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How much does the human medial gastrocnemius muscle contribute to ankle torques outside the sagittal plane? ☆

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ABSTRACT

Ankle movements in the frontal plane are less prominent though not less relevant than movements in the plantar or dorsal flexion direction. Walking on uneven terrains and standing on narrow stances are examples of circumstances likely imposing marked demands on the ankle medio-lateral stabilization. Following our previous evidence associating lateral bodily sways in quiet standing to activation of the medial gastrocnemius (MG) muscle, in this study we ask: how large is the MG contribution to ankle torque in the frontal plane? By arranging stimulation electrodes in a selective configuration, current pulses were applied primarily to the MG nerve branch of ten subjects. The contribution of populations of MG motor units of progressively smaller recruitment threshold to ankle torque was evaluated by increasing the stimulation amplitude by fixed amounts. From smallest intensities (12–32 mA) leading to the firstly observable MG twitches in force-plate recordings, current pulses reached intensities (56–90 mA) below which twitches in other muscles could not be observed from the skin. Key results showed a substantial MG torque contribution tending to rotate upward the foot medial aspect (ankle inversion). Nerve stimulation further revealed a linear relationship between the peak

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torque of ankle plantar flexion and inversion, across participants (Pearson $R > .81$, $p < .01$). Specifically, regardless of the current intensity applied, the peak torque of ankle inversion amounted to about 13% of plantar flexion peak torque. Physiologically, these results provide experimental evidence that MG activation may contribute to stabilize the body in the frontal plane, especially under situations of challenged stability.

1. Introduction

Movements of the foot are often conceived as occurring predominantly in the sagittal plane; these movements are termed dorsal flexion and plantar flexion. Less prominent, though not less relevant, lateral foot movements are equally frequently observed with respect to those occurring in the sagittal plane (e.g., when walking on uneven terrain, taking a side step or shifting weight laterally). Inappropriate control of ankle stability in the frontal plane, may explain the high incidence of lateral ankle sprains (Fong, Hong, Chan, Yung, & Chan, 2007). Lateral ankle motion might occur in the frontal and transverse planes, though both the talocrural and subtalar joints seem more predisposed to movements in the frontal plane (Sheehan, 2010). Given the relatively longer than wider feet dimension, lateral stabilization of the body possibly demands marked control of ankle movement in the frontal plane under circumstances of challenged stability (e.g., stance phase of gait; Cappellini, Ivanenko, Dominici, Poppele, & Lacquaniti, 2010; Henry, Fung, & Horak, 1998). Specific quantifications on the active contribution of leg muscles to ankle torques in the frontal plane, however, are currently unknown.

The pinnate gastrocnemius muscles are possible candidates for the active control of ankle lateral motion (Giordano, Segal, & Abelew, 2009; Lee & Piazza, 2008). Due to the strong relationship between ankle plantar-dorsal flexion and activation of gastrocnemius, these muscles are ubiquitously regarded as ankle extensors. Studies on muscle architecture and activation, nevertheless, suggest a potentially large contribution of these muscles to lateral ankle torques. For instance, the medial (MG) and lateral gastrocnemius attach obliquely to the Achilles tendon (Blitz & Eliot, 2007). Additionally, *in-vivo* estimates indicate significant values of gastrocnemius moment arms in the frontal plane (Lee & Piazza, 2008). Direct evidence from the cat gastrocnemius, indeed, supports the active production of torque outside the sagittal plane (Carrasco, Lawrence, & English, 1999; Lawrence, Nichols, & English, 1993). In humans, active torques in the frontal plane have been inferred from surface electromyograms (EMGs) detected in response to cutaneous reflexes (Zehr, Stein, & Komiyama, 1998), to postural sways occurring in quiet standing (Vieira, Windhorst, & Merletti, 2010) and to surface perturbations applied to subjects during static (Torres-Oviedo & Ting, 2007), as well as during more dynamic conditions, such as walking (Nieuwenhuijzen & Duysens, 2007) and upon landing impacts (Grüneberg, Nieuwenhuijzen, & Duysens, 2003). It seems, therefore, of relevance to estimate the amount of active ankle torque produced in the frontal and sagittal planes. Previously, we used a grid of electrodes to investigate the synchronization of postural EMGs in the gastrocnemius muscles (Vieira, Windhorst, et al., 2010). On occasions, we observed that both gastrocnemius heads were activated synchronously across individual forward sways. On other occasions, medial and lateral heads showed different activation timings. Strikingly, events of asynchronous activation between the two heads were associated to forward sway deviated laterally. This leads us to consider the controversial possibility that the human gastrocnemius muscle produces substantial ankle torque in the frontal plane, likely associated with the stabilization of lateral bodily sways.

In the current study, we used nerve electrical stimulation to test whether MG torques have significant components outside the sagittal plane. With a markedly small stimulation electrode, we aimed to stimulate the nerve branch serving exclusively the MG muscle (Wolf & Kim, 1997) and thus to quantify the electrically elicited twitches in different planes. Previously, Giordano et al. (2009) quantified the amplitude of plantar flexion and inversion moments produced by electrically elicited