Effects of Electrical Stimulation of the Calf Muscles on Jumping Performance

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1 OBJECTIVES

The calf muscles contract almost isometrically while the Achilles tendon stretches and shortens during the contact period when walking (Fukunaga et al., 2001). This interaction between them makes it possible for the muscles to exert a larger force and for the tendinous tissue to function as a spring so that walking can be performed more efficiently. In addition, jumping requires an even larger force than walking, and it is likely then that the functions of the tendinous tissue influence performance considerably. However, it is difficult to control the functions of the tendinous tissue during jumping because it is not innervated by afferent nerves. In this study, therefore, to investigate the effects of tendinous tissue on jumping performance, we induced lengthening and shortening of the Achilles tendon by forcibly contracting the calf muscles by electrical stimulation.

2 METHODS

2.1 Subjects

Fifteen healthy men participated in this study (age, 21.1 ± 1.3 years; height, 173.5 ± 7.0 cm; weight, 69.0 ± 10.5 kg). All subjects were in good health, with no orthopedic or neuromuscular abnormalities. Subjects were fully informed of the nature and possible consequences of the study before providing written informed consent. The experiments were conducted in accordance with the Declaration of Helsinki. Approval was obtained from the Ethics Committee of Kogakkan University.

2.2 Protocol

Subjects were instructed to perform 10 consecutive two-legged jumps at maximum effort (100% jump) and at 50% of the maximal jump height (50% jump). Jumps were performed on a jump-measuring mat (PH-1260, DKH, Tokyo, Japan) to measure jump height, ground contact, and flight time. Subjects were instructed to place both hands on their waist and reduce ground contact time as much as possible. Both normal and electrically stimulated jumps were performed.

An electrical stimulus was applied over the calf muscle during the jump at a frequency of 20 Hz (ES20) or 60 Hz (ES60). Six sets of jumps were performed with intervals of at least 5 min. Electrical stimulation intensity was set to 20% of the maximum ankle plantar-flexion torque, using an electromyography / evoked potential measuring system (MEB-2306, NIHON KODEN, Tokyo, Japan). Two anodes and one cathode were placed on the proximal and distal ends of the triceps surae muscle, respectively. Reference marks were placed on the right caput of the ossis metatarsalis V, ankle joint, knee joint, greater trochanter, acromion, tragus, and on the top of the subject's head.

Jumping movements were filmed in the sagittal plane with a high-speed camera (300 fps; EXLIM-F1, CASIO, Tokyo, Japan) with 2 reference marks placed on the ground at an interval of 2 m. The subjects were questioned about their jump performance and asked to rate the force required for the jump and the ease of control on a 5-point scale (5: very light or easy; 4: light or easy; 3: normal; 2: heavy or difficult; 1: very heavy or difficult). In addition, they were questioned about the extent (1: none to 5: severe) and location of muscle soreness each day for 6 days after the experiment.

2.3 Data Processing

The reference points in each frame were automatically digitized (DARTFISH SOFTWARE, DARTFISH, Fribourg, Switzerland), smoothed, and converted to real coordinates. The ankle, knee, and hip joint angles were computed during the ground contact phase. Distances between the reference mark

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on the ground in front of the subject and the right caput of the ossis metatarsalis V (landing point) were also computed to evaluate the stability of the jump. The rebound jump index was computed using the ground contact and flight times obtained from the jump-measuring mat.

2.4 Statistics

Data are presented as the means ± SD. One-way analysis of variance was used to analyze the differences in jumping performance, movement, and 5-grade evaluations of jumping performance and muscle soreness. Fisher's post hoc comparison was performed when significance was found. The probability level accepted for statistical significance was p<0.05.

3 RESULTS

Jump height was significantly lower in the 100% jump with ES60 than in the 100% normal jump. No significant differences in jump height were observed between the other conditions (Fig. 1).

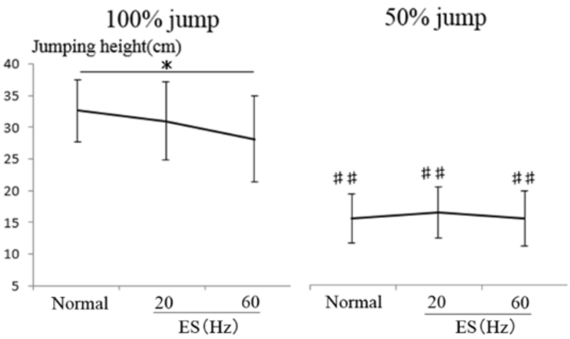

Figure 1: Jump height. * and ## denote significant differences (p<0.05 and p<0.01, respectively) among jump conditions and between 100% and 50% jumps, respectively.

Stability of the jump increased significantly in the 50% jump compared with the 100% jump. Electrical stimulation had no effect on stability (Fig. 2). The results of the self-evaluations were as follows: jump performance was rated significantly lower for 60ES than for 20ES in both the 100% and 50% jumps; force required was rated as high at 20 Hz and almost the same at 60 Hz compared with the normal jump; whereas ease of control was rated almost the same at 20 Hz but lower at 60 Hz compared with the normal jump (Fig. 3).

No obvious differences were observed in angular displacement of the lower joints during jumps between the normal, ES20, and ES60 jumps. Significant differences were observed only in hip flexion in the 50% jump and in ankle plantar-flexion in both the 100% and 50% jumps between the normal and ES60 jumps (Fig. 4).

After the experiment, all subjects reported severe muscle soreness at the myotendinous junction of the gastrocnemius muscle. However, it gradually decreased day by day (Fig. 5).

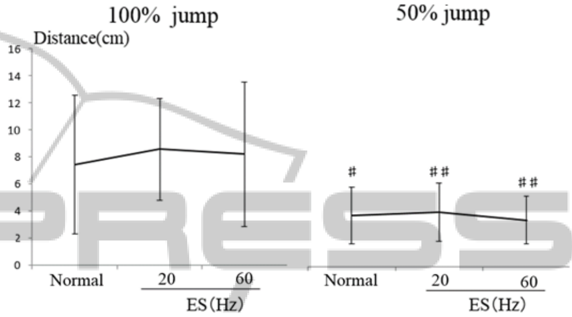

Figure 2: Distances between the reference mark and landing point during jumps. # and ## denote significant differences (p<0.05 and p<0.01, respectively) between 100% and 50% jumps.

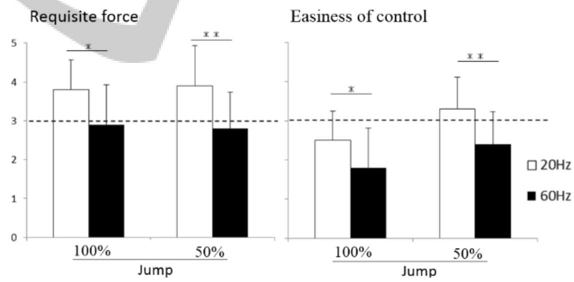

Figure 3: Results of self-evaluations on jump performance by assessing the force required for the jump and ease of control. * and ** denote significant differences (p<0.05 and p<0.01, respectively) between ES20 and ES60.

4 DISCUSSION

In this study, the intensity of the electrical stimulation applied to the calf muscle during jumping was adjusted so that that the calf muscle could generate 20% of the maximum torque at frequencies of 20 Hz and 60 Hz. However, electrical stimulation at 60 Hz did not increase jump height; instead it significantly decreased it when the jump was performed at full effort. This may be related to the difficulty in controlling jumps stimulated at 60 Hz, as revealed by the results of the self-evaluation on ease of control. This implies that jump height was sacrificed to stabilize the landing point and may be supported by the significant decreases in ankle plantar-flexion during the late contact phase of jumps stimulated at 60 Hz. On the other hand, for the electrical stimulation at 20 Hz, subjects reported performing the jump with less effort, although jump height remained unchanged. This suggests appropriate use of the tendinous tissue elasticity during these jumps.

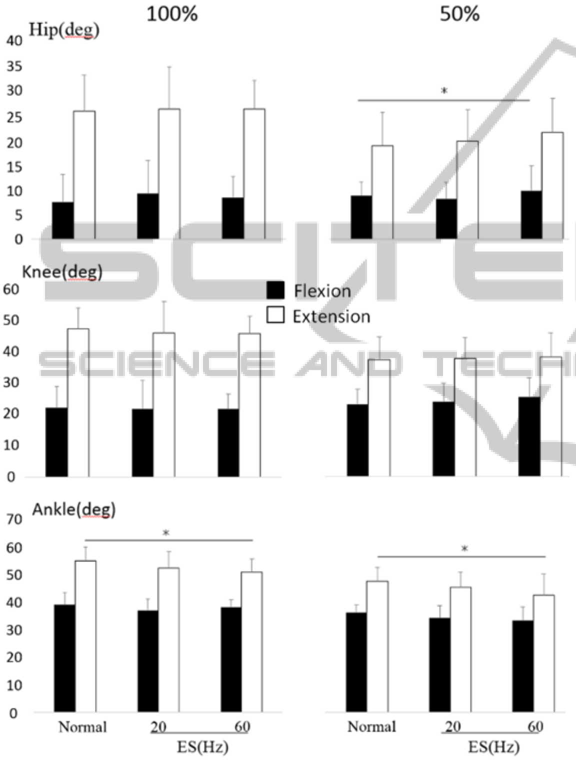

Figure 4: Angular displacement of flexion and extension of each joint during the jumps. * denotes significant differences ($p<0.05$) among jump conditions.

Subjects reported severe muscle soreness after the exercise. Since they performed only 6 sets of 10 consecutive two-legged jumps with sufficient intervals, the pain was likely due to the electrical stimulation applied to the calf muscle. Muscle soreness was concentrated at or near the myotendinous junction of the gastrocnemius muscle. Muscle strain injury that is caused by combining a large force with substantial stretch (Garrett, 1990) has been reported to occur at or near the myotendinous junction (Tidball et al., 1993), and a clinical report revealed that most muscle strain injuries occur at or near the myotendinous junction during high-intensity or explosive voluntary movements such as sprint and quick turn (Okuwaki, 2009). Therefore, forced contraction of the calf muscle by electrical stimulation might induce a large force with substantial stretch at or near the myotendinous junction during jumping. However, it is not clear which experimental condition in the jump exercise induced the muscle soreness reported in this study. Further studies are needed to perform jumps with electrical stimulation applied to the muscle to ensure safe and appropriate training of the myotendinous units.

Figure 5: Change in muscle soreness. * and ** denote significant differences ($p<0.05$ and $p<0.01$, respectively) among days after the experiment.

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