

# Foot positioning effects on reestablishing and maintaining foot contact from ladder perturbations

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## INTRODUCTION

Falls occurring in 2014 were estimated to have associated lifetime costs of \$170 billion [1]. The majority of fatal falls are to a lower level [2] and a plurality of fatal falls to lower levels involve ladders [2]. Understanding the factors that contribute to ladder fall events is an important step in developing fall prevention strategies. Anterior foot placement on a ladder rung is an important determining factor in the occurrence of slipping [3]. Furthermore, reestablishing the feet back on the ladder is a critical component of the ladder recovery process [4]. Specifically, failure to reestablish the feet back on the ladder after a climbing perturbation is associated with greater fall severity [5]. However, a knowledge gap exists regarding whether foot positioning has an impact on reestablishing the feet during the recovery process. The purpose of this study is to quantify the relationship between foot position and a climber's ability to reestablish and maintain contact with the ladder rung after a ladder misstep. Quantifying this relationship may clarify the mechanism by which some climbers fail to recover from a climbing perturbation and inform future interventions.

## METHODS

Thirty-five participants climbed a vertically fixed ladder 30 times with six unexpected ladder misstep perturbations. Three misstep perturbations were experienced in each climbing direction (ascent and descent) and perturbations were separated by three to five baseline climbs. Ladder slip/misstep perturbations were simulated by an automatically controlled release of the fourth ladder rung, which occurred at the time of contralateral foot off. This time was selected since it is the time when a ladder slip typically occurs [4]. Forty-seven reflective markers were placed on each participant and track at 100 Hz. Bilateral toe, 1<sup>st</sup> metatarsal, 5<sup>th</sup> metatarsal,

and heel landmarks were tracked. All participants donned standard tight-fitting attire, a raised-heel work shoe, shin guards, and a safety harness. In addition, participants were protected from injury with a belayer, spotter, and an impact mat below the ladder. Informed consent was obtained prior to testing and this study was approved by the IRB at the University of Wisconsin-Milwaukee.

Foot angle and foot placement was quantified at two time points: perturbation onset and when the foot contacted the rung. Foot angle was measured between the toe and heel markers with respect to the horizontal. Foot placement was quantified as the anterior-posterior distance between the midpoint of the 1<sup>st</sup> and 5<sup>th</sup> metatarsals and the ladder rung. Foot placement was normalized by foot length. Time of perturbation onset, which represents the initial condition of the foot, was the time the fourth rung was triggered to release. Time of foot-rung contact was determined as the time when the foot velocity fell below 10% of the foot's peak velocity [4]. Foot velocity was determined from the midpoint in vertical movement of the markers placed on the 1<sup>st</sup> and 5<sup>th</sup> metatarsal.

Foot contact was classified into three outcomes: no contact (i.e., did not make contact with the ladder), contact/slip (i.e., made contact and then slipped) and contact (i.e., maintained contact on the rung). The unperturbed foot was not considered since only two contact/slip trials were observed in this foot.

ANOVA methods were utilized to determine differences in angle and placement of the perturbed foot at each time point (perturbation onset and foot-rung contact). Ascent and descent were assessed separately. When considering foot angle and foot placement at foot-rung contact time, only contact/slip and contact outcomes were considered

since contact time could not be determined for trials where there was no contact.

## RESULTS AND DISCUSSION

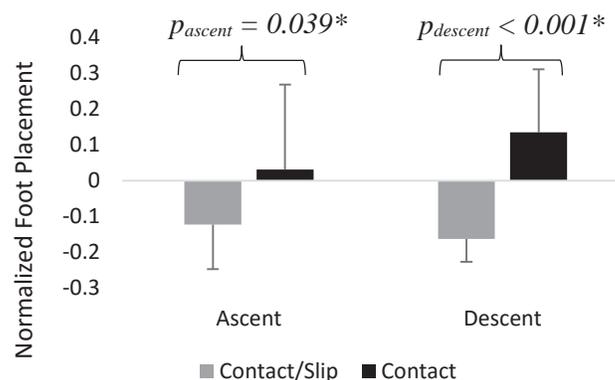
The perturbed foot had 39 no contact, 12 contact/slip, and 36 contact foot outcomes during ascent and 53 no contact, 8 contact/slip, and 19 contact foot outcomes during descent.

*At time of perturbation onset:* Neither foot angle nor foot placement were significantly different between foot contact outcomes at time of perturbation onset across climbing directions (foot angle:  $p = 0.220$  for ascent and  $p = 0.254$  for descent; foot placement:  $p = 0.227$  for ascent and  $p = 0.290$  for descent).

*At time of foot-rung contact:* Foot angle was not different between contact outcomes for either ascent ( $p = 0.146$ ) or descent ( $p = 0.763$ ). Foot placement was significantly different between foot contact outcomes for both ascent ( $p = 0.039$ ) and descent ( $p < 0.001$ ) (Figure 1). A more posterior foot placement was associated with cases where the foot hit the rung and then slipped off. During ascent, the mean (standard deviation) foot placement was  $-0.12$  ( $0.12$ ) and  $0.03$  ( $0.24$ ) for contact/slip and contact foot outcomes, respectively. During descent, the foot placement was  $-0.16$  ( $0.06$ ) and  $0.14$  ( $0.18$ ) for contact/slip and contact foot outcomes, respectively. Negative foot placement indicated that the metatarsal heads were posterior to the ladder. Thus, the contact region in cases where a negative foot placement was observed would have been the phalanges.

Only foot placement at the time of foot contact affected the outcome of whether the climber was able to reestablish their feet on the rung. The finding that a more anterior foot placement reduced the risk of a slip is consistent with previous research on ladder slip risk [3]. Interestingly, foot positioning at perturbation onset was not different across contact outcomes. Thus, the motor response to the perturbation was likely responsible for achieving anterior foot placement as opposed to the initial state of the foot at perturbation onset. Thus, interventions

that promote anterior foot placement after a ladder perturbation are likely to lead to better foot contact outcomes and a reduction in fall risk.



**Figure 1:** Perturbed foot placement at foot-rung contact for contact/slip and contact outcomes during ascent and descent.

## CONCLUSIONS

This study investigated the effects of foot positioning on foot contact outcome after a simulated ladder slip/misstep. Participants who maintained foot contact with the rung had a more anterior foot placement than those whose foot slipped off of the rung. Since no differences were observed at the time of perturbation onset, the motor response to the perturbation likely explains the difference between foot contact outcomes. These findings have important implications for designing safer ladders and ladder climbing training programs.

## REFERENCES

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