

Vertical Clearance Measures Underestimate Risk of Obstacle Contact Compared to Minimum Distance to Collision

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Summary

Vertical clearance measures approximate the risk of foot contact during obstacle avoidance. We compared traditional vertical clearance measures to minimum distance to collision (MDTC), quantifying the distance between the foot and the obstacle for the entire crossing. MDTC values were lower than traditional clearance measures, suggesting vertical clearance measures may underestimate contact risk.

Introduction

Vertical clearance measures are often used to approximate the risk of foot contact with an obstacle, causing trips and falls [1-3]. Vertical clearance measures are captured at the time the foot is directly over the obstacle in the crossing step, but not for the entire trajectory [3-5]. We posit a more robust way to identify when individuals are at greatest risk of contacting an obstacle is to examine the entire trajectory of the crossing steps and determine the minimum distance to collision (MDTC). Thus, we sought to determine if traditionally reported vertical clearance measures at the lead (i.e., the limb that crosses first) and trail limb (i.e., limb that crosses second) are equivalent to MDTC.

Methods

Forty-two adults (16 male, 24 ± 5 yrs, 1.72 ± 0.10 m, 74.7 ± 20 kg) completed 10 obstructed shod walking trials. Shoes were the participant's typical walking shoes and were not standardized. Five reflective markers were placed on each foot, including on the most anterior aspect of the shoe (toe), and the most posterior aspect of the shoe (heel).

Participants were asked to walk "at a comfortable pace and step over the obstacle along the way." The obstacle was a wooden dowel (height: 120 mm; depth: 22 mm), fitted with reflective markers. Marker trajectories were recorded via 3D motion capture (Vicon Motion Systems; 120 Hz), as participants walked down the 8m walkway and crossed the obstacle with their preferred limb. Some participants were not directly over the obstacle in a single frame, so marker trajectories were interpolated to 240 Hz.

For both the lead and trailing limbs, vertical clearance was calculated as the minimum vertical distance between the obstacle and the toe/heel marker, when the toe/heel was directly over the obstacle. MDTC was defined as the

minimum distance between the foot and the obstacle (either the toe or heel) across the entire crossing trajectory. This was computed using Pythagorean's theorem to calculate the non-orthogonal linear distance between the toe and heel markers and the obstacle throughout the crossing trajectory (Fig. 1). The minimum value for both the toe and heel were extracted. Descriptive statistics and one-sample t-tests determined if differences between measures were greater than zero.

Minimum Distance to Collision (MDTC)

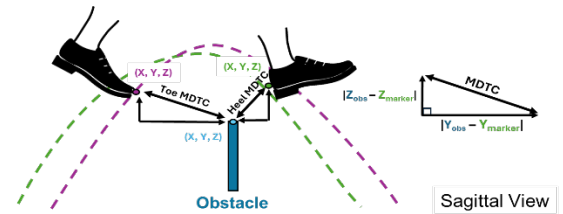


Figure 1: MDTC for the toe and heel. Resultant distance is determined using Pythagorean's theorem for both limbs.

Results and Discussion

Average MDTC was lower (closer to the obstacle) in both the lead and trail limbs (Table 1). MDTC for the lead limb occurred at the heel for 90% of examined trials, whereas MDTC for the trail limb occurred at the toe in 98% of trials. All one-sample t-tests indicated that the differences between vertical clearance measures and MDTC were significantly larger than zero ($p \leq .002$), signifying MDTC measures were significantly lower than traditional clearance measures.

Conclusions

This study suggests participants get closer to the obstacle, and increase the risk of contact, compared to what traditional clearance measures suggest. Future researchers should identify where in crossing MDTC occurs to enhance obstacle avoidance interventions.

References

- [1] Avalos and Rosenblatt. (2024), *Gait Posture*, **107**.
- [2] Heijnen and Rietdyk. (2016), *Hum. Mov. Sci.*, **46**.
- [3] Loverro et al. (2013), *J. Biomech.*, **46**(11)
- [4] Heijnen and Rietdyk. (2018), *Exp Brain Res.*, **236**(1)
- [5] Muir et al. (2019), *Gait Posture*, **70**.

Table 1: Traditional vertical clearance measures and minimum distance to collision (MDTC) measure for the lead and trail limbs in mm.

	Lead Toe Clearance	Lead Toe MDTC	Lead Heel Clearance	Lead Heel MDTC	Trail Toe Clearance	Trail Toe MDTC	Trail Heel Clearance	Trail Heel MDTC
Mean \pm SD	177 \pm 46*	175 \pm 45*	156 \pm 53*	139 \pm 47*	152 \pm 60*	126 \pm 52*	401 \pm 81*	319 \pm 55*

Note: * Indicates comparison between vertical clearance and MDTC was significantly different from zero