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**Title**

Effects of static stretching for 30 seconds and dynamic stretching on leg extension power

**Brief running head**

Effect of stretching on muscular performance

**Laboratory where the research was conducted**

Laboratory of Human Performance and Fitness, Graduate School of Education, Hokkaido

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## INTRODUCTION

Most athletes perform stretching during warm-up prior to physical activity in order to prevent injuries and enhance sports performance by improving flexibility (2,22,24). There are various techniques of stretching, including static, ballistic, proprioceptive neuromuscular facilitation (PNF) and dynamic stretching (1,2,13,14). Static stretching is widely used because it is easy and safe (1,2,13,14,24). Recent studies (4,8,7,9,10,17,23,25), however, have shown that static stretching reduces strength and power production, i.e., muscular performance, of the stretched muscle group. Thus, some researchers (7,17) have proposed that static stretching should not be performed to enhance muscular performance in warm-up for activities that require strength and power production.

In studies that showed muscular performance decreased after static stretching (4,7,8,9,10,17,23,25), a single muscle group was statically stretched for 100 seconds to 30 minutes. However, in warm-up, the muscle groups that are used in actual activity need to be stretched in a limited time (1). Thus, static stretching of a single muscle group was performed for a longer time in previous studies than the stretching time in general warm-up. On the other hand, it has been reported that the effect of static stretching for a period of 20-30 seconds on flexibility is not different from the effect of static stretching for a longer period (3,19). Based on this finding, Alter (2) recommended a period of 20-30 seconds for static stretching during warm-up.

Previous studies (4,9,10,17,23,25) have suggested that mechanisms causing decrement of muscular performance after static stretching are both neurological and mechanical changes. Neurological change, i.e., reduction in neuromuscular activity level, occurred during static stretching for 30 seconds, but it was restored immediately after stretching (12). Furthermore, mechanical change, that is, decrease in viscoelastic properties of muscle-tendon structures, also occurred during static stretching for 30 seconds (18). However, at 30 seconds after static stretching for 45 seconds, the viscoelasticity of muscle-tendon structures had recovered (18). Only by static stretching for 30 seconds, both neurological and mechanical changes may are not continued. Thus, static stretching for 30 seconds may not reduce muscular performance. In any case, static stretching for 100 seconds to 30 minutes has not actually been performed in warm-up. Therefore, in order to determine whether performing static stretching in warm-up is appropriate, the effect of static stretching for 30 seconds on muscular performance needs to be clarified.

It has been reported that ballistic stretching also reduced muscular performance (17), and the effects of PNF stretching on muscular performance have been examined (6,23). However, the effect of dynamic stretching on muscular performance has not been elucidated. Since some muscles are contracted actively and rhythmically to stretch the target muscle, dynamic stretching may raise muscular temperature (11). Dynamic stretching may also cause postactivation potentiation that is the transient improvement of muscular performance after previous contraction (21). These phenomena improve muscular performance (5,21). Thus,

dynamic stretching may enhance muscular performance. If that can be shown, dynamic stretching during warm-up would be an effective technique for enhancement of muscular performance.

Therefore, the purposes of this study were to reveal the effects of static stretching for 30 seconds and dynamic stretching on muscular performance.

## **METHODS**

### **Experimental approach to the problem**

In order to determine the validity of our hypotheses that static stretching for 30 seconds does not reduce muscular performance and that dynamic stretching enhances muscular performance, we examined the effects of both types of stretching on muscular performance using leg extension power as an index of muscular performance. Leg extension power is similar to the power produced during a jumping movement such as a vertical jump (15). Cornwell et al. (7) reported that static stretching decreased vertical power during jump performance. However, based on our hypothesis, leg extension power after static stretching for 30 seconds would not be reduced. On the other hand, dynamic stretching may improve leg extension power.

Prior to the experiments, each subject visited the laboratory to receive instructions and for a preliminary trial to measure leg extension power. Subjects then performed static

stretching, dynamic stretching and non-stretching in a randomized order on separate days, and leg extension power was measured before and after each of these trials. The target muscles of both static stretching and dynamic stretching were five muscle groups in both lower limbs: plantar flexors, hip extensors, hamstrings, hip flexors and quadriceps femoris. The total duration for stretching or non-stretching was set to 500 seconds. Thus, the stretching protocol in this study is regarded as appropriate for warm-up (1).

### **Subjects**

Eleven healthy college male students (mean  $\pm$  standard error; age, 22.8  $\pm$  0.8 yrs; height, 173.3  $\pm$  1.1 cm; weight, 65.9  $\pm$  3.0 kg) took part in this study. All subjects were free of injury. They were recreationally active men and had a training history including weight training. However, the subjects were not performing stretching or weight training when this study started. All subjects were informed of the methods to be utilized as well as the purposes and the risks of this study, and informed consent was obtained from all subjects. The protocol of this study was approved by the ethics committee in Graduate School of Education, Hokkaido University.

### **Measurement of leg extension power**

Leg extension power was measured by a leg extension power measurement system (Combi, Anaero Press 3500, Japan; Figure 1). This system controls the load of the footplate so

that fixed tension is always applied to both legs during leg extension movement, and it calculates explosive power by measuring velocity and time to maximum velocity (15). Each subject sat on the seat and placed both feet on the footplate. The waist and ankles of each subject were firmly fastened by Velcro straps. The seat was moved to a position at which the knee joint angle was about 90 degrees (figure 1a). The load of the footplate was set to equal the subject's weight. Subjects were instructed to push the footplate by extending both legs as quickly and powerfully as possible (figure 1b). Leg extension power was measured five times with rest periods of 15 seconds between trials. The mean of the two highest values in five trials was taken as the leg extension power of each subject (26). The values before each series of trials were not significantly different, and their mean of coefficients of variation was 5.4% (range: 1.7-13.2%). The test-retest correlation ( $r$ ) was 0.934.

### **Experimental conditions**

For static stretching, the experimenter stretched the target muscle of the subject's left leg slowly and carefully until reaching a position at which the subject verbally instructed the examiner to stop the stretching. This position was held for 30 seconds. Next, stretching was performed in the same manner on the same target muscle of the subject's right leg after a 20-second rest period. The purpose of the 20-second rest period was to change the subject's posture and search for his limited position. After stretching the right leg, the next target muscle was stretched after a rest period of 20 seconds. The procedures for static stretching of target

muscles are shown in Table 1. All static stretching procedures were performed with the same experimenter.

For dynamic stretching, each subject contracted the antagonist of target muscle intentionally in standing upright position and flexed or extended some joints once every 2 seconds so that the target muscle was stretched. This stretching was performed 5 times slowly at first and then 10 times as quickly and powerfully as possible without bouncing. The procedure was performed on left leg at first and then on right leg with rest period of 20 seconds. The order of target muscle and the rest periods were the same as those in static stretching. The procedures for dynamic stretching of target muscles are shown in Table 2.

For non-stretching, each subject rested in a sitting or supine position with both legs extended.

### **Statistical analyses**

Repeated measures ANOVAs were used for comparisons of changes in leg extension power in both stretching conditions and the non-stretching condition. If significant interaction was indicated, paired t-tests were used to examine the difference between the leg extension powers at the same time points. Relationships between leg extension power before stretching or non-stretching and the magnitude of change in power after stretching or non-stretching were examined by Pearson's correlation coefficient tests. All values expressed as means and standard errors, and the significant level was  $p \leq 0.05$ .



## RESULTS

No subjects were injured, and all procedures were carried out by all subjects. Figure 2 shows changes in leg extension power for all subjects. In both static stretching and non-stretching conditions, the subjects who had greater leg extension power before static stretching or non-stretching tended to show greater reduction in power. The leg extension power before static stretching or non-stretching was negatively correlated with the magnitude of change in power after static stretching or non-stretching (static stretching:  $r = -0.71$ ,  $p = 0.01$ ; non-stretching:  $r = -0.68$ ,  $p = 0.02$ ; data not shown). On the other hand, leg extension power increased after dynamic stretching for all subjects. The correlation between power before dynamic stretching and magnitude of change after dynamic stretching was not significant ( $r = -0.04$ ,  $p = 0.18$ ; data not shown).

The changes in mean leg extension power in both stretching conditions and the non-stretching condition were compared (Figure 3). The changes in leg extension power in both static stretching condition and non-stretching condition were not significantly interaction (conditions  $\times$  before and after:  $F = 0.38$ ,  $p = 0.54$ ), but the powers after static stretching and after non-stretching tended to be reduced [static stretching:  $1884.8 \pm 107.3$  W ( $28.8 \pm 1.6$  W / kg) before vs.  $1788.5 \pm 85.7$  W ( $27.5 \pm 1.4$  W / kg) after, non-stretching:  $1851.9 \pm 127.0$  W ( $28.3 \pm 1.8$  W / kg) before vs.  $1784.8 \pm 108.4$  W ( $27.4 \pm 1.7$  W / kg) after]. On the

other hand, dynamic stretching increased leg extension power from 1837.6 +/- 130.8 W (28.0 +/- 1.9 W / kg) to 2022.3 +/- 121.0 W (30.8 +/- 1.7 W / kg). The changes in leg extension power in both dynamic stretching condition and non-stretching condition were significantly interaction (conditions  $\times$  before and after:  $F = 35.68$ ,  $p < 0.01$ ), the power after dynamic stretching was significantly ( $p < 0.01$ ) greater than that after non-stretching.

## **DISCUSSION**

The purposes of this study were to clarify the effects of static stretching for 30 seconds and dynamic stretching on muscular performance. The results revealed that leg extension power after static stretching of each muscle group in lower limbs for 30 seconds was not different from that after no stretching and that dynamic stretching enhanced leg extension power. Our hypotheses were that static stretching for 30 seconds does not reduce leg extension power and that dynamic stretching improves leg extension power. Thus, these results support our hypotheses.

Several studies (4,7,8,9,10,17,23) have shown that muscular performance after static stretching was decreased compared with that after no stretching (Table 3). In those previous studies, a single muscle group was statically stretched for 100 seconds to 30 minutes. For instance, Fowles and Sale (10) reported that static dorsiflexion stretching for about 30 minutes (13 sets of 2-minute 15-second stretching) reduced plantar flexion MVC torque. Cornwell et al.

(7) found that both static and countermovement jump performances were diminished after static stretching of hip and knee extensors for 100 sec (each 2 sets of about 50-second stretching). However, static stretching of a single muscle group in general warm-up may be shorter than those in previous studies (4,7,8,9,10,17,23). Therefore, in this study, static stretching of plantar flexors, hip extensors, hamstrings, hip flexors and quadriceps femoris for 30 seconds (each 1 set of 30-second stretching) was used, and its effect on muscular performance was investigated. The results showed that leg extension power after static stretching of each muscle group in lower limbs for 30 seconds did not differ from that after no stretching, suggesting that static stretching for 30 seconds of a single muscle group neither improves nor reduces muscular performance. Although the reason for the discrepancy between results of previous studies and those of this study could not be clarified from the results of this study, previous studies (4,9,10,17,23,25) have suggested that factors causing reduction of muscular performance after static stretching are reduction in neuromuscular activity level and decrease in viscoelasticity of muscle-tendon structures. Guissard et al. (12), however, reported that neuromuscular activity level measured by Hoffmann reflex was reduced during static stretching for 30 seconds but that it was restored immediately after stretching. On the other hand, to our knowledge, the acute effect of static stretching for 30 seconds on viscoelastic properties of muscle-tendon structures has not been clarified. Magnusson et al. (18), however, reported that 30 seconds after static stretching for 45 seconds, decrement of stress relaxation that was measured as an index of viscoelastic properties of muscle-tendon structures was

recovered. In this study, measurement of leg extension power was carried out more than 30 seconds after static stretching (to allow time for subjects to move to a leg power extension measurement system and for belts to be fastened). It is possible that neither the reduction in neuromuscular activity level nor the decrease in viscoelastic properties in muscle-tendon structures continued until the time when leg extension power was measured. Therefore, leg extension power might have been not be reduced by static stretching of each muscle group in the lower limbs for 30 seconds.

Although leg extension power after static stretching for 30 seconds was not different from that after no stretching, the power tended to be decreased. One of the purposes of performing stretching during warm-up is to enhance sports performance (2,22,24). Warm-up for activities that need strength and power production must be aimed at improving muscular performance. Thus, performing static stretching for 30 seconds during warm-up must not necessarily be effective for this purpose. In addition, although the subjects of this study were recreationally active men, it was notable that the subjects who had greater leg extension power before static stretching showed greater reduction in power after stretching. For athletes who have potentially high muscular performance, static stretching for 30 seconds might reduce muscular performance further. Thus, such athletes should consider not performing even static stretching for 30 seconds.

Dynamic stretching has recently become popular (13,14), but the effect of this technique on muscular performance has not been examined. The present results showed that

dynamic stretching of muscle groups of the lower limbs enhanced leg extension power for all subjects and that the power after dynamic stretching was greater than that after no stretching. Nelson and Kokkonen (20) founded that ballistic stretching, like static stretching, of knee extensors and flexors reduced one-repetition maximums of knee extension and flexion compared with that in the case of no stretching. Furthermore, Church et al. (6) reported that countermovement jump performance after warm-up and PNF stretching of knee extensors and flexors was diminished compared with that after only warm-up. These findings suggest that dynamic stretching is an effective technique for enhancing muscular performance. Although the mechanism by which dynamic stretching improves leg extension power could not be determined from the results of the present study, it is thought that muscular performance was improved by elevation of muscular temperature or post-activation potentiation caused by voluntary contractions of the antagonist of the target muscle. The increase in muscular temperature improves dynamic short-duration performance (5). Moreover, post-activation potentiation is that the muscular performance was improved by muscular contractile history (5,21). Hence, these phenomena might affect enhancement of muscular performance by dynamic stretching. However, since muscular temperature and neuromuscular activity level were not monitored in this study, the effects of these phenomena could not be clarified. Further studies are needed to elucidate the mechanisms by which muscular performance is enhanced after dynamic stretching.

## **PRACTICAL APPLICATIONS**

In this study, the effects of static stretching for 30 seconds and dynamic stretching of muscle groups in the lower limbs on leg extension power were investigated. The results showed that leg extension power after static stretching of muscle groups in the lower limbs for 30 seconds was not different from that after no stretching. Previous studies (4,7,8,9,10,17,23) showed that static stretching for 100 seconds to 30 minutes reduced muscular performance. The results of this study are different from those of previous studies. However, static stretching for 30 seconds tended to decrease leg extension power in this study. It was also notable that the subjects who had greater leg extension power before static stretching showed greater reduction in power. Therefore, static stretching for 30 seconds may not be an effective technique for improvement of muscular performance. On the other hand, the results of this study revealed that dynamic stretching enhanced leg extension power, suggesting that dynamic stretching may be an appropriate technique for improving muscular performance. To our knowledge, the effect of dynamic stretching on muscular performance has not been examined in any studies. Hence, the finding regarding dynamic stretching in this study is a new finding. Leg extension power resembles the power produced during a jumping movement such as a vertical jump (15). It is therefore thought that dynamic stretching of muscle groups of the lower limbs enhances the performance of activities that involve jumping or activities that require rapid body movement. Most of the subjects in this study performed dynamic stretching for the first time.

All of the subjects were easily able to perform the stretching, which involved contraction of the antagonist of the target muscle as quickly and powerfully as possible. Therefore, most athletes can probably easily change the stretching protocol in warm-up from static stretching to dynamic stretching. Furthermore, although dynamic stretching was performed on the muscle groups of the lower limb in this study, dynamic stretching by the above-described method can also be performed on various other muscle groups such as those of the upper limbs and the trunk.

Since the subjects of this study were only recreationally active men, the present results are not directly applicable to competitive athletes. Thus, further study is needed to investigate the effect of dynamic stretching on muscular performance of competitive athletes. Another purpose of stretching is to prevent injuries (2,22,24). Therefore, the effect of dynamic stretching on the risk of injury must also be examined.

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**FIGURE CAPTIONS****Figure 1.**

Leg extension power measurement system. a: starting position, b: final position.

**Figure 2.**

Changes in leg extension power for all subjects.

**Figure 3.**

Comparisons of changes in mean leg extension power in the both stretching condition and non-stretching condition. Values are means and standard errors. ★★ significantly ( $p < 0.01$ ) different from non-stretching.

Figure 1

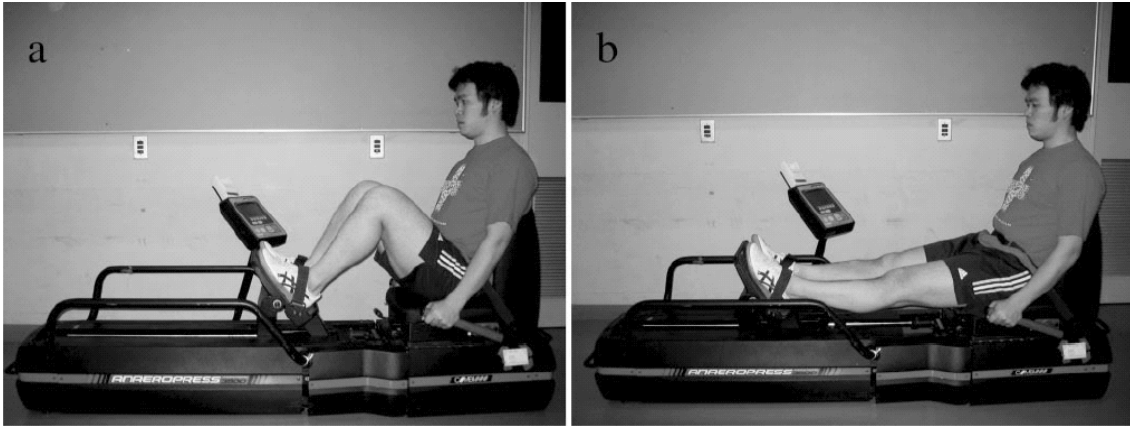


Figure 2

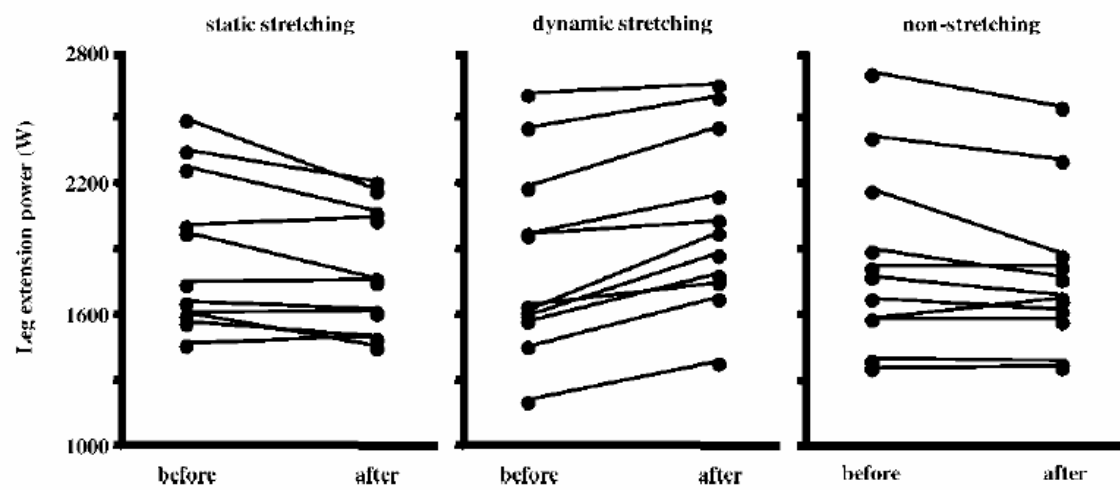
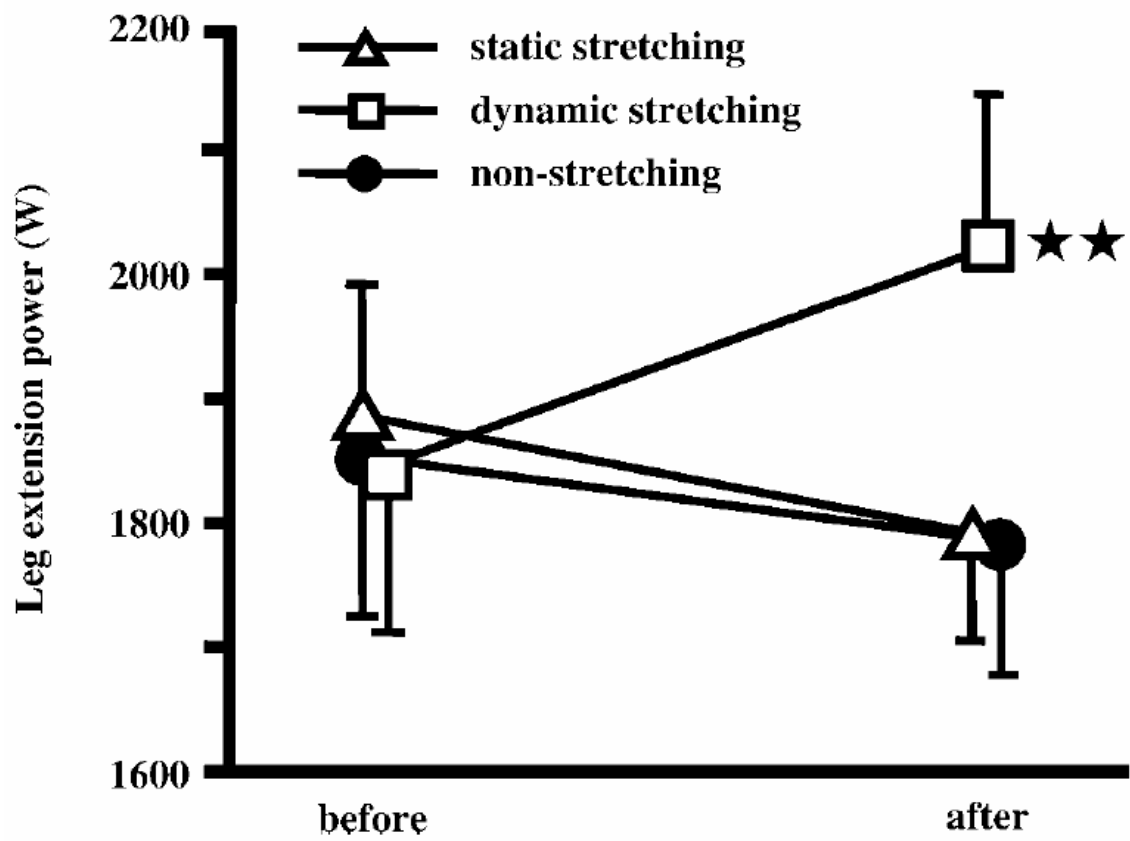







Figure 3



**Table 1**

<b>TABLE 1.</b> The procedures for static stretching of target muscles.	
<b>Plantar flexors</b>	
The experimenter dorsiflexed the ankle joint of the subject while the subject remained in the supine position with knee fully extended.	
<b>Hip extensors</b>	
The experimenter flexed the hip joint of the subject while the subject remained in the supine position with knee fully flexed.	
<b>Hamstrings</b>	
The experimenter flexed the hip joint of the subject while the subject remained in the supine position with knee fully extended.	
<b>Hip flexors</b>	
The experimenter lifted up the knee of the subject while the subject remained in the prone position with knee lightly flexed so that the hip joint was extended.	
<b>Quadriceps femoris</b>	
The experimenter fully flexed the knee joint of the subject in the prone position until the subject's heel touched his buttock, and then the knee was lifted up so that the hip joint was extended.	



**Table 2**


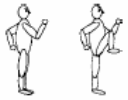



<b>Table 2.</b> The procedures for dynamic stretching of target muscles.	
<b>Plantar flexors</b>	
First, the subject raised one foot from the floor and fully extended the knee. Then, the subject contracted his dorsiflexors intentionally and dorsiflexed his ankle joint so that his toe was pointing upward.	
<b>Hip extensors</b>	
The subject contracted hip flexors intentionally with knee flexed and flexed his hip joint so that his thigh came up to his chest.	
<b>Hamstrings</b>	
The subject contracted the hip flexors intentionally with knee extended and flexed his hip joint so that his leg was swung up to the anterior aspect of his body.	
<b>Hip flexors</b>	
First, the subject raised a foot from the floor and lightly flexed his hip joint with the knee lightly flexed. The subject then contracted his hip extensors intentionally and extended his hip and knee joints so that his leg was extended to the posterior aspect of his body.	
<b>Quadriceps femoris</b>	
The subject contracted his hamstrings intentionally and flexed his knee joint so that his heel touched his buttock.	

Table 3

**Table 3.** Comparison of stretching protocols and results of studies in which the effects of static stretching on muscular performance was investigated.\*

	Study	Performance	Target muscle group(s)	Stretching type, time, set of a single muscle group	Rest between sets of a single muscle group	Total stretching time of a single muscle group	Effect on performance
Strength	Behm et al. (2001) (4)	KE MVC force	Ke	4 type $\times$ 45 s $\times$ 5 set	15 s	20 min	W-up + NS > W-up + SS
	Evetovich et al. (2003) (9)	FF CON ISK torque	Ff	3 type $\times$ 30 s $\times$ 4 set	15 s	9 min	NS > SS
	Fowles et al. (2000) (10)	PF MVC torque	Pf	1 type $\times$ 2 min, 15 s $\times$ 13 set	5 s	30 min, 20 s	NS > SS
	Kokkonen et al. (1998) (17)	KE & KF 1RM	Ke, Kf Pf	2 type $\times$ 15 s $\times$ 6 set 1 type $\times$ 15 s $\times$ 6 set	15 s	6 min 3 min	NS > SS
Jump	Church et al. (2001) (6)	CJ (JH)	Ke, Kf	3 type $\times$ ? s $\times$ ? set	?	?	W-up + NS = W-up + SS
	Cornwell et al. (2001) (7)	SJ, CJ (JH, VP)	Ke, He	2 type $\times$ about 50 s $\times$ 1 set	—	100 s	NS > SS
	Cornwell et al. (2002) (8)	SJ, CJ (JH)	Pf	2 type $\times$ 30 s $\times$ 3 set	0 s	180 s	NS > SS (CJ) NS = SS (SJ)
	Knudson et al. (2001) (16)	CJ (PV)	Ke, Kf, Pf	1 type $\times$ 15 s $\times$ 3 set	?	2 min ?	W-up + NS + jump = W-up + SS + jump
	Young and Behm (2003) (24)	CON J (JH, PF, RFD) DJ (JH, CT, height/time)	Ke, Pf	2 type $\times$ 30 s $\times$ 1 set	—	60 s	Walk + squat + heel rise > SS (PF of CON J) Walk + squat + heel rise = SS (except PF of CON J)
	Young and Elliott (2001) (25)	CON J (JH, PF, RFD) DJ (height/time)	Ke, Kf, Pf	1 type $\times$ 15 s $\times$ 3 set	20 s	105 s	W-up + NS > W-up + SS (height/time of DJ) W-up + NS = W-up + SS (except height/time of DJ)
Power	This study	LE power	Ke, Kf, He, Hf, Pf	1 type $\times$ 30 s $\times$ 1 set	—	30 s	NS = SS

\* KE = knee extension; MVC = isometric maximum voluntary contraction; FF = forearm flexion; CON ISK = concentric isokinetic; PF = plantar flexion; KF = knee flexion; 1RM = 1 repetition maximum; CJ = countermovement jump; JH = jump height; SJ = static jump; VP = vertical power; PV = peak velocity; CON J = concentric jump; PF = peak force; RFD = rate of force development; DJ = drop jump; CT = contact time; LE = leg extension; Ke = knee extensors; Ff = forearm flexors; Pf = plantar flexors; Kf = knee flexors; He = hip extensors; Hf = hip flexors; W-up = warm-up; NS = non-stretching; SS = static stretching.