TITLE:

Acute effect of static stretching on power output during concentric dynamic constant external resistance (DCER) leg extension

BRIEF RUNNING HEAD:

Acute effect of static stretching on muscular performance

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ABSTRACT

The purpose of the present study was to clarify the effect of static stretching on muscular performance during concentric isotonic (dynamic constant external resistance: DCER) muscle actions under various loads. Concentric DCER leg extension power outputs were assessed in twelve healthy male subjects after two types of pre-treatment. The pre-treatments included 1) static stretching treatment performing six types of static stretching on leg extensors (4 sets of 30-sec each with 20-sec rest periods; total duration: 20-min) and 2) non-stretching treatment by resting for 20 minutes in a sitting position. Loads during assessment of the power output were set to 5%, 30% and 60% of the maximum voluntary contractile (MVC) torque with isometric leg extension in each subject. The peak power output following the static stretching treatment was significantly ($P<0.05$) lower than that following the non-stretching treatment under each load (5%MVC: 418.0 ± 82.2 W vs. 466.2 ± 89.5 W; 30%MVC: 506.4 ± 82.8 W vs. 536.4 ± 97.0 W; 60%MVC: 478.6 ± 77.5 W vs. 523.8 ± 97.8 W). The present study demonstrated that relatively extensive static stretching significantly reduces power output with concentric DCER muscle actions under various loads. Common power activities are carried out by DCER muscle actions under various loads. Therefore, the result of the present study suggests that relatively extensive static stretching decreases power performance.

KEYWORDS: stretch, warm-up, performance, torque, velocity, rate of torque development (RTD)

INTRODUCTION

Strength or muscular power output, i.e., muscular performance is an important physical fitness factor for affecting various sport performances. Athletes, therefore, need to improve muscular performance during a warm-up prior to sport activities. A general warm-up protocol consists of low intensity aerobic exercise and stretching exercise (1,2,36). The stretching technique widely utilized as a part of a warm-up is static stretching (36). However, recent studies (3,4,8-10,13,14,21,23,24,26,28,30,33) have showed that static stretching reduces muscular performance. Some researchers (8,21,28) have proposed that static stretching should not be used during a warm-up.

In most of the studies (3,4,8-10,13,23,24,26,28,30,33) that showed a decrease in muscular performance following static stretching, the muscular performance was assessed during isometric or isokinetic muscle action. Actual sport activities, however, consist of isotonic (dynamic constant external resistance: DCER) muscle action. Therefore, the effect of static stretching on muscular performance with DCER muscle action should be clarified in order to determine whether the use of static stretching is inappropriate as a part of a warm-up. The effect of static stretching on muscular performance with concentric DCER muscle action was investigated in a few studies (14,21), but only the effect on relatively heavy loaded performance was examined. Thus, the effect of static stretching on muscular performance with concentric DCER muscle actions under relatively light or moderate loads was not clarified.

In order to demonstrate optimum muscular performance with concentric DCER muscle action, rapid and powerful contraction is required. Rosenbaum and Hennig (31) showed that static stretching causes a reduction in peak force, as well as a prolongation of the time to peak force, and that those changes result in a decrease of the rate of force development (RFD). The decrease in the RFD hinders rapid and powerful contraction. Hence, static stretching may reduce muscular performance with maximum effort concentric DCER muscle action under various loads. The purpose of the present study was to determine whether static stretching reduces muscular performance with concentric DCER muscle actions under various loads.

METHODS

Approach to the Problem

Our hypothesis was that static stretching reduces muscular performance with concentric DCER muscle actions under various loads. In order to determine the validity of our hypothesis, experiments consisting of three testing days interspersed with 3-7 days of rest were performed. On day 1, each subject visited our laboratory to receive instructions. Assessment of maximum voluntary contractile (MVC) torque with isometric leg extension and preliminary trials to measure concentric DCER leg extension power output were performed. On day 2, the concentric DCER leg extension power outputs were assessed after one of two types of pre-treatment in each subject. The two types of pre-treatment were

1) static stretching treatment carrying out six types of static stretching on the leg extensors, and 2) non-stretching treatment by resting for 20 minutes in a sitting position. The pre-treatment on day 2 was determined at random for each subject. On day 3, the assessments of power output were performed after the other pre-treatments different from that on day 2. Loads during the assessments of power output were set to 5% (relatively light load), 30% (moderate load) and 60% (relatively heavy load) of the MVC torque assessed on day 1 for each subject. The peak power output during concentric DCER leg extension was compared between the static stretching treatment and the non-stretching treatment under each load condition in order to examine the effects of static stretching of leg extensors on power output with concentric DCER leg extensions under three kinds of load.

Subjects

Twelve healthy men (mean ± standard deviation; age, 23.8 ± 2.3 yr; height, 173.2 ± 6.5 cm; weight, 64.1 ± 7.4 kg) took part in the present study. All subjects were free of injury in their lower extremities. They were recreationally active men but not involved in regular training. All subjects were informed of the methods to be utilized as well as the purpose and risks of the present study, and informed consent was obtained from all subjects. The protocol of the present study was approved by the ethics committee of Hokkaido University.

Pre-treatments

In the static stretching treatment, six types of static stretching were carried out on the right leg extensors. Three were unassisted stretching exercises carried out by the subject, and the other three were assisted stretching exercises carried out by the same experimenter. Each stretching exercise consisted of four successive repetitions. All stretching repetitions were held for 30 seconds at a point where the subject felt discomfort. Between each stretching repetition, and at that time of changing stretching exercise, each subject's leg extensors were returned to a neutral position for a 20 seconds rest period. The total duration of the static stretching treatment was approximately 20 minutes. The order of stretching exercises is shown below.

Unassisted standing stretching. The subject stood upright position with the left hand against a wall for balance, grasped the right ankle with the right hand, fully flexed the knee joint until the heel touched the buttock, and extended the hip joint (Figure 1a).

Assisted prone stretching. With the subject in a prone position on a mat, the experimenter grasped the subject's right ankle and flexed the right knee joint of subject until the subject's heel touched his buttock, lifting up the subject's right knee so that the hip joint of subject was extended (Figure 1b).

Unassisted standing stretching with resting foot. The subject stood upright with his back to a chair, rested the right foot on the back of the chair with the knee joint flexed and extended the hip joint (Figure 1c).

Assisted standing stretching with resting foot. The subject stood upright with both hands grasping the back of the chair. The experimenter flexed and lifted up the subject's right knee joint so that the hip joint of the subject was extended (Figure. 1d).

Unassisted supine stretching on the table. In a supine position on a padded table with the right leg hanging off the table, the subject grasped the right ankle with the right hand and flexed the knee joint, while extending the hip joint (Figure 1e).

Assisted supine stretching on the table: The subject remained in the same supine position as above. The experimenter pressed down the subject's right knee so that the hip joint of the subject was extended (Figure 1f).

In the non-stretching treatment, each subject rested in a sitting position for 20 minutes. The concentric DCER leg extension power outputs were assessed approximately five minutes after pre-treatment. The five minutes interval was the duration allowed for the subject to move to the power measurement system and for straps to be fastened.

Experimental Setups

The MVC torque and the concentric DCER leg extension power output were assessed using a power measurement system (Figure 2a) based on a commercially available machine, Power Processor (Vine Co. Ltd., Tokyo, Japan). This machine controlled the load of a wire uniformly with an electro-magnetic disk brake. The tension and velocity when the wire was pulled were recorded by the strain gauge and the rotary encoder attached to the axis of inertia wheel mounted in the Power Processor (16,17). Electrical signals from load cell and rotary encoder were stored on a personal computer at a sampling frequency of 500

Hz. The variable data were calculated with a commercially designed software program (VPM21, Vine Co. Ltd., Tokyo, Japan). Since the load of the wire was constant while the wire was pulled, the power output with concentric DCER muscle contraction was measured using this machine. Starting positions in all assessments were as follows. The subject sat on the seat of the measurement system with his knee and hip joint angle at about 90 degrees. The trunk, pelvis and both thighs of each subject were firmly fastened by straps. The wire of the measurement system was attached to the subject's right ankle with a strap. The subject was instructed to cross the arms in front of the chest and not to shout during each measurement.

Measurement of the maximum voluntary contractile torque. The length of the wire of the measurement system was fixed at the start position during measurement of the MVC torque. The subject was instructed to extend the right knee joint with maximum effort for five seconds. The peak tension over five seconds was taken as the MVC torque. The MVC torques were measured two times with a rest period of 2 minutes between trials. The higher torque of the two trials was taken as the variable MVC torque data for each subject.

Measurement of the concentric dynamic constant external resistance leg extension power output. The load of the wire of the measurement system was set to 5%, 30% or 60% of the MVC torque in each subject. The power outputs were measured in the order of 5%MVC, 30%MVC and 60%MVC after each treatment in all subjects, since our primary purpose was to determine the acute effects of static stretching on concentric DCER leg extension power outputs under relatively light and moderate load. The subject was instructed to pull the wire of the measurement system by extending the right leg as quickly and powerfully as possible from the starting position (Figure 2a). The measurements of power output under each load were performed two times with a rest period of 2 minutes. Each subject also rested for 2 minutes while the load was changed. The power output was derived by multiplying the tension and velocity recorded by the Power Processor. The peak power output [PP ($N \cdot m \cdot sec^{-1}$=W)] was recorded as the peak value in power-time curve (Figure 2b). The higher peak power output of the two measurements was taken as the variable peak power output data under each load in each subject. In addition, the tension [torque at peak power output: T_{PP} (N)] and velocity [velocity at peak power output: V_{PP} ($m \cdot sec^{-1}$)] at the peak power output, and the time from initial rise of power output to peak power output [time to peak power output: TPP (sec)] were analyzed (Figure 2b). Furthermore, the peak tension [peak torque: PT (N)], the time from 20% of peak torque to peak torque [time to peak torque: TPT (sec)], the PT/TPT ratio [rate of torque development: RTD ($N \cdot sec^{-1}$)], and the peak velocity [PV ($m \cdot sec^{-1}$)] during concentric DCER leg extension were also calculated (Figure 2b).

Statistical Analyses

The paired t-test or Wilcoxon signed-ranks test was utilized to examine the differences between variable data after the static stretching treatment and the non-stretching treatment. All variable data were expressed as the mean and standard deviation, and the significance level was $P \leq 0.05$.

Reliability

Previous test-retest reliability from our laboratory for all of dependent variables during MVC and concentric DCER leg extensions indicated that, for 5 men measured 3-7 days apart, there were no significant differences ($P>0.05$) between mean values for test vs. retest. The intraclass correlation coefficients (*R*) are shown Table 1.

RESULTS

The T_{PP} and the T_{PP}/MVC torque ratio (%MVC_{PP}) were not significantly different between the static stretching treatment and the non-stretching treatment under each load condition (Table 2). On the other hand, the V_{PP} after the static stretching treatment was significantly ($P<0.05$) slower than that after the non-stretching treatment under each load condition (Table2). The PP was also significantly ($P<0.05$) lower after the static stretching treatment, compared with the non-stretching treatment under each load condition (Figure 3; 5%MVC: -12%; 30%MVC: -6%; 60%MVC: -9%). In contrast, no significant differences were observed in the mean TPP between the two treatments (Table 2).

The PT was not significantly different between the two treatments under each load condition, although the TPT after the static stretching treatment was significantly ($P<0.05$) longer than that after the non-stretching treatment (Table 2). The RTD after the static stretching treatment was significantly ($P<0.05$) lower than that after the non-stretching treatment under the load conditions of 5%MVC and 60%MVC. The mean RTD under the load condition of 30%MVC was lower after the static stretching treatment than that after the non-stretching treatment, although we did not calculate a statistical significance (Table2; P=0.06). The PV was significantly (P<0.05) slower after the static stretching treatment under each load condition (Table 2).

DISCUSSION

The primary result of the present study was that static stretching of leg extensors reduced peak power outputs with concentric DCER leg extensions under all three kinds of load consisting of a relatively light load, a moderate load and a relatively heavy load. Our hypothesis was that the muscular performance with concentric DCER muscle actions under various loads decreases after static stretching. Therefore, the result of the present study supports our hypothesis. To our knowledge, this is the first evidence that shows acute effect of static stretching on muscular performance with concentric DCER muscle actions under various loads.

Before interpreting the main results of the present study, a mention should be made of the methodology used to assess the power output with concentric DCER muscle action. The results of the present study demonstrated that the T_{PP}, the $\%MVC_{PP}$ and the PT were not significantly different between the static stretching treatment and the non-stretching treatment under each load (Table2). Therefore, we were able to assess the power output with concentric DCER muscle action under each load.

Previous studies (3,4,8-10,13,23,24,26,28,30,33) showed a decrease in muscular performance after static stretching by using force or torque with isometric or isokinetic muscle action as an index of muscular performance. For example, Behm et al. (4) demonstrated that the isometric leg extension force decreased following static stretching of the leg extensors. Cramer et al. (8,9) showed that a concentric isokinetic leg extension torque declined after static stretching of the leg extensors. However, isometric or isokinetic muscle action is rarely used in actual sport activities. Most sport activities involve isotonic (DCER) muscle actions. Therefore, the effect of static stretching on muscular performance with DCER muscle action should be clarified in order to comprehend the effect of static stretching on actual sport performance. Regarding the effect of static stretching on muscular performance with concentric DCER muscle action, Kokkonen et al. (21) showed that one repetition maximums (1RM) in both leg extension and leg flexion decreased after static stretching on leg extensors, leg flexors and plantar flexors. Furthermore, Fry et al. (14) found that the mean power output for bench press exercise under load at 85% of the 1RM was reduced following static stretching. The 1RM is the maximum strength with concentric DCER muscle action and is equivalent to only 60-80% of the MVC force or torque (15,22,31). Therefore, only the effect of static stretching on muscular performance with concentric DCER muscle action under relatively heavy load was examined in the studies of Kokkonen et al. (21) and Fry et al. (14). The present study, in contrast, indicated that static stretching of leg extensors decreased the peak concentric DCER leg extension power output under three kinds of loads consisting a relatively light load (5%MVC), a moderate load (30%MVC) and a relatively heavy load (60%MVC) (Figure 3). Furthermore, when the relationships between torque (%MVC_{PP}) and power output (PP) at the peak power output following static stretching and non-stretching were plotted (Figure 4), the torque-power curve after static stretching was consistently located below that after non-stretching. In other words, it is suggested that static stretching reduces power output with concentric DCER muscle actions under various loads.

Previous studies (3,4,8-10,13,21,24,26,28,30,31,33) have suggested that the mechanisms causing stretching-induced decrease in the muscular performance are mechanical change, i.e., decrease in stiffness of muscle-tendon structures, and/or neurological change, that is, reduction in neuromuscular activity. It is difficult to determine reasons why static stretching reduced the power output from the results of the present study. However, the two findings of the present study suggested that a stretching-induced mechanical change contributed to the decrease in the power output.

First, the TPT was prolonged significantly for all loads, and the RTD was reduced significantly (5%MVC and 60%MVC load conditions) or tended to decrease (30%MVC load condition) after static stretching (Table 2). These findings are consistent with a previous study. Rosenbaum and Hennig (31) measured the Achilles' tendon tap reflex force after static stretching on plantar flexors, and showed the prolongation of the time to peak force (TPF ≅ TPT) and the decrease in the RFD (≅ RTD). Jewell and Wilkie (18) reported that the RFD depended on both the stiffness of the series elastic component consisting of muscle and tendon structures and the force-velocity characteristics of the contractile component including muscle structure. Indeed, Kubo et al. demonstrated both a reduction in the RTD accompanied by a decrease in the stiffness of tendon structures (19) and enhancement in the RTD accompanied by an increase in the stiffness of tendon structures (20). In addition, Wilson et al. (34) showed that the maximum RFD was positively correlated with muscle-tendon stiffness. They also demonstrated that the maximum RFD of subjects with stiffer muscle-tendon systems was greater than that of pliant subjects. Therefore, the result of the present study that static stretching reduced the RTD suggested a decrease in muscle-tendon stiffness.

Second, the TPP did not change in the present study, although both the V_{PP} and the PV decreased significantly following static stretching for each load (Table2). These findings suggested that smaller leg extension movement was required for peak power output after static stretching. In other words, the peak power output was produced at a greater leg flexion angle. This finding is consistent with previous studies (8,13) that have shown a decrease in peak torque accompanied by change in joint angle at peak torque following static stretching. Cramer et al. (8) demonstrated a decrease in peak torque with isokinetic leg extension as well as an increase in leg flexion angle at peak torque after static stretching of the leg extensors. Fowles et al. (13) also showed that static stretching of the plantar flexors reduced the plantar flexion MVC peak torque in connection with an increase in dorsiflexion angle at peak torque. Previous studies (8,10,13,21,26,28) suggested that the change of joint angle at peak torque was produced by a shift of the muscle length-tension relationship due to the stretching-induced mechanical change. Namely, these studies implied that the optimum muscle length for producing greater torque alters after static stretching, so that the peak torque is produced at a point where the muscle length is longer. As described above, the results of the present study suggested that the concentric DCER leg extension power output decreased due to a stretching-induced mechanical change.

On the other hand, it was difficult to suggest whether a stretching-induced neurological change contributed to the decrease in the power output from the results of the present study. Previous studies (3,4,9,13,24,30) examined neurological changes through the utilization of an electromyogram or an interpolated twitch technique, suggesting that several neurological changes were responsible for stretching-induced reduction in muscular performance, including: (a) autogenic inhibition, (b) afferent inhibition from mechanoreceptors or noreceptors, (c) fatigue-induced inhibition, (d) joint pressure feedback inhibition, (e) stretch reflex inhibition, and (f) supraspinal fatigue-induced inhibition.

PRACTICAL APPLICATIONS

The present study demonstrated that relatively extensive static stretching on leg extensors reduced power output with concentric DCER leg extensions under various loads. Common power activities are carried out by DCER muscle actions under various loads. Therefore, the result of the present study suggests that relatively extensive static stretching decreases power performance. Future studies are needed to investigate the effect of usual mild static stretching on muscular performance with concentric, eccentric and eccentric-concentric (plyometric) DCER muscle actions under various loads. In addition, the present study implied that a stretching-induced mechanical change contributed to the decrease in leg extension power output.

Several other studies showed that static stretching reduced power performances, including jump performance (6,7,25,38,37) and sprint running performance (12,27). Incidentally, at least one previous study (29) showed that ballistic stretching also reduced the leg extension and flexion 1RM. It was also demonstrated that the concentric isokinetic leg extension torque and power (24), and jump performance (5) decreased after proprioceptive neuromuscular facilitation (PNF) stretching. On the other hand, a few studies revealed that dynamic stretching improved leg extension power output (35), jump performance (11) and sprint running performance (11,12). Thus, dynamic stretching may be an effective technique for improving sports performance during warm-up prior to power activities.

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FIGURE LEGENDS

Figure 1

The six types of static stretching in the static stretching treatment. a: unassisted standing stretching. b: assisted prone stretching. c: unassisted standing stretching with resting foot. d: assisted standing stretching with resting foot. e: unassisted supine stretching on the table. f: assisted supine stretching on the table.

Figure 2

a: Side view of the power measurement system during measurement of dynamic constant external resistance (DCER) knee extension power output. b: Typical data of power-, tension-, and velocity-time curves measured by the measurement system and variable data: PP=peak power output, TPP=time to peak power output, PT=peak torque, T_{PP}=torque at peak power output, RTD=rate of torque development, TPT=time to peak torque, PV=peak velocity, and V_{PP}=velocity at peak power output.

Figure 3

The mean (+ S.D.) peak dynamic constant external resistance (DCER) knee extension power outputs (PP) following the static stretching treatment and the non-stretching treatment under loads of 5%MVC, 30%MVC, and 60%MVC. * indicates significantly (P<0.05) lower than the non-stretching treatment.

Figure 4

The torque (%MVC at peak power output: $\%MVC_{PP}$) -power (peak power output: PP) curves following the static stretching treatment and the non-stretching treatment. Values are mean and S.D.

Figure 1

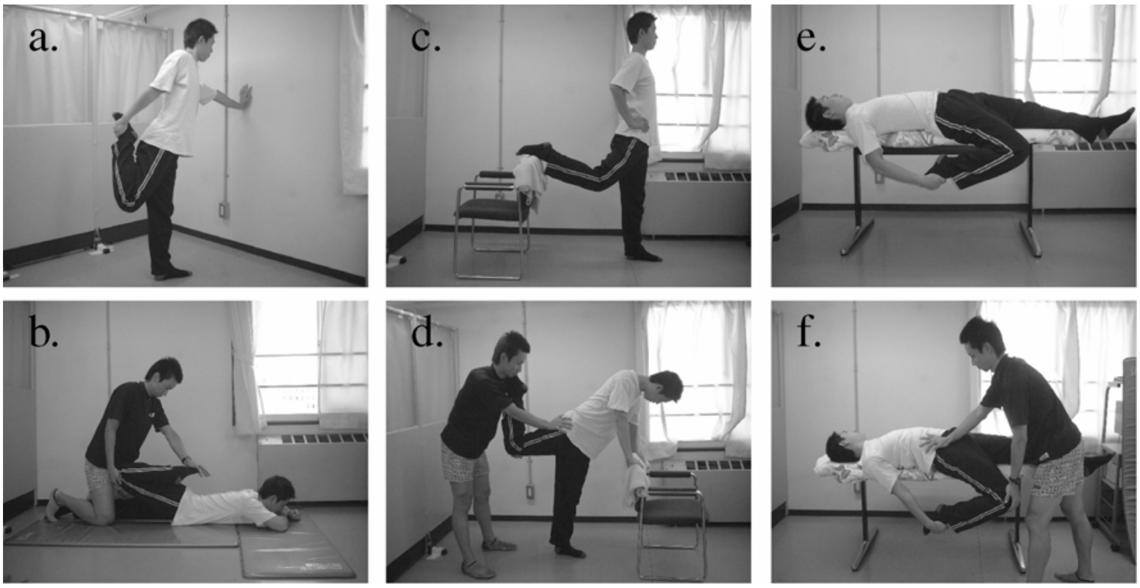

Figure 2

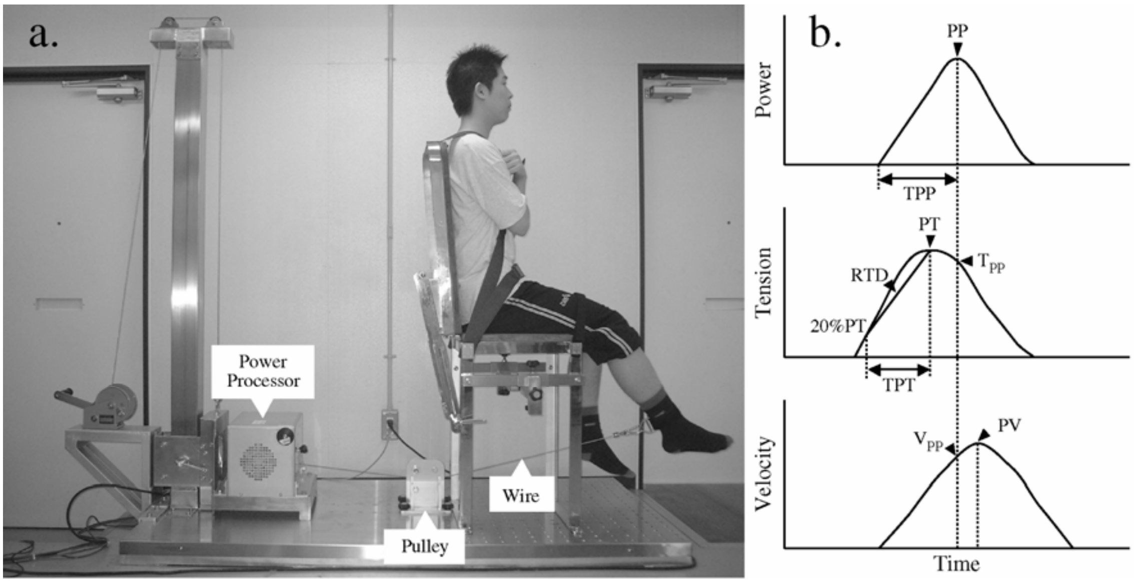
a.
Power
Processor
Pulley
Wire
b.
PP
Power
TPP
PT
Tension
RTD
T_PP
20%PT
TPT
Velocity
V_PP
PV
Time

Figure 3

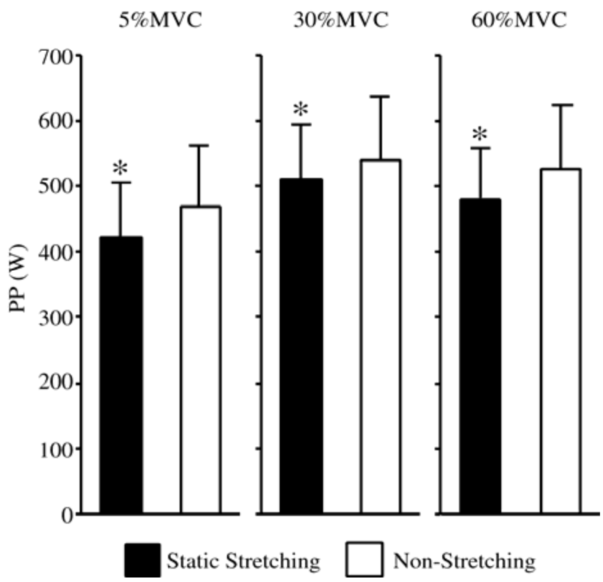
5%MVC
30%MVC
60%MVC
700
600
500
400
300
200
100
0
PP (W)
*
*
*
Static Stretching
Non-Stretching

Figure 4

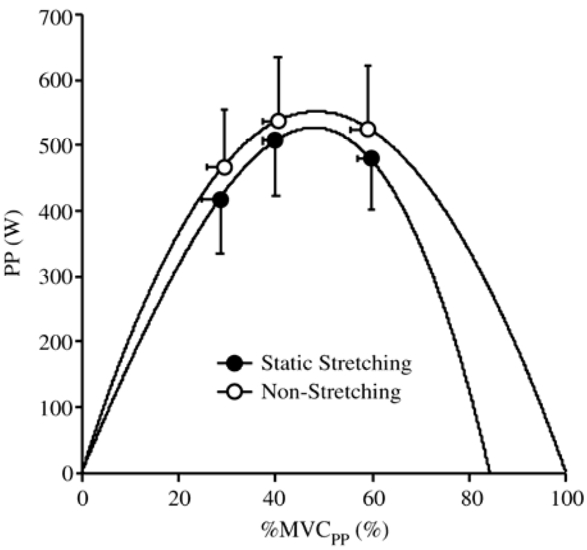
700
600
500
400
300
200
100
0
PP (W)
0
20
40
60
80
100
%MVC$_{PP}$ (%)
Static Stretching
Non-Stretching

Table 1. The intraclass correlation coefficients (*R*) for variable data.

	5%MVC	30%MVC	60%MVC	MVC
PP	0.96	0.98	0.94	-
T_{PP}	0.94	0.90	0.97	-
V_{PP}	0.89	0.87	0.88	-
TPP	0.86	0.86	0.96	-
PT	0.87	0.95	0.98	0.99
TPT	0.99	0.98	0.96	-
RTD	0.99	0.98	0.97	-
PV	0.96	0.85	0.88	-

PP=peak power, T_{PP}=torque at peak power, V_{PP}=velocity at peak power, TPP=time to peak power, PT=peak torque, TPT=time to peak torque, RTD=rate of torque development, PV=peak velocity.

Table 2. The mean (± S.D.) variable data following the static stretching treatment and the non-stretching treatment under loads of 5%MVC, 30%MVC and 60%MVC.

		5%MVC		30%MVC		60%MVC	
T_{PP} (N)	Static Stretching	167.8 ± 19.1		237.5 ± 31.2		354.0 ± 52.3	
	Non-Stretching	172.5 ± 18.9		239.2 ± 26.0		350.0 ± 43.0	
$\%MVC_{PP}$ (%)	Static Stretching	28.6 ± 3.9		40.1 ± 2.6		59.7 ± 2.8	
	Non-Stretching	29.3 ± 3.3		40.6 ± 3.3		59.2 ± 3.5	
V_{PP} ($m \cdot sec^{-1}$)	Static Stretching	2.48 ± 0.33	**	2.13 ± 0.20	*	1.38 ± 0.28	*
	Non-Stretching	2.69 ± 0.29		2.24 ± 0.25		1.50 ± 0.25	
TPP (sec)	Static Stretching	0.117 ± 0.017		0.158 ± 0.016		0.173 ± 0.049	
	Non-Stretching	0.122 ± 0.014		0.155 ± 0.016		0.180 ± 0.034	
PT (N)	Static Stretching	189.0 ± 29.8		276.5 ± 29.7		390.5 ± 47.1	
	Non-Stretching	199.0 ± 22.6		271.2 ± 29.1		386.3 ± 53.9	
TPT (sec)	Static Stretching	0.078 ± 0.027	*	0.119 ± 0.028	*	0.174 ± 0.037	**
	Non-Stretching	0.063 ± 0.025		0.102 ± 0.020		0.152 ± 0.035	
RTD ($N \cdot sec^{-1}$)	Static Stretching	2222.1 ± 1010.3	*	2013.7 ± 775.6		1878.4 ± 453.2	*
	Non-Stretching	2999.8 ± 1459.0		2259.6 ± 755.8		2144.1 ± 627.4	
PV ($m \cdot sec^{-1}$)	Static Stretching	3.03 ± 0.33	*	2.27 ± 0.18	**	1.38 ± 0.29	*
	Non-Stretching	3.20 ± 0.29		2.46 ± 0.28		1.55 ± 0.26	

*: $p<0.05$; **: $p<0.01$ significantly different between the static stretching treatment and the non-stretching treatment. T_{PP}=torque at peak power, $\%MVC_{PP}$=%MVC at peak power, V_{PP}=velocity at peak power, TPP=time to peak power, PT=peak torque, TPT=time to peak torque, RTD=rate of torque development, PV=peak velocity.