INTRODUCTION
The intrinsic muscles of the foot have a primary role in stance stabilization. The importance of these muscles for dynamic control of the medial longitudinal arch (MLA) has been demonstrated in the literature [5,6,8,9] as has their training potential for rehabilitation and prevention of injury been emphasised [5].

The abductor hallucis (m.AH) represents the largest superficial foot muscle and has been shown to elevate the arch in-vitro when hallux range of motion was restricted [9], and depress the arch when paralysed following tibial nerve anaesthesia [5]. Moreover, an acute session of neuromuscular electrical stimulation (NMES) elicited prolonged synaptic facilitation resulting in lasting postural adjustments [6].

NMES can be enhanced by way of high-frequency low-intensity wide pulse stimulation (WPS). WPS appears to activate motor units in accordance with the normal physiological manner, and concomitantly induce post-tetanic potentiation and/or plateau potential phenomena [3]. This technique has previously only been addressed during recumbent tasks. Whether this reported neural plasticity produces a substantial functional effect in an activity such as walking, when reflexes are both task and phase dependent, remains unknown. In order to understand this adaptation from a biomechanical perspective, recent advancements in vector coding techniques [2] allow interpretation of kinematic coupling through phasic coordinate strategies between adjacent segments. Such strategies are able to identify characteristics of a stable foot during the stance phase of gait, specifically anti-phase forefoot (FF) - rearfoot (RF) motion and a decreased MLA angle [2].

The aim of the study was to investigate an acute session of NMES (WPS) applied to m.AH on forefoot (FF)-rearfoot (RF) kinematic coupling patterns. Specifically, it was hypothesised that this would induce greater stability during the mid- and late stance periods of the gait cycle.

METHODS
Ten subjects (5 male, 5 female, 30.6 ± 5.2yrs, 172.7 ± 8.7cm, 73.0 ± 17.4kg) performed five walking trials at self-selected speed before and after 10 x 15s trains of 2s alternating frequency (20Hz-100Hz-20Hz). Square wave (1ms) pulses were delivered by a constant-current stimulator (DST7A, Digitimer, UK) and driven by a custom written sequencer through an A/D convertor (micro1401, CED, UK) at 150% of motor threshold. Stimulation was performed on the left foot during standing while the right served as the control. Two minutes seated rest was given between each stimulation train. Subjects were accustomed to the protocol prior to performing the intervention, which included motor point determination and threshold verification of m.AH [4].

Surface EMG of both m.AH using active bipolar electrodes (1mm width, 10mm pole spacing; Delysis Inc., USA) were pre-amplified (x1000), sampled at 2kHz and recorded for approximately 60s for each train to ascertain baseline and post-stimulation activity. Each signal was high-pass filtered at 20Hz and subsequently decomposed into spectral density with a bin resolution of 0.5023Hz and median frequency (MDF) measured.

Kinematic data collection and analysis was consistent with previously reported methods [2]. Nine retro-reflective markers (12mm diameter) defined a multi-segment foot model. Kinematic (8 x Oqus-3, Qualisis, Sweden) and kinetic (Kistler, UK) data were captured synchronously (500Hz) and processed in Visual 3D (C-Motion Inc, USA). Segmental angles were calculated relative to a fixed laboratory coordinate system (XYZ). Segmental angle-angle plots were derived in the sagittal, frontal and transverse planes of motion. Coordination was inferred from a coupling angle (γ) subtended from a vector adjoining two successive time points relative to the right horizontal, where 0 ≤ γ ≤ 360° [2] (Figure 1). The summations of the frequencies of γ for each phase/plane/time were plotted as histograms. MLA was calculated in accordance with methods described [2].

Figure 1. RF motion is plotted relative to FF for each percentile of stance. Coordination is classified as anti-phase (112.5°≤γ≤157.5°; 292.5°≤γ≤337.5°), in-phase (22.5°≤γ≤67.5°; 202.5°≤γ≤247.5°), proximal dominance (0°≤γ≤22.5°; 157.5°≤γ≤202.5°; 337.5°≤γ≤360°) and distal dominance (67.5°≤γ≤112.5°; 247.5°≤γ≤292.5°).

Data were tested for normal distribution and then analysed using a two factor repeated measures ANOVA (α = 0.05).
RESULTS
A statistically significant increase (p=0.014; effect size: 51%) in frontal plane FF-RF anti-phase motion of the experimental foot was observed during mid-stance as a result of the NMES (Figure 2). However, no difference (p>0.05) was observed between the control and experimental medial longitudinal arch angle during the instant corresponding with minimum GRF. No other phase/plane/time differences were found (p>0.05).

No effect (p=0.965) was observed for a positive shift in median frequency (MDF) of the EMG spectrum following NMES. Of the five subjects that demonstrated a kinematic response (>95%CI: -0.4 ± 3.62; Figure 2), only two demonstrated plateau potential phenomena during NMES (Figure 3).

DISCUSSION
An acute session of NMES had a significant effect on frontal plane FF-RF anti-phase coupling during the middle (34-66%) section of stance phase. This finding in part supports our hypothesis of inducing increased stability to foot function [2] during this critical period. No main effect was observed for this parameter during late stance however. The data in fact points to more of an in-phase relationship, which is akin with the literature [2] and potentially corroborates the evidence that the intrinsic foot muscles supersede the influence the plantar aponeurosis in maintaining the windlass mechanism [1].

NMES applied to m.AH during standing has been shown to raise the MLA as a result of insufficient abduction of the metatarsophalangeal joint of the hallux [9]. If we accept that this did indeed occur during stimulation in the present study then a potential short-term plasticity as a result of electrical stimulation, which has been reported [7], might well have impacted on the divergent axes of the transverse tarsal joint, thereby enhancing increased stability of the foot [8]. Our data appear to support this assumption as the directional nature of anti-phase coupling (Figure 1) during mid-stance was consistent with RF inversion and the FF eversion.

The experimental intervention was derived from recent advancements in NMES (WPS) and its ability to maximize the sensory volley to the peripheral nervous system and therefore the synaptic recruitment of motoneurons [3]. In studies from this research group, plateau potential phenomena have consistently been reported. This was not the case in the present study with only two subjects demonstrating such excitability. The mechanism(s) behind this is/are difficult to explain. Previous studies were performed on recumbent subjects; it is plausible that the task-dependent nature of reflexes during stance might have induced inhibitory responses such as from GABAergic mechanisms [7]. In addition, three subjects demonstrated kinematic changes but no apparent plateau potential phenomena. Potentially this might reflect post-tetanic potentiation rather than the development of plateau potentials [3]. Finally, the strength of the reported effect size of our main finding would suggest further electrophysiological evidence is required to substantiate any claim that kinematic changes are a result of neural plasticity. Future work will address cortico-spinal excitation in response to high-frequency low-intensity wide-pulse stimulation and re-evaluate its application with reference to methods previously ascribed [3].

REFERENCES