PLYOMETRIC TRAINING EFFECTS ON GASTROCNEMII MUSCLE AND TENDON PASSIVE STIFFNESS

1, 2Alexandre Fouré, 1Antoine Nordez and 1Christophe Cornu
1Laboratoire Motricité, Interactions, Performance (MIP), EA 4334, University of Nantes
2Laboratoire de Physiologie de l’Exercice (LPE), EA 4338, University of Savoie
Email: alexandre.foure@univ-savoie.fr

SUMMARY
Plyometric training is commonly used to improve athletic performance but it is unclear how each component of the muscle-tendon complex (MTC) is affected by this intervention. The effects of fourteen weeks of plyometric training on the passive stiffness of the gastrocnemii muscle and Achilles tendon was determined simultaneously in order to assess possible local adaptations of elastic properties. The ankle joint range of motion, passive force of the gastrocnemii MTC and elongation of the gastrocnemii muscle and Achilles tendon were determined using ultrasonography during passive cyclic stretching in nineteen subjects divided into trained (n=9) and control (n=10) groups. A significant increase in vertical jump performances was found for the trained group (P < 0.05). Considering the passive force-length relationship, an upward trend in stiffness of the gastrocnemii MTC (P = 0.09) and in the gastrocnemii muscle stiffness (P = 0.07) were found. In contrast, no significant change in gastrocnemii tendon stiffness and in MTC geometry was determined (P > 0.05). The change in intrinsic muscle stiffness might be mainly due to change in intramuscular collagen concentration.

INTRODUCTION
Plyometric training is classically used by athletes to improve jumping and sprinting abilities [1]. Since it was shown that passive ankle joint moment plays an important role in various tasks as standing and walking [2], functional performances should also be influenced by elastic properties of the passive musculo-articular complex (MAC). Yet, effects of plyometric training on MAC passive stiffness focused low attention in the literature.

Passive cyclic stretches are classically performed in order to obtain passive torque-angle relationships, from which mechanical properties of the MAC could be extracted [3]. Recently, a mathematical model developed by Hoang et al.[4] and improved by Nordez et al.[5] has been developed to assess passive force-length relationship of the gastrocnemii MTC. Using this method, Fouré et al.[6] have shown that 8 weeks of plyometric training increased the gastrocnemii MTC stiffness. However, Hoang et al.[7] have shown that ultrasonography is usable during passive stretches to determine the passive force-length relationships of gastrocnemii muscle and Achilles tendon.

The aim of this study was then to determine the effects of plyometric training on the passive force-length relationship of both gastrocnemii muscles and Achilles tendon to determine possible specific adaptations of the gastrocnemii MTC mechanical properties.

METHODS
Nineteen males volunteered to participate in this study and were assigned to the trained group (n = 9) or control group (n = 10). Training program and jump tests were detailed in two previous studies [8, 9].

Measurements of the Achilles tendon cross-sectional area (CSAAT) and length were carried out by ultrasonographic imaging scans as described previously [8, 9]. Assessment of the gastrocnemii muscles cross-sectional area (CSAGAS) was performed using ultrasonography as described in details previously [9].

To determine the passive force-length relationships of gastrocnemii muscle and Achilles tendon, five cyclic passive motions of ankle joint for six randomly tested knee flexion angles (θk = 0°, 15°, 30° 45° 60° and 80°). Subjects were lying prone with thighs, the hip and shoulders secured by adjustable lap belts and held in position [6]. The reference angle of the knee joint (θk = 0°) corresponded to the knee fully extended. The linear array probe mounted on an externally fixed bracket was strapped onto the skin of subjects to obtain longitudinal ultrasonic images of the distal myotendinous junction of the GM. Surface electromyographic (sEMG) signals of involved muscles were recorded to check the passive behavior during stretches (Figure 1).

Figure 1: Subject position during passive cyclic stretches.
During passive stretches, passive external torque, ankle angle and displacement of the distal myotendinous junction of the GM were determined during the dorsiflexion of the fifth cycle at each knee angle. The MTC length of the gastrocnemius was then calculated using anthropometric data from study on cadaveric legs [10]. Elongation of the gastrocnemius muscles was determined as the total displacement of the myotendinous junction of the GM. Elongation of the gastrocnemius tendon was calculated as the difference between MTC and muscle length changes [11].

To determine the passive force of the gastrocnemius MTC, an optimization procedure performed on the differences between the torque-angle relationships obtained at 0°, 15°, 30°, 45°, 60° and 80° of knee angle. [5]. The exponential model used in the present study was the model of Sten Knudsen [3, 5, 12] where the passive force (Fg) could be calculated using Equation 1:

$$F_g = \frac{1}{\text{S}_{\text{MTC}}} \left( e^{\text{S}_{\text{MTC}}(l - l_0)} \right) \quad (1)$$

where $l$ is the gastrocnemius length (i.e., assessed using Grieve’s model), $\text{S}_{\text{MTC}}$ is the stiffness index of the gastrocnemius MTC, and $l_0$ the gastrocnemius slack length determined using the optimization.

Relationships between $F_g$ and length of the gastrocnemius muscles and tendon were characterized. Then, Sten Knudsen model was fitted on these two relationships in order to determine stiffness index of the gastrocnemius muscles and Achilles tendon (i.e., $\text{S}_{\text{M}}$ and $\text{S}_{\text{T}}$ respectively). The relationships between stress (i.e., force divided by cross sectional area) and strain (i.e., elongation divided by length) of the gastrocnemius muscles and Achilles tendon were determined and Sten Knudsen model was fitted on these two relationships for each subject in order to determine intrinsic stiffness index of muscle and tendon of the gastrocnemius MTC (i.e., $\text{S}_{\text{IM}}$ and $\text{S}_{\text{IT}}$ respectively).

Two-way multivariate analyses of variance (ANOVA) (group × time) were performed to assess the statistical significance of changes in geometrical and stiffness parameters. A Newman-Keuls post-hoc analysis was conducted where appropriate. The critical level of significance in the present study was set at $P < 0.05$.

RESULTS AND DISCUSSION

A significant increase for the trained group was found in vertical jump performances (between $+7.4\%$ to $+27.7\%$ according to the jump form, $P < 0.05$). Range of change in vertical jump performances were in accordance with previous studies [1, 6]. Therefore, our jumps results demonstrated the functional efficiency of our plyometric training program.

An upward trend in stiffness of the gastrocnemius muscle stiffness ($P = 0.07$) was found. In contrast, no significant change in gastrocnemius tendon stiffness and in muscles and tendon geometry (CSA$_T$ and CSA$_{\text{GAS}}$) was determined ($P > 0.05$). This result is astonishingly different with results obtained in active condition [8]. Although the tendon is a passive structure, its behaviour seems to be different when determined in active and passive conditions.

A significant increase of 26.1% in $\text{S}_{\text{IM}}$ ($P < 0.05$) was determined for the trained group. No significant change in $\text{S}_{\text{IT}}$ was found in trained group ($P > 0.05$). Qualitative adaptations in mechanical properties of gastrocnemius muscles stiffness to plyometric training is mainly due to change in intrinsic mechanical properties of muscular tissues rather than to geometrical change of MTC structures. The results observed in the present study could be linked to an increase in intra-muscular collagen concentration as previously described on isolated muscle after jump training [13].

CONCLUSIONS

This study has allowed for the determination of the effects of 14 weeks of plyometric training considering dissociated change in passive stiffness of the gastrocnemius MTC, muscle and Achilles tendon stiffness. This dissociation allows for assessment of specific adaptations of each component that belong to the gastrocnemius MTC non-invasively after 14 weeks of plyometric training. The main conclusions are that plyometric training induces an increase in functional performances associated with change in intrinsic mechanical properties of the gastrocnemius muscle. Then, passive structures of the gastrocnemius muscle seem to be more exposed than tendinous tissues. Further researches including invasive measurement of MTC collagen concentration and type could be relevant to determine implication of collagen in muscle passive stiffness change after plyometric training.

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REFERENCES