Human Movement Science 50 (2016) 30–37

Contents lists available at ScienceDirect

Human Movement Science

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

Full Length Article

Selective activation of lower leg muscles during maximum voluntary isometric contractions

Marco Hagen PhD [a,*], Gerrit Schwiertz BSc [a], Karl B. Landorf PhD [b,c], Hylton B. Menz PhD [b], George S. Murley PhD [b]

[a] Biomechanics Laboratory, Institute of Sport and Movement Sciences, University Duisburg-Essen, Gladbecker Str. 182, 45141 Essen, Germany
[b] Discipline of Podiatry and Sport and Exercise Medicine Research Centre, School of Allied Health, La Trobe University, Bundoora, VIC 3086, Australia
[c] Department of Allied Health, Melbourne Health, 300 Grattan St, Parkville, VIC 3050, Australia

ARTICLE INFO

Article history:
Received 13 March 2016
Revised 2 September 2016
Accepted 3 October 2016
Available online 7 October 2016

Keywords:
Muscles
Electromyography
Joint axis
Agonist
Synergist
Foot posture

ABSTRACT

The pronators and supinators play a key role in the medio-lateral stability of the ankle joint complex (i.e. talo-crural and subtalar joints). We hypothesized that each shank muscle has a specific activation pattern determined by its anatomical course around the axes of the subtalar and talo-crural joints. A secondary objective was to examine the effect of foot posture on these activation patterns. Forty-nine young adults (25 normal-arched feet, 24 flat-arched feet) performed maximum voluntary isometric contractions against manual resistance in four movement directions: plantarflexion (PF), dorsiflexion (DF), pronation (PRO) and supination (SUP). Electromyographic activity was recorded from tibialis posterior (TP) and peroneus longus (PL) with intramuscular electrodes, and gastrocnemius medialis (GM) and tibialis anterior (TA) with surface electrodes. When compared to their agonist function, all muscles were co-activated at significantly lower levels in their synergistic function (GM: 23% during SUP, TA: 72% during SUP; TP: 42% during PF, PL: 52% during PF) ($p < 0.001$). A significant interaction between foot posture and contraction type was evident for TA. During isometric contractions, the electromyographic activity of the shank muscles is geared to their biomechanical advantage according to their position relative to the subtalar and talo-crural joint axes.

1. Introduction

Muscles that cause pronation and supination of the foot play a key role in the medio-lateral stability of the ankle joint complex. For example, in the prevention of recurrent lateral ankle sprains, specific pronator strength training is recommended to counteract peroneal muscle weakness (Tropp, 1986; Willems, Witvrouw, Verstuyft, Vaes, & de Clercq, 2002). Doing so enhances the pronator-to-supinator strength-ratio (Baumhauer, Alosa, Renström, Trevino, & Beynnon, 1995; Yildiz et al., 2003) and regulates inappropriate foot positioning before ground contact (Konradsen, 2002). In contrast, strengthening the supinators increases the anti-pronator capacity of the deep plantar flexors (tibialis posterior, flexor

Abbreviations: EMG, electromyography; GM, medial gastrocnemius; PL, peroneus longus; TA, tibialis anterior; TP, tibialis posterior; MVIC, maximum voluntary isometric contraction; DF, dorsiflexion; PF, plantarflexion; PRO, pronation; SUP, supination.

* Corresponding author.
E-mail addresses: marco.hagen@uni-due.de (M. Hagen), gerrit.schwiertz@stud.uni-due.de (G. Schwiertz), k.landorf@latrobe.edu.au (K.B. Landorf), h.menz@latrobe.edu.au (H.B. Menz), g.murley@latrobe.edu.au (G.S. Murley).

http://dx.doi.org/10.1016/j.humov.2016.10.002
0167-9457/

hallucis longus and flexor digitorum longus) (Hagen, Lescher, Gerhardt, Felber, & Hennig, 2010), which is potentially beneficial in the prevention of running-related overuse injuries related to excessive foot pronation (Feltner et al., 1994; Hintermann & Nigg, 1998).

Due to the orientation of the axis of the subtalar joint, pronation and supination movements have components in all three cardinal planes. In the non-weightbearing position, pronation is described as simultaneous calcaneal eversion with foot abduction and dorsiflexion, while supination is a combination of calcaneal inversion, foot adduction and plantarflexion (Edington, Frederick, & Cavanagh, 1990). Each shank muscle, that crosses the rearfoot complex, acts as a plantar or dorsiflexor of the talo-crural joint and as a pronator or supinator of the subtalar joint.

Triceps surae, tibialis anterior (TA), tibialis posterior (TP) and peroneus longus (PL) are considered the prime movers; that is, the muscles that present the main plantarflexion, dorsiflexion, supination and pronation muscle moments, respectively. When developing exercise programs it is necessary to know in which movement plane the target muscles have to be stimulated to increase strength. For instance, the deep plantarflexors of the shank (TP, flexor hallucis longus and flexor digitorum longus muscles) are plantarflexors as well as supinators of the foot. Anatomical studies have shown that TP, whose tendon uses the medial malleolus as a fulcrum, has a 2.4-fold supination lever arm as compared to the more voluminous supinators – soleus and gastrocnemius (Klein, Mattys, & Rooze, 1996). Hence, TP reaches nearly the same supination capacity as soleus and gastrocnemius (Silver, de la Garza, & Rang, 1985). As shown by Hagen et al. (2010), strengthening TP by applying supination resistance training enhances the medial stability of the ankle joint complex, while traditional plantar flexor training does not. The authors concluded that, compared to specific supinator training, non-specific exercises like traditional plantarflexor training might not stimulate TP sufficiently because the dominant triceps surae may 'overpower' the smaller deep plantarflexors. As a consequence, the higher-threshold motor units of TP would not be exceeded and the likelihood of muscle strength enhancement of TP would be reduced.

To our knowledge, there is no study that has compared the activation patterns of shank muscles during resisted isometric plantarflexion, dorsiflexion, pronation and supination. Each of these isolated movements requires complex intermuscular coordination due to the anatomy of the talo-crural and subtalar joint axes, which is based on the meta-organisation principle (Pellionisz & Llinás, 1985). This suggests that the interaction of motor output (muscle moment) and proprioception is coordinated within the central nervous system, which regulates the activation of the target muscles according to the demands of the motor action. As shown by Bergenheim, Ribot-Ciscar, and Roll (2000), each shank muscle has a specific preferred sensory direction, within which it is capable of sending sensory information to the central nervous system. Thus, it may be speculated that anatomical differences, e.g. variable lever arm lengths of TP and gastrocnemius, are transferred into different activation levels when these muscles are activated during resisted plantarflexion and supination movements. Previous studies (Nakazawa, Kawakami, Fukunaga, Yano, & Miyashita, 1993; Van Zuylen, van Velzen, & Denier van der Gon, 1988) found that the activation of the brachioradialis muscle during an isometric contraction depends on the anatomical elbow angle. It was concluded that muscle activation depends on the mechanical advantage in such a way that the muscle with the larger mechanical advantage receives the larger activation. Similarly, Butler, Hudson, and Gandevia (2014) showed that the activity of the inspiratory muscles is higher in the muscles with the greatest mechanical advantage geared by a principle of "neuromuscular matching" in which neural drive is. It is likely that a similar principle applies to leg muscles.

Therefore, the primary aim of this study was to determine if the level of activation is lower for each lower limb muscle when functioning as a synergist rather than an agonist. A secondary aim was to compare the activation patterns of the prime movers (gastrocnemius medialis (GM), TP, TA, PL) during maximum voluntary isometric contractions (MVIC) between flat- and normal-arched foot feet, as we previously found that foot posture influences muscle activity during walking (Murley, Menz, & Landorf, 2009a). In a flat-arched foot, the spatial location of the subtalar joint axis is medially translated (Kirby, 2001), which might change the muscle lever arm lengths and, following our first hypothesis, lower leg muscle activation.

2. Materials and methods

2.1. Participants

Forty-nine adults aged 18–47 years were recruited to this study. Of these, 25 had normal-arched feet (12 male and 13 female) and 24 had flat-arched feet (13 male and 11 female). Participant characteristics are presented in Table 1. A foot screening protocol that included both clinical and radiographic measures to classify foot posture was used to recruit participants with normal- and flat-arched feet (Murley, Menz, & Landorf, 2009b). This protocol was derived from normative foot posture values for two clinical measurements (the arch index and navicular height) and four angular measurements obtained from antero-posterior and lateral X-rays (talus-second metatarsal angle, talonavicular coverage angle, calcaneal inclination angle and calcaneal-first metatarsal angle) (Murley et al., 2009b).

The participants were without symptoms of macrovascular disease (e.g. angina, stroke, peripheral vascular disease), neuromuscular disease, or any biomechanical abnormalities that affected their ability to walk. Ethical approval was obtained for the study from the La Trobe University Human Ethics Committee (Ethics ID: FHEC14/016) and the study was registered with the Radiation Safety Committee of the Victorian Department of Human Services. The X-rays were performed in accordance with the Australian Radiation Protection and Nuclear Safety Agency Code of Practice for the Exposure of Humans to Ionizing Radiation for Research Purposes. All subjects were informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document to participate in the study.