

Climbing Direction, Number of Contact Points and Gender Influence Recovery from Ladder Falls but not Glove Use

¹ Erika M. Pliner, ² Na Jin Seo and ³ Kurt E. Beschorner

¹ The University of Wisconsin-Milwaukee, Milwaukee, WI, USA

² Medical University of South Carolina, Charleston, SC, USA

³ The University of Pittsburgh, Pittsburgh, PA, USA

email: beschorn@pitt.edu

INTRODUCTION

Ladder falls account for 16% of fatal falls and 8% of non-fatal falls [1]. Injuries from ladder falls are severe, but can be prevented from safer ladder climbing practices and proper ladder climbing training [2]. Previous research has investigated the effects of gloves on grasping ladder rungs in hopes to improve ladder climbing practices [3, 4]. High friction gloves were found to increase the maximum gripping force when the rung is forcibly pulled from their hand [3]. Also, more muscle activity is needed to stabilize the rung with low-friction gloves [4]. However, these studies only considered the interaction between the hand and the rung, which may be an over-simplification of ladder recovery.

Other risk factors for ladder falls may include gender, utilizing 3 points of contact and climbing direction. For example, differences in strength across genders [5] may alter recovery risk. Three points of contact is a common safety suggestion and requirement of OSHA. Lastly, falls have been observed more frequently during egress of mining equipment than ingress suggesting that ladder descent may be more difficult than ascent [6]. A paucity of objective data exists regarding how each of these factors impacts recovery from a ladder fall event.

The purpose of this study was to quantify the impact of gloves, 3-point contact, gender and climbing direction on recovery after a ladder perturbation.

METHODS

Thirty-five (10 female, 25 male) healthy participants between the ages of 18 and 29 were recruited for this study. IRB approval and written informed consent were obtained prior to testing. All participants were equipped with standardized attire, footwear and a safety harness that was equipped with a load cell to measure the support force (1000 Hz). Forty-seven reflective markers were placed on

participant's anatomical landmarks to record their kinematic data (100 Hz), including the hands, feet, and the anterior/posterior superior iliac spines.

Participants climbed a vertical 12-foot custom-designed ladder. The ladder was equipped with strain gauges and load cells to estimate forces placed on several of the ladder rungs. The fourth rung on the ladder was designed such that the rung could be released under the participants' foot electronically. The armed rung was programmed to release when the contralateral leg stepped off of the previous rung. This timing corresponds approximately to when subjects typically slip [7], leaving the hands as the primary means of recovery. Each participant experienced six simulated ladder missteps corresponding to three glove conditions (bare hands, high friction gloves and low friction gloves) and two climbing directions (ascent and descent). Participants performed between five and eight baseline trials before each perturbation to minimize anticipation. The order of gloves and climbing direction were randomized.

A participant's ability to recover was based on the force supported by the safety harness. The harness force was normalized to the participant's body weight and calculated as the peak harness force between the start of fall and end of fall time points. The start of fall was the point in time the fourth rung was triggered to release. The end of fall was the point in time of the first minimum of the mid-hip joint center's vertical displacement after the start of fall. Hip joint centers were calculated based on the pelvic markers [8]. The number of body to ladder contact points at the start of fall was visually determined from kinematic data. Point of contact varied between two point contact (2 Pt, 1 hand and 1 foot) and three point contact (3 Pt, 2 hands and 1 foot). An ANOVA was performed with gender, climbing direction, point of contact and glove

condition as independent variables and harness force as the dependent variable.

RESULTS AND DISCUSSION

Females had higher harness forces than males ($p < 0.001$). Descending perturbations resulted in higher harness forces ($p < 0.001$). Participants who had three point contact with the ladder at the start of fall had lower harness forces ($p < 0.05$). Glove condition did not affect harness force (Figure 1).

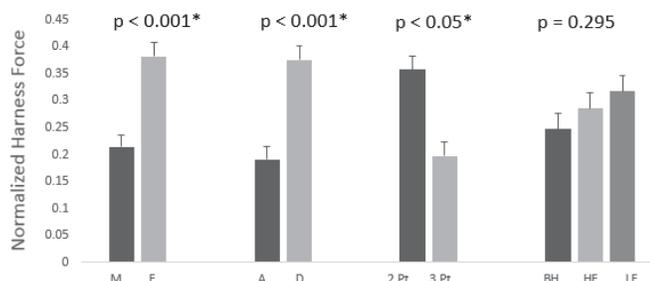


Figure 1: Average harness force normalized to body weight for males (M) vs. females (F), ascend (A) vs. descend (D), 2-point contact (2 Pt) vs. 3-point contact (3 Pt) and bare hand (BH), high-friction (HF) vs. low-friction (LF).

The discrepancy between males' and females' ability to recover may be due to physiological factors. Young male adults typically have higher upper body strength [5] than female adults, which may have assisted their ability to recover from a fall.

The difference in harness forces of ascending and descending perturbations may be due to the momentum of the body at the time of perturbation. Ascending the ladder may provide climbers with more time to respond since downward falling will be delayed and downward fall velocity is reduced. Thus, descending a ladder may be a more hazardous task than ascending a ladder, which may explain the higher injury rates reported during the egress process over the ingress process on mining equipment [6].

The finding that 3 points of contact enhances recovery is largely consistent with safety practices that promote utilizing three points of contact at all times on ladders. Less supporting points of contact will increase the required reaction load at each contact point, which may be too much for a single

hand after losing the support foot. It should be noted that few subjects maintained 3 points of contact during the whole climbing process (40%) and that the number of points of contact was just assessed at the moment of perturbation onset. Thus, the results of this study indicate that utilizing 3 points of contact when the body is most vulnerable to a slip (i.e., just after foot off [7]) may be sufficient to reduce fall risk.

Surprisingly, no effects were found between gloves and harness forces. Increased force capability from high friction gloves may not necessarily translate to better recovery during full body recovery. One potential reason for this finding may be that other factors (positioning of the hands, personal strength) may be more important than the maximum pull strength when an actual fall event is occurring.

CONCLUSIONS

This study found that fall risk was higher for female participants than male participants, for descent than ascent and when only 2 extremities are contacting the ladder compared with 3 extremities. Gloves did not affect recovery. This study suggests that ladder safety should prioritize maintaining three points of contact over glove use. Also, this study suggests that additional protection may be needed during ladder descent and for female ladder climbers.

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