Effects of 6-Week Static Stretching of Knee Extensors on Flexibility, Muscle Strength, Jump Performance, and Muscle Endurance

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Abstract

Ikeda, N and Ryushi, T. Effects of 6-week static stretching of knee extensors on flexibility, muscle strength, jump performance, and muscle endurance. *J Strength Cond Res* 35(3): 715–723, 2021—The purpose of this study was to evaluate the changes in flexibility and muscular performance after stretching training for 6 weeks. Twelve healthy young men were assigned to a stretching group and 13 to a control group. The subjects of the stretching group performed static stretching of knee extensors for 6 weeks. Knee flexion range of motion (KFROM), leg extension strength, rate of force development (RFD) in leg extension, jump performance (squat and countermovement jump height, and index of rebound jump), and strength decrement index of 50 repetitions of isokinetic knee extension (muscle endurance) were measured before and after the interventions. In the stretching group, KFROM significantly increased from 145.2 $\pm$ 17.3 to 158.7 $\pm$ 6.3° ($p < 0.05$), whereas RFD significantly improved from 10,173 $\pm$ 2,401 to 11,883 $\pm$ 2,494 $N \cdot s^{-1}$ ($p < 0.05$). By contrast, leg extension strength and jump performance of each jump type did not improve significantly. Furthermore, muscle endurance decreased significantly. All variables remained unchanged in the control group. In conclusion, 6 weeks of stretching training of knee extensors improved KFROM and RFD in leg extension, but not leg extension strength and jump performance; moreover, muscle endurance decreased. These findings indicate that this stretching training protocol can be used by athletes in sports who require high flexibility and those who require high-power exertion.

Key Words rate of force development, squat jump, countermovement jump, rebound jump

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Introduction

In addition to the skills required for their respective sport, it is necessary for athletes to achieve and maintain muscular strength, power, endurance, and flexibility of the main muscle groups (22). Therefore, many athletes routinely perform muscle stretching, static stretching, or dynamic stretching to improve and maintain flexibility, in addition to training for their respective sport. Previous studies have shown that long-term static stretching (stretching training) improves flexibility (7,10,23,25). In addition, it has been reported that stretching training exerts a positive effect on exercise performance and is particularly effective in improving muscle strength (24,26). However, although some studies have reported improvements in maximal muscular strength (15,21,28), rate of force development (RFD) (11), and jump performance (12,15,17) with stretching training, others have reported no improvement (2,4,11,12,16). Thus, the effects of stretching training on muscular strength and power have not been clearly established.

The reasons behind the inconsistent results in these previous studies seem to be the lack of a control group and nonuniformed levels of activities among the subjects (11,17). In addition, one main contributing factor is the high variability of training volume depending on the protocol used in these studies, in terms of the duration of the training period (3–10 weeks) (2,4,11,12,15–17,21,28), training frequency (3–14 times per week) (4,11,15,17,21,28), and duration of training per day (1.5–40 minutes) (4,15,17,21,28). The study with the most amount of training (15) demonstrated obvious improvements in muscle strength/muscle power index (such as maximum muscle strength and jump performance) and muscle endurance index. The protocol included 15 types of static stretching moves for the lower-limb muscles for 10 weeks, 3 days per week, and 40 minutes per day. However, the stretching duration and training period were longer than those recommended by the American Sports Medicine Society (ACSM). American Sports Medicine Society protocols aimed at improving flexibility involve stretching 2–3 times per week for at least 60 seconds per muscle group (7). Athletes require a lot more time with skill training than with stretching; therefore, verification of the effects of stretching training on the indices of muscular strength, power, and endurance using a shorter protocol is required.

Mechanical stress on the muscle by stretching causes a protein synthesis response, which results in structural changes in collagen and a muscle hypertrophic response (6). Findings from an animal study indicate that the mechanism underlying the improved muscular performance after stretching training is the result of muscle hypertrophy (15,24,26). Muscle hypertrophy has been suggested to occur rapidly up to 6 weeks from the start of training (27). Therefore, if muscle hypertrophy is caused by stretching training in this study, muscular performance is expected to improve after 6 weeks of training. However, reports on the effects of stretching training on muscular performance using a shorter protocol are limited. Decreasing muscle-tendon unit (MTU) stiffness (4,10,23), which is one of the main factors of enhanced flexibility after stretching training, negatively affects RFD (19). Therefore, it is estimated that isometric maximum muscle strength is improved by stretching training, whereas RFD does not improve. In addition, it cannot be expected to greatly improve the jump performance associated with RFD. However, stretching training improves stretch-shortening cycle (SSC) performance (14). This means that the influence of stretching training on jump performance might differ depending on the countermovement and its intensity. It has been reported that muscle endurance, as evaluated by the number of knee extensions (load of 60% of 1 repetition maximum), improved by stretching training (15). However, in the evaluation using the strength decrement index, it is estimated that only the performance in the first phase of the measurement task is increased by improving muscular performance, whereas muscle endurance decreased.

Therefore, the purpose of this study was to identify the changes in flexibility, muscle strength, RFD, jump performance, and muscle endurance after stretching training for 6 weeks.

Methods

Experimental Approach to the Problem

This study was designed to test the effects of stretching training for 6 weeks on flexibility and muscular performance. Twenty-five healthy men were randomly assigned to 2 groups: the stretching group ($n = 12$) and the control group ($n = 13$). The subjects of the stretching group performed static stretching of the knee extensors for flexibility training for 6 weeks ($3\ \text{d}\cdot\text{wk}^{-1}$). The subjects in the control group maintained their daily activities during the study period. The following dependent variables were evaluated before and after training: knee flexion range of motion (KFROM), leg extension strength, RFD in leg extension, jump performance, and strength decrement index of 50 repetitions of isokinetic knee extension (muscle endurance).

Subjects

The subjects were 25 healthy men without apparent neurological, orthopedic, or neuromuscular disorders in their lower limbs. They did not undergo resistance training or flexibility training within the previous 6 months. They were not athletes in any specific sporting event but had participated in several sports activities (as described below). Based on the standard values of vertical jump height in athletes (excellent, >70 cm; very good, 61–70 cm; above average,

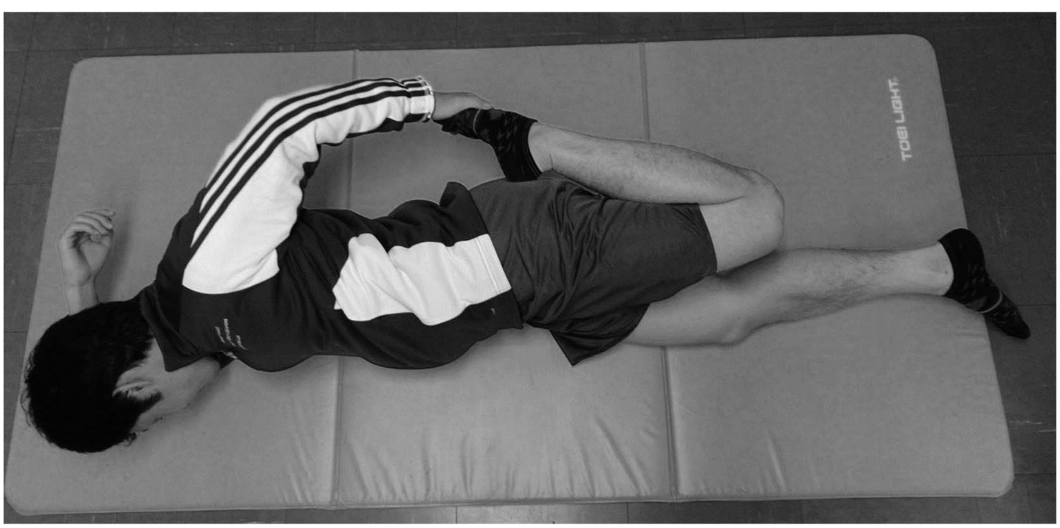

Figure 1. A picture demonstrating static stretching.

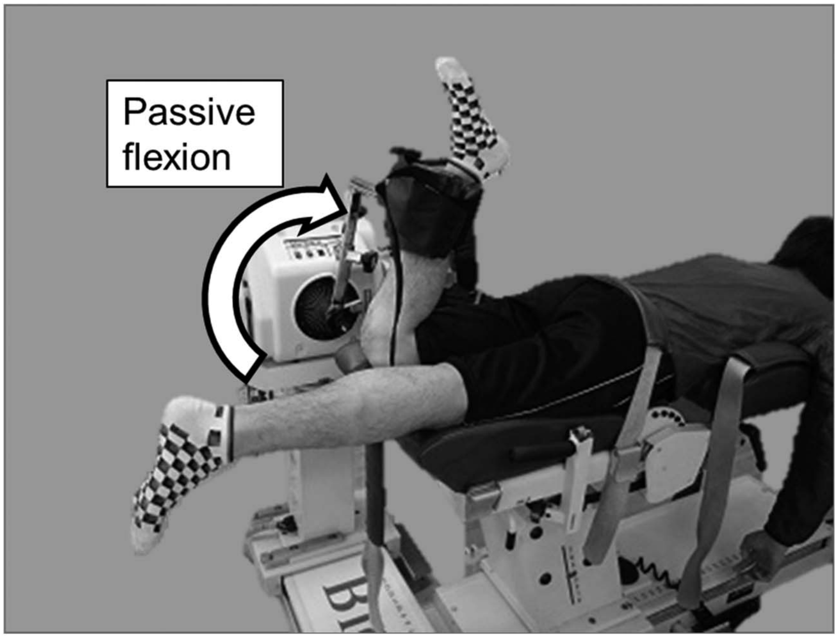

Figure 2. Illustration of knee flexion range of motion measurement.

51–60 cm; and average, 41–50 cm), the mean score among our subjects (mean ± *SD*, 41 ± 6 cm) was in the average range (5). They were randomly allocated into 2 groups: the stretching group (n = 12; age, 22 ± 1 years [age range: 20–24 years]; height, 1.70 ± 0.05 m; body mass, 65.0 ± 8.5 kg) and the control group (n = 13; age, 22 ± 2 years

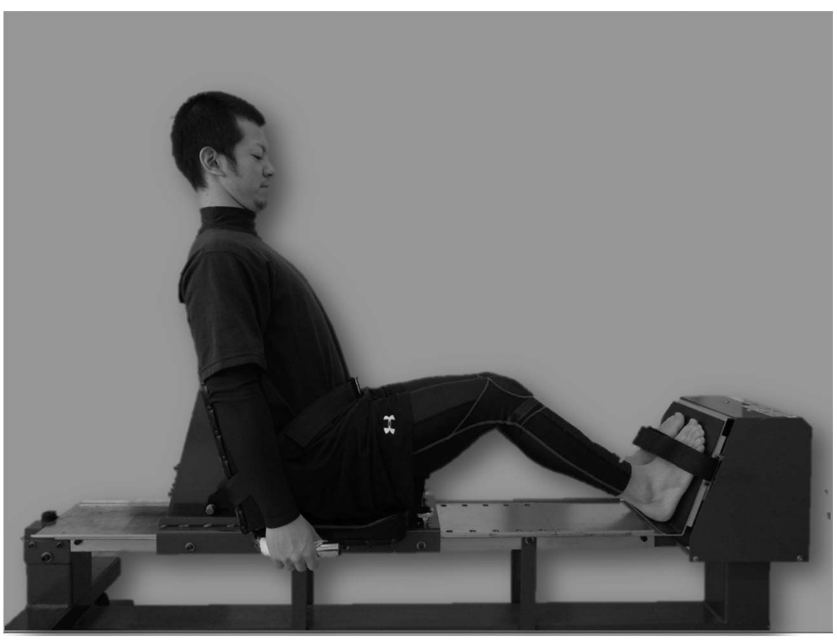

Figure 3. Illustration of maximal voluntary isometric muscle strength measurement.

Table 1. Changes in flexibility between before (pre-) and after (post-) the stretching training or control period (KFROM = knee flexion range of motion).*

	Stretching group		Control group	
	Pre	Post	Pre	Post
KFROM (°)	145 ± 17	159 ± 6†	133 ± 24	130 ± 24

*Values are expressed as mean ± *SD*.
†Significantly changed compared with preintervention ($p < 0.05$).

[age range: 20–26 years]; height, 1.70 ± 0.06 m; body mass, 64.3 ± 8.9 kg). Six subjects in each group had participated in sports activities (mostly ball games such as baseball, soccer, and volleyball) once or twice per week at a recreational level. The remaining subjects did not engage in regular sports activities. Approximately half of the subjects in each group had participated in sports at a competitive level in the past. Other subjects only had previous experience at the recreational level. All subjects had practiced sports activities for 3–12 years. This experience included ball games ($n = 18$), long-distance running ($n = 3$), sprint and long jump ($n = 2$), wrestling ($n = 1$), and boxing ($n = 1$). None of the subjects had previously participated in sports requiring high joint flexibility, such as gymnastics or dance. Furthermore, few subjects had undergone full-scale resistance training. The subjects had little experience with stretching training (designed to increase flexibility), except for stretching as a warm-up and cool-down before/after sports activities. There was no statistically significant difference in terms of age, height, and body mass between the groups. All subjects agreed and provided written consent to participate in this study after they were informed of its contents and purpose, as well as the benefits and risks associated with it. This study was approved by the Ethics Review Committee on Sports and Health Science Division, Graduate School of Sports and Health Science of Daito Bunka University.

Procedures

Stretching Training Program. The subjects of the stretching group performed static stretching of the knee extensors for flexibility training for 6 weeks (3 $d \cdot wk^{-1}$). Stretching involved flexion of the knee joint in the lateral decubitus position, whereas the subject held the ipsilateral foot with his hand (Figure 1). The flexion angle of the knee joint (stretching intensity) during stretching was chosen such that the knee extensors were maximally stretched but within the limit of pain. This stretch was performed for 30 seconds per set for 6 sets per day (180 seconds in total; interval between sets, 60 seconds). Stretching training was scheduled such that there were no more than 3 training days per week. For example, in a week, the training days of subject A were Monday, Tuesday, and Thursday; and for subject B, Monday, Wednesday, and Friday. This study's protocol was similar to that recommended by ACSM for improving flexibility. A previous study using the ACSM-recommended protocol reported improved flexibility with stretching training after 4

Table 2. Changes in strength between before (pre-) and after (post-) the stretching training or control period (RFD = rate of force development).*

	Stretching group		Control group	
	Pre	Post	Pre	Post
Maximal strength (N)	4,182 ± 958	4,607 ± 1,015	3,732 ± 714	3,725 ± 754
RFD ($N \cdot s^{-1}$)	10,173 ± 2,401	11,883 ± 2,494†	11,437 ± 4,391	9,757 ± 3,528

*Values are expressed as mean ± *SD*.
†Significantly changed compared with preintervention ($p < 0.05$).

Table 3. Changes in jump performance between before (pre-) and after (post-) the stretching training or control period (SJ = squat jump; CMJ = counter movement jump; RJ = rebound jump).*

	Stretching group		Control group	
	Pre	Post	Pre	Post
SJ height (cm)	36.4 ± 6.7	37.3 ± 4.5	35.6 ± 5.0	34.9 ± 5.7
CMJ height (cm)	41.3 ± 5.8	41.4 ± 4.4	40.0 ± 5.2	39.6 ± 5.0
RJ index ($m \cdot s^{-1}$)	1.61 ± 0.43	1.64 ± 0.47	1.66 ± 0.47	1.59 ± 0.39

*Values are expressed as mean ± *SD*.

weeks (25). The subjects in the control group maintained their daily activities during the study period. We studied only one muscle group (the quadriceps) as the study of all muscle groups of the lower limbs required a large sample size.

Measurements. The measurements in both groups included KFROM, leg extension strength, RFD in leg extension, jump performance, and muscle endurance before (pre-) and after (post-) the stretching training or control period. After measuring KFROM, the subjects underwent running and jumping at intensities of their own choice. The subjects were tested within 2–7 days of the last training day. They were instructed to maintain their usual meals and water intake on measurement day and immediately ingest a cold sports drink on feeling thirsty during the measurements.

Measurement of Knee Flexion Range of Motion. Knee flexion range of motion was measured using an isokinetic dynamometer (BIODEX SYSTEM3; Biodex Medical Systems, Shirley, NY) in the supine position with the hip joint at 0° (anatomical position) on the dynamometer and the hips fixed to the dynamometer with a belt (Figure 2). The knee joint was flexed at $10° \cdot s^{-1}$ starting from complete extension (0°: anatomical position), and KFROM was measured as the angle at which the subject felt "a little pain." The subjects were instructed to relax during the measurements without resisting passive knee flexion. The signal of the left knee joint angle obtained from the dynamometer was then digitally converted at 400 Hz through an analog-to-digital (A/D) converter (PowerLab/16SP; ADInstruments, Bella Vista, Australia), which was fed into a personal computer (FMV Lifebook, Fujitsu, Tokyo, Japan), and recorded using a software (LabChart5; ADInstruments). Knee flexion range of motion measurement was performed 5 times, and with the exclusion of the maximum and minimum values, the average value of the remaining 3 values was calculated.

Measurement of Maximal Voluntary Isometric Muscle Strength and Rate of Force Development. Maximal voluntary isometric leg extension strength was measured using an isometric leg extension dynamometer (S91034; Takei Scientific Instruments, Niigata, Japan; Figure 3). The posture for this measurement involved sitting with the knee joint at 60° flexion and the hip joint at 90° flexion. The recording and processing of the signals obtained from the dynamometer were as previously described. The measurement was performed 3 times, and the peak force was analyzed once. The highest of the values was considered as the final data.

Measurement of RFD of isometric leg extension was similar to that of maximal isometric muscle strength. The subjects were instructed to exert their strength "as fast and forcefully as possible" (1,19). Based on the force waveforms obtained, peak force and muscle contraction time (motor time) were obtained for each trial. Motor time was defined as the duration between the time at which the force exceeded the baseline and the time when peak force was observed. Rate of force development was calculated by dividing the obtained peak force by motor time. Rate of force development measurement was performed 5 times and the average value of 3 times, with the exclusion of the maximum and minimum trials, was calculated. In addition, data of subjects with motor time of more than 1 second (one each in the stretching group and control group) were excluded.

Measurement of Jump Performance. Vertical jump performance (squat jump [SJ] and countermovement jump [CMJ] heights, and rebound jump [RJ] index) was measured using a force plate (Type 9286 A; Kistler, Winterthur, Switzerland). The posture involved flexion of 90° at both the knee joint and hip joint. The subject was instructed to leap without countermovement. Countermovement jump was defined as a jumping motion with countermovement to bend the knee joint from the arbitrary angle in the standing posture. For RJ, the subjects performed 6 consecutive vertical jumps, as described in a previous study (8). The subjects were instructed to jump as high as possible for SJ and CMJ; for RJ, they were instructed to jump as high as possible with the shortest possible ground contact time. The signal of the ground reaction force in the vertical direction obtained from the force plate

TABLE 4. Changes in muscle endurance between before (pre-) and after (post-) the stretching training or control period.*

	Stretching group		Control group	
	Pre	Post	Pre	Post
Strength decrement index (%)	46.5 ± 11.2	54.5 ± 7.7†	55.4 ± 15.7	55.1 ± 12.6

*Values are expressed as mean ± *SD*.
†Significantly changed compared with preintervention ($p < 0.05$).

was converted to a digital signal at 250 Hz through an A/D converter (PH-780; DKH, Tokyo, Japan), which was fed into a personal computer (Precision T3500; Dell, Round Rock), and recorded using a software (TRIAS; DKH). The flight time and ground contact time (only RJ) of each jump were determined from the waveform of the ground reaction force. The jump height of each jump was calculated from the flight time by the following formula: jump height (m) = $gt^2/8$, where g is the acceleration due to gravity (9.81 $m \cdot s^{-2}$) and t the flight time (seconds) (1).

The RJ index was calculated by dividing the RJ height by the ground contact time before the jump. Squat jump and CMJ were performed thrice, and the highest value was adopted as data. For the RJ index, we adopted the highest value out of the 5 jumps, with the exclusion of the first jump (the first jump was regarded as a preliminary jump without contact time). The data of RJ height and RJ ground contact time were assumed to be the jump of the record of the highest value of the RJ index.

Measurement of Muscle Endurance. The muscular endurance of the knee extensors was measured using an isokinetic dynamometer (described above). The subjects performed maximal voluntary 50 repetitions of isokinetic knee extension at an angular velocity of $180° \cdot s^{-1}$ with the left leg. They were placed in a sitting position with the knee joint at 90° flexion (test ROM was from 90° of flexion to 0°) and the hip joint at 60° flexion. The measurer returned the joint angle to the starting position after each knee joint extension. With the software system of the isokinetic dynamometer, the total workload of the first 17 repetitions (workload of the first phase) and the last 17 repetitions (workload of the last phase) was calculated. Strength decrement index was obtained by dividing the workload of the last phase by that of the first phase as a percentage. We defined this as the index of muscle endurance of knee extensors.

Statistical Analyses

All measurement values are presented as mean ± *SD*. For all measurement values before and after the training or control period, 2-way repeated-measure analysis of variance was performed for each group (training and control) and time (pre- and post-) using SPSS 23v (SPSS Inc., Tokyo, Japan). When an interaction or main effect for time was observed, the Bonferroni post hoc test was performed in each group. The absence of statistically significant differences between each group before training or control period was confirmed by performing the independent t-test. The effect size (δ) was calculated by dividing the difference between the average premeasurement value and the average postmeasurement value by the *SD* of the premeasurement value. To clarify the reliability of the measurements, intraclass correlation coefficient (ICC) for each measurement variable was calculated using the premeasurement and postmeasurement values in the control group. Intraclass correlation coefficient values of 0.70 or more were interpreted as good reliability (18). The level of statistical significance was set at $p \leq 0.05$.

RESULTS

The ICC values for each measurement variable were 0.70 or more, indicating good reliability: KFROM, 0.895; maximal voluntary isometric leg extension strength, 0.835; RFD of isometric leg extension, 0.747; peak force for RFD, 0.959; motor time for RFD, 0.700; SJ height, 0.966; CMJ height, 0.916; RJ index, 0.929; RJ height, 0.748; RJ ground contact time, 0.779; strength decrement index, 0.900; workload of the first phase, 0.885; and workload of the last phase, 0.953.

A significant interaction between the groups and time was observed in KFROM ($p < 0.05$; $\eta_P^2 = 0.202$). Knee flexion range of motion significantly increased in the stretching group after training ($p < 0.05$; $\delta = 0.78$; 95% confidence interval [CI] [−25.0 to −1.9]), whereas no change was observed in the control group ($p > 0.05$; $\delta = -0.11$; 95% CI [−6.5 to 11.6]) (Table 1). The maximal voluntary isometric leg extension strength remained unchanged in both groups, and the main effect of time was not significant ($p > 0.05$) (Table 2). A significant interaction between the groups and time was observed in RFD of isometric leg extension ($p < 0.05$, $\eta_P^2 = 0.280$); significant improvement was observed in the stretching group ($p < 0.05$; $\delta = 0.71$; 95% CI [−3,137 to −283]) and remained unchanged in the

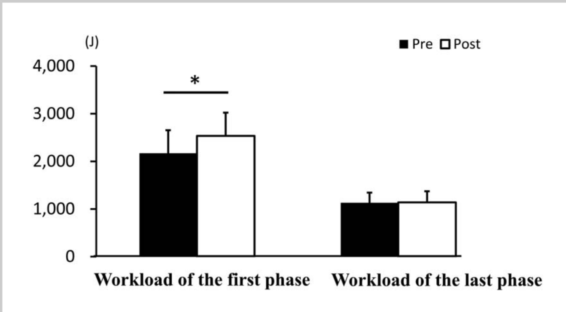

Figure 4. Changes in the workload in the first phase and last phase of 50 repetitions of isokinetic knee extensions in the stretching group. *Significantly changed compared with preintervention ($p < 0.05$). Values are expressed as mean ± *SD*.

control group ($p > 0.05$; $\delta = -0.38$; 95% CI [−456 to 3,816]) (Table 2). No main effect of time or interaction between groups and time was observed in peak force and motor time for RFD ($p > 0.05$; peak force: stretching group, 3,308 ± 1,266 to 3,446 ± 829 N; control group, 3,030 ± 1,051 to 2,939 ± 915 N) ($p > 0.05$; motor time: stretching group, 0.325 ± 0.129 to 0.299 ± 0.116 seconds; control group, 0.306 ± 0.158 to 0.350 ± 0.201 seconds).

There was no interaction and main effect of time for SJ and CMJ height ($p > 0.05$) (Table 3). Neither interaction nor main effect of time was observed in RJ index and RJ ground contact time ($p > 0.05$; contact time for RJ: stretching group, 0.207 ± 0.038 to 0.187 ± 0.015 seconds; control group, 0.204 ± 0.034 to 0.206 ± 0.050 seconds) (Table 3). However, the main effect of time was observed in RJ height ($p < 0.05$; $\eta_P^2 = 0.233$), with the stretching group demonstrating a significant decrease (32.8 ± 8.2 to 30.2 ± 7.3 cm; $p < 0.05$, $\delta = -0.32$; 95% CI [0.648–4.47]). In the control group, there were no significant differences between the pre-test and post-test sessions (32.7 ± 5.1 to 31.5 ± 3.7 cm; $p > 0.05$; $\delta = -0.24$; 95% CI [−1.21 to 3.60]).

Interaction between group and time was observed in the strength decrement index ($p < 0.05$; $\eta_P^2 = 0.162$). The strength decrement index significantly increased in the stretching group ($p < 0.05$; $\delta = 0.72$; 95% CI [−14.8 to −1.10]) but did not change in the control group ($p > 0.05$; $\delta = -0.02$; 95% CI [−5.01 to 5.73]) (Table 4). The workload of the first phase showed interaction with time ($p < 0.05$, $\eta_P^2 = 0.228$), which significantly increased in the stretching group (2,171 ± 482 to 2,535 ± 487 J; $p < 0.05$; $\delta = 0.76$; 95% CI [−650 to −77.9]) (Figure 4), and remained unchanged in the control group (2,144 ± 463 to 2,114 ± 429 J; $p > 0.05$; $\delta = -0.07$; 95% CI [−149 to 209]). In the workload of the last phase, group and time interaction and the main effect of time were not observed (stretching group, 1,130 ± 213 to 1,140 ± 232 J; control group, 930 ± 319 to 922 ± 253 J) (Figure 4).

Discussion

This study demonstrated that the incorporation of 6 weeks of stretching training to increase the flexibility of the knee joint also improved KFROM, RFD, and leg extension, while decreasing muscle endurance. In addition, this study clarified that maximal isometric leg extension strength and jump performances were not affected.

The 6-week stretching training protocol used in this study was sufficient to improve flexibility, as reflected in the significant improvement in KFROM. According to previous studies, improvement in flexibility by stretching training is reported to be secondary to reduced stiffness of the MTU (particularly due to reducing muscle tissue stiffness) (4), modulation of neurophysiological properties (such as excitability of motor neuron pool of the spinal cord and stretch-reflex sensitivity), and change in stretch tolerance (4,10,23). These might be the reasons for the improvement seen in KFROM in this study.

The maximal isometric leg extension remained unchanged in the stretching group. Muscle hypertrophy (increase in the muscle cross-sectional area) is one of the main factors for increasing maximal muscle strength. Therefore, muscle hypertrophy caused by stretching training that was suggested in previous studies (15,24,26) might not have occurred in this study. Conversely, RFD of isometric leg extension improved in the stretching group, which is speculated to be attributed to changes in the fiber composition of the muscle, and the recruitment pattern of the motor units during RFD (19). These peripheral changes that positively affect RFD seem to have offset the negative influence on RFD by the decrease in MTU stiffness because of stretching training.

Protocols for improving the maximal muscle strength (15,21,28) involve longer training periods and durations of stretching per day, as well as higher training frequency than those in this study. Therefore, a certain amount of training is necessary for stretching training to improve the maximal muscle strength, and it is speculated that this study's protocol cannot improve maximal muscle strength. However, the results of this study demonstrate that RFD of isometric leg extension increased even with a protocol aimed at improving flexibility, demonstrating that the training volume and frequency of previously reported protocols (11) are not absolutely necessary to improve RFD. On the other hand, another study (4) reported that RFD remained unchanged after stretching training for a brief period (3 weeks). Therefore, improvement in RFD requires the same training period as that in this study. Further studies with different training periods and frequencies are required to clarify the training volume needed to improve muscle strength or RFD.

Although the effects of stretching training on CMJ have been previously examined, little attention has been paid to SJ performance without countermovement after stretching training. In addition, stretching training has been shown to influence CMJ and drop jump differently (12). Therefore, 3 types of jumps (SJ, CMJ, and RJ) were assessed in this study. However, the values of the 3 types of jumps were unchanged in the stretching group. It is believed that the improvement in jump performance by stretching training is caused by improvement in muscle strength (15) and SSC performance (14,15). In this study, although RFD of leg extension improved, the jump performance, irrespective of the countermovement, did not improve in the stretching group. These results may be attributed to the changes in the mechanical and neurophysiological properties of the MTU of the knee extensors (4,10,23) because of stretching that render the technical aspects of the jump motion, including the kinetic chain, inefficient. In the stretching group, the height of RJ altered without a change in the ground contact time, which may be due to the aforementioned reasons.

Muscle fatigue is caused by voluntary continuous force demonstration. Major factors affecting muscle fatigue consist of those of the central nervous system and peripheral factors, such as muscle metabolic characteristics, including resistance to lactic acid (3,9). The workload of the first phase of 50 repetitions of isokinetic knee extensions increased in the stretching group, suggesting that the factors responsible may be changes in the intramuscular environment (such as the kinetics of Ca^{2+}) or modulation of the recruitment pattern of motor units, whereas since the workload of the last phase was unchanged, it was assumed that the central nervous system and the muscles were fatigued. In other words, the characteristics of the central nervous system and peripheral muscles were unchanged by the stretching training protocol. The findings regarding muscle endurance in this study were different from those of a previous study (15). This may be due to differences in the study protocols, whereby the training volume and training period was higher and longer, respectively, in the previous study.

This study has the following notable points: the subjects were healthy young men, and the study was a single training experiment examining only stretching. Therefore, further studies are required with subjects of different ages and physical conditions to examine the effects of combined training of stretching with training for different sports. In addition, since leg extension involves the simultaneous extension of the knee joint and hip joint, the knee extensors are the part of the main contributors of leg extension strength and vertical jumping. Several studies have reported a correlation between knee extension strength and lower-limb performance (13,20). Thus, the target muscle group of this study was the knee extensors. Further studies are required to clarify the effect of this study's protocol on other muscle groups. Meanwhile, stretching training does not affect the maximal strength in athletes or recreationally active subjects (11,16); however, it increases maximal strength by approximately 30% in physically inactive or minimally recreationally active subjects (15,21). Although these studies used different protocols for stretching training, they suggest that the effect of stretching training is influenced by the level of sports and training background, as well as the physical performance level of each subject. The results of this study are therefore also expected to be affected by the characteristics of each subject. Stretching training using the protocols in this study might have a lesser effect among top athletes and a greater effect on the otherwise physically inactive subjects. Thus, using this study's protocols, the degree of the effect of stretching training on muscular performance was presumed to be related to the sports and training background, as well as the physical performance level of a subject.

Practical Applications

The results of this study suggest that stretching training performed to increase the flexibility of athletes can not only be used for sports that require high flexibility, but also for those requiring high-power exertion. When prescribing training that combines other training and stretching exercises, a coach should consider that stretching also influences the ability to exert power. Contrary to the principle of behavioral (task) specificity, improvement in power exertion by static training supports the effectiveness of using stretching training for rehabilitation. Our results suggest that practitioners aiming to improve the power exertion ability of patients unable to perform power exercises should consider static stretching as part of their management. The decrease in muscle endurance after stretching training was caused by the increase in the workload in the first phase of the measurement task; however, the workload in the last phase did not change. Therefore, it is not a negative aspect from the viewpoint of athletic performance.

Acknowledgments

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