TITLE:

Acute effects of dynamic stretching exercise on power output during concentric dynamic constant external resistance leg extension

BRIEF RUNNING HEAD:

Acute effects of dynamic stretching exercise on muscular performance

LABORATORY WHERE THE RESEARCH WAS CONDUCTED:

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ABSTRACT

The purpose of the present study was to clarify the acute effect of dynamic stretching exercise on muscular performance during concentric dynamic constant external resistance (DCER, formally called isotonic) muscle actions under various loads. Concentric DCER leg extension power outputs were measured in twelve healthy men students after two types of pre-treatment. The pre-treatments were 1) dynamic stretching treatment including two types of dynamic stretching exercise of leg extensors and the other two types of dynamic stretching exercise simulating the leg extension motion (2 sets of 15 times each with 30 seconds rest periods between sets; total duration: about 8 minutes), and 2) non-stretching treatment by resting for 8 minutes in a sitting position. Loads during measurement 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 power output after the dynamic stretching treatment was significantly ($P<0.05$) greater than that after the non-stretching treatment under each load (5%MVC: 468.4 ± 102.6 W vs. 430.1 ± 73.0 W; 30%MVC: 520.4 ± 108.5 W vs. 491.0 ± 93.0 W; 60%MVC: 487.1 ± 100.6 W vs. 450.8 ± 83.7 W). The present study demonstrated that dynamic stretching routines, such as dynamic stretching exercise of target muscle groups and dynamic stretching exercise simulating the actual motion pattern, significantly improve power output with concentric DCER muscle actions under various loads. These results suggested that dynamic stretching routines in warm-up protocols enhance power performance, because common power activities are carried out by DCER muscle actions under various loads.

KEYWORDS

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

INTRODUCTION

The main purposes of warm-up prior to sports activity are prevention of sports related injury and enhancement of performance (2,3,31,36). Therefore, most athletes and coaches need to select and perform optimal warm-up routines. General warm-up consists of low intensity aerobic exercise (e.g., running, cycling) and stretching exercises (2,3,31,36,39). It has been a common belief that stretching exercises enhance sporting ability by improving muscular performance (i.e., muscular strength and power output) (2,3,31,36,39). A widely used warm-up technique is static stretching (36,39). However, recent studies have shown that static stretching decreases muscular performance during isometric (4,5,15,20,24,28,34), isokinetic (10-12,22,26) or dynamic constant external resistance (DCER, formerly called isotonic) (21,37) muscle action, and explosive performances, i.e., sprint running time (14,25,32) and vertical jump height (8,9,23,33,38,40). Some researchers, therefore, proposed that static stretching should not be included in warm-ups (8,10,21,26,37).

As for stretching techniques other than static stretching, there are ballistic, proprioceptive neuromuscular facilitation (PNF) and dynamic stretching techniques (2,3,18,19,36). If some of these techniques produce positive effects on muscular performance, they may be incorporated into warm-up protocols. However, previous studies reported that ballistic and PNF stretching, as well as static stretching, reduced muscular or explosive performance (7,22,27). For example, Nelson and Kokkonen (27) demonstrated that ballistic stretching of leg extensors, leg flexors and plantar flexors decreased one repetition maximums (1RMs) of leg extension and leg flexion. Moreover, Marek et al. (22) reported that PNF stretching (contract relax method) on leg extensors decreased peak torque and mean power output with isokinetic leg extension at angular velocities of 60 and 300 deg·sec^{-1}. On the other hand, Yamaguchi and Ishii (35) clarified that dynamic stretching exercises of leg muscle groups improved DCER leg press power. Fletcher and Jones (14) and Faigenbaum et al. (13) also reported that sprint and jump performances were enhanced by dynamic stretching exercises of leg muscle groups. However, in those previous studies (13,14,35), only the acute effect of dynamic stretching exercise on each subject's body weight loaded muscular or explosive performance was examined. Actual sporting activities are performed under not only the load of body weight but various loads. In order to recommend dynamic stretching as a suitable stretching exercise during warm-ups for various sporting activities, previous findings (13,14,35) are insufficient. Therefore, the acute effect of dynamic stretching exercise on muscular performance under various loads needs to be examined.

Dynamic stretching exercise is method to increase dynamic flexibility in the target muscle group by contracting the antagonist muscle group without bouncing (35), and/or to improve dynamic flexibility related to actual sports motion by simulating the motion (18,19). In addition, previous reviews (16,18,19) suggested that dynamic stretching exercise might produce positive effects on muscular performance, including: postactivation potentiation (6,28,29), or increase in muscular temperature (6). Therefore, dynamic stretching exercise may improve muscular performance under various loads.

The purpose of the present study was to examine whether dynamic stretching exercise improves muscular performance with concentric DCER muscle actions, which constitute common sports activities, under various loads.

METHODS

Approach to the Problem

Our hypothesis was that dynamic stretching exercise improves 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 3-6 days of rest were performed. On day 1, each subject visited our laboratory to receive instructions. Maximum voluntary contractile (MVC) torque with isometric leg extension was assessed to determine each subject’s relative load while measuring concentric DCER leg extension power output. In addition, preliminary trials for measuring 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: 1) dynamic stretching treatment including dynamic stretching exercises of leg extensors and dynamic stretching exercises simulating the leg extension motion, and 2) non-stretching treatment by resting in a sitting position. Pre-treatment on day 2 was determined at random for each subject. On day 3, power output was also assessed after the other pre-treatments different from that on day 2. Loads during assessment of power output were set at 5% (relatively light load), 30% (moderate load) and 60% (relatively heavy load) of the MVC torque assessed on day 1 for each subject (37) (Figure 1). The peak power outputs during concentric DCER leg extensions under three kinds of load were compared between the two pre-treatments of dynamic stretching and non-stretching in order to examine the acute effects of dynamic stretching exercise on power output with concentric DCER leg extensions under various loads.

Subjects

Twelve healthy men students (mean ± standard deviation; age, 24.1 ± 2.3 yr; height, 171.8 ± 7.2 cm; weight, 62.0 ± 8.1 kg) took part in the present study. All subjects were free of injury in their lower extremities. They were recreationally active men and participated in a variety of activities (baseball, cycling, swimming, volleyball, etc.), but not involved in regular training when the present study started. All subjects were informed of the protocol, purpose and risks of the present study, and informed consent was obtained from all subjects. The protocol was approved by the ethics committee in Graduate School of Education, Hokkaido University.

Pre-Treatments

In dynamic stretching treatment, the subjects performed four types of dynamic stretching exercise in a standing position (16,19,35,36). Two stretched the right leg extensors (Figure 2a, b), and the other two simulated the leg extension, which is motion during actual power assessment (Figure 2c, d). The subjects performed each stretching exercise 5 times, slowly at first in order to accurately perform the motion, and then 10 times as quickly and powerfully as possible in synchrony with the rhythm of a digital metronome at 30 beats/min, without bouncing (35). Prior to performing each stretching exercise, we explained to the subjects the muscle groups which should be contracted. Each stretching exercise consisted of two successive repetitions. Between stretching repetitions and while changing stretching exercises, each subject stood upright for a 30-second rest period. Total duration of the dynamic stretching treatment was approximately 8 minutes. The order of stretching exercises is shown below:

Buttock kick. The subject contracted his hamstrings and flexed his knee joint so that his heel kicked his buttock (Figure 2a).

Leg extension posterior aspect of body. The subject lent forward and raised his foot from the floor with his hip and knee lightly flexed. Then, the subject contracted his hip extensors and extended his hip joint so that his leg was extended to the posterior aspect of his body (Figure 2b).

Thigh up. The subject contracted his hip flexors with his knee flexed and flexed his hip joint so that his thigh came up to his chest (Figure 2c).

Leg extension anterior aspect of body. The subject contracted his hip flexors and flexed his hip joint, raising his thigh parallel to the ground with his knee joint flexed at about 90 degrees. Then, the subject contracted his quadriceps with the height of his thigh maintained and extended his knee joint so that his leg extended to the anterior aspect of his body (Figure 2d).

In the non-stretching treatment, each subject rested in a sitting position for 8 minutes. Concentric DCER leg extension power outputs commenced assessment within 5 minutes after pre-treatment. This was the interval allowed for the subject to move to the power measurement system and for straps to be fastened.

Measurement of Maximum Voluntary Contractile Torque and Concentric Dynamic Constant External Resistance Leg Extension Power Outputs

The MVC torque and concentric DCER leg extension power output were assessed using a power measurement system (37) based on a commercially available machine, Power Processor (Vine Co., Ltd., Tokyo, Japan). Variable data were stored on a personal computer at a sampling frequency of 500 Hz and calculated with a commercially designed software program (VPM21, Vine). Starting positions in all assessments were as follows. The subject sat on the seat of the measurement system with the hip joint angle at about 90 degrees. The trunk, pelvis and thighs were firmly fastened by strap belts. The wire of the measurement system was attached to the subject's right ankle with a strap, and wire length was adjusted so that the knee joint angle was 90 degrees. Subjects were instructed to cross the arms in front of the chest and not to shout during measurement.

Measurement of the maximum voluntary contractile torque. The wire length of the measurement system was fixed at the starting position during the MVC torque measurement (37). 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. This was measured two times with a rest period of 2 minutes. The higher torque value 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 measurement system wire was set to 5%, 30% or 60% of the MVC torque measured on day 1 in each subject (37). Power outputs were measured in the order of 5%MVC, 30%MVC and 60%MVC after each treatment in all subjects. Each 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. Power output under each load was measured two times with a rest period of 2 minutes. Each subject also rested for 2 minutes while the load was changed. Peak power output was recorded as the peak value in the power-time curve as assessed by the Power Processor. The higher peak power output of the two measurements was taken as the variable peak power output data (PP) under each load in each subject. In order to investigate the mechanism of PP change after dynamic stretching exercises, the tension (torque at peak power output: T_{PP}), T_{PP}/MVC torque (measured on day 1) ratio (%MVC at peak power output: $\%MVC_{PP}$) and velocity (velocity at peak power output: V_{PP}) at peak power output, and the time from initial rise of power output to peak power output (time to peak power output: TPP) were analyzed. Furthermore, the peak tension (peak torque: PT), the time from 20% of peak torque to peak torque (time to peak torque: TPT), the PT/TPT ratio (rate of torque development: RTD), and the peak velocity (PV) during concentric DCER leg extension were also calculated. In addition, intra-class correlation coefficients (*R*) for the test-retest of variable data measured by the Power Processor ranged from 0.85 to 0.99, with no significant differences between mean values for test vs. retest at either load (37).

Statistical Analyses

The paired t-test or Wilcoxon signed-rank test was utilized to examine the differences between variable data under each load after the dynamic stretching and the non-stretching treatments. Relationships between variable data were analyzed by Pearson's correlation coefficient. All variable data were expressed as the mean and standard deviation, and the significance level was $P \leq 0.05$.

RESULTS

Peak Power Output. The PP after the dynamic stretching treatment was significantly (P<0.05) greater than that after the non-stretching treatment under each load (Figure 3; 5%MVC: +8.9%; 30%MVC: +6.0%; 60%MVC: +8.1%).

Torque and Velocity at Peak Power Output. The results of comparisons in the T_{PP} and the V_{PP} between both treatments differed under each load. As for the load of 5%MVC, the T_{PP} was significantly (P<0.05) greater (+6.5%) following the dynamic stretching treatment compared with the non-stretching treatment. On the other hand, the V_{PP} after the dynamic stretching treatment tended to be higher (+2.0%) than after the non-stretching treatment, but there was no significant difference (Table 1). Moreover, the correlation coefficient (r) of the % change of T_{PP} or V_{PP} and the % change of PP was 0.81 or 0.34, respectively, and only the relationship in the %

changes of T_{PP} and PP was significantly (P<0.01) positively correlated (data not shown).

As for the load of 30%MVC, T_{PP} and V_{PP} after the dynamic stretching treatments tended to be greater than those after the non-stretching treatment (Table 1; T_{PP}: +3.0%; V_{PP}: +2.8%), but these were not significant. In addition, there was no significant correlation in the % change of T_{PP} or V_{PP} and the % change of PP (data not shown; T_{PP}: r=0.38; V_{PP}: r=0.44).

As for the load of 60%MVC, both T_{PP} and V_{PP} were significantly (P<0.05) greater after the dynamic stretching treatment compared with the non-stretching treatment, although the % change in V_{PP} (+5.0%) tended to be higher compared with that in T_{PP} (+3.2%). Furthermore, only the relationship of the % change in V_{PP} and PP was significantly (P<0.01) positively correlated (data not shown; T_{PP}: r=0.28; V_{PP}: r=0.83).

Time to Peak Power Output. There were no significant differences in mean TPP between the dynamic stretching and the non-stretching treatments under all loads, although in the load of 60%MVC, the TPP after the dynamic stretching treatment tended to shown shorter than the non-stretching treatment (Table 1; -7.4%; P=0.08).

Peak Torque. There is no significant difference in mean PT between the dynamic stretching and the non-stretching treatments, but TPT was significantly (P<0.05) shorter with dynamic stretching treatment compared to the non-stretching treatment under each load. RTD following the dynamic stretching treatment was significantly (P<0.05) greater than that following the non-stretching treatment under each load (Table 1).

Peak Velocity. PV after the dynamic stretching treatment was significantly (P<0.05) higher than that after the non-stretching treatment under each load (Table 1).

DISCUSSION

The present study demonstrated that dynamic stretching routines, which include dynamic stretching exercises of leg extensors and dynamic stretching exercises simulating the leg extension motion, improve peak power outputs with concentric DCER leg extensions under all three loads (relatively light load, moderate load and relatively heavy load) (Figure 3), and that the time to peak torque is reduced and the rate of torque development and peak velocity are increased after dynamic stretching exercise under each loads (Table 1). On the other hand, the present study showed that the tendency in changes of torque and velocity at peak power output differed under each load (Table 1), suggesting that improvement in peak power output after dynamic stretching exercise was load-specific.

In previous studies that investigated the acute effects of static, ballistic and PNF stretching, almost all demonstrated the three techniques decreased muscular performance (4,5,7-12,14,15,20-28,32-34,37,38). No studies, however, have revealed that the three stretching techniques actually improved muscular performance. On the other hand, regarding dynamic stretching, one study (35) clarified that dynamic stretching exercises of leg muscle groups improved DCER leg press power output under a load of each subject's body weight. However, the acute effects of dynamic stretching exercise on power output during DCER muscle actions under various loads have not been clarified. The present study, therefore, examined the acute effects of dynamic stretching exercises on power output during concentric DCER leg extensions under a relatively light load (5%MVC), a moderate load (30%MVC) and a relatively heavy load (60%MVC). The results of the present study demonstrated that dynamic stretching exercises improved peak power outputs under all loads (Figure 3). Furthermore, when the relationships between torque (%MVC_{PP}) and power output (PP) at peak power output following the dynamic stretching treatment and the non-stretching treatment were depicted (Figure 4), the torque-power curve after dynamic stretching exercise was consistently located above that after no stretching. These facts suggest that dynamic stretching exercise improves power output with concentric DCER muscle actions under various loads.

It is necessary to consider the reason why dynamic stretching exercises improved concentric DCER leg extension power output. In the dynamic stretching treatment, the motions simulating actual motions during assessment of power output (i.e., leg extension) were included (Figure 2c and d). In addition, the subjects performed dynamic stretching exercises 5 times, slowly at first in order to accurately perform the motion, and then 10 times as quickly and powerfully as possible. Thus, it is reasonable to assume that the subjects contracted their leg extensors, which are agonist muscle groups in the leg extension motion, at maximum before assessment of power output. After previous contractile activities, transient improvement in muscular performance, that is, postactivation potentiation (PAP), occurs (29,30). The principal mechanisms of PAP are considered to be phosphorylation of myosin regulatory light chains, which renders the actin-myosin interaction more sensitive to Ca^{2+} released from the sarcoplasmic reticulum. Increased sensitively to Ca^{2+} has greatest effect at low myoplasmic levels of Ca^{2+}, improving muscular performance. PAP shortens the time to peak torque and increases the rate of torque development (30). The results of the present study also demonstrated that dynamic stretching exercises shortened the time to peak torque and increased the rate of torque development (Table 1). In addition, Sale (30) suggested that PAP would shift the load (torque)-velocity relationship upward and rightward. When the torque (%MVC_{PP}) -velocity (V_{PP}) relationships at peak power output with concentric DCER leg extension after the dynamic stretching treatment and the non-stretching treatment in the present study were depicted (Figure 5), the result supported the suggestion of Sale (30), that is, the torque-velocity relationship after dynamic stretching exercises shifted upward and rightward.

Therefore, it was likely that PAP occurred after dynamic stretching exercises in the present study.

The present result also showed that dynamic stretching exercises increased peak velocity with concentric DCER leg extension under all loads (Table 1). This is consistent with the finding of the previous study, which showed that dynamic stretching exercises of lower muscle groups improved power output and increased the peak velocity with DCER leg press (35; unpublished data about peak velocity). The increase in peak velocity after dynamic stretching exercises may be attributed to the high velocity muscle action involved in dynamic stretching exercises. This relatively high velocity muscle action may increase contractile velocity in leg extensors and improve the dynamic range of motion with leg extension (17), so peak leg extension velocity would be increased after dynamic stretching exercises. Therefore, it is also suggested that dynamic stretching exercises may improve peak velocity based on velocity-specificity in the exercises.

In the present study, as for the load of 5%MVC, % increase in torque (+6.5%) at peak power output after dynamic stretching exercises tended to be greater than that in velocity (+2.0%), and only the relationship in % change of torque and peak power output was significantly positively correlated. In contrast, as for the load of 60%MVC, % increase in velocity (+5.0%) at peak power output tended to be greater than that in torque (+3.2%), and only the relationship in % change of velocity and peak power output was significantly positively correlated. Regarding the load of 30%MVC, % increases in torque (+3.0%) and velocity (+2.8%) at peak power output were similar. These results indicate that dynamic stretching exercise-induced improvement of peak power output was due to the torque-related factor under the relatively light load and the velocity-related factor under the relatively heavy load, and that the factor shifted from torque-related to velocity-related as load increased. These findings suggest that dynamic stretching exercise-induced improvement in peak power output was load-specific.

It is unknown why dynamic stretching exercise-induced improvement in peak power output was load-specific. Abbate et al. (1), however, showed that the effects of PAP were dependent on the contractile velocity, i.e., increases in the force and power output were found at high contractile velocities, whereas no effects were detected at low contractile velocities. Naturally, the contractile velocity of leg extensors during power assessment was relatively high at 5%MVC (relatively light load), but relatively low at 60%MVC (relatively heavy load) in the present study. In the light of the previous study (1), the effect of PAP may occur notably at 5%MVC. On the other hand, the effect may not be induced at 60%MVC. Therefore, the increase in torque at peak power output probably contributed to the improvement in peak power output at 5%MVC. In contrast, as for the load of 60%MVC, since there was a correlation between the increases in velocity at peak power output and the improvement of peak power output, it is speculated that the dynamic stretching exercise-induced positive effect on peak velocity contributed to improvement of peak power output.

A previous study (37) investigated the acute effects of static stretching of leg extensors on concentric DCER leg extension power outputs under the loads of 5%MVC, 30%MVC and 60%MVC, as in the present study. The previous results demonstrated that static stretching reduced peak power outputs under all loads, in contrast with the present study. In addition, the previous study indicated that the velocity at peak power output was decreased following static stretching under each load. On the other hand, the torque at peak power output was not changed. Thus, the previous results suggested that the factor of static stretching-induced reduction in peak power output was velocity-related and not load-specific. Furthermore, the previous study revealed that the velocity at peak power output decreased after static stretching, although the time to peak power output was not prolonged, suggesting that the knee joint angle at peak power output was in a more flexed position; in other words, peak power output occurred with elongating leg extensors. The present study indicated that dynamic stretching exercises did not alter the velocities at peak power output at 5%MVC and 30%MVC (Table 1). On the other hand, at 60%MVC, the velocity at peak power output was increased, although the time to peak power output tended to be shortened (Table 1). It is thus speculated that the knee joint angle at peak power output was not changed after dynamic stretching exercises. Consequently, it is likely that there are differences between the factors of static stretching-induced reduction and dynamic stretching exercise-induced improvement in peak power outputs.

PRACTICAL APPLICATIONS

The present study demonstrated that dynamic stretching routines, which include dynamic stretching exercises of leg extensors and dynamic stretching exercises simulating leg extension motion, improved concentric DCER leg extension power under various loads. Common power activities consist of concentric DCER muscle actions. Therefore, the results of the present study suggest that dynamic stretching exercise enhances various power performances, and so that dynamic stretching exercise in warm-up protocols may be more effective. Indeed, previous studies reported that warm-up protocols including dynamic stretching exercises improved jumping [vertical and long jumps (13)] and sprinting [20-m sprint (14) and shuttle run (13)] performance. It is likely that dynamic stretching exercise enhances other explosive performances (e.g., throwing, kicking, etc.). Future studies are needed to investigate the relationship between the methods (e.g., exercise selection, repetition, rest period) of dynamic stretching exercise and changes in muscular performance, and to examine the acute effect of dynamic stretching exercise on muscular performance with eccentric or eccentric-concentric (plyometric) DCER muscle actions under various loads, in order to propose a suitable dynamic stretching routine in warm-up protocols prior to various sporting activities.

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FIGURE LEGENDS

Figure 1

A summary of experimental protocol. DCER = dynamic constant external resistance.

Figure 2

The four types of dynamic stretching exercise in the dynamic stretching treatment. a: buttock kick; b: leg extension to posterior aspect of body; c: thigh up; d: leg extension to anterior aspect of body.

Figure 3

The mean (+ S. D.) peak power outputs (PP) during concentric dynamic constant external resistance (DCER) leg extension under the loads of 5%MVC, 30%MVC and 60%MVC following the dynamic stretching treatment and the non-stretching treatment. * (P<0.05); ** (P<0.01) indicates a significant difference between the dynamic stretching and the non-stretching treatments under each load.

Figure 4

The torque (%MVC at peak power output: $\%MVC_{PP}$) –power (peak power output: PP) relationships following the dynamic stretching and the non-stretching treatments. Values are means and S. D.

Figure 5

The torque (%MVC at peak power output: $\%MVC_{PP}$) –velocity (velocity at peak power output: V_{PP}) relationships following the dynamic stretching and the non-stretching treatments. Values are means

Figure 1

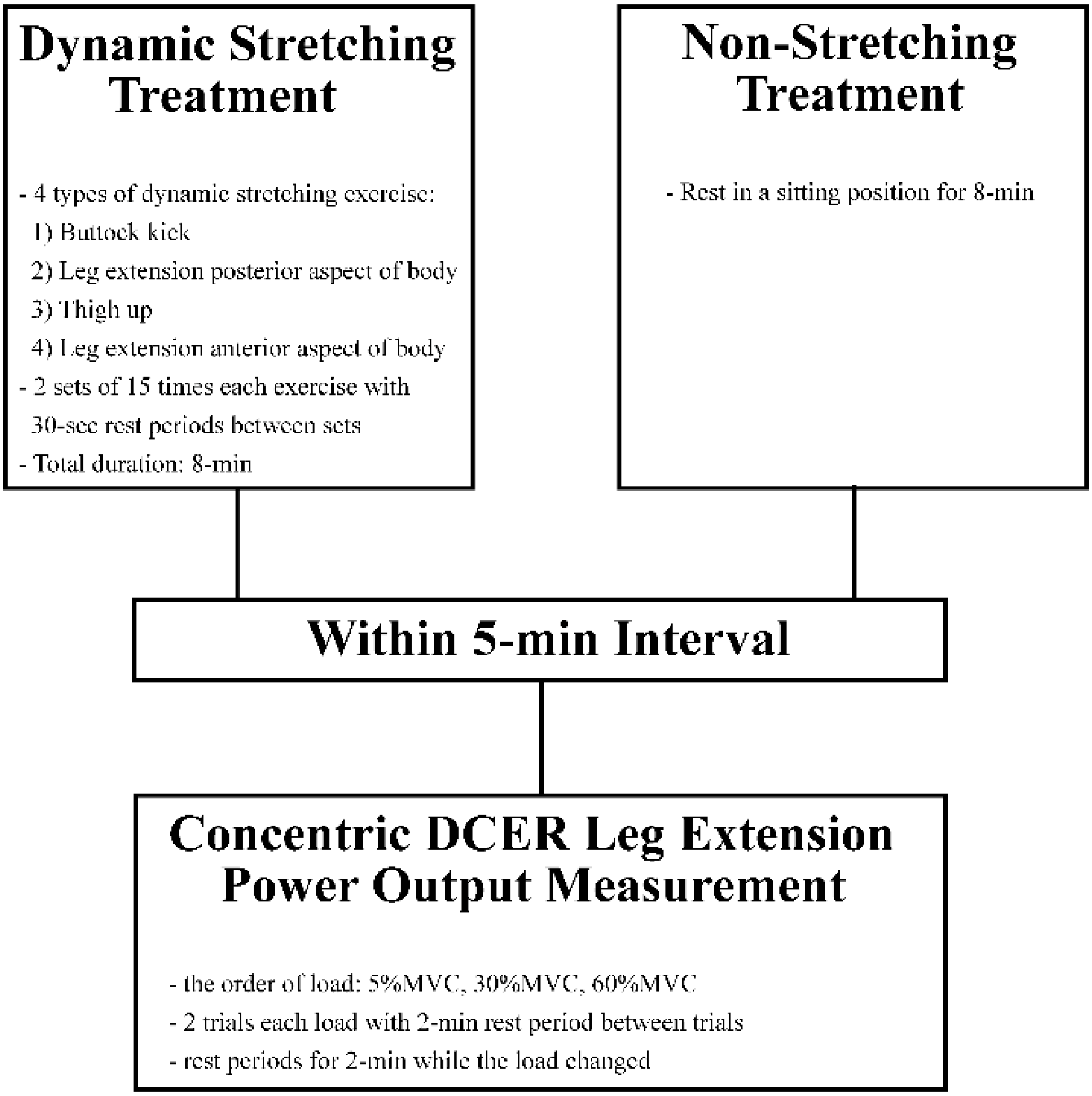
Dynamic Stretching Treatment
- 4 types of dynamic stretching exercise:
1) Buttock kick
2) Leg extension posterior aspect of body
3) Thigh up
4) Leg extension anterior aspect of body
- 2 sets of 15 times each exercise with 30-sec rest periods between sets
- Total duration: 8-min
Non-Stretching Treatment
- Rest in a sitting position for 8-min
Within 5-min Interval
Concentric DCER Leg Extension Power Output Measurement
- the order of load: 5%MVC, 30%MVC, 60%MVC
- 2 trials each load with 2-min rest period between trials
- rest periods for 2-min while the load changed

Figure 2

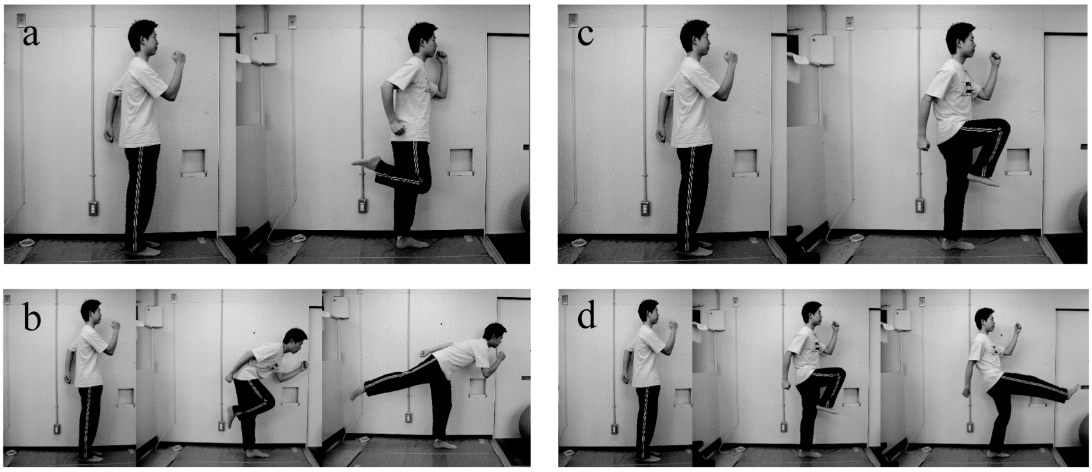

Figure 3

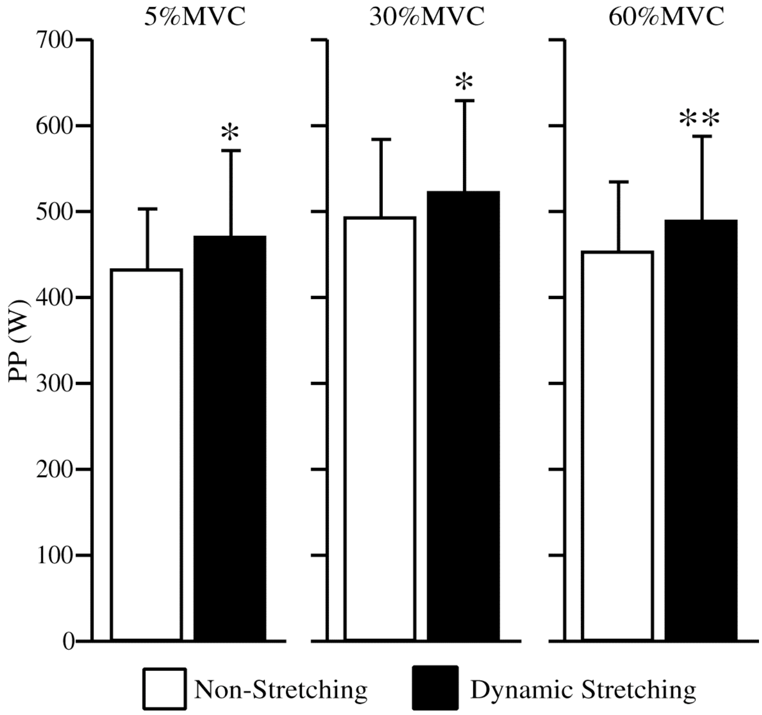
5%MVC
30%MVC
60%MVC
PP (W)
700
600
500
400
300
200
100
0
*
*
**
Non-Stretching
Dynamic Stretching

Figure 4

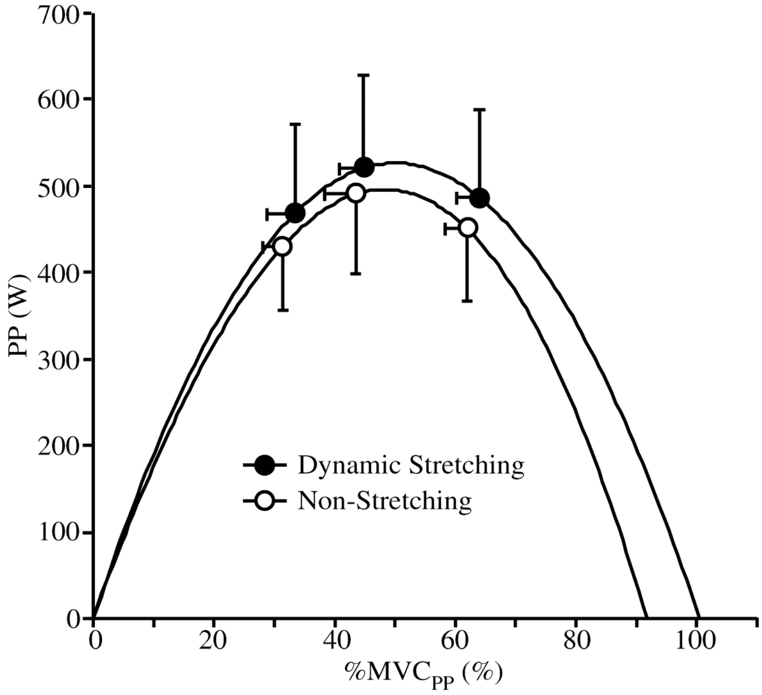
700
600
500
400
300
200
100
0
PP (W)
0
20
40
60
80
100
%MVC$_{PP}$ (%)
Dynamic Stretching
Non-Stretching

Figure 5

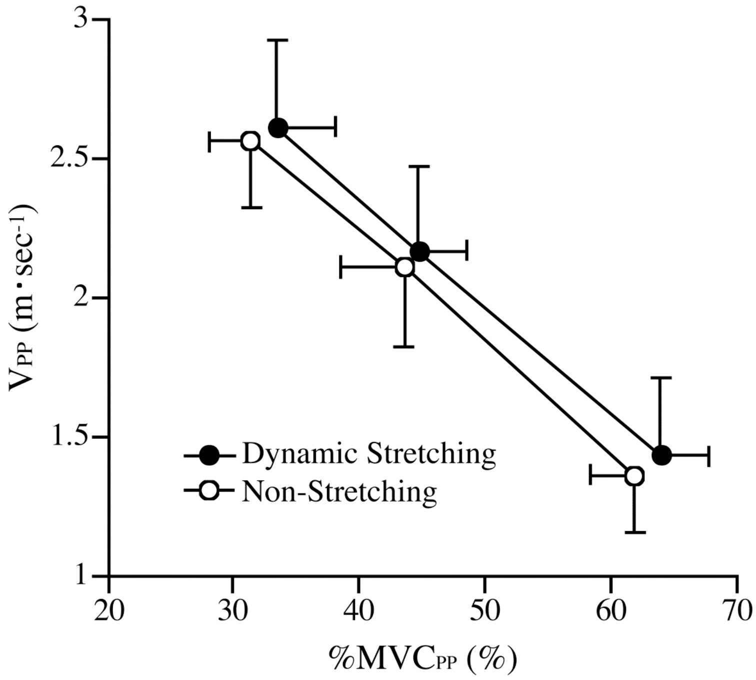
3
2.5
2
1.5
1
20
30
40
50
60
70
V_{PP} (m・sec^{-1})
%MVC_{PP} (%)
Dynamic Stretching
Non-Stretching

Table 1

Mean (± S. D.) variable data under the loads of 5%MVC, 30%MVC and 60%MVC following the dynamic stretching and the non-stretching treatments.

		5%MVC		30%MVC		60%MVC	
T_{PP} (N)	Dynamic Stretching	178.3 ± 23.0	*	239.0 ± 26.2		342.2 ± 33.4	*
	Non-Stretching	167.5 ± 17.6		232.0 ± 22.1		331.5 ± 35.2	
$\%MVC_{PP}$ (%)	Dynamic Stretching	33.4 ± 4.6	*	44.7 ± 3.8		63.9 ± 3.7	*
	Non-Stretching	31.4 ± 3.2		43.6 ± 5.2		61.9 ± 3.6	
V_{PP} (m sec^{-1})	Dynamic Stretching	2.61 ± 0.31		2.17 ± 0.30		1.43 ± 0.28	*
	Non-Stretching	2.56 ± 0.24		2.11 ± 0.29		1.36 ± 0.21	
TPP (sec)	Dynamic Stretching	0.116 ± 0.015		0.145 ± 0.022		0.177 ± 0.026	
	Non-Stretching	0.120 ± 0.013		0.149 ± 0.019		0.191 ± 0.030	
PT (N)	Dynamic Stretching	206.2 ± 20.0		277.7 ± 19.7		380.5 ± 34.5	
	Non-Stretching	202.5 ± 24.4		268.8 ± 24.7		376.2 ± 37.7	
TPT (sec)	Dynamic Stretching	0.060 ± 0.027	*	0.089 ± 0.031	*	0.142 ± 0.038	**
	Non-Stretching	0.075 ± 0.028		0.107 ± 0.026		0.173 ± 0.034	
RTD (N sec^{-1})	Dynamic Stretching	3385.3 ± 1894.3	**	2899.2 ± 1459.8	*	2282.1 ± 614.0	**
	Non-Stretching	2332.5 ± 807.9		2163.6 ± 776.4		1786.9 ± 347.0	
PV (m sec^{-1})	Dynamic Stretching	3.23 ± 0.30	**	2.43 ± 0.30	*	1.45 ± 0.30	*
	Non-Stretching	3.06 ± 0.25		2.34 ± 0.28		1.36 ± 0.21	

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. * ($P<0.05$); ** ($P<0.01$) indicates a significant difference between the dynamic stretching and the non-stretching treatments under each load.