INVESTIGATING THE RELATIONSHIP BETWEEN JOINT COUPLING COORDINATION AND MUSCLE ACTIVITY DURING WALKING

Alex Ong[1], Lim Zixing[1], and Joseph Hamill[1,2,3]

[1]School of Sports, Health & Leisure, Republic Polytechnic, Singapore
[2]Biomechanics Laboratory, University of Massachusetts, Amherst, USA
Dept. of Physical Education & Sports Sciences, University of Limerick, Ireland

The study aimed to investigate the relationship between joint coupling coordination and muscle activity of the lower limb during normal gait in shod and barefoot walking. Ten healthy participants served in this study. We assessed joint coordination and muscle activity while the participants walked on a treadmill at their self-selected speed in shod and barefoot conditions. T-tests were used to determine the differences between walking conditions in the early, mid and late phases of support. A cross-correlation analysis was used to determine the similarity between the coordination angle and EMG profiles in the three phases of support. The study suggested no differences between shod and barefoot coordination. The correlation coefficients were moderately high (r=0.6) for both shod and barefoot. It was concluded that the rearfoot/tibia coordination may be under passive rather than active control.

KEY WORDS: joint coupling, coordination, emg, cross-correlation.

INTRODUCTION: There is increasing interest in joint/segment coordination using a dynamical system approach to assess the coordination (Hamill, van Emmerik, Heiderscheit, & Li, 1999; DeLeo, Dierks, Ferber, & Davis, 2004; Chang, Van Emmerik, & Hamill, 2008). From a dynamical systems perspective, joint/segment coupling, assessed by a vector coding approach, is essential in understanding coordination (Hamill et al., 1999). Such studies have identified particular aspects of gait that could not be observed by traditional methods (Hamill et al., 1999; Ferber, Davis, & Williams, 2005). Coordination is arguably related to muscle activity in the lower limb (Von Tscharner & Goepfert, 2006; Mundermann, Wakeling, Nigg, Humble, & Stefanyshyn, 2006). However, there is a dearth of studies on the relationship between joint coupling and the corresponding muscle activity. To investigate this relationship, two conditions in which the foot/ankle complex would be constrained (shod) and unconstrained (barefoot) were used in this study. Hence, the aim of this study was to investigate the relationship between joint coupling coordination and muscle activity of the lower limb during normal gait. We hypothesized that there would be differences in the coordination patterns between the shod and barefoot conditions. Second, we hypothesized that there will be a higher relationship between joint coordination and muscle activity in shod condition (i.e. a restricted environment) as compared to barefoot condition.

METHODS: Ten healthy subjects (4 males and 6 females; 26 ±7 y, 60 ±10 kg, 1.66 ±0.08 m) consented to participate in this study that was approved by the school ethics review committee. All were healthy and free of lower extremity injury.
Equipment: The experimental set-up consisted of a Gaitway motorized treadmill (H/P Cosmos Gaitway II S, Germany) that was surrounded by an eight camera Motion Analysis System (Motion Analysis Corp., Santa Rosa, CA). Data sampling was accomplished at 100 Hz. EMG recordings were made using a portable EMG system (ME6000, MEGA Electronics Ltd., Finland). This system has a built in amplification, a 3 dB bandpass filter of 8–500 Hz in the measuring unit, and a unity gain. The EMG electrodes (Blue Sensor, Medicotest A/S, Denmark) were pre-amplified and the EMG signals were sampled at 1000 Hz via a 12 bit A\D converter. Both the EMG and motion capture systems were synchronized using footswitches placed at the heel to detect the heel strike, and at the forefoot to detect toes off. After cleaning the skin with isopropyl alcohol, and shaving the area if necessary, EMG recording

electrodes were placed on tibialis anterior (TA), peroneus longus (PL), soleus (SOL) and lateral gastrocnemius (GA) at standardized sites in according to the recommendations provided in the MegaWin software (Mega Electronics, version 3).

Protocol: Prior to the treadmill session, maximal voluntary isometric contraction (MVIC) was performed on the 4 muscles for 3 seconds each (Symonette, Watson, Koopman, Nicolle, & Doherty, 2010). Footswitches were used to detect the heel strike and toe- off during gait. The participants then had retro-reflective markers placed on the right lower extremity in accordance with Dierks & Davis (2007). The marker set consisted of 6 individual markers and two clusters of four (leg) and three markers (rearfoot) respectively. The EMG electrodes were then placed on the four lower extremity muscles. The subjects walked on the treadmill at self-selected speed (3.5-4km/hr) in randomised shod and barefoot conditions. In the shod condition, the subjects wore their own exercise walking shoes that were worn at least over a month and less than 6 months. Subjects walked on the treadmill for approximately seven minutes (Lavcanska et al., 2005) and kinematic and EMG data were measured for 30 seconds during the 8th minute.

Data Reduction: The first three consecutive complete strides that were recorded on the 8th minute were used for analysis. The kinematic data were filtered with a Butterworth low-pass filter with a cut-off of 6 Hz. The time histories were normalized to 100% of the gait cycle. Three-dimensional leg and ankle angles were calculated using the Visual3D software (C-motion Inc, USA). Segment coordination coupling between the rearfoot (inversion/eversion) and tibial (internal/external) rotation angles were calculated based on the Chang et al. (2008) approach. In this technique, phase angles, ⍰, from 0^0 to 360^0, were derived using a modified vector coding technique. The phase angles were computed to describe in-phase, anti-phase, or out-of-phase motion between the two rotations of the segments. EMG data were full wave rectified and low-pass filtered at 20 Hz to form linear envelops for each muscle. The EMG data were then converted to the percentage of MVIC, followed by time normalization to a percent of the gait cycle.

Statistical Analysis: The mean and standard deviation of the coordination angles of all trials (footfalls) for each subject was determined using circular statistics (Bachelet, 1981). Each mean profile was then divided into third representing early, mid and late support. The mean data of the shod and barefoot conditions were statistically analysed using a correlated t-test with an alpha level of 0.05 for each portion of the stance phase and between each portion of the stance phase. Cross correlation between the coordination angles and each of the four different muscles was performed with the each of the three phases. The cross-correlation coefficients for each trial were Z-transformed in order to determine differences between the two conditions. A t-test was then performed on the Z-scores (a=0.05). The corresponding Z-scores for all trials were then re-transformed to report the correlation coefficient values (Derrick & Thomas, 2004).

RESULTS: There were no statistically significant differences in the coordination in the three phases of the support phase between the shod and barefoot conditions ($p > 0.05$) (Figure 1). The cross-correlation coefficients ranged from 0.37 in the PL during the mid phase of support to 0.70 in the SOL during the late phase of support (Figure 2). The statistical test on the transformed cross-correlation coefficients indicated that the difference between the shod and barefoot conditions was not significant ($p > 0.05$).

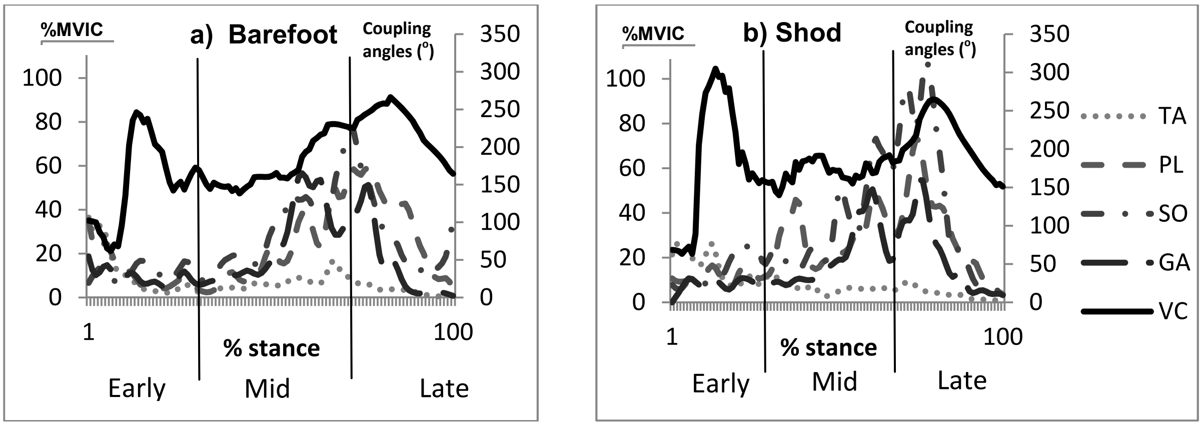

Figure 1. Average vector coding (VC) angle plot with muscle activity of tibialis anterior (TA), peroneus longus (PL), soleus (SO) and gastrocnemius (GA) in a) Barefoot and b) Shod conditions during early, mid and late phases of stance. %MVIC and coupling angles are reflected on the left and right vertical axes respectively.

Figure 1: Average vector coding (VC) angle plot with muscle activity of tibialis anterior (TA), peroneus longus (PL), soleus (SO) and gastrocnemius (GA) in a) Barefoot and b) Shod conditions during early, mid and late phases of stance. %MVIC and coupling angles are reflected on the left and right vertical axes respectively.

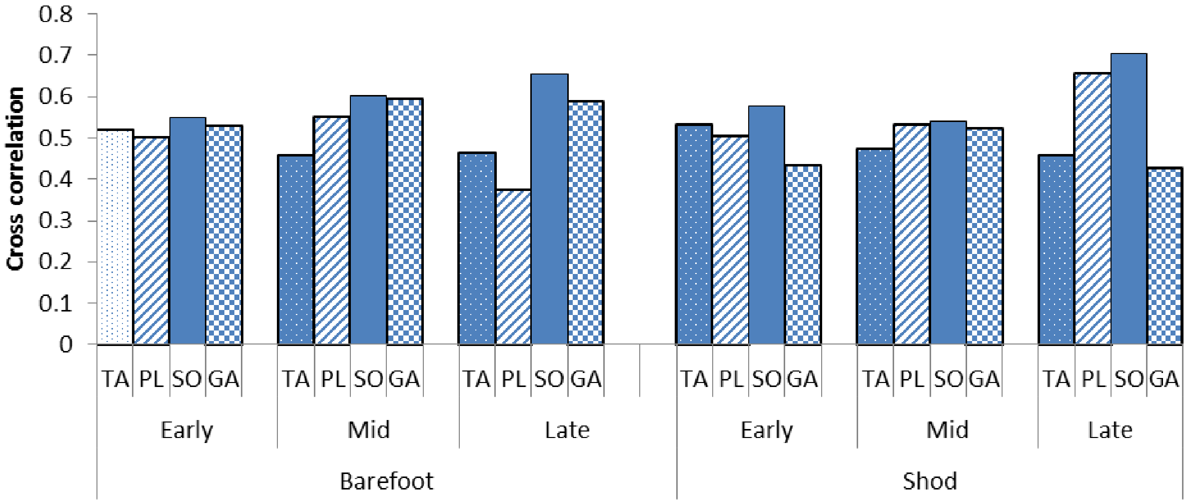

Figure 2: Cross correlation of coordination profile of the rearfoot and tibial rotation with tibialis anterior (TA), peroneus longus (PL), soleus (SO) and gastrocnemius (GA) during early, mid and late phase of stance during walking in shod and abrefoot consitions.

DISCUSSION: The purpose of this study was to investigate the relationship between joint coupling coordination and muscle activity of the lower limb during normal gait. We hypothesized that there would be different coordination patterns between the shod and barefoot conditions. The results of the study indicate that we must reject this hypothesis. Constraining the related and coordinated actions of ankle eversion/inversion and internal/external tibial rotation by placing the foot in a shoe did not alter the coordination profile. Secondly, we hypothesized that there would be a greater relationship between the coordination and muscle activity profiles in the shod condition. However, we must reject this hypothesis based on the results of the study.

CONCLUSION: While it seems logical that a relationship between segment coordination and muscle actions that control that coordination should exist, these data suggest that the relationship is not very strong. It appears that these segment actions, while strongly coordinated in both shod and barefoot conditions, may not be under strong muscular control. It may be that this particular segment relationship may be more a result of passive control rather than active control.

REFERENCES:

Bachelet, E. (1981). *Circular Statistics in Biology*. London: London Academic Press.

Chang, R., Van Emmerik, R., & Hamill, J. (2008). Quantifying rearfoot-forefoot coordination in human walking. *Journal of Biomechanics,* 41(14): 3101–3105.

DeLeo, A.T., Dierks, T.A., Ferber, R., & Davis, I.S. (2004). Lower extremity joint coupling during running: a current update. *Clinical Biomechanics,* 19(10), 983-991.

Derrick, T.R. & Thomas, J.M. (2004). Time-Series Analysis: The Cross Correlation Function. In N. Stergiou (Ed.). *Innovative Analyses of Human Movement. Champaign, IL: Human Kinetics Publishers, pp. 189-205.*

Dierks, T.A. & Davis, I. (2007). Discrete and continuous joint coupling relationships in uninjured recreational runners. *Clinical Biomechanics,* 22(5), 581-591.

Ferber, R., Davis, I.M.C., & Williams, D.S. (2005). Effect of foot orthotics on rearfoot and tibia joint coupling patterns and variability. *Journal of Biomechanics,* 38(3), 477-483.

Hamill, J., van Emmerik, R.E.A., Heiderscheit, B.C., & Li, L. (1999). A dynamical systems approach to lower extremity running injuries. *Clinical Biomechanics,* 14(5), 297-308.

Mundermann, A., Nigg, B.M., Humble, N.R., & Stefanyshyn, D.J. (2003). Foot orthotics affect lower extremity kinematics and kinetics during running. *Clinical Biomechanics,* 18(3), 254-262.

Ong, A. and Koh, M., & Hamill, J. (2011).Quantifying lower limb gait coordination in off-the-shelf orthotic shoes. *Footwear Science,* 3(2), 83-90.

Lavcanska, V., Taylor, N.F,. & Schache, A.G. (2005). Familiarization to treadmill running in young unimpaired adults. *Human Movement Science,* 24(4), 544–557.

Mundermann, A., Wakeling, J.M., Nigg, B.M., Humble, R.N., & Stefanyshyn, D.J. (2006). Foot orthoses affect frequency components of muscle activity in the lower extremity. *Gait and Posture,* 23(3), 295-302.

Symonette, C. J., Watson, B.V., Koopman, W.J., Nicolle, M.W.,& Doherty, T.J. (2010). Muscle strength and fatigue in patients with generalized myasthenia gravis. *Muscle and Nerve,* 41(3), 362–369.

Von Tscharner, V. & Goepfert, B. (2006). Estimation of the interplay between groups of fast and slow muscle fibers of the tibialis anterior and gastrocnemius muscle while running. *Journal of Electromyography and Kinesiology,* 16(2), 188-197.