

RELATIONSHIP BETWEEN ANKLE PLANTAR FLEXOR POWER AND EMG MUSCLE ACTIVITY DURING GAIT

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It is thought that the ankle power (A2) burst observed in human gait is solely generated by rapid concentric contraction of the ankle plantar flexors. Recent work, however, suggests that the return of elastic energy may play a role. This study investigated the temporal relationship between the maximum electromyographic activity (EMG) of the ankle plantar flexors and A2. The natural gait of eight young adults were recorded across level ground. Collectively, the maximum EMG of the Soleus, Gastrocnemius and Peroneus Longus fell 92 ms before A2. The period between maximum EMG and A2 were longer than the electromechanical delay reported in the literature (e.g. 8 to 45 ms). It is reasonable to conclude, therefore, that it may be partly produced by the return of elastic energy stored in the musculotendinous units of the plantar flexors during the A1 absorption period.

KEY WORDS: ankle plantar flexors, ankle power generation, emg.

INTRODUCTION: The generation of ankle power (A2) during late stance in human gait is important for forward progression of the body, trunk stabilization and leg swing initiation ([Winter 1983](#); Judge, Davis & Ounpuu, 1996a; Riley, Croce & Kerrigan, 2001; Cofré, Lythgo, Morgan & Galea). It has been identified as a strong predictor of step length and walking speed which are key measures of gait functionality in populations such as older adults (e.g. Judge et al, 1996a). It is important to identify the neuromuscular mechanisms behind the generation of ankle power since it plays a critical role in human locomotion. Past studies investigating the mechanisms behind A2 power generation have not specifically examined the relationship between ankle plantar flexor muscle activity and the A2 power burst ([Ishikawa](#), Komi, Grey, Lepola & Bruggemann, 2005).

It is commonly thought that concentric contraction of the ankle plantar flexors is the main mechanism behind ankle power generation (Eng & Winter, 1995). A study by Ishikawa et al. (2005), however, suggests that the return of energy stored in the ankle plantar flexors musculotendinous units is an important mechanism behind A2. Energy return was found to occur at the same time as A2 in a group of young adults walking at natural cadence (gait speed $\approx 1.4 \text{ m}\cdot\text{s}^{-1}$). They found the electromyographic (EMG) activity of the soleus (SOL) and gastrocnemius (GM) muscles was significantly diminished at this point of the gait cycle. Recent work partly supports this idea by suggesting that concentric contraction of the GM muscle plays an important role in storing elastic energy in the Achilles tendon in late stance (Stewart, Postans, Schwartz, Rozumalski & Roberts, 2007).

Although studies have shown that ankle power generation increases with walking speed, other work has shown that the magnitude of the ankle moments generated in late stance remain relatively unaffected by walking speed (Riley, Croce & Kerrigan, 2001a; 2001b). Moreover, Ishikawa et al. (2005) found that ankle plantar flexor muscles reach maximum activation during late midstance or just prior to heel-off during gait. These findings support the idea that increased A2 power generation is not primarily achieved through increased plantar flexors activity but through increased angular velocity of the foot, possibly through the return of elastic energy stored in the ankle plantar flexors (Riley et al., 2001a; 2001b). It is reasonable to propose, therefore, that A2 power may not be solely produced by concentric muscle contraction but may be partly produced by the return of elastic energy stored in the Achilles tendon ([Stewart, Postans et al. 2007](#)). This storage of energy most probably occurs

during the power absorption period commonly known as A1 and reduces muscle work during gait (Neptune, Sasaki, & Kautz, 2008). The aim of this study was to investigate the relationship between A2 peak power generation and ankle plantar flexor muscles activity in a group of healthy adults when walking at self-selected speeds. It specifically investigated the timing of maximum EMG activity of the ankle plantar flexor muscles relative to the A2 power burst.

METHODS: Eight healthy young adults (31.0 ± 4.8 y; 1.67 ± 0.1 m; 66.3 ± 20.6 kg) participated in this study. Ethics approval was obtained from The University of Melbourne. Written informed consent was obtained from all participants. Exclusion criteria were any medical condition to affect gait. Bilateral data were recorded by an 8-camera VICON MX System (Oxford, UK) sampling at 500 Hz and three force plates (model OR6-7, AMTI, Watertown, MA) sampling at 2000 Hz embedded in the centre of a 12 m level walkway. The high sample rates were used to minimize the propagation of error along the kinematic chain ([McGibbon 2006](#)). Timing gates (NAM7R Takenaka Co., Ltd) positioned in the middle of the walkway (3 m apart) were used to record gait speed. EMG signals from the gastrocnemius lateralis (GL) and medialis (GM), soleus (SOL) and peroneus longus (PL) muscles in the right leg were recorded at 2000 Hz with an Aurion ZeroWire (Aurion S.r.l., Milan, Italy) 16 channel EMG system (CMRR=90 dB, SNR>50dB, 20 M Ω impedance). Dual electrodes with 10 mm separation were used (Myotronics Inc., WA, USA). Fifteen passive spherical reflective markers (14 mm diameter) were placed on known anatomical landmarks on the lower extremities (Vicon Plug-in-Gait marker set). A gait trial was considered successful if the entire foot landed within the bounds of an occluded force plate. Subjects completed 5 successful trials at self-selected speed. Prior to the trials, participants were given the following instruction: "Walk at your normal or comfortable speed". Kinetic and EMG data were extracted by Nexus software (Vicon, Oxford, UK). The Vicon Plug-in-Gait model (version 1.3.109, Oxford, UK) was used to calculate joint powers (Woltring filter, MSE=20). These data were processed with in-house software written in Igor Pro version 6.0.0.0 (Wavemetrics Inc., Oregon, USA) to extract peak joint powers and gait speed. Temporal events and periods for joint power measures were normalized to the period of stance (%ST). These include the occurrence of A1 and A2 peak powers and the onset of A2 power. EMG signals were initially rectified and filtered by a 10-500 Hz 6th order Butterworth band pass filter. EMG linear envelopes were then obtained by passing data through a 6th order Butterworth filter with a 6 Hz cutoff frequency. Descriptive statistics were calculated for all measures of interest. Temporal measures were normalized to stance time (%ST).

RESULTS: On average, the participants walked at 1.42 ± 0.02 m/s. Table 1 lists the descriptive statistics for the timing of EMG_{max} activity (SOL, GL, GM, and PL), A1 peak power absorption and the onset of ankle power generation relative to the point of A2 peak power generation. The table lists the timing as an absolute measure in milliseconds and as a percentage of the stance period (% ST). On average, EMG_{max} activity was found to occur 92 ms before A2. This equated to 15% of the stance period. At the onset of ankle power generation (onset of positive ankle mechanical work), average muscle EMG activity across all muscles was 88% of EMG_{max} activity. These activation patterns declined rapidly over the last 20% of stance and fell to 60% of maximum activation by the time of A2 (89% ST). Ankle power generation at the EMG_{max} activity of SOL and PL was 20% and 34% of the magnitude of peak A2 power generation respectively. Furthermore, ankle power generation at the EMG_{max} activity of the GM and GL was 0.8% and 11% of the magnitude of A2 peak power generation respectively.

DISCUSSION: Ankle peak power generation (A2) is known to be a strong predictor of step length and gait speed which are considered to be important measures of the gait functionality in populations such as the elderly (Judge et al., 1996a; Judge, Schechtman & Cress, 1996b). The mechanism behind A2 is thought to be the rapid concentric contraction of the ankle plantar flexor muscles in late stance (Eng & Winter, 1995). This study, however, found no synchrony between the maximum EMG activity of the primary ankle plantar flexors (SOL,

GM, GL, PL) and the A2 power burst. Collectively, the EMG_{max} activity of the SOL, GM, GL and PL muscles fell 92 ms before the A2 power burst.

Table 1: Descriptive statistics for the timing (relative to the point of A2 peak power generation) of EMG_{max} activity (SOL, GL, GM, PL), A1 peak power absorption and the onset of A2 ankle power generation. These measures were normalized to the period of stance.

Event	Time (ms)	Time (% Stance)
A1 Peak Power	147 (29)	24.2 (4.8)
A2 onset	82 (15)	13.6 (2.6)
SOL _{max} EMG	84 (52)	13.8 (8.8)
GL _{max} EMG	82 (36)	13.4 (5.9)
GM _{max} EMG	119 (64)	19.7 (10.8)
PL_{max} EMG	82 (110)	13.6 (19.0)

It is well known that there is a period of electromechanical delay (EMD) between muscle activation (EMG response) and muscle force output. This has been reported to fall around 11.6 ms for the ankle plantar flexor muscles (Nordez, Gallot, Catheline, Guevel & Hug, 2009). This shows that even when accounting for EMD, maximum EMG activity of the SOL, GL, GM and PL recorded in our study occurred well before the A2 power burst. It is also reasonable to propose that the delay between maximum ankle plantar flexor torque and A2 peak power falls around 40 to 50 ms (Schwartz, Rozumalski & Trost, 2008). This suggests that maximum EMG activity occurs well before maximum ankle plantar flexor torque. It is also possible that the cyclical muscle activation/deactivation dynamics of gait may partly account for the lack of synchrony between the EMG activity of the ankle plantar flexors muscles and A2. It may allow for better utilization of the energy stored in the Achilles tendon in late stance during gait (Neptune & Kautz, 2001).

During the period of A1 power absorption which occurs before the heel-off event in stance, the fall of the body's centre of mass is primarily controlled by eccentric contraction of the ankle plantar flexors (Winter, Eng & Ishac, 1995). During this period it is likely that elastic energy is stored in the Achilles tendon. Moreover, ankle power generation begins as the heel of the contralateral limb is grounded (opposite heel contact) and the body mass is transferred from the ipsilateral to the contralateral limb (Perry 1992). This allows the ipsilateral or trailing limb to generate power through concentric contraction of ankle plantar flexors leading to the onset of A2 power generation. After this onset, ankle plantar flexor muscle activity diminishes yet the A2 power generation continues to rise which probably reflects the return of elastic energy stored in the Achilles tendon.

During the A2 power period, the EMG activity of SOL and PL was greater than GL and GM. This is probably due to the fact that SOL, a monoarticular muscle, is the primary ankle plantar flexor whereas PL both plantar flexes and everts the foot during the push-off period. It is reasonable to conclude that SOL makes the greatest contribution to A2 power generation. On the other hand, GL and GM are biarticular muscles that plantar flex the ankle and flex the knee during the period of A2 power generation (around heel-off). This supports the idea that a major role of GL and GM (A1 absorption period) is to store elastic energy in the Achilles tendon that can be returned to assist A2 power generation (Neptune & Kautz, 2001; Stewart et al., 2007). It is reasonable to propose, therefore, that any reduction in A2 power as seen in older adult populations may result from either a reduced ability of the ankle plantar flexors to generate muscle power or a reduction in the capacity of these muscles to store and return elastic energy.

CONCLUSION: This study investigated the relationship between maximum EMG activity of ankle plantar flexor muscles (SOL, GM, GL, PL) and the A2 power burst in human gait. The period between maximum EMG activity and the A2 power burst were significantly longer (92 ms) than the electromechanical delay reported in the literature (8.5 to 44.9 ms). This shows

that A2 is not solely produced by concentric contraction of the plantar flexor muscles. It is likely that the return of elastic energy, stored in the musculotendinous units of the ankle plantar flexors during the A1 absorption period, plays a major role in propelling the leg into swing and advancing the body.

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