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The effect of inclination on lower extremity inter-joint coordination during treadmill walking

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Background

Inclined walking is a challenging daily task in comparison with level walking. It requires specific control from central nervous system and exhibits increases in muscle activities and alternations of joint kinematics in lower extremities.[1]

However, the knowledge of the inclination effect on the inter-joint coordination is limited.

Previous studies have shown the benefits of investigating the inter-joint coordination in patients with pathological gait.[2]

This study aimed to evaluate such coordination in healthy young adults during inclined walking.

Methods

Subjects: 19 healthy young adults (13 females, 6 males; age: 24.2±2.6 years old; weight: 69.43±15.3 kg; height: 1.70±10.1 m)

Experimental protocol and data analysis: Subjects walked at their comfortable speeds for 2 minutes in four inclined treadmill walking conditions (0%, 5%, 10%, and 15% grade). Three-dimensional kinematics data were captured at 100 Hz by an eight-camera Qualisys motion capture system using Qualisys Tracker Manager (QTM) software. The kinematic data during stance phase were normalized to 100 points and then used to calculate the inter-joint coordination.

Continuous relative phase (CRP) measures: The phase portraits were created by plotting the specific segment's angular position versus its angular velocity (Fig. 1). The trajectories of these phase portraits were converted from Cartesian coordination to polar coordination to get phase angles(θ). CRP(φ) was calculated by $\varphi_{Shank-Thigh} = \theta_{Shank} - \theta_{Thigh}$; $\varphi_{Foot-Shank} = \theta_{Foot} - \theta_{Shank}$. CPR values throughout the stance phase were plotted (Fig. 2). A mean absolute value of the ensemble CRP curve values (MARP) was calculated by averaging the absolute values of all point of the entire ensemble curve. Low MARP indicated that two segments approached to in-phase and vice versa.

Figure 1. Sample Phase Portrait

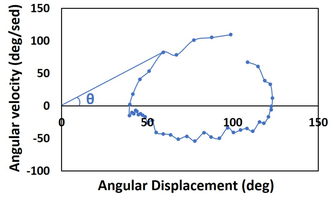
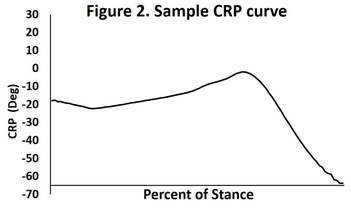


Figure 2. Sample CRP curve



Statistical analysis: A two-way repeated ANOVA with Bonferroni correction was used to determine the effect of inclination and the effect of segmental combinations (shank-thigh and foot-shank) on MARP.

Results

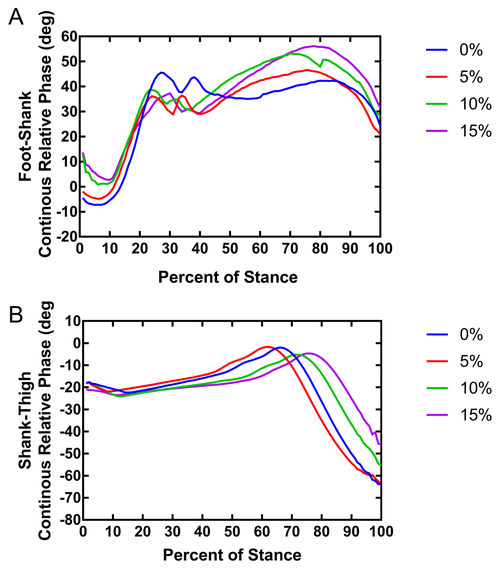


Figure 3. Mean ensemble CRP dynamics for the foot–shank (A) and the shank–thigh (B) combinations during the stance phase. Blue: 0% grade; Red: 5% grade; Green: 10% grade; Purple: 15% grade.

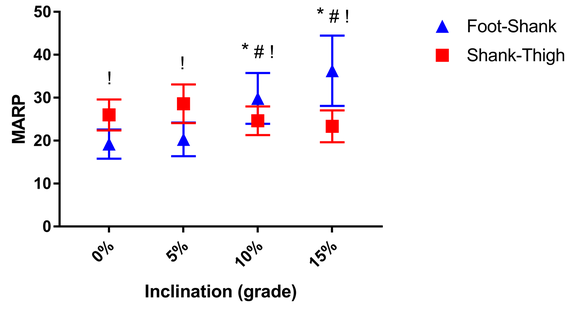


Figure 4. Effects of inclination on the MARPs of foot-shank (blue) and shank-thigh (red) combinations during the stance phase. *: significant difference in comparison with 0% grade walking in terms of foot-shank combination. #: significant difference in comparison with 0% grade walking in terms of shank-thigh combination. !: significant difference between foot-shank and shank-thigh combinations during walking on the treadmill with the same grade.

Results

There was a significant interaction between the effect of inclination and the effect of segmental combinations on MARP ($F(3,108) = 85.85$, $p < 0.001$).

The MARP of foot-shank combination was lower than that of shank-thigh combination when walking on 0% grade ($p < 0.001$, approximately 26% less) and on 5% grade ($p < 0.001$, approximately 28% less).

However, the MARP of foot-shank combination was higher than that of shank-thigh combination when walking on 10% grade ($p < 0.001$, approximately 26% more) and on 15% ($p < 0.001$, approximately 55% more).

Discussion and Conclusions

When the grade increased to a certain level, the inter-joint coordination changed to different patterns during treadmill walking.

Inclined treadmill walking could be used for lower extremity strengthening, gait training, and cardiopulmonary conditioning. The inclination of walking should challenge the patients properly without increased risk.

Our study provided a further understanding of inclination effect on gait pattern and could be used as a reference for clinical decision making.

Our results suggested that the pattern of the inter-joint coordination significantly changed when the grade was between 5% to 10%. Therefore, treadmill walking with an inclination less than 5% grade might be a safer training protocol comparing to walking on a higher inclination.

References

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