Human Movement Science 36 (2014) 35–45

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Gastrocnemius and soleus are selectively activated when adding knee extensor activity to plantar flexion

Takahito Suzuki [a,b,*], Kentaro Chino [c], Senshi Fukashiro [a]

[a] Department of Life Sciences, Graduate School of Arts and Sciences, The University of Tokyo, Tokyo, Japan
[b] Department of Human Sciences, Kanagawa University, Kanagawa, Japan
[c] Department of Sports Sciences, Japan Institute of Sports Sciences, Tokyo, Japan

ARTICLE INFO

Article history:
Available online 10 June 2014

PsycINFO classification:
2330
2530

Keywords:
Biarticular muscle
Electromyography
Load share
Synergist
Triceps surae

ABSTRACT

The gastrocnemius is a biarticular muscle that acts not only as a plantar flexor, but also as a knee flexor, meaning that it is an antagonist during knee extension. In contrast, the soleus is a monoarticular plantar flexor. Based on this anatomical difference, these muscles' activities should be selectively activated during simultaneous plantar flexion and knee extension, which occur during many activities of daily living. This study examined the selective activation of gastrocnemius and soleus activities when voluntary isometric activation of knee extensors was added to voluntary isometric plantar flexion. Ten male volunteers performed isometric plantar flexion at 10%, 20%, and 30% of maximum effort. During each plantar flexion task, isometric knee extension was added at 0%, 50%, and 100% of maximum effort. When knee extension was added, the average rectified value of the electromyographic activity of the medial gastrocnemius was significantly depressed ($P = .002$), whereas that of the soleus was significantly increased ($P < .001$) regardless of the plantar flexion level. These results suggest that plantar flexion with concurrent knee extensor activity leads to selective activation of the soleus and depression of the synergistic activity of the gastrocnemius.

* Corresponding author at: Department of Human Sciences, Kanagawa University, 3-27-1 Rokkakubashi, Kanagawa-ku, Yokohama 221-8686, Japan. Tel.: +81 45 481 5661.

E-mail address: takahito.suzuki.hg@alum.riken.jp (T. Suzuki).

http://dx.doi.org/10.1016/j.humov.2014.04.009
0167-9457/

1. Introduction

Most activities of daily living involve the simultaneous movement of multiple joints. For example, simultaneous motion of the ankle and knee joints is required for many activities, including standing (Horak & Nashner, 1986), running (Duysens, Tax, van der Doelen, Trippel, & Dietz, 1991), swimming (Troup, 1999), and cycling (Andrews, 1987; De Marchis, Schmid, Bibbo, Bernabucci, & Conforto, 2013). During these multijoint movements, biarticular muscles, such as the gastrocnemius, have direct effects on two joints at the same time (Lombard, 1903). These effects depend on task constraints, including the movement direction, joint displacement, and external force (Andrews, 1987; Zajac, 1993). Therefore, control of biarticular muscles is complex and important to multijoint movements.

The gastrocnemius, a biarticular muscle that crosses the ankle and knee, functions as both a plantar flexor and knee flexor. Partly because of this anatomical characteristic, the muscle activation level of the gastrocnemius increases when voluntary knee flexion is added to voluntary isometric plantar flexion (Gravel, Arsenault, & Lambert, 1987). However, when both plantar flexion and knee extension are required, the activity of the gastrocnemius, which is an antagonist during knee extension, may be depressed. Such depression of antagonist activity is induced by agonist activity through neural pathways, an action termed reciprocal inhibition. This well-known phenomenon has been carefully investigated in the ankle (Nielsen & Pierrot-Deseilligny, 1996) and elbow (Katz, Penicaud, & Rossi, 1991). Few previous studies, however, addressed reciprocal inhibition at the human knee (Bayoumi & Ashby, 1989; Hamm & Alexander, 2010; Kudina, 1980), and none focused on the gastrocnemius as a knee flexor. Therefore, how voluntary activation of knee extensors influences gastrocnemius activity remains unclear. If activation of knee extensors decreases gastrocnemius activity while meeting the total demand of plantar flexion torque, the activities of monoarticular plantar flexors, such as the soleus (Sol), increase. This changes the load share among the plantar flexors.

In this study, it was hypothesized that gastrocnemius activity is depressed and Sol activity is increased during simultaneous plantar flexion and knee extension. To test this hypothesis, we investigated the activation of the triceps surae when voluntary isometric knee extension was added to voluntary isometric plantar flexion.

2. Methods

2.1. Subjects

Ten male volunteers participated in the experiment. Their ages, heights, and body masses (mean ± standard deviation) were 25.3 ± 3.6 years, 173.0 ± 5.3 cm, and 68.2 ± 8.7 kg, respectively. They had no medical history or signs of neurological disorders. All subjects gave written informed consent to participate in the study after receiving a detailed explanation of the purposes, potential benefits, and risks associated with participation. The Human Research Ethics Committee at the Department of Life Sciences, The University of Tokyo approved all of the procedures used in the study.

2.2. Force and electromyography recordings

For all trials, each subject was required to maintain a prone posture with no joint angle changes. A knee was fully extended on a bed with pads that elevated the knee to avoid contact between the bed and the electrode on the rectus femoris (RF). The ankle was fixed at 0° (neutral position), and the right foot was tightly strapped to the plate of a dynamometer (VTF-002; VINE Bionic Systems, Tokyo, Japan) with a strain gauge (LTZ-500KA; Kyowa, Tokyo, Japan) amplified by a strain amplifier (CDV-700A; Kyowa) or torque-measuring system (Biodex System 3; Biodex Medical Systems, Shirley, NY, USA) (Fig. 1). The angles of the right ankle and knee were carefully fixed to remove any influence of angular variations on the electromyography (EMG) tracings of the triceps surae (Cresswell, Loscher, & Thorstensson, 1995). In seven subjects, the constancy of the knee angle was checked by a goniometer (SG150; Biometrics, Gwent, UK); in the remaining three subjects, the goniometer was removed to immobilize the knee as much as possible. In the pilot study, we confirmed that isometric knee