Effects of Training on Muscle and Tendon in Knee Extensors and Plantar Flexors in Vivo

Keitaro Kubo, Toshihiro Ikebukuro, Hideaki Yata, Naoya Tsunoda, and Hiroaki Kanehisa

The purpose of this study was to compare the effects of resistance training on muscle and tendon properties between knee extensors and plantar flexors in vivo. Twenty healthy young men voluntarily participated in this study. The subjects were randomly divided into two training groups: knee extension group (n = 10) and plantar flexion group (n = 10). They performed five sets of exercises with a 1-min rest between sets, which consisted of unilateral knee extension for the knee extension group and plantar flexion for the plantar flexion group at 80% of 1 repetition maximum with 10 repetitions per set (4 days/wk, 12 wk). Before and after training, muscle strength, neural activation level (by interpolated twitch), muscle volume (by magnetic resonance imaging), and tendon stiffness (by ultrasonography) were measured. There were no differences in the training-induced increases in muscle strength, activation level, muscle volume, and tendon stiffness between knee extensors and plantar flexors. These results suggested that if the used protocol of training (i.e., intensity, repetition, etc.) were the same, there were no differences in the training-induced changes in muscle and tendon properties between knee extensors and plantar flexors.

Keywords: muscle strength, tendon stiffness, cross-sectional area, activation level

Resistance training is generally expected to bring an increase in muscle strength and mass. Previous studies showed that while resistance training resulted in smaller increases in plantar flexors mass compared with other muscles, muscle strength increases were comparable (Ishida et al., 1990; Kubo et al., 2008; McCarthy et al., 1997; Weiss et al., 1996). According to many previous findings (e.g., Higbie et al., 1996; Kubo et al., 2001), the muscle volume and cross-sectional area of knee extensors increased significantly by 7–20% after knee extension training. On the other hand, Weiss et al. (1996) showed that eight weeks of heavy resistance training involving the triceps surae muscles increased isotonic muscle strength by about 13% without a concurrent increase in muscle thickness. Ishida et al. (1990) demonstrated that maximal voluntary isometric plantar flexion increased by 31.7% after 8 weeks of isotonic training of calf muscles with a slight increase (+1.6%) in the maximal calf girth. More recently, we reported that the muscle thickness in plantar flexors did not change after 6 months of walking training, while that of knee extensors increased significantly (Kubo et al., 2008). Although the mechanisms of these results are unknown, these may be due to differences in “plasticity” among the measured muscles.

Recent studies using ultrasonography demonstrated that the stiffness of human tendons increased after resistance training in vivo (Arampatzis et al., 2007; Kongsgaard et al., 2007; Kubo et al., 2007; Reeves et al., 2003). According to these previous findings, the increases in tendon stiffness after plantar flexion training (+36% Arampatzis et al., 2007; +20% Duclay et al., 2009; +16% Kubo et al., 2002) were lower than those after knee extension training (+58% Kubo et al., 2001; +65% Reeves et al., 2003). Moreover, there is a wide variability in the previously reported increase in tendon stiffness, ranging between 17% and 65%. These results may be related to the differences in the measured sites, training protocols, and condition of subjects among the previous studies. Furthermore, if there were site-differences in the relative increase in muscle mass after training as mentioned above, the training-induced changes in tendon properties would be different between knee extensors and plantar flexors because the tendon properties were related to the muscle functions (e.g., Muraoka et al., 2005). On the other hand, Kubo et al. (2004) reported that 3 weeks of bed rest reduced the stiffness of human tendon structures and increased hysteresis, and that these changes were found in knee extensors, but not plantar flexors. Considering these previous findings, it is hypothesized that the training-induced increase in tendon stiffness in plantar flexors was lower than that in knee extensors.
As mentioned above, the relative changes in muscle and tendon properties after training and bedrest tended to be lower in plantar flexors than in knee extensors according to the previous finding (e.g., Ishida et al. 1990; Kubo et al. 2002). Although the reasons for these discrepancies are unknown, there are two possible explanations, i.e., the differences in “daily activity levels” and “plasticity” between knee extensors and plantar flexors. For the latter, it is necessary to compare the effects of training using the same protocol of training (i.e., intensity, repetition, set, frequency, period, etc.). At present, however, few studies have simultaneously assessed these variables of muscles and tendons in knee extensors and plantar flexors. The purpose of this study was to compare the effects of resistance training on muscle and tendon properties between the two muscle groups.

Methods

Subjects

Twenty healthy young men voluntarily participated in this study. The subjects were randomly divided into two training groups (Table 1): knee extension group (n = 10) and plantar flexion group (n = 10). Some of data for both groups were derived from our previous reports (weight training group in Kubo et al., 2007; dynamic training group in Kubo et al., 2009). There were no differences in age or physical characteristics between the two groups (Table 1). Before training, we confirmed that there were no differences in the muscle strength, activation level, and tendon stiffness in knee extensors and plantar flexors between the two groups (Table 1, see below). The subjects were fully informed of the procedures to be used as well as the purpose of this study. Written informed consent was obtained from all subjects. This study was approved by the Department of Sports Sciences, University of Tokyo, and complied with their requirements for human experimentation.

Table 1 Age, physical characteristics, measured variables of both knee extension and plantar flexion groups before training; mean (SD)

<table>
<thead>
<tr>
<th></th>
<th>Knee Extension</th>
<th>Plantar Flexion</th>
</tr>
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<tbody>
<tr>
<td>Age (years)</td>
<td>22.3 (1.1)</td>
<td>22.5 (1.6)</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>171.4 (6.1)</td>
<td>169.8 (3.3)</td>
</tr>
<tr>
<td>Body mass (kg)</td>
<td>63.8 (8.7)</td>
<td>62.7 (7.8)</td>
</tr>
<tr>
<td>Thigh length (cm)</td>
<td>39.3 (1.7)</td>
<td>38.8 (1.7)</td>
</tr>
<tr>
<td>Lower leg length (cm)</td>
<td>39.1 (2.2)</td>
<td>38.5 (1.2)</td>
</tr>
<tr>
<td>MVC of knee extensors (N·m)</td>
<td>220 (51)</td>
<td>225 (44)</td>
</tr>
<tr>
<td>Activation level of knee extensors (%)</td>
<td>90.8 (5.3)</td>
<td>90.5 (7.9)</td>
</tr>
<tr>
<td>Tendon stiffness of knee extensors (N/mm)</td>
<td>72.4 (20.2)</td>
<td>68.7 (29.1)</td>
</tr>
<tr>
<td>MVC of plantar flexors (N·m)</td>
<td>119 (19)</td>
<td>115 (25)</td>
</tr>
<tr>
<td>Activation level of plantar flexors (%)</td>
<td>92.3 (8.6)</td>
<td>91.2 (8.0)</td>
</tr>
<tr>
<td>Tendon stiffness of plantar flexors (N/mm)</td>
<td>34.0 (7.6)</td>
<td>32.5 (5.0)</td>
</tr>
</tbody>
</table>

Training

The subjects trained four times (Monday, Wednesday, Thursday, Saturday) per week for 12 weeks. They performed five sets of exercises with an interest interval of 1 min, which consisted of unilateral knee extension for the knee extension group and plantar flexion for the plantar flexion group at 80% of 1 repetition maximum with 10 repetitions per set. After a standardized warm-up, three to five repetitions were performed with 60–80% of the perceived maximum. Thereafter, three to four subsequent attempts were made to determine the 1 repetition maximum, with 3–5 min of rest between attempts. The measurement of 1 repetition maximum was made every 4 weeks to adjust the training load. At the end of the training session, the one-repetition maximum increased significantly by 53 ± 13% for the knee extension group and 58 ± 13% for the plantar flexion group, respectively (both p < .001).

For the knee extension group, the subjects performed a unilateral knee extension exercise in a seated position with an isotonic knee extension machine (Everynew, Tokyo, Japan). The range of knee joint motion was from 90 deg to 0 deg (0 deg = full extension). They were instructed to lift and lower the load at an approximately constant velocity, taking about 1 s for concentric action and 3 s for eccentric action.

For the plantar flexion group, the subjects performed a unilateral plantar flexion exercise using a sledge apparatus (VR-4100, Cybex Corp., USA) with an inclination of 17 deg from the horizontal position. The subjects lay on the sliding table of this apparatus. The table was designed to slide with minimal friction with a constant load through a steel cable connected to adjustable weights. The subjects were instructed to lift and lower the load at an approximately constant velocity, taking about 1 s for the concentric action and 3 s for the eccentric action. The exercise was performed over the range of motion from the fully dorsiflexed position (about 80 deg) to the fully plantar-flexed position (about 130 deg).
Muscle Strength and Activation Level

Maximal voluntary isometric strength (MVC) was determined by means of specially designed dynamometers (Applied Office, Tokyo, Japan). Before the test, each subject performed a standardized warm-up and sub-maximal contractions to become accustomed to the test procedure. For the knee extension group, the subject sat in an adjustable chair with support for the back and the hip joint flexed at an angle of 80 deg (full extension = 0 deg) to standardize the measurements and localize the action to the appropriate muscle group. The ankle was firmly attached to the lever arm of the dynamometer with a strap and fixed with the knee joint flexed at an angle of 90 deg. For the plantar flexion group, the subject lay prone on a test bench and the waist and shoulders were secured by adjustable lap belts and held in position. The ankle joint was set at 90 deg with the knee joint at full extension. The foot was securely strapped to a footplate connected to the lever arm of the dynamometer.

During MVC, evoked twitch contractions were imposed by supramaximal electrical stimulations to assess the activation level of the muscles. The experimental procedures have been described in detail previously (Kubo et al., 2007, 2009). The stimulating electrodes were placed on the skin over the femoral nerve at the inguinal region (cathode) and the midbelly of the quadriceps muscle (anode) for knee extensors, and on the skin of the popliteal fossa and oriented longitudinal to the estimated path of the tibial nerve with the anode distal for plantar flexors. Rectangular pulses (triple stimuli with a 500 μs duration for one stimulus and an interstimulus interval of 10 ms) were delivered using a high-voltage stimulator. The difference between peak twitch torque and MVC (twitch torque) was measured. Shortly (within 1–2 s) after MVC, the same stimulation was given to the muscle at rest (control twitch torque). The measured values shown below are the means of two trials. The neural activation level (%) of the knee extensor muscles was calculated as [1 – (twitch torque during MVC / control twitch torque)] × 100, as previously reported (Kubo et al., 2007, 2009).

Stiffness of Tendon Structures

Elongations of the tendon structures (tendon and aponeurosis) in knee extensors (vastus lateralis muscle; VL) and plantar flexors (medial gastrocnemius muscle; MG) were also assessed during ramp isometric knee extension and plantar flexion. An ultrasonic apparatus (SSD-2000, Aloka, Tokyo, Japan) with an electronic linear array probe (7.5-MHz wave frequency with 80 mm scanning length; UST 5047–5, Aloka) was used to obtain longitudinal ultrasonic images of VL and MG by procedures described previously (Kubo et al., 2004, 2005). The ultrasonic images were recorded on videotape at 30 Hz, and synchronized with recordings of a clock timer for subsequent analyses. The point at which one fascicle was attached to the aponeurosis was visualized on the ultrasonic images. This point moved proximally during isometric torque development up to a maximum (see Figure 1 of Kubo et al., 2005). The displacement of this point is considered to indicate the lengthening of the deep aponeurosis and the distal tendon (Kubo et al., 2004, 2005).

According to Kubo et al. (2005) and Reeves et al. (2003), angular joint rotation needs to be accounted for to avoid overestimation of tendon displacement during contraction. To monitor joint angular rotation, an electrical goniometer (Penny and Giles, Biomechanics Ltd., Gwent, UK) was placed on the lateral aspect of each joint. To correct the measurements taken for the tendon and aponeurosis elongation, additional measurements were taken under passive conditions. The displacement of each site caused by rotating the knee joint from 90 deg to 70 deg (full extension = 0 deg) and ankle joint from 90 deg to 110 deg (>90 deg = plantar flexed position) was digitized in sonographs taken. Thus, for each subject the displacement of each site obtained from the ultrasound images could be corrected for that attributed to joint rotation alone (Kubo et al., 2005). In the current study, only values corrected for angular rotation are reported.

The measured torque (TQ) during isometric knee extension and plantar flexion were converted to force units (Fm) by the following equations (Kubo et al., 2004, 2005):

\[ Fm = k \times TQ \times MA^{-1} \]

where k is the relative contribution of VL within the knee extensors and MG within the plantar flexors in terms of the ratio of the muscle volume, and MA is the moment arm length in each of quadriceps femoris muscles at 90 deg and triceps surae muscle at 90 deg, which was estimated from the limb length of each subject as described by Visser et al. (1990) and Grieve et al. (1978). In the current study, Fm and L values above 50% of MVC were fitted to a linear regression equation, the slope of which was adopted as stiffness (Kubo et al., 2004, 2005).

Electromyographic Activity

The electromyographic activity (EMG) was recorded during the measurement of the muscle strength and tendon properties. Bipolar surface electrodes (5 mm in diameter) were placed over the bellies of VL, the rectus femoris muscle (RF), vastus medialis muscle (VM) and biceps femoris muscles (BF) for knee extension and MG, lateral gastrocnemius (LG), soleus (SOL) and tibial anterior (TA) for plantar flexion with a constant interelectrode distance of 25 mm. The positions of the electrodes were marked on the skin by small ink dots. These stained dots ensured the same electrode positioning in each test during the experimental period. The electrodes were connected to a preamplifier and a differential amplifier with a bandwidth of 5 Hz to 500 Hz (model 1253A, NEC Medical Systems, Tokyo, Japan). The EMG signals were transmitted to a computer at a sampling rate of 1 kHz. The EMG was full-wave rectified and integrated for a 1.0 s period of steady-force output to measure MVC to give integrated EMG. In addition, the mean of integrated EMG in the knee extensors (VL, RF, VM) and plantar flexors (MG, LG, SOL) was defined as mEMG. To investigate
the antagonist muscle activity of the BF during knee extension and TA during plantar flexion (coactivation level), the integrated EMG of BF and TA was measured during knee extension and plantar flexion contractions. To determine the maximal activation of the BF and TA, a maximal knee flexion and dorsi-flexion isometric contractions were performed at the same angle. We normalized the integrated EMG values of BF and TA with respect to the integrated EMG values of BF and TA at the same angle when acting as an agonist at maximal effort.

**Cross-Sectional Area of Muscle and Tendon**

Measurements of muscle and tendon cross-sectional area (CSA) were carried out by magnetic resonance imaging scans (Resona, 0.5 Tesla System, GE). T1-weighted spin-echo, axial-plane imaging was performed with the following variables; TR 450 ms, TE 20 ms, matrix 256 × 172, field of view 300 mm, slice thickness 10 mm, and interslice gap 0 mm. The subjects were imaged in a prone position with the knee kept at 0 deg. Consecutive axial images were obtained from the spina iliaca anterior superior to extremities distal of the tibia. The muscles investigated were as follows; RF, VL, vastus intermedius (VI), and VM for knee extensors and MG, LG, and SOL for plantar flexors. From the series of axial images, outlines of each muscle were traced, and the traced images were transferred to a computer for calculation of the anatomical CSA using digitizing software. The muscle volume was determined by summing the anatomical CSA of each image times the thickness (10 mm).

In addition, the measurement of tendon CSA was taken at two positions (one below the patella and the other at 20 mm distal from the patella for the patella tendon, one above the calcaneous and the other at 10 mm proximal from the calcaneous for the Achilles tendon). The average CSA at two positions was calculated as the representative tendon CSA.

**Statistics**

Values are reported as means ± SD unless otherwise stated. Differences in the measured variables at each session (before and after training) within each group were determined by using a paired $t$ test, and a comparison of relative changes in measured variables between groups (knee extension training, plantar flexion training) was performed using one-way analysis of variance (ANOVA). Linear regression analysis was performed on the relationships between relative changes in muscle strength, muscle volume, and activation level. The level of significance was set at a $p$ value of less than 0.05.

**Results**

Before training, there were no differences in the measured variables of muscle and tendon properties between the knee extension and plantar flexion groups (Table 1). The muscle volume increased significantly by 5.6% for the knee extension group ($p = .003$) and 5.4% for the plantar flexion group ($p < .001$), respectively (Table 2). No significant difference in the relative increase in muscle volume was found between the knee extension and plantar flexion groups ($p = .933$) (Figure 1). Furthermore, no significant changes in the patella or Achilles tendon

![Figure 1](image-url)
Neither protocol produced any significant change in the tendon structures before and after training. The maximal elongation of tendon structures for both the knee extension and plantar flexion groups did not change after training (Table 2). The stiffness of tendon structures increased significantly by 30.0% for the knee extension group (p = .003) and 37.5% for the plantar flexion group (p = .046), respectively (Table 2). There was no significant difference in the relative increase in stiffness between the two protocols (p = .862) (Figure 1).

### Table 2  Measured variables of muscle and tendon for knee extension and plantar flexion groups; mean (SD)

<table>
<thead>
<tr>
<th></th>
<th>Knee Extension</th>
<th>Plantar Flexion</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td>Muscle volume (cm³)</td>
<td>1817 (270)</td>
<td>1920 (313)*</td>
</tr>
<tr>
<td>MVC (N⋅m)</td>
<td>220 (51)</td>
<td>285 (59)*</td>
</tr>
<tr>
<td>Activation level (%)</td>
<td>90.8 (5.3)</td>
<td>95.2 (2.9)*</td>
</tr>
<tr>
<td>mEMG (mV)</td>
<td>0.21 (0.06)</td>
<td>0.26 (0.06)*</td>
</tr>
<tr>
<td>Coactivation level (%)</td>
<td>12.5 (6.6)</td>
<td>13.8 (4.7)</td>
</tr>
<tr>
<td>Maximal tendon elongation (mm)</td>
<td>22.0 (6.2)</td>
<td>22.4 (3.4)</td>
</tr>
<tr>
<td>Tendon stiffness (N/mm)</td>
<td>72.4 (20.2)</td>
<td>95.7 (36.8)*</td>
</tr>
<tr>
<td>Tendon CSA (mm²)</td>
<td>66.1 (8.4)</td>
<td>67.9 (7.9)</td>
</tr>
</tbody>
</table>

*Significantly different from before.

CSA were found in the knee extension and plantar flexion groups (Table 2). The MVC value increased significantly by 31.5% for the knee extension group (p < .001) and 19.3% for the plantar flexion group (p = .003), respectively (Table 2). Activation level of the muscles assessed by superimposing electrical stimuli increased significantly by 7.6% for the knee extension group (p = .009) and 5.8% for the plantar flexion group (p = .049), respectively (Table 2). Similarly, the mEMG of the muscles increased significantly by 32.2% for the knee extension group (p = .026) and 38.9% for the plantar flexion group (p = .011), respectively (Table 2). No significant differences in the relative increase in MVC (p = .162), activation level (p = .987) or mEMG (p = .415) were found between the knee extension and plantar flexion groups (Figure 1).

For both the knee extension and plantar flexion groups, the coactivation levels of BF and TA did not change after training (Table 2). Furthermore, the relative increase in MVC was significantly correlated to that of activation level (knee extensor; r = .650, plantar flexor; r = .725: all p < .01), but not to muscle volume (knee extensor; r = .035, plantar flexor; r = -.0.105; r = .051: all p > .05) (Figure 2).

Figure 3 shows the relationships between Fm and L of the tendon structures before and after training. Neither protocol produced any significant differences in the tendon elongation values at any force production levels after training. The maximal elongation of tendon structures for both the knee extension and plantar flexion groups did not change after training (Table 2). The stiffness of tendon structures increased significantly by 30.0% for the knee extension group (p = .003) and 37.5% for the plantar flexion group (p = .046), respectively (Table 2). There was no significant difference in the relative increase in stiffness between the two protocols (p = .862) (Figure 1).

### Discussion

This study demonstrated that there were no differences in the training-induced increases in muscle strength, activation level, muscle volume, or tendon stiffness between knee extensors and plantar flexors. To our knowledge, this is the first study to simultaneously assess these variables of muscle and tendon properties in knee extensors and plantar flexors in vivo.

According to some previous studies (Ishida et al., 1990; Kubo et al., 2008; McCarthy et al., 1997; Weiss et al., 1996), the training-induced increase in muscle mass in plantar flexors tended to be lower than that in other muscles. For example, McCarthy et al. (1997) reported that the muscle volume of the plantar flexors increased 3.8% after 12 weeks of resistance training. Therefore, we hypothesized that the relative increase in muscle volume in plantar flexors would be lower than that in knee extensors. In the current study, however, the relative increases in muscle volume were 5.6% for knee extensors and 5.4% for plantar flexors (Table 2). On the other hand, we reported that the decline in muscle thickness with aging was marked in VL (knee extensors) and slight in MG (plantar flexors) (Kubo et al., 2003). Taking the present result into account together with the finding of Kubo et al. (2003), we can say that the site-differences in age-related changes in muscle thickness are related to the intensity and/or duration activities of muscle groups during daily life, but not to the age-related changes biologically of each muscle group.

Some previous researchers indicated that the muscle strength in plantar flexors increased by 20–50% over a period of training lasting from 6–12 weeks (Bond et al., 1996; Ishida et al., 1990; Young et al., 1985). Accordingly, we hypothesized that there was no difference in the increase in muscle strength after training between knee extensors and plantar flexors. In the current study, there...
were no differences in the relative increases in activation level, as well as muscle strength, between knee extensors and plantar flexors. Furthermore, the relative increase in muscle strength was significantly correlated to that of activation level, but not to muscle volume (Figure 2). Considering these findings, it is likely that the same protocol of resistance training (i.e., intensity, repetition, frequency, period, etc.) causes similar increases in muscle strength and activation level of both knee extensors and plantar flexors.

In the current study, there was no difference in the relative increase in tendon stiffness between knee extensors and plantar flexors. According to some previous findings, the increases in tendon stiffness after plantar flexion training (Arampatzis et al., 2007; Ducray et al., 2009; Kubo et al., 2002) were lower than those after knee extension training (Kubo et al., 2001; Reeves et al., 2003). On the other hand, the previous study demonstrated that bed rest reduced the stiffness of human tendon structures and increased hysteresis, and that these changes were found in knee extensors, but not plantar flexors (Kubo et al., 2004). Although the previous researchers gave the difference in “plasticity” of each muscle group as a reason for these results (Kubo et al., 2002, 2004), the results obtained in the current study contradicted this hypothesis. Considering the present and previous findings, we may
say that the site-differences (between knee extensors and plantar flexors) in the changes in tendon properties after training and/or bed rest were related to the intensity and/or duration activities of muscle groups during daily life and the used training protocols (i.e., intensity, repetition, frequency, period, etc.).

Tendon CSA did not change during training (Table 2), which is in agreement with the previous studies (Kubo et al., 2007; Reeves et al., 2003). Most of the previous studies using animals have documented that only small changes in the size of tendons can be induced by immobilization (e.g., Almeida-Silveira et al., 2000) or training (e.g., Woo et al., 1981). However, more recent studies have demonstrated tendon hypertrophy following heavy resistance training (Arampatzis et al., 2007; Kongsgaard et al., 2007). As a reason for the difference in the results for tendon hypertrophy after training, the intensity and mode of training, condition of subjects, and the performance of magnetic resonance imaging may be involved. According to cross-sectional studies in vivo (Kongsgaard et al., 2005; Rosager et al., 2002), the Achilles tendon CSA of trained athletes has been shown to be greater than in untrained subjects. Therefore, it is likely that the tendon hypertrophy may be caused by longer term of resistance training. Furthermore, we may say that the human tendon did not change in terms of mass and/or collagen concentration after only the 12 weeks of resistance training. The mechanisms which resulted in the increase in the stiffness remain in question, although the training did not induce a significant hypertrophic change in tendons. To explain the increased stiffness, it is hypothesized that the training induced the changes in internal structures of the tendon and/or aponeurosis. Rollhauser (1954) pointed out that, as a result of 42-day training for pigs, the only way which mature tendons could make positive responses to chronic exercise was to improve the internal structures of tendons.

In the current study, the subjects performed five sets at 80% of 1 repetition maximum with 10 repetitions per set (4 days/wk, 12 wk). These training regimens have been shown to be effective in increasing muscle strength and mass (e.g., MacDougall, 1986). Indeed, the relative increases in MVC and muscle volume were similar to those previously reported (e.g., Higbie et al., 1996; Kubo et al., 2009). We used the same duration of concentric and eccentric actions for both knee extension and plantar flexion training. However, the angular “velocity” was different between knee extension (90 deg/s during concentric action, 30 deg/s during eccentric action) and plantar flexion (50 deg/s during concentric action, 17 deg/s during eccentric action) groups. It is well known that there is a “specificity” of angular velocity (i.e., velocity of action) in isotonic and isokinetic training (e.g., Kanehisa and Miyashita, 1983). Unfortunately, as far as we know, no studies have examined the effects of a narrow range of angular velocity on the training-induced changes in muscle strength and mass. Therefore, we concluded that these differences in the angular velocities did not affect the main results of this study.

In addition, we tried to investigate using the same training protocol (i.e., intensity, repetition, frequency, period, etc.) whether the differences in the training-induced changes between knee extensors and plantar flexors were related to the “plasticity” of each site. To achieve this aim, it is necessary to make the mechanical stimulus to the muscle and tendon during training strictly. However, it is very difficult to make the same range of muscle length (corresponding to sarcomere length), since there are differences in muscle fiber length, moment arm length, etc. For example, if we used the same range of motion in knee extension (50 deg: 90 deg – 40 deg) and plantar flexion (50 deg: 80 deg – 130 deg), there is no guarantee that the ranges of sarcomere length are the same between knee extensors and plantar flexors. Furthermore, if we used the same intensity (relative load to 1RM), the exerted muscle force would be different between knee extensors and plantar flexors due to the different moment arm length. Considering these points, we would like to inspect the difference of “plasticity” between knee extensors and plantar flexors using the same training protocol, which we can control the items (e.g., repetition, set, etc.) completely. Regardless, further investigations are needed to clarify this point.

In conclusion, these results suggested that if intensity and volume of training were the same, there were no differences in the changes in mechanical and morphological properties of muscles and tendons between knee extensors and plantar flexors.

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References


