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# Differential contributions of ankle plantarflexors during submaximal isometric muscle action: A PET and EMG study

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ABSTRACT

The objective of this study was to investigate the relative contributions of superficial and deep ankle plantarflexors during repetitive submaximal isometric contractions using surface electromyography (SEMG) and positron emission tomography (PET). Myoelectric signals were obtained from twelve healthy volunteers (27.3 ± 4.2 yrs). A tracer ([$^{18}$F]-FDG) was injected during the exercise and PET scanning was done immediately afterwards. The examined muscles included soleus (Sol), medial gastrocnemius (MG), lateral gastrocnemius (LG), and flexor hallucis longus (FHL). It was found that isometric maximal voluntary contraction (MVC) force, muscle glucose uptake (GU) rate, and SEMG of various plantarflexors were comparable bilaterally. In terms of %EMG MVC, FHL and MG displayed the highest activity (~34%), while LG (~21%) had the lowest activity. Cumulative SEMG from all parts of the triceps surae (TS) muscle accounted for ~70% of the combined EMG signal of all four plantarflexors. As for GU, the highest quantity was observed in MG (2.4 ± 0.8 μmol $*$ 100 g$^{-1}$ $*$ min$^{-1}$), whereas FHL (1.8 ± 0.6 μmol $*$ 100 g$^{-1}$ $*$ min$^{-1}$) had the lowest uptake. Cumulative GU of TS constituted nearly 80% of the combined GU. The findings of this study provide valuable reference for studies where individual muscle contributions are estimated using models and simulations.



## 1. Introduction

Ankle plantarflexion in humans is brought about by the activation of two different sets of muscles; superficial (triceps surae) and deep (e.g. flexor hallucis longus, FHL) (Fukunaga et al., 1992). The extent to which these two muscle groups contribute to a plantarflexion task varies in individuals. Relative activation of different plantarflexors during various tasks has been investigated using an in situ buckle-type force transducer on the Achilles tendon (Gregor et al., 1991), estimations based on cadaver moment arm lengths and total muscle cross-sectional areas (van Zandwijk et al., 1996), recordings of tendon forces with in vivo optic-fiber technique (Finni et al., 2000), and calculations of individual muscle contraction velocities using velocity-encoded cine phase-contrast MRI (Finni et al., 2006). The amount of reported triceps surae (TS) contribution to the total plantarflexion moment ranges from ~65% (Gregor et al., 1991) to ⩾88% (van Zandwijk et al., 1996).

Previous studies have also established that the distribution of stress within different compartments of TS muscle is not homogenous. Cadaver studies have shown differences in the mediolateral forces within the Achilles tendon depending on how TS components were loaded (Arndt et al., 1999; Lersch et al., 2012), and calcaneal angle (Lersch et al., 2012). When all three muscles are loaded, lateral tendon forces are higher than the medial forces, while, on the other hand, medial forces tend to be greater when medial gastrocnemius is loaded alone (Arndt et al., 1999).

Investigation of differential contributions of superficial and deep plantarflexors is challenging and leads to uncertainties due to the estimations and assumptions that are involved. While in vivo studies are scarce, surface electromyography (SEMG)

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provides a convenient and non-invasive tool for studying skeletal muscle activation (Merletti and Lo Conte, 1997) and the contribution of individual TS components to the Achilles tendon force during functional tasks (Gregor et al., 1991).

One of the limitations of the SEMG method is that it provides information about muscle activity only from superficial regions, which may not represent the whole muscle (Knight and Kamen, 2005). To study the whole muscle function, positron emission tomography (PET) enables non-invasive investigation of muscle glucose uptake as a measure of muscle activation (Nuutila and Kalliokoski, 2000; Kalliokoski et al., 2007; Tashiro et al., 2008). Since skeletal muscle glucose uptake rises in parallel with exercise intensity, it reflects muscle's metabolic activity (Kemppainen et al., 2002). High resolution PET, combined with tracers like [$^{18}$F]-Fluorodeoxyglucose ([$^{18}$F]-FDG), has been employed to image and quantify glucose uptake as a result of exercise in healthy tendons (Kalliokoski et al., 2005; Bojsen-Møller et al., 2006) and skeletal muscles (Hannukainen et al., 2005; Kalliokoski et al., 2007; Bojsen-Møller et al., 2010a; Heinonen et al., 2012; Rudroff et al., 2013).

Despite recent advances in PET imaging which enable assessment of muscle use during plantarflexion, no reports on the attempts to validate it against EMG have surfaced thus far. Although both SEMG and PET provide important insight into muscle behavior during exercise, no study to-date has incorporated them to investigate the behavior of ankle plantarflexors in voluntary contractions. Therefore, the purpose of this study was to evaluate plantarflexor muscle use during submaximal isometric contractions by both SEMG and PET. Specifically, we were interested whether the electrical and metabolic measures of muscle activity are comparable in describing the relative contribution of superficial (TS) and deep plantarflexors. Since FHL is the most important deep plantarflexor (Klein et al., 1996), and the only deep muscle accessible for both SEMG and PET, it was considered to represent the deep plantarflexors.

## 2. Materials and methods

### 2.1. Subjects

Twelve healthy volunteers were recruited for the study through public advertisements. These included eight males and four females with no history of a major leg injury over the past 12 months. The mean age, height, and body mass were 27.3 ± 4.2 (21–34) yrs, 173.8 ± 4.6 (163–180) cm, and 67.7 ± 6.4 (59–78) kg respectively. Informed written consent, following the explanation of the procedures and the risks involved, was obtained from all participants before the testing. The study protocol was approved by the Ethics Committee of the Hospital District of South-Western Finland and conformed to the Declaration of Helsinki.

### 2.2. Experimental protocol

Each subject took part in a series of tests at the Turku PET Centre, University of Turku, Finland. A diagram of the experimental design is given in Fig. 1. All components of the study were carried out on the same day for a subject. Participants were required to fast for at least 8 h prior to the PET scans. At the beginning, anthropometric measurements were obtained which included body mass, height, and leg length readings.

*Subject preparation* comprised shaving, abrading, and cleaning of skin for surface electromyography (SEMG), placement of electrodes on both legs, securing an electronic goniometer to the ankle. In addition, catheters were inserted into the antecubital veins in both arms: one for venous blood sampling and the other for [$^{18}$F]-FDG tracer injection. This was followed by positioning of the subject in the exercise apparatus for force and SEMG measurements. Subjects were allowed to familiarize themselves with the task by performing submaximal isometric plantarflexion contractions with each leg. After a warm-up, three trials of isometric plantarflexion maximal voluntary contractions (MVC), separated by 90 s rest period, were recorded individually from each leg. The highest of the three trials was selected for calculation of submaximal force target level that was subsequently used during the exercise protocol.

#### 2.2.1. Exercise protocol

Each set of the exercise protocol comprised five, 5-s unilateral "constant-force" submaximal isometric plantarflexion contractions, separated by a 5-s rest period. This was accomplished alternately, one leg at a time. Subjects performed the task while sitting on a seat placed on the floor with knees in full extension, hips in 90° of flexion, and ankle in neutral position (Fig. 2). The target force level selected for this task was 30% of the MVC. Subjects received visual feedback of the plantarflexion force on a monitor in front of them. After 2 sets of warm up contractions for both legs, about 150 MBq of [$^{18}$F] FDG tracer was infused and subsequently 10 sets of 5-s isometric contractions were performed, five repetition each, for both legs. Thus the total time of exercise and rest before tracer injection was about 6–7 min and the submaximal exercise protocol lasted for about 15 min post-injection. Blood sampling for plasma radioactivity assessment was carried out repeatedly from the time of tracer injection until cessation of the PET scan.

Immediately after the exercise bout, the subject was moved to the PET scanner on a wheelchair in order to minimize additional use of leg musculature. Magnetic Resonance Imaging (MRI) was performed after the PET scanning.

### 2.3. SEMG electrode placement

For triceps surae muscle, conventional bipolar SEMG silver-silver chloride Ambu *BlueSensor* N electrodes (*Ambu* A/S, Ballerup,

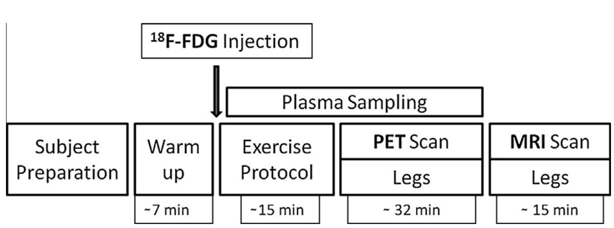


**Fig. 1.** Schematic diagram of the experimental protocol.

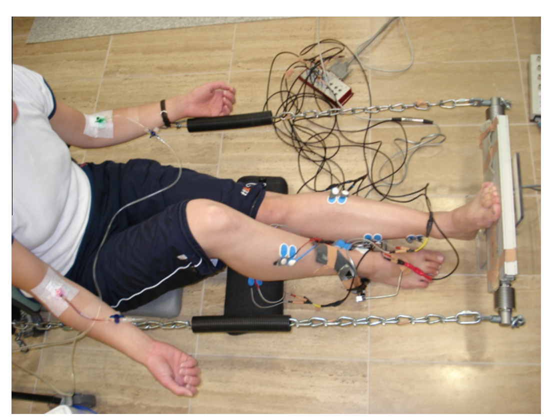

**Fig. 2.** Experimental setup. The subject is pressing with her left foot against the force transducer during a submaximal contraction. Intravenous catheters can be seen on both arms for blood sampling and tracer injection. Also visible are some of the SEMG electrodes connected to the acquisition device and an electronic goniometer around the right ankle.