O119- Soleus is not responsible for "Push-off", during normal gait

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Much debate exists in the literature about the functional role of the soleus (SOL) muscle during gait. Most results obtained from inverse and forward dynamics acknowledge the role of SOL in "Push-off"; while those obtained after tibial nerve block seem to undermine it. The role of equilibrium control has been contrasted by that of SOL pushing off the ground. In order to determine whether SOL is responsible for push-off or equilibrium control, the gait initiation paradigm was utilised, where subjects must initiate gait without (Control) and with an added load. The added load of 30% bodyweight increased propulsion forces. SOL EMG activity remained constant regardless of the increase in propulsive forces. These results show that the role of SOL is not responsible for push-off but to maintain equilibrium control during normal gait.
Keywords: Equilibrium Control, Gait, Push-off, Soleus.

INTRODUCTION:

In human gait, equilibrium control adds up as a prerequisite to the generation of propulsion forces in order to resist gravity. Plantar-flexor muscles acting about the ankle joint during single stance appear to be most adequate for propelling the body by creating the necessary torque as the foot is constrained to the floor. However, under dynamic conditions, the postural role of the plantar flexors, notably the soleus (SOL) muscle, would be enhanced and could indirectly but efficiently contribute to whole-body forward displacement by restraining forward tibial rotation and stabilising the knee joint (Sutherland et al, 1980), thereby keeping the body from falling throughout single stance.

Initially, Winter (1983) interpreted the existing covariation between SOL EMG activity and walking velocity as "Push-off". This hypothesis was later accepted by modelling the net ankle moment (Neptune et al, 2001). However, blocking the tibial nerve (i.e paralysing ankle flexors) showed an increase in forward velocity of the centre of mass (CoM) during mid to late stance (Sutherland et al, 1980). Our goal is to extricate the role of SOL during single stance. In order to do so, the gait-initiation paradigm (Berniere et al, 1981) was used while walking normally (Control) and with an added load. If the walking velocity remains unchanged between the unloaded and loaded condition, then greater propulsion force must be generated in the loaded condition with respect to control. Our hypothesis is that the main role of SOL is to maintain equilibrium control and not "Push-off". If SOL electromyography (EMG) measurement do not change with the increase of propulsive force in the loaded condition for a constant walking velocity then our hypothesis is verified. Therefore, SOL is mainly activated to control the vertical fall of the centre of mass during single stance.

METHODS

Seven healthy volunteers (age 34 ± 11.2 yrs, height 1.73 ± 0.08 cm, weight 67.69 ± 9.38 Kg) took part in the experiment after giving their written informed consent as required by the Helsinki declaration and the EA 4042 local Ethics committee. The cumulative mass of the added load was 20 Kg. It was positioned and distributed homogenously roughly around the CoM position. The added load increased the bodyweight (BW) by a range of 25% to 33%, depending on the subject. Unloaded and loaded trials will be referred to as N and N+20, respectively, in the text. The mean step length of the subjects collected during practice trials was drawn on the platform. They were then instructed to readjust their step length in order to reproduce the same walking velocity. Data was collected from a force platform (0.90 m x 1.80 m, AMTI, Massachusetts-USA) and was synchronised with SOL EMG data (Aurion Zerowire EMG, Milan-Italy) at a sampling frequency of 1000 Hz, throughout the entire first step.

RESULTS

The instant of foot off, and foot contact as well as the walking velocity and step length of the first step did not show any significant differences between the unloaded and loaded trials (see Table 1).

Table 1: Kinematic variables measured for the first step

	Foot Off (s)	Foot Contact (s)	Walking Velocity (m/s)	Step Length (m)
N	0.524 ± 0.091	0.881 ± 0.105	1.12 ± 0.165	0.59 ± 0.07
N+20	0.558 ± 0.084	0.913 ± 0.088	1.15 ± 0.192	0.62 ± 0.08

Peak antero-posterior ground reaction force (pAP-GRF), which occurs slightly after foot contact, was significantly higher in the N+20 condition [F(1,6) = 30.1 ; P=0.0015]. The surface area of the rectified and normalized SOL EMG from onset to offset, which gives the unitless average EMG intensity (iSOLn) did not change between N and N+20 conditions [F(1,6) = 0.02 ; P=0.89] (see Figure 1).

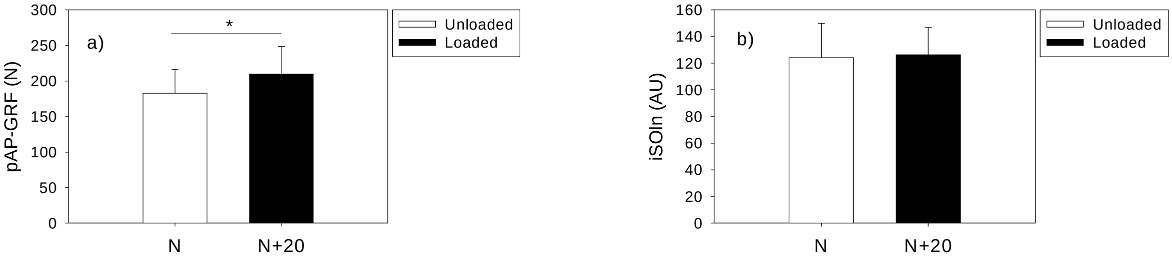

Figure 1: Mean and standard deviation of the measured Peak A/P force (a) and average SOL EMG intensity (b), for the two conditions N and N+20.(*: P<0.05)

DISCUSSION-CONCLUSION

For the same walking velocity, EMG activity remained constant between the control and the loaded series while stronger propulsive forces were generated during the loaded trials. This shows clearly that SOL does not play a role in push-off. Since both the soleus and the gastrocnemii work on ankle plantar flexion and that the activation and deactivation of both muscles are highly correlated in time during single support, we believe that neither participate in generating propulsion force. However, the gastrocnemii are biarticulate and might be controlling knee extension while SOL restrains tibial advancement. Future work might be useful to determine this hypothesis whatsoever. We believe that our findings confirm the pioneer investigation of Cavagna & Franzetti (1986), who stated that the fall of CoM during the single stance phase is sufficient to transform potential energy into forward kinetic energy during normal level walking. In conclusion, while gravity is responsible for generating propulsion force, SOL activity controls the fall of CoM during single support stance.

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