Limitation of Ankle Mobility Challenges Gait Stability While Walking on Lateral Inclines

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Limitation of Ankle Mobility Challenges Gait Stability While Walking on Lateral Inclines

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Abstract Exoskeletons often allow limited movement of the ankle joint. This could increase the chance of falling while walking, particularly on challenging surfaces, such as lateral inclines. In this study, the effect of a mobility limiting ankle brace on gait stability in the frontal plane was assessed, while participants walked on lateral inclines. The brace negatively affected gait stability when it was worn on the leg that was on the vertically lower side or 'valley side' of the lateral incline, which would indicate an increased risk of falling in that direction.

1 Introduction

STABILITY of gait is challenged by slopes, such as laterally inclined surfaces. Computer controlled walking devices, such as humanoid robots and exoskeletons, should be able to adapt to changes in surface angle to reduce the risk of falling. Many of such devices have limited joint mobility in the lower extremities compared to healthy humans. This could hamper the ability to adapt to slopes while walking. In

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this study, we evaluated the effect of a mobility limiting ankle brace on gait stability while walking on laterally inclined surfaces.

2 Methods

2.1 Participants, Equipment and Protocol

Twenty healthy participants (9 female, age 40 (SD 12) years, height 1.78 (SD 0.09) (m), weight 74 (SD 13) (kg)) were recruited for this study. Subjects walked on an instrumented treadmill that is part of a Computer Assisted Rehabilitation ENvironment (CAREN) (as shown in Fig. 1). Retroreflective markers were placed on the subjects to determine the movements of the center of mass and both feet. During the experiment, the speed of the treadmill was fixed at 0.6 (m/s). At the beginning of each trial, the treadmill was oriented horizontally. After a minimal number of 48 strides was recorded, the slope of the treadmill changed to a lateral incline of -3 degrees (i.e. right side up), followed by +3, −6, +6, etc. until a lateral incline of +15 degrees was reached. All subjects completed this experiment without joint mobility limitation. Five subjects performed the same experiment again with a custom made carbon ankle brace on the right ankle that blocked virtually any ankle movements.

2.2 Outcome Metrics

We assessed overall gait changes from wearing the ankle brace using stride time and stride width. Gait stability was expressed in terms of lateral margin of stability [1] (Fig. 2). The margin of stability expresses how close the body, modelled as an inverted pendulum, gets to toppling over the stance leg by taking the position and

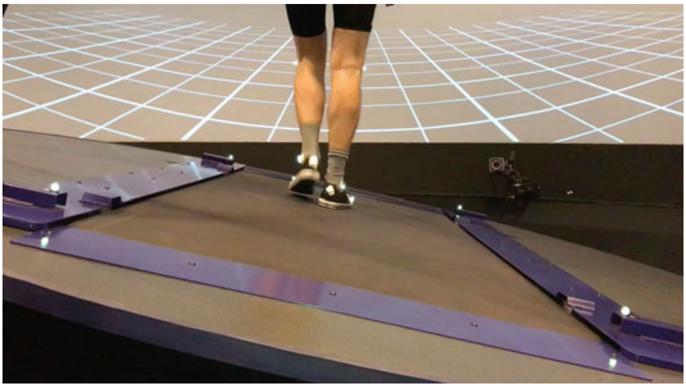

Fig. 1 The CAREN-system. The lateral incline of the treadmill was changed between + and − 15° by a motion base underneath the round platform

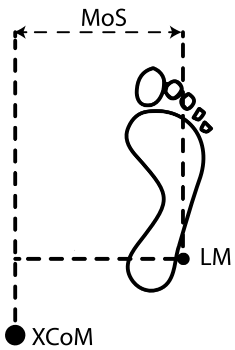

Fig. 2 Visual representation of the lateral margin of stability (MoS). At the start of the swing phase of the contralateral leg, the lateral margin of stability was defined as the mediolateral distance between the extrapolated center of mass (XCoM) and the lateral malleolus (LM) of the stance leg. The XCoM would predict the maximum excursion of the CoM given its current velocity and position. The XCoM would need to remain medial to the LM to prevent the body from toppling over the stance leg

velocity of the center of mass into account. To get further insight into why subjects might have had a reduced lateral margin of stability, we also compared the velocity of the centre of mass, as well as the distance between the center of mass and the base of support.

3 Results

When subjects wore an ankle brace, they walked with shorter and wider strides for all lateral inclines. With the right ankle braced, the lateral margin of stability towards the left side was unaffected. However, margin of stability towards the braced side increased for negative inclines (i.e. braced leg towards the vertically higher side or ‘hill side’) when compared to normal walking (Fig. 3). When the leg with the ankle brace was on the vertically lower side or ‘valley side’ (i.e. for positive angles), there was a smaller margin of stability on that side. Analysis of the underlying variables with the braced leg on the ‘valley side’ showed an increased maximum velocity of the center of mass towards the valley and a smaller distance of the center of mass relative to the base of support at toe off compared to the the ipsilateral leg during the unbraced condition and compared to the contralateral leg during the same trial.

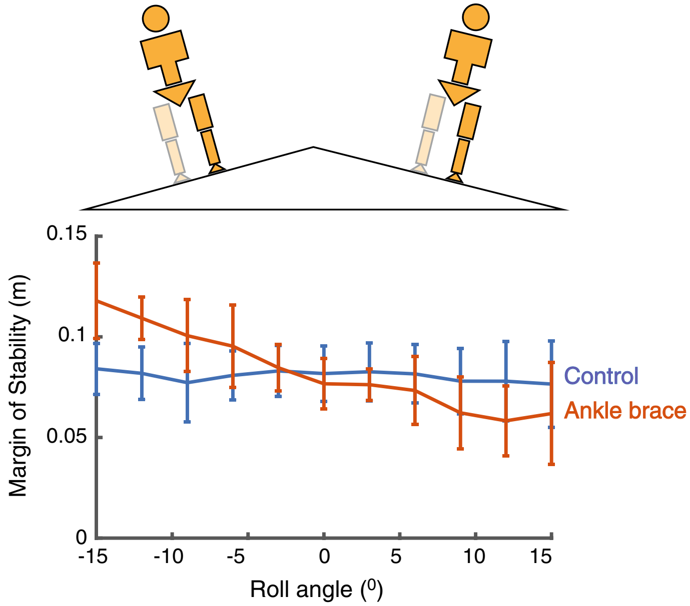

Fig. 3 Margin of stability for the right leg without (blue) and with (red) ankle brace. Negative roll angle indicate slopes to the left (i.e. where the leg represented here is on the 'hill side'), whereas positive roll angles indicate slopes to the right (i.e. where the leg represented here is on the 'valley side')

4 Discussion and Conclusion

Our results suggest that constraining the ankle leads to changes in spatiotemporal gait parameters that are thought to have a stabilizing effect, such as shorter and wider strides [2–4]. When walking on a lateral incline with the braced ankle on the 'hill side', the lateral margin of stability was indeed better for that leg. However, with the brace on the 'valley side', the lateral margin of stability was reduced. A possible explanation for this finding is that the orientation of the foot does not fully adapt to the walking surface while wearing a brace. The stiffness of the ankle brace foot plate was relatively high, and subjects most likely placed their foot horizontally on the inclined treadmill as a result of this stiffness. This means that the effective base of support of the 'valley leg' would be the medial side of the foot (Fig. 4). Hence, the center of pressure off the 'valley leg' would be relatively close to the center of mass, reducing the braking effect on the center of mass in the medial direction, which could explain the relatively high velocity of the center of mass in the direction of the braced 'valley-side' leg. Note that the margin of stability in this study was calculated with the lateral malleolus as base of support and that the reduction in lateral margin of stability with the ankle brace at the 'valley side' would probably be even larger when the effective base of support (the area where the CoP can be located) would be used.

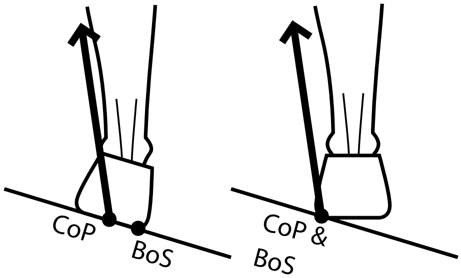

Fig. 4 Left: with unrestrained ankle mobility, the orientation of the foot can be adjusted to the incline of the walking surface. In that case, the center of pressure (CoP) can fluctuate between the medial side of the foot and the lateral side of the foot, or base of support (BoS). Right: with the ankle fixated in a neutral position, the orientation of the foot will not fully adapt to the orientation of the walking surface. As a result, the effective BoS size will be reduced with an upper boundary closer to the medial side of the foot, limiting the area where the CoP can be located

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