Walking Coordination Changes With Incline

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***Abstract*— There are known differences in mechanical energy, kinematics and muscle activation patterns when comparing walking at inclines above 15% to those less than 15%. The purpose of this research was to quantify coordination changes with respect to incline angle. Participants walked on a treadmill at 2 and 3mph at inclines between 0-30%. Continuous relative phase was determined for three sagittal plane joint couples: Hip-Knee, Hip-Ankle, and Knee-Ankle. All joint couples were significantly more in-phase at inclines 15%-30% during the first part of the contact phase compared to lower inclines. Additionally, there were no substantial differences between 2 and 3mph for any of the joint couples.**

Keywords—coordination, incline walking

I. INTRODUCTION

As humans walk, gait mechanics change with respect to incline. For example, hip and knee angles become more flexed at touch down with increasing surface angles [1]. Efficiency also plateaus at incline angles greater than 15%, equaling that of concentric muscle activity, suggesting that at these inclines work is only done to lift the body [2]. Additionally, muscle activations have been shown to resemble different coordination patterns at extreme incline angles [3]. Coordination variables, such as continuous relative phase (CRP) [4], might also reflect this change. Therefore, the purpose of this research was to utilize kinematic coordination variables to asses a potential walking coordination transition with incline and to evaluate the effect of speed on these variables.

II. METHODS

Twelve individuals (6M, 6F: height: 1.7±0.05m, weight: 65.13±5.3kg, age: 20.42±1.1 years) walked on a treadmill at 2 and 3 mph at inclines from 0% to 30% at 5% intervals. Reflective markers were placed on the pelvis and right leg and foot, from which segment and joint angles and angular velocities were determined. Kinematic data (120Hz) was collected for 20 seconds and filtered with a Butterworth Filter. This data was used to calculate CRP based on the methods explained in reference [4]. Three sagittal plane joint couples were calculated: Hip-Knee, Hip-Ankle, and Knee-Ankle. CRP is used to describe a couple as more in-phase (0°) or more out-of-phase (antiphase) (±180°). CRP was compared at each data point across the 7 inclines for the 3mph stages using an ANOVA ($\alpha=0.05$). Cross-correlations were used to determine if the 2mph CRP was different from that of 3mph.

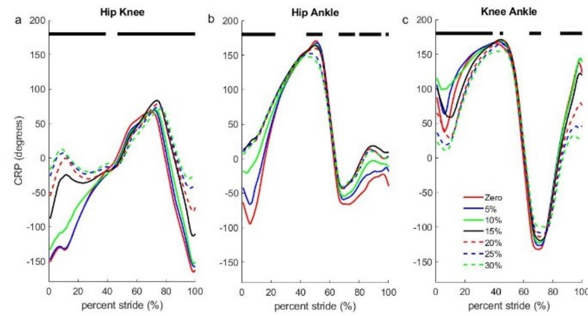

Figure 1: Average CRP for the three joint couples for all inclines through a complete stride.

III. RESULTS

There were significant differences ($p<0.05$) in all three joint couples during the stride cycle (black bars, Figure 1). All three couples were more in-phase at inclines of 15% and higher during the first 20% of the stride compared to lower inclines. Correlations between 2 and 3mph for all inclines were greater than 0.89. The largest differences with speed occurred on 0% incline in Hip-Ankle, lag of 3 ($r=0.929$) and in Knee-Ankle, lag of 4 ($r=0.894$). For all three couples at inclines 15% or steeper, $r>0.97$ and lags were less than 3.

IV. DISCUSSION

CRP values for all three sagittal plane joint couples at 3mph were more in-phase during the first 20% of the stride for inclines at and above 15%. These changes in coordination compared to lower inclines did not appear to be affected by speed as all correlations between speeds were high, and lags were small, especially at inclines at and above 15%. These findings support the previous muscular activation studies [3] and indicate a synchronized effort to lift the center of mass at these extreme inclines [2]. In conclusion, there is a transition in walking coordination due to surface incline, similar to that of walking to running as speed increases.

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