stretch degree (Budini et al., 2018; Budini and Tilp, 2016). Therefore, in the present study, it is possible that the inhibition of H-reflex occurred strongly during SS at high intensity. However, the inhibition of H-reflex recovers immediately as the joint is returned to its neutral position after a period of SS (Budini et al., 2018; N. Guissard et al., 2001; Yapicioglu et al., 2013). It is necessary to examine change in the H-reflex after high-intensity SS as one of the mechanisms of change in ROM.

The present study used SS for 20 seconds, and the results showed that peak torque of isokinetic knee flexion showed no change at all intensities, but the knee angle at peak torque was increased at 120%POD and MaxPOD intensities. Previous studies reported that peak torque during maximum contraction decreased after SS (Avela et al., 2004; Behm and Chaouachi, 2011; Fowles et al., 2000; Kay and Blazevich, 2009). The decrement in muscle strength after SS is attributed to a decrease in muscle-tendon unit stiffness (Fowles et al., 2000; Mizuno et al., 2014) and neural activity (Behm and Chaouachi, 2011; Trajano et al., 2013; Trajano et al., 2014; Trajano et al., 2017). SS theoretically reduces the force transfer efficiency from the contractile component to the skeleton (Huijing, 1999) with the decrement in muscle-tendon unit stiffness (Fowles et al., 2000; Mizuno et al., 2014). Trajano et al. reported that central factors were strongly related to the torque reduction immediately after stretching and during torque recovery (Trajano et al., 2013). To our best knowledge, influence of SS of short duration (< 1 min) on neural activity is unclear. In the present study, neither muscle-tendon unit stiffness nor peak torque of isokinetic knee flexion showed a change in POD. These data suggested that neither decrement in muscle-tendon unit stiffness nor neural activity occurred in POD, and as a result, peak torque of isokinetic knee flexion did not change. Kataura et al. (2017) reported that peak torque of isometric knee flexion and passive stiffness were both decreased after 180 seconds of SS at 120%POD intensity. However, in the present study, the peak torque of isokinetic knee flexion did not change despite muscle-tendon unit stiffness being decreased at 120%POD and MaxPOD intensities. The following two points can be suggested as the reasons for the discrepancy. Firstly, the present study measured peak torque during isokinetic contraction, while the previous study measured it during isometric contraction (Kataura et al., 2017). It is reported that the length-tension relationship is altered after SS (Behm et al., 2016; Cramer et al., 2007; Weir et al., 2005). The results of the present study showed that the knee angle at peak torque increased after 120%POD and MaxPOD intensities, which indicated that the length-tension relationship was changed. Therefore, in the previous study in which the peak torque was measured during isometric contraction (Kataura et al., 2017), it is possible that the changes in the length-tension relationship may have resulted in a decrement in the peak torque. Secondly, it is possible that the pain during SS at 120%POD and MaxPOD intensities increased neural activity. NRS during SS at 120%POD and MaxPOD intensities indicated higher values than that at POD intensity. Previous studies reported that sympathetic nerve activity is activated following pain and discomfort level (Matsubara et al., 2011; Shiro et al., 2012). The sympathetic nerve plays a crucial role in the blood flow and neural activity during muscle contraction (Katayama and Saito, 2019). These data suggested that SS at high intensity activated sympathetic nerve activity and increased muscle activity. Therefore, it is possible that a decrement in the peak torque after SS at high intensity because of a decrement in muscle-tendon unit stiffness was offset by an increment in muscle activity. Previous reports have suggested that SS before sports activities should be avoided because it decreases muscle strength (McHugh and Cosgrave, 2010), though SS prevents sports-related injuries through a decrement in muscle-tendon unit stiffness. The results of the present study showed that SS at high intensity could decrease muscle-tendon unit stiffness without a decrement in muscle strength.

NRS during SS, immediately after SS and 24 hours after SS were described to confirm the safety of SS at high intensity. The results showed that NRS during SS increased with the intensity of SS. However, NRS immediately after SS disappeared at all intensities of SS. Furthermore, NRS at 24 hours after SS was at 0 level at all intensities. Kataura et al. (2017) reported that 180 seconds of SS at 120%POD intensity caused mild to moderate pain (NRS; 4.3-5.0 level). In their previous study, the time course of NRS after SS was not examined. However, from the results of this study, 20-seconds of SS at high intensity may not be dangerous for healthy people. Many athletes have histories of muscle-tendon injuries such as muscle strain. To our best knowledge, there is no study that has examined muscle-tendon unit stiffness after muscle strain. However, it is possible that muscle-tendon unit stiffness could be changed after muscle strain because connective tissue increases after muscle strain in the hamstrings (Silder et al., 2008). The present study examined the effect of SS at high intensity in healthy people. Therefore, further research is necessary to confirm the safety of SS at a high intensity of SS for persons with a history of muscle-tendon injuries.

Conclusion

The present study showed that ROM and passive torque were increased regardless of intensity of SS for 20 seconds. However, muscle-tendon unit stiffness decreased in SS at high intensity. Moreover, the peak torque of knee flexion was not changed at all intensities. These data suggested that SS for 20 seconds at high intensity was effective in a warm-up program, because a decrement in muscle-tendon unit stiffness is important to prevent sports-related injuries.

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Key points

- Effect of high intensity of static stretching (SS) for 20 seconds on hamstring was examined.
- SS at high intensity decreased muscle-tendon unit stiffness.
- The peak torque of knee flexion during isokinetic contraction was not changed after SS.
- The pain during the stretching disappeared immediately after the stretching.

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