Recruitment of the plantar intrinsic foot muscles with increasing postural demand

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SUMMARY
An electromyographic investigation of the deep plantar intrinsic foot muscles was conducted. Here we provide evidence that increased recruitment in these muscles occurs with increasing postural difficulty. In addition, we report that recruitment of these muscles during single leg stance is correlated with medio-lateral sway, suggesting that these muscles act to stabilise medial movements of the foot and leg.

INTRODUCTION
Electromyographic (EMG) studies have reported that the plantar intrinsic foot muscles act to stabilise the foot in propulsion and may aid in supination of the sub-talar joint [1,2]. Furthermore, weakness in these muscles has been described to be related to poor balance and an increased risk of falling [3]. Whilst a relationship between falls, balance and weakness of the plantar intrinsic foot muscles has been posed, it remains unclear what role these muscles play in postural control.

Therefore, the aim of this study was to measure and describe the individual activation patterns of the deep plantar intrinsic foot muscles during two quiet standing tasks with increasing postural difficulty.

METHODS
Ten healthy participants attended testing sessions on two separate occasions. The first occasion was to familiarise the subject to the required balance tasks, while the second was to collect EMG activity from the deep plantar intrinsic muscles while performing the balance tasks. Bi-polar fine-wire electrodes (0.051mm stainless steel, Teflon coated) with a detection length of 2mm and inter-electrode distance of approximately 2mm were inserted under ultrasound guidance into the bellies of the abductor hallucis (AH), flexor digitorum brevis (FDB) and quadratus plantae (QP) muscles. The size of the active area and separation between sites was chosen to give the best chance of recording representative activity from each muscle, while reducing the possibility of cross-talk from nearby muscles. Further confirmation of electrode placement was performed in two subjects using Computed Tomography.

Two quiet standing postures, with increasing balance difficulty, were used to appraise any relationship between postural sway and intrinsic foot muscle activity (standing quietly on two legs, double leg stance, DLS; and one leg, single leg stance, SLS, Fig 1). The DLS task was performed once only, for a 120-s period. The SLS task was performed three times, each for a 60-s period. All tasks were performed with the subject standing relaxed on a force platform, facing forward with their eyes open. Force platform signals were used to calculate movements of the centre of pressure (COP) in both the antero-posterior (AP) and medio-lateral (ML) directions and were synchronised in time with the recorded EMG data.

Figure 1. Subject performing the single leg balance condition, and a representative sample of the raw intra-muscular electromyographic data recorded from flexor digitorum brevis (FDB), quadratus plantae (QP) and abductor hallucis (AH).

COP path excursion in both AP and ML directions was calculated for all tasks over the entire standing period. Mean COP velocity for the combined AP and ML directions was also determined. Mean EMG root-mean-square (RMS) amplitude was calculated over the duration of both the DLS and SLS trials, in addition to an unloaded condition (relaxed, REL). EMG data was additionally rectified, low pass filtered and down-sampled to enable cross-correlations between the COP (ML and AP) and EMG waveforms. Cross-correlations were also performed between the three processed inter-muscular EMG waveforms.
RESULTS AND DISCUSSION
SLS induced a higher postural demand as evidenced by a significantly greater mean COP velocity in SLS than for the DLS task (0.24 ms$^{-1}$ versus 0.06 ms$^{-1}$, $P\leq0.05$, respectively). Mean EMG RMS amplitudes for AH, FDB and QP were significantly higher in the SLS task compared to DLS task (Fig 2).

![EMG RMS (mV)](image)

Figure 2. Shows the mean EMG RMS amplitude + SEM, during resting unloaded (REL), double leg stance (DLS) and single leg stance (SLS) tasks. * indicates that the RMS amplitude was significantly higher in all muscles for SLS compared to both DLS and REL ($P\leq0.05$).

Rectified and smoothed EMG waveforms were moderately to strongly correlated with postural sway (Fig 3). Recruitment of QP ($r=0.39$), FDB ($r=0.40$) and AH ($r=0.62$) were correlated to ML sway during the SLS task, with increased recruitment during medial shifts of the COP. No correlation was evident for AP sway and muscle recruitment (all $r<0.2$) nor were there any significant COP-muscle correlations during the DLS task (all $r<0.2$). Strong correlations were observed between all muscles during both the SLS and DLS tasks (all $r>0.85$).

![Waveform correlations for medio-lateral COP (ML), abductor hallucis (AH), flexor digitorum brevis (FDB) and quadratus plantae (QP) during single leg balance (SLS) for a representative subject. Moderate – high correlations between ML excursion of COP and muscle recruitment in AH, FDB and QP (all $r>0.4$). High inter-muscular correlations are also observed between all muscles (all $r>0.85$).](image)

Figure 3. Waveform correlations for medio-lateral COP (ML), abductor hallucis (AH), flexor digitorum brevis (FDB) and quadratus plantae (QP) during single leg balance (SLS) for a representative subject. Moderate – high correlations between ML excursion of COP and muscle recruitment in AH, FDB and QP (all $r>0.4$). High inter-muscular correlations are also observed between all muscles (all $r>0.85$).

CONCLUSIONS
This is the first study to describe the role of the plantar intrinsic foot muscles as postural stabilisers, with the use of ultrasound guided intra-muscular EMG. Our results indicate that recruitment of the plantar intrinsic foot muscles is regulated in response to postural demand. These muscles respond in a synchronised manner to stabilise the leg/foot during medio-lateral movements and are therefore important in balance control.

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