Cover Page

Title: Effectiveness of Level Tools and Instruction on Optimal Ladder Setup

Lead Organization: University of Utah

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University of Utah

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Final Report

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a. Project Report Synopsis

This is the final project report for the "*Effectiveness of Level Tools and Instruction on Optimal Ladder Setup*." Highlights from this project comprise finding (1) ladders with levels (HyperLite and SumoStance ladders) to aid residential construction workers in achieving the recommended ladder setup angle of 75.5°; (2) explicit instruction on ladder level tools to aid with safe ladder setup but implicit instruction to be detrimental to safe ladder setup; (3) a critical barrier exists in retaining benefits from explicit instruction; (4) trends showing passive instruction to be a potential barrier to safe ladder use; (5) new safety equipment as a promising intervention that would be accepted by residential construction workers; and (6) data trends showing ground condition to effect ladder setup accuracy and slip risk. In addition, we conducted analyses on the available coefficient of friction (ACOF) and modeled the required coefficient of friction (RCOF). A lower ACOF and greater RCOF increase ladder slip risk. We found ACOF to be affected by ground condition and ladder shoe. Modeled RCOF was affect by ladder angle and the climber's location up the ladder. Further, methods on the extraction of ACOF shows promise to become a portable device to assess ladder slip risk in any environment. Details on this project and findings are provided below in this final report.

b. The Team

i. Principle Investigators

Erika Pliner – Biographical Sketch

BIOGRAPHICAL SKETCH

NAME: **Erika M. Pliner**

POSITION TITLE: **Assistant Professor, Dept. of Mechanical Engineering, University of Utah**

EDUCATION/TRAINING

INSTITUTION AND LOCATION	DEGREE	Start Date	Completion Date	FIELD OF STUDY
University of Wisconsin-Milwaukee, Milwaukee, WI, USA	B.S.	09/2010	12/2014	Mechanical Engineering
University of Wisconsin-Milwaukee, Milwaukee, WI, USA	M.S.	09/2014	08/2015	Engineering
Neuroscience Research Australia, Sydney, NSW, AUS		08/2017	08/2018	Physiology
University of Pittsburgh, Pittsburgh, PA, USA	Ph.D.	08/2015	04/2020	Bioengineering
Neuroscience Research Australia, Sydney, NSW, AUS	Post-doc.	03/2020	07/2020	Physiology
University of Florida, Gainesville, FL, USA	Post-doc.	08/2020	12/2023	Neuromechanics

A. Personal Statement

I am an Assistant Professor in the Department of Mechanical Engineering at the University of Utah. I have training and expertise in human factors & ergonomics, biomechanics, neuromechanics and falls in occupational and older adult populations. I have led eight research studies and received funding from the National Science Foundation Graduate Research Fellowship Program (NSF GRFP), the Whitaker International Fellowship Program and the National Institutes of Health – National Institute on Aging (T32 & F32). My previous research related to ladder safety has focused on identifying individual, environmental and biomechanical factors that contribute to ladder falls. In total, I have shared my research in 20 peer-reviewed publications, 12 invited talks, and 23 podiums presentations across national and international research conferences. In addition, I have experience translating my research findings to the community via presentations at safety focused meetings and providing my expertise to safety and government committees.

My combined expertise and experiences foster a high probability in successfully accomplishing the project aims. The following are six of my publications most related to this project.

- **Pliner, E.M.**, Campbell-Kyureghyan, N.H., Beschorner, K.E., 2014, Effects of foot placement, hand positioning, age and climbing biodynamics on ladder slip outcomes, *Ergonomics* 57 (11), 1739-1749.
- Martin, E.R., **Pliner, E.M.**, Beschorner, K.E., 2020, Characterizing the Shoe-Rung Friction Requirements during Ladder Climbing, *Journal of Biomechanics* 99, 109507.
- **Pliner, E.M.**, Novak, A.C., Beschorner, K.E., 2020, Hand-rung force after a ladder climbing perturbation, *Journal of Biomechanics* 106 (9), 109790.
- Deschler, C.L., **Pliner, E.M.**, Sturnieks, D.L., Lord, S.R., Beschorner, K.E., 2023, Correlation between center reach, lean and ladder tipping risk, *Journal of Biomechanics* 150, 111508.
- Williams, D.D., Beschorner, K.E., Sturnieks, D.L., Lord, S.R., **Pliner, E.M.**, 2022, Situational Factors that Influence Overreaching on a Ladder during a Gutter Clearing Task among Older Adults, *Applied Ergonomics*, 104, 103794
- Hicks, C., **Pliner, E.M.**, Lord, S.R., Sturnieks, D.L., 2021, Ladder use in older people: type, frequency, task and predictors of risk behaviours, *International Journal of Research and Public Health* 18, 9799.

B. Positions and Honors

<u>Academic and Professional Employment</u>

04/12-08/15	Research Assistant, Dept. of Industrial Engineering, University of Wisconsin-Milwaukee, Milwaukee, WI, USA
08/17-08/17	Visiting Scientist, Falls, Balance and Injury Research Centre, Neuroscience Research Australia, NSW, AUS
09/15-04/20	Research Assistant, Dept. of Bioengineering, University of Pittsburgh, Pittsburgh, PA, USA
03/20-07/20	Postdoctoral Fellow, Falls, Balance and Injury Research Centre, Neuroscience Research Australia, NSW, AUS
08/20-09/20	Postdoctoral Associate, Dept. of Biomedical Engineering, University of Florida, Gainesville, FL, USA
10/20-08/21	Postdoctoral Fellow, Dept. of Aging and Geriatric Research, University of Florida, Gainesville, FL, USA
09/21-12/23	Postdoctoral Fellow, Dept. of Biomedical Engineering, University of Florida, Gainesville, FL, USA
04/23-12/23	Adjunct Assistant Professor, Dept. of Mechanical Engineering, University of Utah, Salt Lake City, UT, USA
01/24-Present	Assistant Professor, Dept. of Mechanical Engineering, University of Utah, Salt Lake City, UT, USA
01/24-Present	Faculty, Rocky Mountain Center for Occupational and Environmental Health, University of Utah, Salt Lake City, UT, USA

<u>Honors</u>

2012-2014	Captain of the University of Wisconsin-Milwaukee Women’s Swim and Dive Team
2014	University of Wisconsin-Milwaukee Senior Student-Athlete of the Year
2014	Laureate of National Engineering Honor Society (Tau Beta Pi)
2014	University of Wisconsin-Milwaukee Student-Startup Challenge Winner

2015	1st Place at College of Engineering Research Competition, Graduate Level, University of Wisconsin-Milwaukee
2015	NSF Graduate Research Fellowship Recipient
2017	Whitaker International Fellowship Recipient
2019	American Society of Biomechanics Pre-Doctoral Young Scientist Award
2020	NIH Institutional Postdoctoral Research Fellowship
2021	NIH Individual Postdoctoral Research Fellowship

C. Contributions to Science on Ladder Safety

Ladder climbing slips

My research is the first to perturb participants while climbing a ladder, providing critical insight on factors that contribute to a ladder climbing slip. We found climbers 6x more likely to slip while climbing a vertical ladder if the toe clearance (distance between ladder rungs and fixed surface) was 3 inches. A 3-inch toe clearance is within safety regulations for the mining sector, which may contribute to ladder falls being a leading cause of injuries in this sector. This work unexpectedly found younger workers to slip more than older works while climbing. Furthermore, a greater foot angle and a more variable foot and body angle while climbing the ladder were found to increase slip risk. Complementing this work was a study investigating the required coefficient of friction (RCOF) during ladder climbing across different ladder inclinations. A greater RCOF is known to be associated with a greater slip risk. This work found a higher RCOF for more vertical ladder climbing and a greater foot angle to be associated with a higher RCOF. This suggests climbing a vertical ladder compared to an inclined ladder, and a greater foot angle (agreeing with our ladder slip experiment) to increase slip risk. These findings have implications for training programs, ladder redesign and changes to safety standards.

- **Pliner, E.M.**, Campbell-Kyureghyan, N.H., Beschorner, K.E., 2014, Effects of foot placement, hand positioning, age and climbing biodynamics on ladder slip outcomes, *Ergonomics* 57 (11), 1739-1749.
- Martin, E.R., **Pliner, E.M.**, Beschorner, K.E., 2020, Characterizing the Shoe-Rung Friction Requirements during Ladder Climbing, *Journal of Biomechanics* 99, 109507.

Ladder fall recovery

My research was the first to investigate the upper and lower body responses after a ladder falling event. Arresting a ladder fall (recovery) was more challenging for females compared to males and during descent when compared to ascent. Furthermore, individuals with greater upper body strength had an easier time recovering than lower strength individuals. Reestablishing a higher hand placement and at least one foot back onto a ladder rung also improved recovery. Benefit to a higher hand placement agrees with individuals being able to generate more force with higher hand postures. However, higher hand-rung forces after a climbing perturbation were found to be in response to the severity of the fall as opposed to the climber’s ability to generate force. These findings can guide interventions to reduce ladder falls via personal protective equipment, strength and perturbation training, and ladder redesign.

- **Pliner, E.M.**, Seo, NJ., Beschorner, K.E., 2017, Factors affecting fall severity from a ladder: impact of climbing direction, gloves, gender and adaptation, *Applied Ergonomics* 60, 163-170.
- Beschorner, K.E., Slota, G.P., **Pliner, E.M.**, Spaho, E., Seo, NJ., 2017, Effects of gloves and pulling task on achievable downward pull forces on a rung, *Human Factors* 60(2), 191-200..
- **Pliner, E.M.**, Seo, NJ., Ramakrishnan, V., Beschorner, K.E., 2019, Effects of upper body strength, hand placement and foot placement on ladder fall severity, *Gait & Posture* 68, 23-29.
- **Pliner, E.M.**, Novak, A.C., Beschorner, K.E., 2020, Hand-rung force after a ladder climbing perturbation, *Journal of Biomechanics* 106 (9), 109790.

Domestic ladder use in older adults

My research was the first to experimentally investigate domestic ladder use in older adults, which is surprising as they have the highest fall rates in the domestic setting. The ability of older adults to complete household ladder tasks (i.e. changing a light bulb on a stepladder and clearing a gutter on a straight ladder) was predicted by clinical assessments. Specifically, better task performance was associated with better upper arm control, greater knee extensions strength, faster cognitive processing speed, greater everyday risk-taking and a reduced fear of falling. Further, this work found situational factors (e.g. self-selected ladder position) to predict reaching behavior, where a farther reach is associated with a greater ladder tipping risk. Overreaching was commonly observed and reported in our participants. This knowledge can help guide safety interventions in the domestic setting, particularly among older adults. These interventions can be in the forms of health screenings to inform individuals at greater ladder fall risk, improved safety instruction and ladder redesign.

- Deschler, C.L., **Pliner, E.M.**, Sturnieks, D.L., Lord, S.R., Beschorner, K.E., 2023, Correlation between center reach, lean and ladder tipping risk, *Journal of Biomechanics* 150, 111508.
- Williams, D.D., Beschorner, K.E., Sturnieks, D.L., Lord, S.R., **Pliner, E.M.**, 2022, Situational Factors that Influence Overreaching on a Ladder during a Gutter Clearing Task among Older Adults, *Applied Ergonomics*, 104, 103794
- Hicks, C., **Pliner, E.M.**, Lord, S.R., Sturnieks, D.L., 2021, Ladder use in older people: type, frequency, task and predictors of risk behaviours, *International Journal of Research and Public Health* 18, 9799.
- **Pliner, E.M.**, Sturnieks, D.L., Beschorner, K.E., Redfern, M.S., Lord, S.R., 2021, Individual factors that influence task performance on a stepladder, *Safety Science* 136, 105152.
- **Pliner, E.M.**, Sturnieks, D.L., Lord, S.R., 2020, Individual factors that influence task performance on a straight ladder in older people, *Experimental Gerontology* 142, 111127.

D. Additional Information: Research Support

<u>Completed Research Support</u>

1F32AG072808-01 Pliner (PI) 09/2021-09/2023
National Institute of Health – National Institute on Aging
Efficacy of Balance Training with Intermittent Sensory Perturbations
Role: Principal Investigator (Sponsor: Daniel Ferris; Co-Sponsor: David Clark)

T32 AG062728 Manini (PI) 10/2020-08/2021
National Institute of Health – National Institute on Aging
Efficacy of Balance Training with Visual Occlusions
Role: Project Leader (PI: Todd Manini; Sponsor: Daniel Ferris; Co-Sponsor: David Clark)

Graduate Research Opportunities Worldwide 03/2020-07/2020
National Science Foundation
Judgement Error and Behavioral Risk during Ladder Use
Role: Project Leader (Sponsor: Stephen Lord)

Whitaker International Fellowship Program 08/2017 – 08/2018
Institute of International Education
Physiological Indicators and Assessments of Overbalance Risk on Ladders
Role: Project Leader (Sponsor: Stephen Lord)

GRFP 1247842 09/2015 – 08/2017, 09/2018 – 08/2019
National Science Foundation
Impact of Ladder Use and a Secondary Task on Balance in Young and Old Adults
Role: Project Leader (Sponsor: Kurt Beschorner)

BIOGRAPHICAL SKETCH

NAME: Kurt Beschorner, Ph.D.

POSITION TITLE: Associate Professor, University of Pittsburgh, Department of Bioengineering

EDUCATION/TRAINING

INSTITUTION AND LOCATION	DEGREE	Completion Date	FIELD OF STUDY
University of Illinois Urbana-Champaign, Urbana, IL	B.S.	05/04	Mechanical Engineering
University of Pittsburgh, Pittsburgh, PA	Ph.D.	12/08	Bioengineering

A. Personal Statement

Over the previous eighteen years, I have utilized three core competencies (tribology or friction mechanics; biomechanics; and ergonomics) to identify risk factors for slip and fall accidents. The project relies on these core competencies since this work: 1) focuses on falls that happen at heights such as those involving ladders (Publications A.1., A.2., C.2.); and 2) is motivated by ergonomic principles of user-centered design (Publications A.4. and C.3.4.). My research to date has led to numerous peer-reviewed publications that the tribology of shoe-floor friction including experimental studies (See Section C.1.), consider fall risk at elevated surfaces (See Section C.2.), have developed safety training materials for workers (See Section C.3.), improved knowledge of the biomechanics of slip and fall accidents (See Section C.3.), and have improved knowledge through friction modeling studies (See Section C.5.). This research has been published in ergonomics, biomechanics and tribology journals to ensure that the studies meet rigorous standards in each of these fields. In addition to my research output, I have PI experience managing research studies including a National Institute on Aging R44 (SBIR Phase 2) grant, two NIOSH R01 grants, a NIOSH R01 sub-contract, a NIOSH R21 grant, and a NIOSH R03 grant. I have overseen over 10 IRB protocols as PI, been the primary supervisor for five MS students (thesis track), four PhD students and four post-doctoral scholars. Beyond the lab, I have been active in observing safety conditions in field conditions and translating research to practice by developing slip, trip and fall prevention training programs through the Susan Harwood Grant Program (OSHA) (See Section C.4.). All of my previous research efforts have involved collaboration across research teams with diverse expertise. I have had active collaborations with all other personnel on this application. I have worked extensively with PI Pliner (Publications A.1., A.2., C.2.1-C.2.4., C.4.3., C.4.4.).

Ongoing and recently completed projects that I would like to highlight include:

NIOSH R01 OH011799
Beschorner (PI)
08/01/2020-07/31/2024
Predicting slips during ladder climbing: novel methods for assessing shoe-rung friction

NIOSH R21 OH012126

Beschorner (PI) and Jacobs (MPI)
9/30/2021-9/29/2023 (no cost extension to 9/29/2024)
Reducing slip-and-fall accidents in the workplace: Role of small-scale roughness of floor surfaces to improve friction

NIOSH R01 OH010940
Beschorner (PI)
9/1/2023-8/31/2027
Preventing Slips in Food Service: Development of Tools for Shoe Selection and Replacement

NIOSH Contract #75D30123P16637
Beschorner (PI)
6/6/2023-8/31/2026
Evaluation of stability, slipping, & intervention methods for roofing workers

A.1. Pliner, E.M., Campbell-Kyureghyan, N., **Beschorner, K.E.**, 2014, Effects of foot placement, hand positioning, age and climbing biodynamics on ladder slip outcomes, *Ergonomics* **57(**11), pp. 1739-1749.
A.2. Deschler, C.L., Pliner, E.M., Sturnieks, D.L., Lord, S.R., **Beschorner, K.E.**, 2023, Correlations between Reach, Lean and Ladder Tipping Risk Journal of Biomechanics, *Journal of Biomechanics,* **150**, 111508.
A.3. Iraqi, A., Vidic, N., Redfern, M.S., **Beschorner, K.E.**, 2020, Prediction of coefficient of friction based on footwear outsole features, *Applied Ergonomics*, **80**, 102963.
A.4. **Beschorner, K.E.**, Siegel, J.L., Hemler, S.L., Sundaram, V.H., Chanda, A., Iraqi, A., Haight, J.M., Redfern, M.S., 2020, An observational ergonomic tool for assessing the worn condition of slip-resistant shoes, *Applied Ergonomics* **88**, 103140.

B. Positions and Honors

Positions and Scientific Appointments

2017-present	Associate Professor, Bioengineering, University of Pittsburgh
2022-present	NIOSH Occupational Safety & Health Study Section, member
2021-present	Applied Ergonomics, editorial board member
2014-2022	NIOSH Occupational Safety & Health Study Section, ad hoc reviewer
2019-present	Associate Professor (secondary), Mechanical Engineering, University of Pittsburgh
2019-present	IISE Transactions on Occupational Ergonomics & Human Factors, editorial board member
2019-2020	NIOSH Occupational Safety & Health Conflict Study Section, ad hoc reviewer
2019	NIH Motor Function, Speech and Rehabilitation Study Section, ad-hoc reviewer
2018	NIH Musculoskeletal, Oral and Skin Sciences (MOSS) Small Business Review Session ad-hoc reviewer
2014-2017	Research Assistant Professor, Bioengineering, University of Pittsburgh
2009-2013	Assistant Professor, Department of Industrial Engineering, UW–Milwaukee
2009	Post Doctoral Scholar, Human Movement and Balance Laboratory, Department of Bioengineering, University of Pittsburgh
2004-08	Graduate Student Researcher, Human Movement and Balance Laboratory, Department of Bioengineering, University of Pittsburgh

Honors

2021	Nike Footwear Award: Best Paper

C. Contribution to Science (PI is bolded, *student advisees are italicized*)

C.1. Experimental Tribology: I have developed and validated experimental approaches for measuring friction as it relates to falling events. Previous research had established important foundational knowledge that footwear outsoles have a large effect on shoe-floor friction and proposing tribology mechanisms that might contribute to friction. Our research built on this previous work by robustly validating our shoe-floor friction measurement methods and developing new methods for directly measuring and modeling the tribological phenomena (hysteresis and fluid pressures). These new measurements have enabled us to determine the operating conditions under which each tribology phenomenon is relevant and allowed us to quantitatively determine their contribution to overall friction and slip risk (C.1.1. and C.1.2.). Our research team has pioneered the use of fluid-pressure sensors to measure under-shoe hydrodynamic pressures and the use of contact pressures/contact area to predict hysteresis friction. These novel methods have enabled us to identify worn region area (A.4., C.1.3.) as a critical footwear design features with a strong influence on shoe-floor friction. We have also identified features of footwear that predict slips (C.1.4.). My role in this research has been the lead investigator either acting as the first author or the senior/corresponding author.

C.1.1. **Beschorner, K.E.**, Chanda, A., Moyer, B.E., Reasinger, A., Griffin, S.C., Johnston, I.M., 2023, Validating the ability of a portable shoe-floor friction testing device, NextSTEPS, to predict human slips, *Applied Ergonomics*, **106**, 103854.

C.1.2. Iraqi, A., Cham, R., Redfern, M.S., **Beschorner, K.E.**, 2018, Coefficient of friction testing parameters influence the prediction of human slips, *Applied Ergonomics*, **70**, 118-126.

C.1.3. *Hemler, S.L.*, *Charbonneau, D.N.*, *Iraqi, A.*, Redfern, M.S., Haight, J.M., Moyer, B.E., **Beschorner, K.E.**, 2019, Changes in Under-Shoe Traction and Fluid Drainage for Progressively Worn Shoe Tread – Implications for Replacement Threshold, *Applied Ergonomics* **80**, pp. 35-42.

C.1.4. Jones, T.G., Iraqi, A., **Beschorner, K.E.**, 2018, Performance testing of work shoes labeled as slip resistant, *Applied Ergonomics*, **68,** 304-312.

C.2. Ladder slip and fall studies: My research has aimed to improve knowledge and understanding of ladder falling risk. Prior to my contributions in this area, other researchers had primarily focused on sway while standing on a ladder, the biomechanics of unperturbed ladder climbing or the achievable forces between the hands and rung. These studies could only make inferential conclusions regarding the link between ladder designs and falling risk (C.2.1. to C.2.2.). My research has applied two types of perturbations (slip and simulated misstep) during ladder climbing and identified ergonomic factors (toe clearance and grasping orientation), personal factors (gender, strength, C.2.2-C.2.3.) and biomechanical factors (foot and body angle during climbing) with a direct link to slip and fall risk. We have more recently, expanded this research to also consider tasks and circumstances that contribute to overreaching during ladder use tasks related to roof/gutter access. My role has been PI in these studies.

C.2.1. Pliner, E.M., Sturnieks, D.L., Beschorner, K.E., Redfern, M.S., Lord, S.R., 2021, Individual factors that influence task performance on a stepladder, *Safety Science*, **136,** 105152.

C.2.2. *Pliner, E.*, Seo, N.J., Ramakrishnan, V., **Beschorner, K.E.**, 2019, Effects of upper body strength on ladder fall severity while controlling for hand and foot placement, *Gait & Posture* **68**, 23-29.

C.2.3. **Beschorner, K.E.**, Slota, G.P., *Pliner, E.M.*, Spaho, E., Seo, N.J., 2018, Effects of gloves and pulling task on achievable downward pull forces on a rung, *Human Factors*, **60** (2), 191-200.

C.2.4. Williams, D., **Beschorner, K.E.**, Sturnieks, D.L., Lord, S.R., Pliner, E.M., 2022, Situational Factors that Influence Overreaching on a Ladder during a Gutter Clearing Task among Older Adults, *Applied Ergonomics*, **104**, 103794.

C.3. Field Research and Translating Research to Safety Interventions: I have been active in performing research that includes the workplace and that translates our work into field practices. The motivation for this research is that scholarly research articles are often inaccessible to greater society due to high costs associated with journal subscriptions and the technical language used in these articles. Thus, developing materials that are accessible to targeted aspects of the population (like employees or testing labs) is important to make sure that research findings get translated into actual safety practice. I have collected on-site data collection at job sites in various sections (Publications C.4.1.-C.4.3.). We have also tracked the change in friction performance in footwear worn in work environments (Publications A.4. and C.4.4.). The materials that I have developed include safety training programs for employees in the energy sector (Publications C.4.1.-C.4.3.) and a simple method for assessing worn condition of tread that was the basis for a communications website (Publication A.4., C.3.4.). The training materials have led to low-cost interventions like how to recognize slipping hazards, how to inspect shoe tread and proper techniques for climbing a ladder. The trade publication made our new research methods available to a broad tribologist audience to enable broader adoption of these methods. I was a Co-Investigator for the safety training program and senior author for the research on developing the low-cost footwear assessment method.

C.4.1. Campbell-Kyureghyan, N., **Beschorner, K.E.,** Ahmed, M.S. 2015, Safety and Ergonomics Awareness Training and Best Practices for Wind Energy Generation, 4 hour training program.
C.4.2. Campbell-Kyureghyan, N., **Beschorner, K.E.,** Ahmed, M.S. 2013, Employee Safety and Ergonomics Awareness Training and Best Practices for Power Plants, 4 hour training program.
C.4.3. Campbell-Kyureghyan, N., **Beschorner, K.E.**, Cooper, K., 2011, Ergonomics and Safety Awareness Training for Gas Utilities and Contractors, 4 hour training program.
C.4.4. **Beschorner, K.E.**, 2021, A Guide for When to Replace Slip-resistant Shoes Using a AA Battery, https://www.engineering.pitt.edu/subsites/Labs/hmbl/worn-shoes/.

C.4. Biomechanics of Slips and Falls: My previous research has also utilized biomechanics techniques with human subjects to determine environmental, footwear and personal risk factors for slip, trip and falling accidents. These experimental results have provided basic understanding of shoe dynamics during slipping (Publications C.4.1.-C.4.2.), which serve as the basis for the shoe angle and force utilized for our proposed tread scanner and proposed shoe traction testing. Furthermore, we have conducted studies to understand slip events on ladders (Publications A.1., A.2., C.4.3., C.4.4.). My role has been either the lead researcher or the study PI for each of these studies.
C.4.1. *Iraqi, A.*, Cham, R., Redfern, M.S., Vidic, N., **Beschorner, K.E.**, 2018, Kinematics and Kinetics of the Shoe during Human Slips, *Journal of Biomechanics* 74, 57-63.
C.4.2. **Beschorner, K.E.**, Iraqi, A., Redfern, M.S., Cham, R., Li, Y., 2019, Predicting slips for the SATRA STM 603 whole-shoe tribometer under different coefficient of friction testing conditions, *Ergonomics*, **62** (5), 668-681.
C.4.3. Pliner, E.M., Novak, A. C., **Beschorner, K.E.**, 2020, ASB Young Investigator Award Paper: Hand-rung forces after a ladder climbing perturbation, *Journal of Biomechanics*, **106,** 109790.
C.4.4. Martin, E.R., Pliner, E.M., **Beschorner, K.E.**, 2020, Characterizing the Shoe-Rung Friction Requirements during Ladder Climbing, *Journal of Biomechanics*, **99**, 109507.

C.5. Tribology Modeling: My research has contributed to slip and fall prevention by developing physics-based models that are able to quantify the contribution of different shoe, floor or contaminant properties to ACOF. We have developed fluid-film models (Publication C.5.1 and C.5.4.) and finite element models that have been validated against experimental results (Publications C.5.2. and C.5.3.). These models have been critical to understanding shoe-floor friction, which informs our understanding of when friction results generalize across floor and contaminant conditions. These models represent the first successful attempts to predict shoe-floor-fluid ACOF based on physics-based equations using measurable inputs (i.e., shoe and floor material properties, topography, geometry and fluid viscosity). My role in this research has been either as the lead investigator or as the primary advisor in the cases where a student was the lead investigator.
C.5.1. Hemler, S.L., Charbonneau, D., **Beschorner, K.E.**, 2020, Predicting Hydrodynamic Conditions under Worn Shoes using the Tapered-Wedge Solution of Reynolds Equation, *Tribology International*, **145**, 106161.
C.5.2. *Moghaddam, S.R.M.*, Redfern, M.S., **Beschorner, K.E.**, 2015, A Microscopic Finite Element Model of Shoe-Floor Hysteresis and Adhesion Friction, *Tribology Letters* **59**(3), 1-10
C.5.3. *Moghaddam, S.R.M.*, *Hemler, S.L.*, Redfern, M.S., **Jacobs, T.**, **Beschorner, K.E.**, 2019, Computational Model of Shoe Wear Progression, *Wear* **422-423**, 235-241.
C.5.4. **Beschorner, K.E.**, Lovell, M.R., Higgs III, Redfern, M.S. 2009, Modeling mixed-lubrication of a shoe-floor interface applied to a pin-on-disk apparatus, *Tribology Transactions* 52 (4), 560-8.

A complete list of my publications can be found at:
https://www.ncbi.nlm.nih.gov/myncbi/kurt.beschorner.1/bibliography/public/.

ii. Student Researchers

<u>Current</u>

Carson Davis

Education

- MS in Mechanical Engineering, University of Utah, *pursuing*
- BS in Biomedical Engineering, University of Utah, *2025*

Contribution to project

- Wrote a research protocol for data collection procedures.
- Designed and constructed a mechanical frame that attaches to four force plates, adjusts to two inclination angles, and can accommodate multiple ground conditions.
- Facilitated orders for study materials.
- Translation of study materials to Spanish.
- Leading recruitment and screening of potential participants.
- Leading ladder use data collections.
- Leading ladder use data analysis.
- Presenter of preliminary results at academic conferences.

Cole Ward

Education

- BS in Neuroscience and Behavior, Wesleyan University, 2025

Contribution to project

- Created safety materials to operate tools for project construction.
- Designed and built a frame to complete a construction task at an elevated level.
- Created first draft of implicit and explicit instructional videos.
- Collected and analyzed available coefficient of friction data.
- Refined instructional videos.
- Assisted with ladder use data collections
- Presenter of preliminary results at an academic conference.

Simeon Tanner

Education

- BS in Mechanical Engineering, University of Utah, *pursuing*
- AS in University Studies, Utah Valley University, 2024

Contribution to project

- Assisted with ladder use data collections.
- Created a physics-based model of ladder slip risk.

Previous

Pengshun Tang

Education
- MS in Mechanical Engineering, University of Utah, *Pursuing*
- BS in Mechanical Engineering, University of Kentucky, *2021*

Contribution to project
- Designed a mechanical testing system of the available coefficient of friction (ACOF).
- Collected pilot data on the ACOF between three ladder feet designs and ground surface conditions.
- Dissmeinated ACOF pilot results at the National Occupational Research Agenda (NORA) Symposium (shared in Quarter1 Report).

Reason for Discharge
- Completed the independent study project.

Ashmita Shanthakumar

Education
- MS in Occupational Health, University of Utah, *Pursuing*
- MS in Media, Communication, and International Journalism, University of Glasgow, *2022*
- BA in English & Political Science, University of Utah, *2021*
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Contribution to project
- Constructed a structured interview on perceived barriers to ladder safety.
- Produced scripts to implicit and explicit training videos for ladder safety.

Reason for Discharge
- Falsified work hours.

c. Title and Brief Narrative

i. Title

Effectiveness of Level Tools and Instruction on Optimal Ladder Setup

ii. Brief Narrative

The purpose of this project is to quantify the barriers of safe ladder setup. Prior ladder safety research has identified the optimal ladder setup to prevent movement of the ladder base – movement that causes a ladder fall. Yet, ladder slipping is still a common cause of ladder falls in the construction industry. These incidents are more prevalent in residential construction, commonly associated with small companies where safety knowledge and resources are limited. There is a need to isolate the disconnect between recommended ladder setup and users' performance in achieving the optimal ladder setup. This disconnect can be linked to lack of adequate leveling tools, poor instruction, environmental conditions, or other work task related barriers (e.g. time). This project is designed to quantify the effects of level tools, instruction, and ground surface on safe ladder setup. In addition, this project is extracting perceived barriers to safe ladder setup from construction workers through observed behaviors and structured interviews. This knowledge is required to eliminate the disconnect between safe ladder setup practices and user performance. Further, this work will motivate follow up research to produce a level tool attachment that can be utilized with most commercial ladders. Immediate benefits to this project will comprise level tool-specific instructional videos to improve safe ladder setup. These deliverables will be validated from residential construction workers via our outcome measures of ladder setup accuracy and ladder slip risk. The instructional videos will foster user accessibility and be made publicly available to facilitate safer ladder setup practices.

iii. Target Audience

Residential construction workers from small companies in the Salt Lake City area.

d. Problem Statement & Motivation

i. Problem Statement

Workplace fatalities are more prevalent in construction than other industries, accounting for over 1,000 deaths each year (BLS 2022). Falls are a leading cause of these accidents, contributing to 36% of fatal construction injuries (BLS 2022). The proportion of fatal injuries from a fall increases to 50% in residential construction (Dong et al. 2014). These fatal injuries primarily occur from a height (i.e. workers fall to a lower level) (BLS 2022; Dong et al. 2014). Working from heights is a known hazard, but inherent to residential construction. Construction workers are commonly required to work from ladders, roofs, scaffolding and structural steel. All of these elevated heights contribute to fatal falls, but ladder use is the leading cause of fatal falls from a height (BLS 2012).

A ladder fall commonly occurs when the ladder slips (both laterally or outward from the supporting surface), leading to a fall of the ladder and climber (Shepherd et al. 2006). The ladder setup and the friction between the ladder feet and ground are two interacting mechanisms that affect ladder slip risk. Ladder safety research has determined a ladder slant of 75.5° from the horizontal to be optimal to reduce outward ladder slip (Chang et al. 2004; Chang et al. 2005a; Chang et al. 2005b). Despite this work and current safety practices, inaccurate ladder setup still occurs (Chang et al. 2016) and ladder slipping remains prominent in residential construction (Bentley et al. 2006; Dong et al. 2014). 46% of ladder falls have been attributed to ladder movement with lack of ladder safety training and inadequate ladder setup (particularly in sloped or slippery ground conditions) reported as contributing factors in 54% and 26% of ladder falls cases (Cabilan et al. 2018). While level tools and instruction exist to aid workers in optimal ladder setup, there is a need to investigate the disconnect between optimal ladder setup and user performance. This disconnect is likely linked to the usability of the leveling tools, detail of instruction, ground surface conditions and other perceived barriers from the worker (e.g. time).

ii. Motivation for Work

This project is designed to quantify the effects of level tools, instruction, and ground surface on safe ladder setup in residential construction workers. In addition, this project is extracting perceived barriers to safe ladder setup from construction workers through observed behaviors (setup time, level tool choice) and structured interviews. This knowledge is required to eliminate the disconnect between safe ladder setup practices and user performance.

Further, this work will motivate follow up research to produce a level tool attachment that can be utilized with most commercial ladders. Immediate benefits from this project will comprise level tool-specific instructional videos to improve safe ladder setup. These deliverables will be validated from residential construction workers via our outcome measures of ladder setup accuracy and ladder slip risk. The instructional videos will foster user accessibility (ease of use, language) and be made publicly available to facilitate safer ladder setup practices.

e. Furtherance of JSI Objectives

The following JSI objectives will be advanced through this project:

Protect the health and well-being of all persons involved in the residential and commercial construction industry and construction-related trades.

- This project focuses on the health and well-being of residential construction workers due to common limitations in safety knowledge and resources in this population.
- Deliverables from this project will be guided by measured outcomes and feedback from residential construction workers.
- Deliverables will be beneficial to all ladder users.

Promote worker safety by eliminating construction job-site injuries and fatalities through research, education, training, and innovation in establishing best practices in the construction industry.

- Deliverables from this project will assist in reducing ladder falls due to inadequate ladder setup. Ladder falls are a leading cause of fatality in the construction industry.
- Deliverables from this study are being obtained from ladder safety research experts in state-of-the-art laboratories at the University of Utah.
- Deliverables will be made publicly available for educating and training best practices in the construction industry.

Foster the most protective work environment possible within the construction industry.

- This project will determine the level tool(s) and instruction that is most effective towards achieving safe ladder setup.

Develop collaborative relationships with local, state, and federal government as well as colleges and universities to encourage the exchange of ideas and technologies to better understand and mitigate the inherent risks and dangers with the construction industry.

- The assessment of level tools and instruction on optimal ladder setup among residential construction works will be a collaboration between JSI, the University of Utah and local residential construction companies in the Salt Lake City area.

f. Research Project

i. Specific Objectives & Findings

Aim 1: To determine the leveling tool that yields the optimal ladder setup angle and lowest ladder tip risk.

H1: A ladder instrumented with levels will result in greatest ladder setup accuracy and the lowest ladder tip risk compared to other level tools.

H1 was confirmed. Residential construction workers utilizing the HyperLite and SumoStance ladders, setup the ladder closer to the recommended 75.5° setup angle to avoid a ladder slip than the other ladder level tools (Figure 1). The setup of the HyperLite and SumoStance ladder were significantly greater than the setup of a standard ladder (too shallow) ($F_{3,28}=6.0;\ p=0.003$). This suggests that the HyperLite and SumoStance level tools (ladders with built in levels) yield a safer ladder setup.

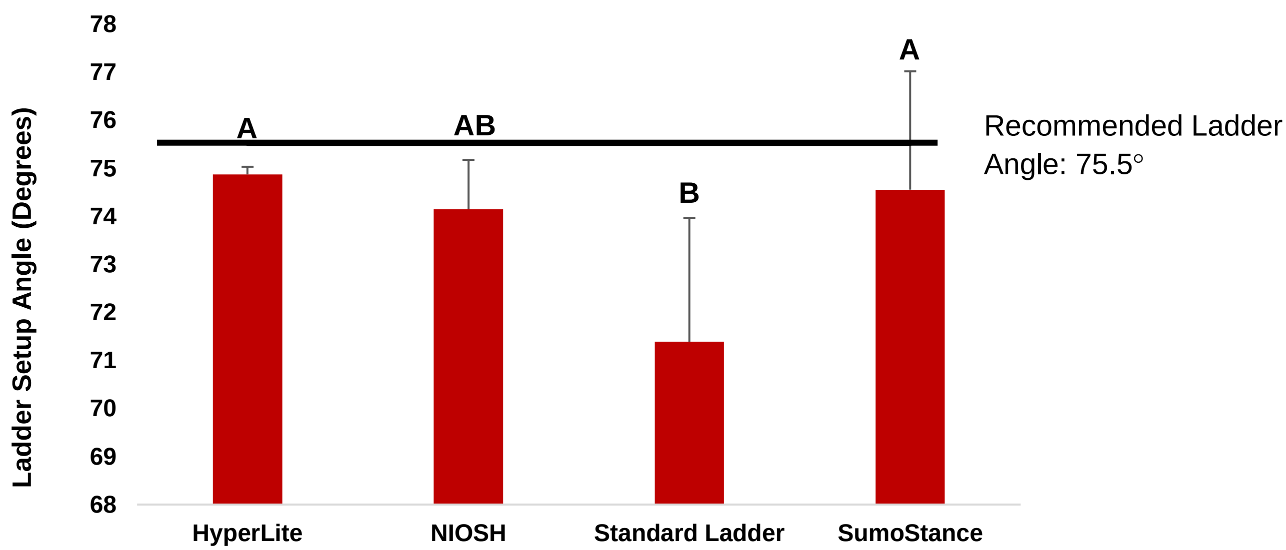


Figure 1: Mean ladder setup angle across level tools. Error bars denote the standard deviation. Different letters denote level tools with significantly different ladder setup angles. The black horizontal line denotes the recommended ladder setup angle of 75.5°.

Aim 2: To determine the impact of instruction on optimal ladder setup.

H2.1: Explicit instruction will result in greater ladder setup accuracy than no instruction and implicit instruction.

H2.1 was confirmed. Residential construction workers achieved a ladder setup closer to the recommended 75.5° setup angle after listening to explicit instructional videos on ladder setup (Figure 2).

The ladder setup angle was significantly different between implicit and explicit instruction ($F_{2,27}=8.6$; $p=0.001$). Interestingly, this worked showed implicit instruction to lead to a ladder setup with a greater slip risk. This suggests that workers need explicit instruction on how to use the level tools safely and implicit instruction to be detrimental to their safety.

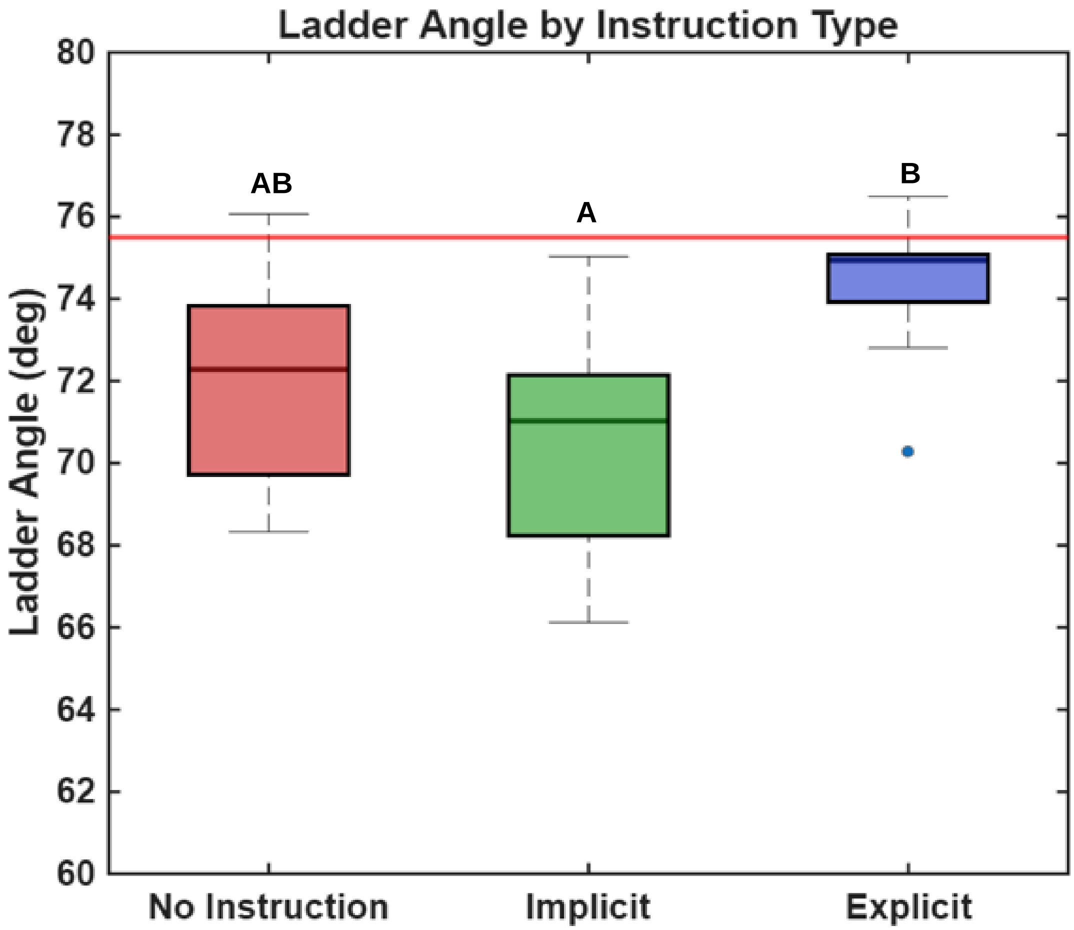


Figure 2: Box plots of the ladder setup angle across instruction. The midline denotes the median of the data. Boundaries of the boxes denote the first quartile (25th percentile of the data) and the third quartile (75th percentile of the data). Whiskers denote 1.5 times the interquartile range. Data points outside the whiskers are outliers. Different letters denote instruction conditions with significantly different ladder setup angles. The red horizontal line denotes the recommended ladder setup angle of 75.5°.

H2.2: Ladder setup accuracy will be comparable between explicit and retention trials.

H2.2 was rejected. Residential construction workers did not maintain the recommended 75.5° ladder setup angle in retention trials (Figure 3). The ladder setup angle was significantly lower (increasing ladder slip risk) in the retention than the explicit trials ($F_{1,30}=5.3$; $p=0.029$). This work identifies a critical barrier in achieving safe ladder setup. Specifically, explicit instruction can assist residential construction workers in achieving a safe ladder setup, but the benefit of this instruction in not maintained. This highlights a need to improve the retention of this instruction/training or the development of new tools to foster safer ladder setup (e.g. active alert systems on the ladder).

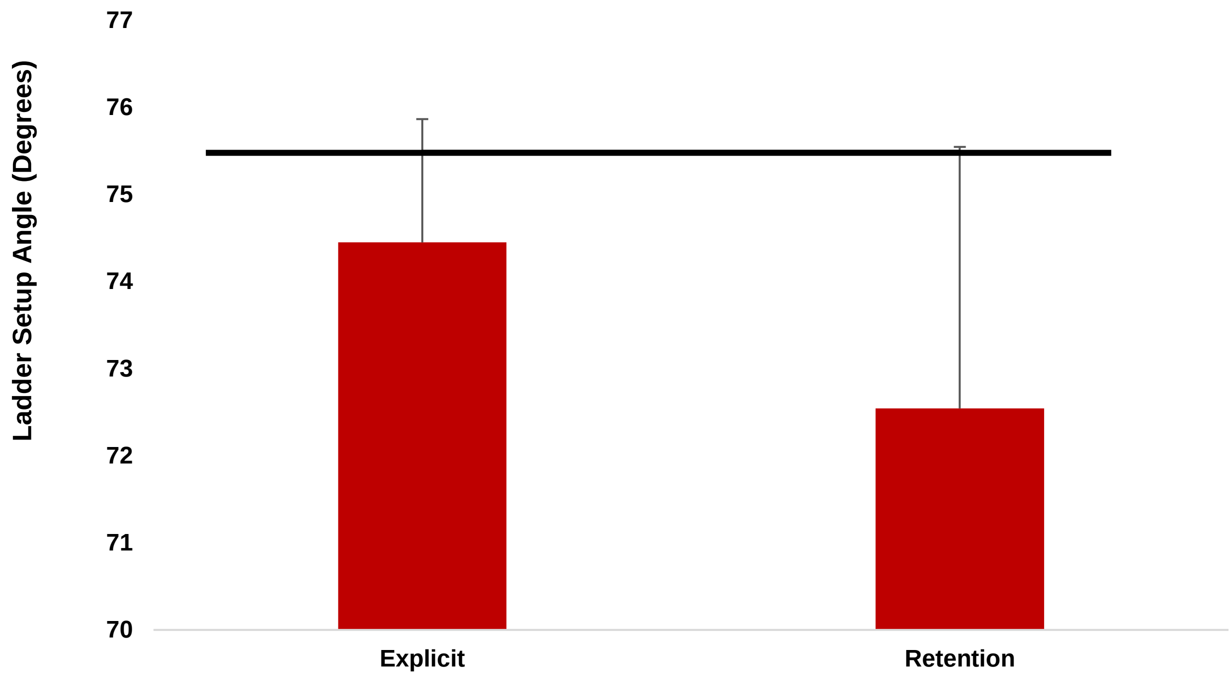


Figure 3: Mean ladder setup angle across explicit and retention trials. Error bars denote the standard deviation. The black horizontal line denotes the recommended ladder setup angle of 75.5°.

Aim 3: To assess level tool preference for ladder setup and extract the observed and perceived barriers towards safe ladder setup.

H3.1: Workers will prefer the ladder instrumented with levels for setup as opposed to handheld leveling tools.

Residential construction workers felt more confident setting up the standard and HyperLite ladders than the SumoStance ladder or ladder with the NIOSH App. However, workers preference on which ladders they would use and the leveling tool they found easiest to use varied.

H3.2: Longer setup times will be associated with reduced user preference in level tools.

To prevent bias in our other analyses, we opted to not measure ladder setup time and focused solely on ladder setup accuracy.

H3.1 & 3.2 was not confirmed. There is currently too much variability in the response from participants on their preferred level tool. We will continue to monitor these responses and look for common tendencies across participants in the structured interviews. However below are some common perspectives from residential construction workers that we have extracted:

- They feel extremely confident in setting up a ladder for work.
- Most had been trained on ladder safety or setup.
- They do not receive refresher training on the job.
- Most do not look at ladder safety instructions before use.
- They feel they are given adequate time to setup a ladder.
- If provided new safety equipment, they would use it.
- Most workers know someone who has experienced a ladder fall at work in construction.

This commentary is critical as it highlights potential barriers to safe ladder setup (e.g. overconfidence, lack of refresher training; passive instruction is ineffective) and direction for future safety interventions (e.g. workers are willing to use new safety equipment).

Aim 4: To determine the impact of ladder-ground surface on optimal ladder setup and ladder tip risk.

H4.1: Ladder setup accuracy will be reduced in sloped and gravel ladder setup conditions compared to the flat and other surface material conditions.

H4.1 was not confirmed. The effect of ground condition on ladder setup angle is inconclusive. Specifically, not enough data has been captured to assess the eight conditions (4 surface materials and 2 slopes). We will collect more trials to confirm the effects of ground condition on ladder setup angle. Below depicts preliminary data on this analysis (Figure 4).

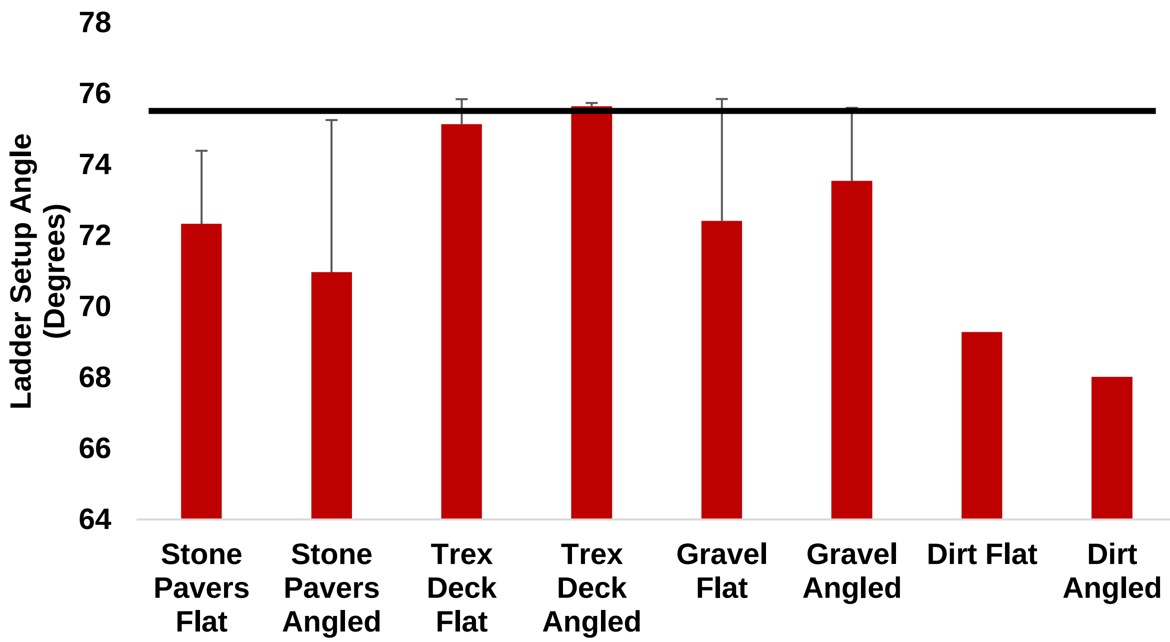


Figure 4: Mean ladder setup angle across ground conditions (surface material and slope). Error bars denote the standard deviation. No error bars denote conditions with only one trial. The black horizontal line denotes the recommended ladder setup angle of 75.5°.

H4.2: Ladder slip risk will be greatest on sloped and interior flooring compared to flat and other surface material conditions.

H4.2 was not confirmed. The effect of ground condition on ladder setup angle is inconclusive. Specifically, not enough data has been captured to assess the eight conditions (4 surface materials and 2 slopes). We will collect more trials to confirm the effects of ground condition on ladder slip risk (quantified from the required coefficient of friction [RCOF]). Below depicts preliminary data on this analysis (Figure 5). While preliminary, ladder slip risk is greatest (higher RCOF values) when transitioning off the ladder during ascending climbs. Sloped surfaces appear to increase ladder slip risk when transitioning on the ladder and during the climbing phase. Ladder slip risk varies across ground conditions, but more data is needed for robust interpretation.

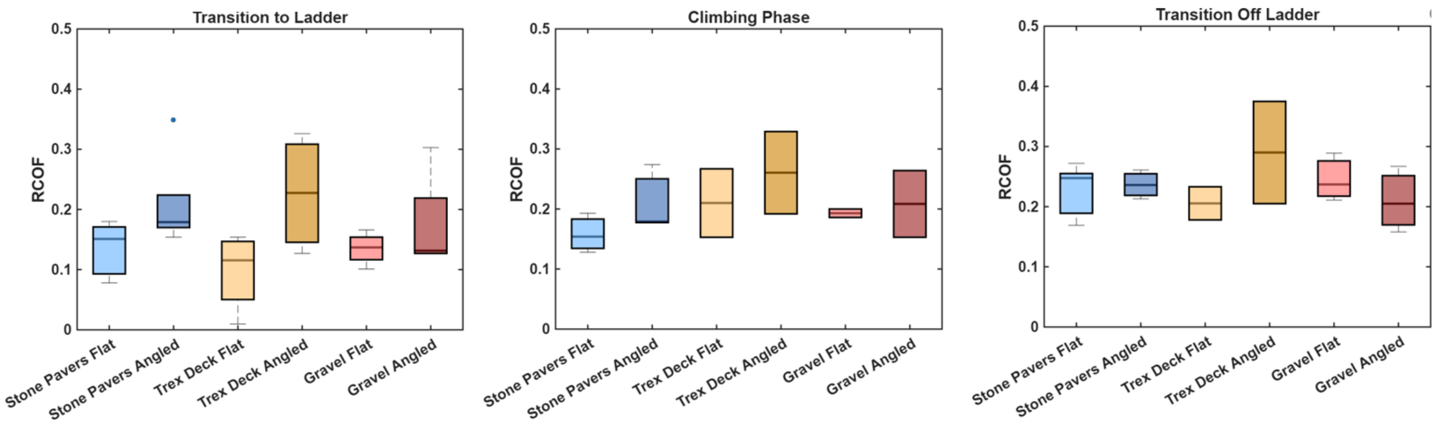


Figure 5: Box plots of the required coefficient of friction across ground conditions. The midline denotes the median of the data. Boundaries of the boxes denote the first quartile (25th percentile of the data) and the third quartile (75th percentile of the data). Whiskers denote 1.5 times the interquartile range. Data points outside the whiskers are outliers.

ii. Additional Analyses

The Available Coefficient of Friction (ACOF) across Ladder Shoes. The ACOF was captured across three surface materials (concrete, tile, wood) and three ladder shoes (A, B, C) (Figure 6). The ACOF was greater in concreate than tile or wood, regardless of ladder shoe ($F_{2,36}=152; p<0.001$) (Figure 7). The effect of ladder shoe on ACOF varied by ground conditions.

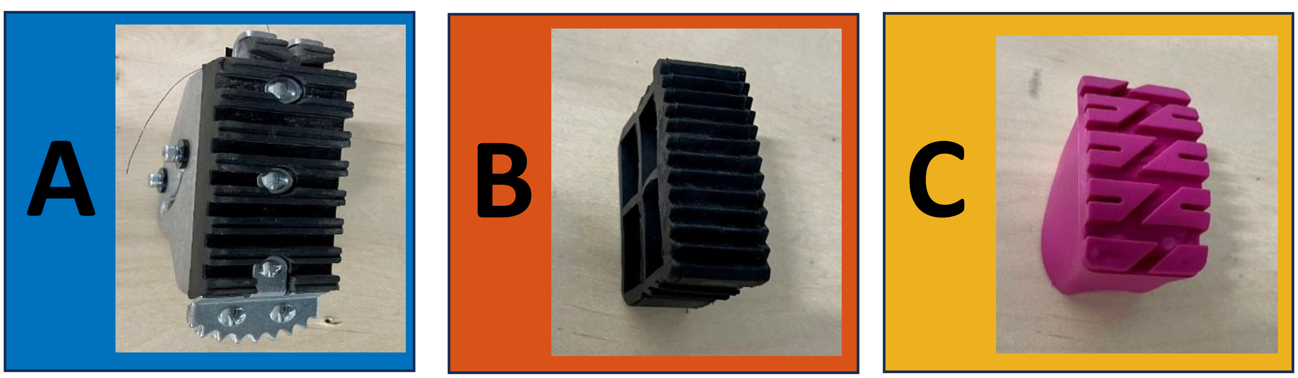


Figure 6: Three different ladder feet. A ladder shoe from Little Giant Ladder Systems with a flat and rectangular tread grove pattern (A); a ladder shoe with a flat and linearly, spiked tread grove pattern (B); and a ladder shoe with a curved and unique tread grove pattern (C).

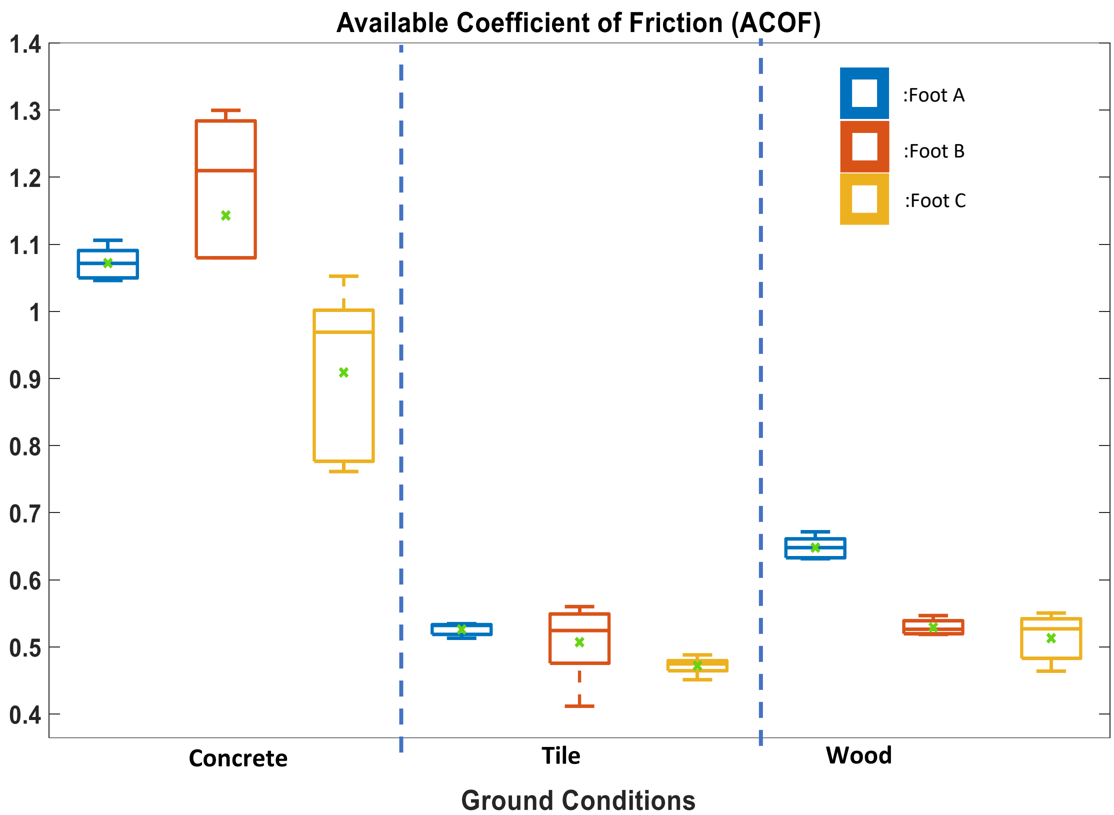


Figure 7: Box plots of the available coefficient of friction (ACOF) value across ground condition and ladder shoe. The green 'x' denotes the mean. The midline denotes the median of the data. Boundaries of the boxes denote the first quartile (25th percentile of the data) and the third quartile (75th percentile of the data). Whiskers denote 1.5 times the interquartile range.

The Available Coefficient of Friction (ACOF) across Ground Condition. The ACOF was captured across three surface materials (vinyl, stone pavers, Trex decking) and two weather conditions (dry, muddy). The ACOF was greater in stone pavers than vinyl and Trex decking in both the dry and muddy conditions (Figure 8). The effect of mud on the ACOF varied by ground conditions ($F_{2,68}=130; p<0.001$). This works gives important context to the ACOF between the ladder feet and ground type.

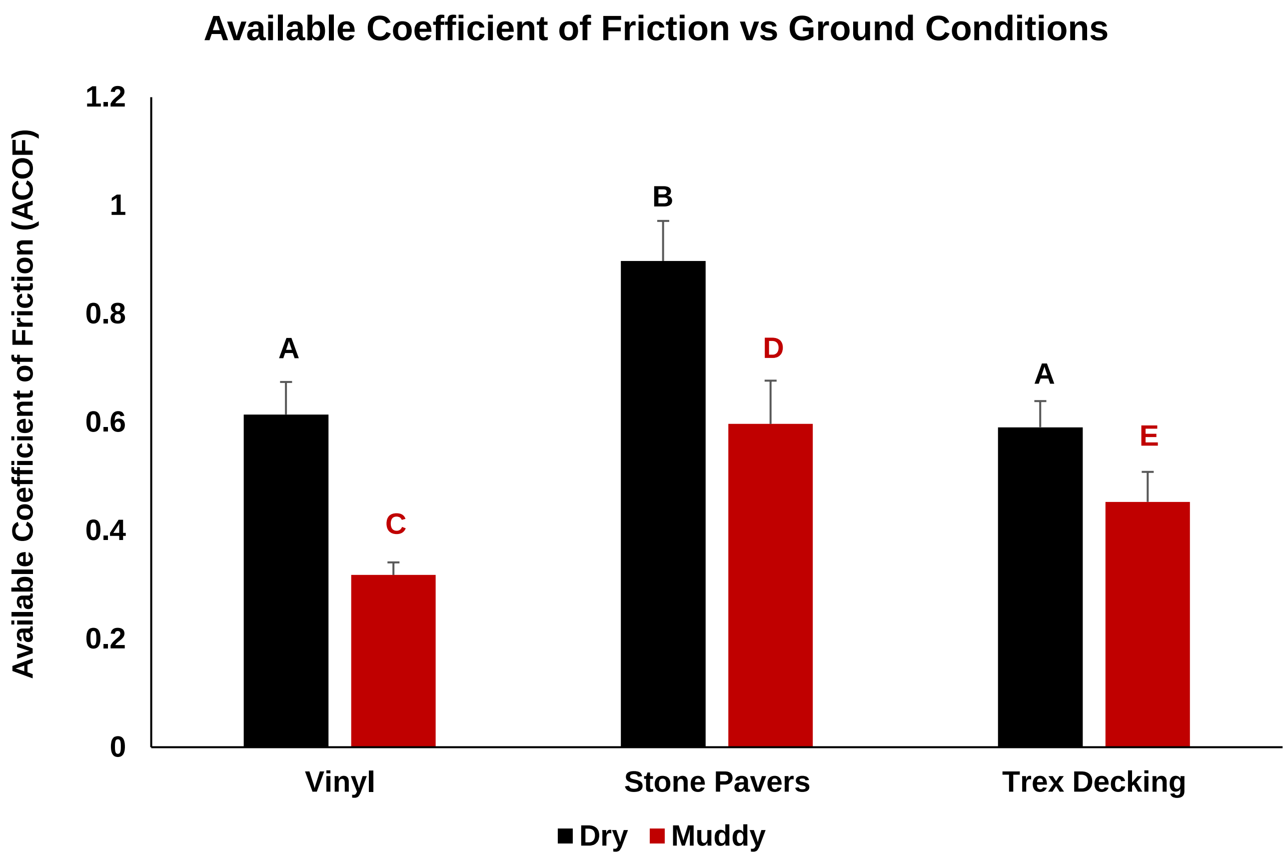


Figure 8: Mean available coefficient of friction (ACOF) value across ground conditions (surface material and weather). Error bars denote the standard deviation. Different letters denote ground conditions with significantly different ACOF values.

Validation of Available Coefficient of Friction (ACOF) Capture across Laboratory Force Plates and a Portable Device. Our methods to extract the ACOF from a portable device are valid across multiple ground conditions (Figure 9).

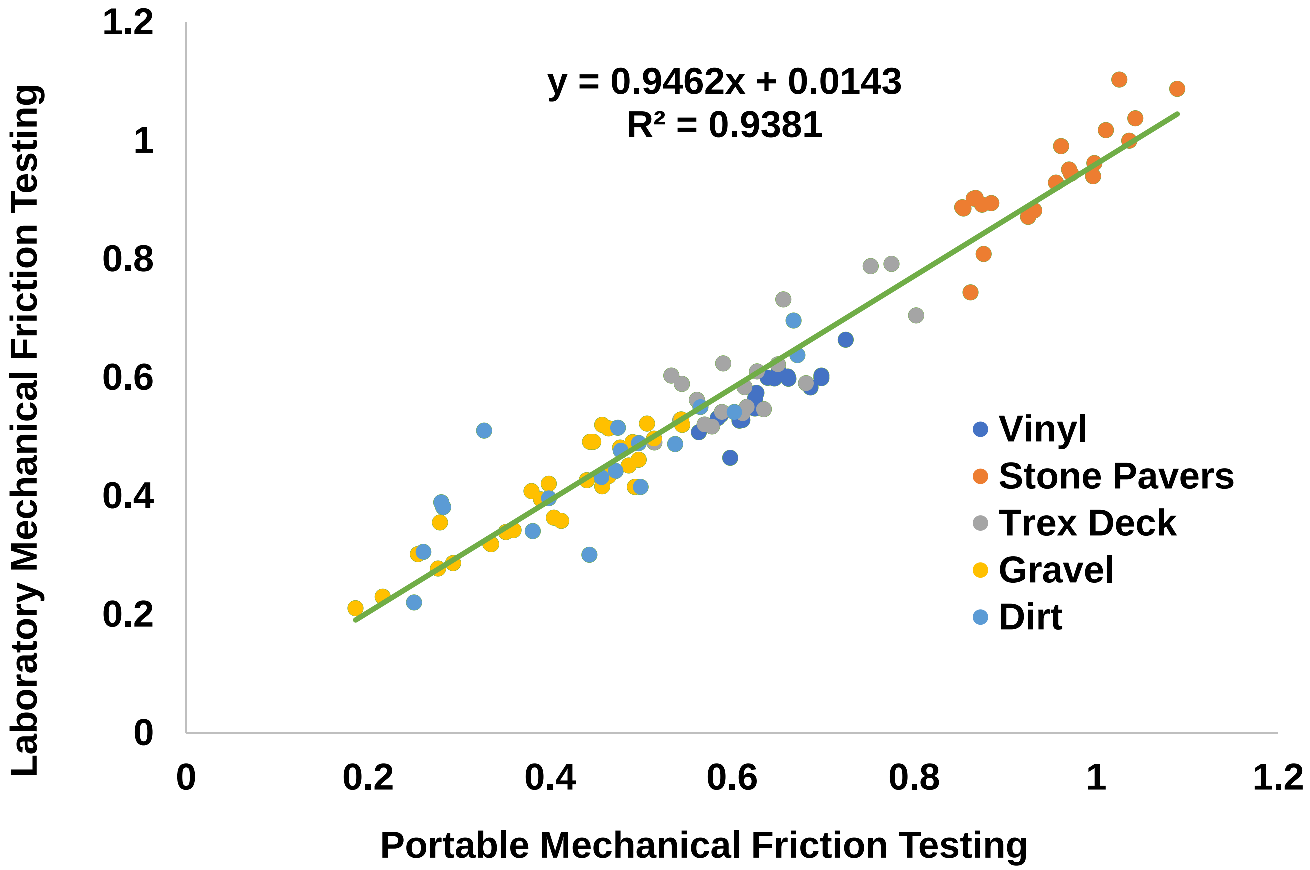


Figure 9: Extracted available coefficient of friction (ACOF) values across laboratory force plates and a portable device for vinyl, stone pavers, Trex deck, gravel, and dirt.

Modeling the Required Coefficient of Friction (RCOF) across User-Environment. The shallower the ladder angle, the greater the RCOF a worker will require when climbing the ladder. As the worker climbs up the ladder the influence of ladder setup angle on the RCOF increases (Figure 10). Additional modeling simulations can be found in the attached supplementary material: Computation Model of Ladder System Friction Requirement.

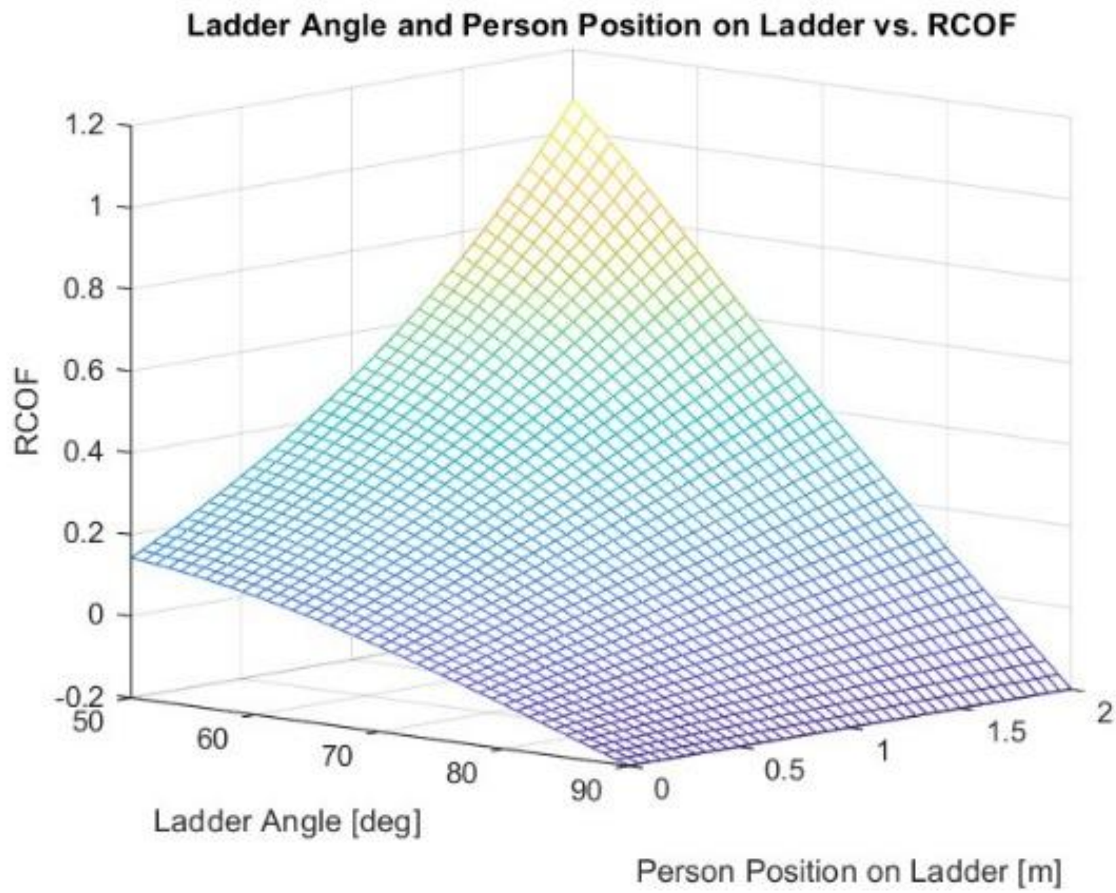


Figure 10: Modeled required coefficient of friction (RCOF) across ladder setup angle and person's position up the ladder.

iii. Brief Description of Study Design

10 residential construction workers we recruited from the Salt Lake City area to assess the effects of level tools and instruction on safe ladder setup. Only 5 of the 10 participants enrolled to participate in the study. Five participants refused to participate due to fatigue, refusal to file a W9 (University of Utah policy for compensation over $100), or did not provide a reason. Participants were asked to setup and climb an extension ladder to access a scaffolding platform to complete a work task. Prior to the task, participants were given a tool belt and asked to select any tools to complete the task. A variety of residential construction tools were display on a table for the participant to choose from. Participants were asked to complete the ladder setup and associated work task across multiple level tool, instruction and ground surface conditions. **Level tool** conditions comprised a standard ladder setup (the 4-to-1 Rule), the NIOSH ladder safety phone application on achieving the optimal slanted ladder angle, a Little Giant HyperLite ladder, and a Little Giant SumoStance ladder. **Instruction** was informed via short videos on how to complete the overall work task and how to utilize the tools provided to the participant. Specifically, the recommended angle for setting up a ladder was provided (implicit instruction) and how to use each tool to setup the ladder at the recommended angle was provided (explicit instruction). Ladder setups with no instruction were assessed before providing participants with instruction (implicit instruction trials followed by explicit instruction trials). Post explicit ladder setup trials, retention trials were performed. In the retention trials, ground condition was varied. **Ground Condition** was varied by surface material (gravel, unlevel dirt, Trex decking, stone pavers) and surface slope (flat, sloped). Ground condition for all trials prior to retention trials utilized a flat interior surface (vinyl flooring). This experiment was conducted in a motion capture volume instrumented with force plates and motion capture cameras. The ladders were instrumented with reflective markers to track the ladder position to quantify ladder setup accuracy. The participants were instructed to place the ladder feet in a region that was on top of the force plates when setting up the ladder.

Between explicit and retention trials, participants completed a structured interview. The structured interview provided participants with a rest period and extracted workers' preferred level tool for ladder setup and perceived barriers to safe ladder setup.

In addition, the available coefficient of friction between the ladder feet and ground was quantified across ground surface materials. Value in these mechanical tests (no human data collection) assists in assessing ladder slip risk across more real-world conditions and may guide future research directions.

Lastly, we performed physical based models on a ladder climber's required coefficient of friction. The models were performed to assess alterations in the ladder user-environment on ladder slip risk.

iv. Independent Variables

Level tool – standard setup, NIOSH app, Little Giant HyperLite ladder, Little Giant SumoStance ladder.

Instruction **–** no instruction, implicit instruction, explicit instruction, retention.

Ground surface material **–** gravel, unlevel dirt, Trex decking, stone pavers.

Ground surface slope – flat, sloped.

v. Measurable Outcomes

Ladder setup accuracy – measured as the difference between observed ladder slant setup angle and NIOSH's recommended ladder slant setup angle (75.5°) from the horizontal (ground level). A lower degree is associated with a more accurate ladder setup.

Ladder slip risk – measured from the available coefficient of friction (ACOF) or the required coefficient (RCOF).

- Available Coefficient of Friction (ACOF) was measured as the ratio of horizontal to vertical force between the ladder feet and ground surface material before sliding between the two surfaces occur. A lower ACOF is indicative of a greater slip risk.
- Required Coefficient of Friction (RCOF) was quantified as the ratio of the horizontal to vertical ground reaction forces during experimental or modeled ladder use. A greater RCOF is indicative of a greater slip risk.

Level tool preference – no level tool preference was found in this analysis. More data needed.

Perceived barriers – trends of common barriers were found and listed above. However, more data is needed to confirm these trends. We will continue to extract these barriers through structured interviews.

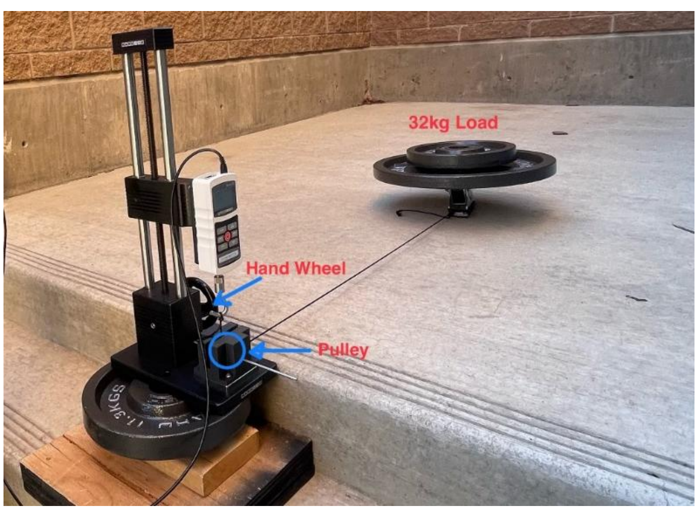
vi. Project Achievements

<u>Quarter 1 Achievements</u>

- Hiring and onboarding of 4 student researchers.

- Met with Little Giant Ladder Systems to discuss custom ladder designs for our laboratory.

- Design and testing of mechanical testing apparatus to assess the available coefficient for friction (ACOF) between ladder feet and various ground surfaces.



- Dissemination of piloted ACOF results at the National Occupational Research Agenda Symposium (see attached poster).

- Optimizing laboratory renovations with this study and future ladder safety research in focus (see Unanticipated Setbacks section below).
- Initiated review process from the Institutional Review Board (IRB) for human-based experiments in the research project.
- Written study protocol.
- Development of structured interview and questionnaires.
- Developing script for implicit and explicit instructional videos.

Quarter 2 & 3 Achievements

- Completion of necessary lab renovations.
  - Raised flooring installed
  - Motion capture system installed

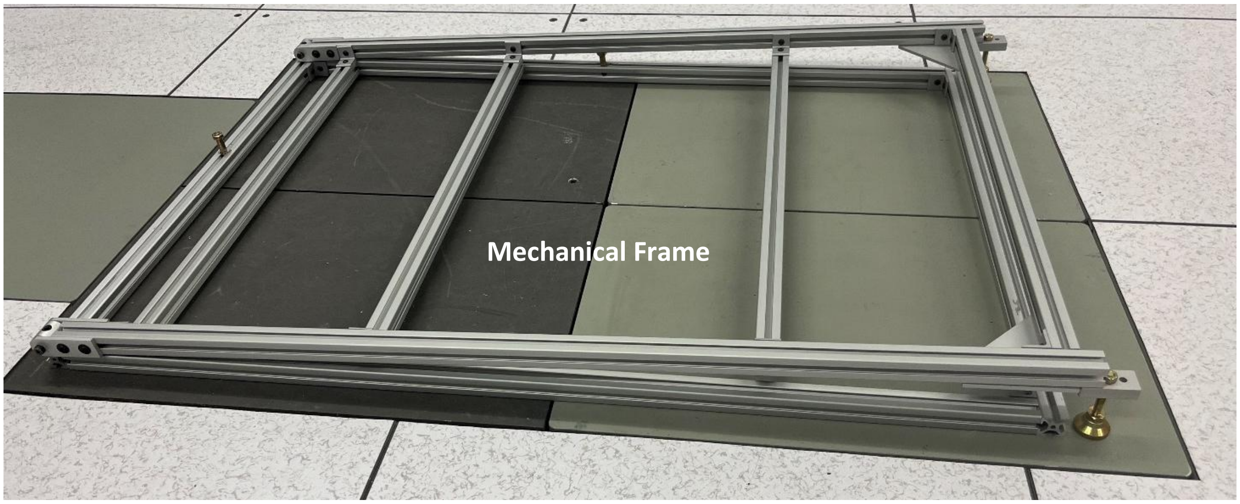

- Conditional University of Utah IRB approval for the study (materials in English, awaiting approval for Spanish translation).

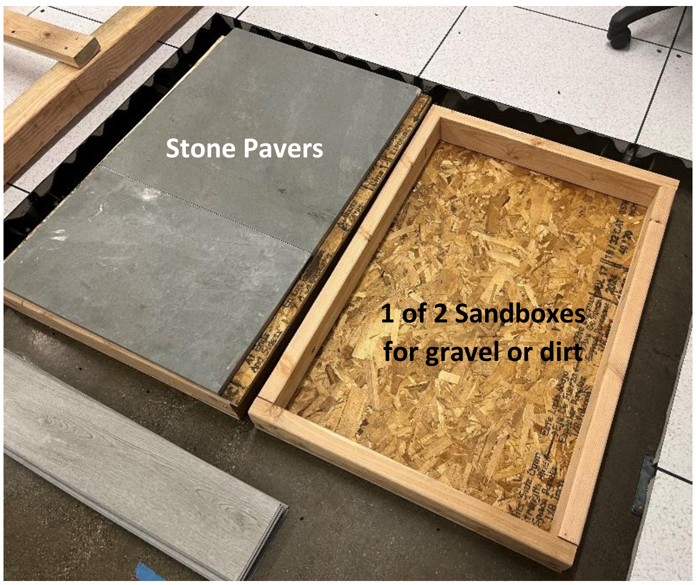
- Translation of documents to Spanish.

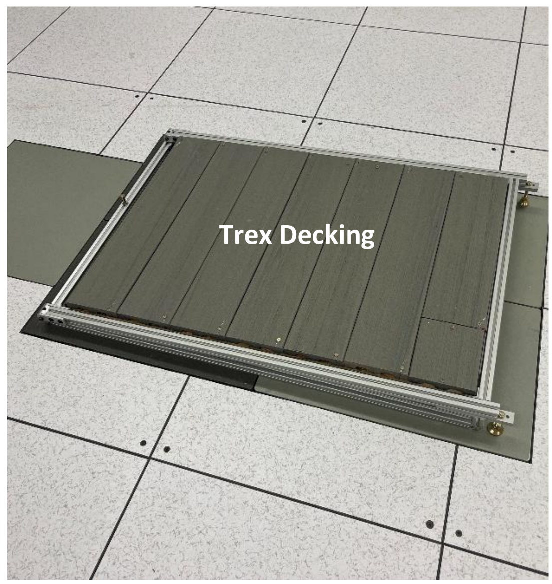
- Carson Davis was awarded funding from the University of Utah to support his work on this project: Undergraduate Research Opportunity Program (UROP). News link.

- Design and construction of framing to complete a construction task at an elevated level.

- Design and construction of a mechanical frame that attaches to four force plates, adjusts to two inclination angles, and can accommodate multiple ground conditions.







- Recording of implicit and explicit instructional video.

- Editing of implicit and explicit videos for study instruction.
- Initiated recruitment of participants through flyers.

Quarter 4 & 5 Achievements

- Completed participant payment training modules and set up of participant payment portal.
- Completed data collection of two residential construction workers. Participant below (tattoos and face covered to remove participant identifiable information).

- Completed data entry of collected participants (e.g. motion capture trials, health and lifestyle questionnaire response, structed interview survey data).

- Completed 160 available coefficient of friction (ACOF) data collection trials. This comprised 5 dry (flooring, stone pavers, trex decking, gravel, dirt) and 3 muddy (flooring, stone pavers, trex decking) ground conditions across two new ladder feet.

- Completed custom codes to process available coefficient of friction (ACOF) and required coefficient of friction (RCOF) data.

- Initiated the kinematic data processing of ladder angle setup.

- Preliminary data analysis and dissemination of ACOF at a regional conference (see attached abstract and poster).

- Preliminary data analysis and dissemination of RCOF at a regional conference (see attached abstract and poster).

- Carson Davis presented the preliminary ACOF and RCOF findings at the Rocky Mountain American Society of Biomechanics Conference and the University of Utah Undergraduate Research Symposium.

- Substantial participant recruitment efforts:
    i. Distribution of over 500 flyers in local areas, contracting business, construction connections, and community groups.
    ii. Contacting 40 construction-related businesses (e.g. general contractors, renovation companies).
    iii. Contacting 32 companies focused on residential work (e.g. handyman and handywomen professionals.
    iv. Requesting external recruitment support from the Rocky Mountain Center for Occupational and Environmental Health at the University of Utah, the Associated Builders and Contractors trade association, and the Salt Lake City Home Builders Association.

v. Promotion through the University of Utah's *Studies for You* outreach system.
vi. Paid advertising through local news website (i.e. KSL.com), reaching an additional 49 local business.
vii. Posting advertising on job announcement platforms (i.e. Monster).
viii. Posting to construction related groups on Facebook.

- Carson Davis graduated with a Bachelor's of Science in Biomedical Engineering at the University of Utah. Carson was also accepted in the Master's of Mechanical Engineering program at the University of Utah. Carson will continue to lead the ladder safety research in our laboratory at a part of his Master's Thesis work.

<u>Quarter 6 Achievements</u>

- Completed data collections of five residential construction workers.

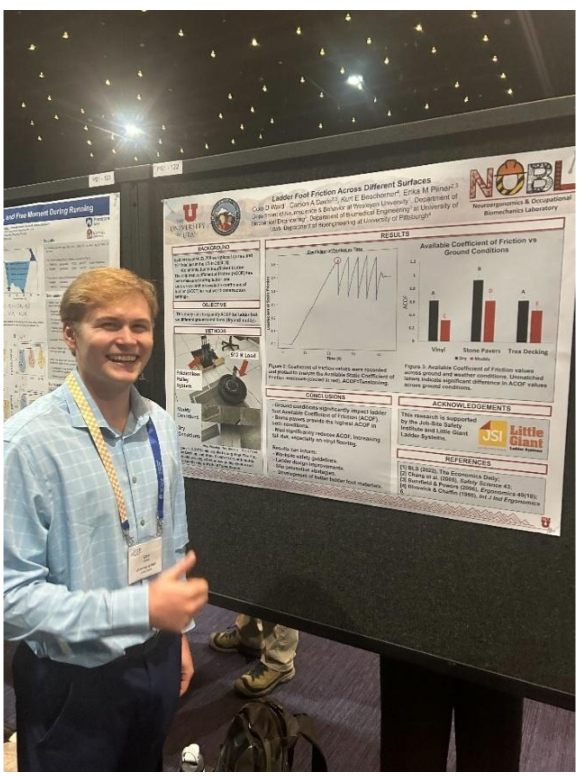
- Completed data entry of collected participants (e.g. motion capture trials, health and lifestyle questionnaire response, structed interview survey data).

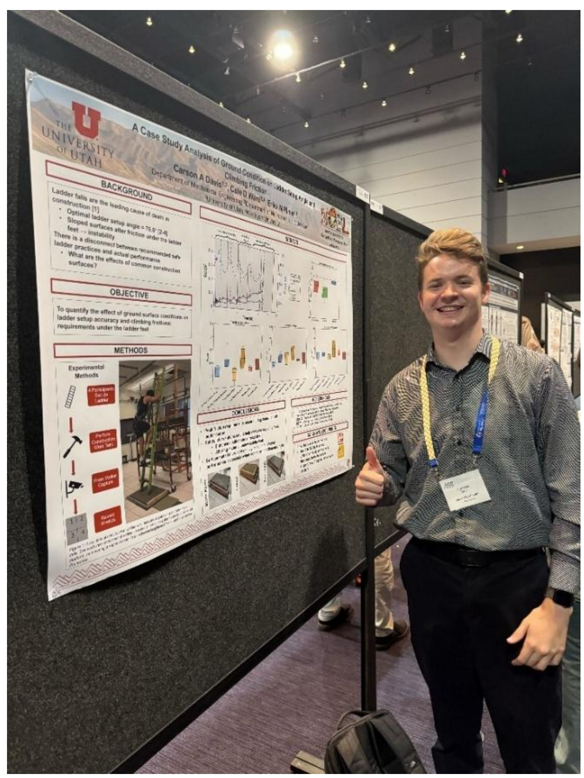
- Completed kinematic data processing of all participants to assess ladder angle setup.

- Preliminary data analysis and dissemination of ACOF at a national conference (see attached abstract and poster).

- Preliminary data analysis and dissemination of RCOF at a national conference (see attached abstract and poster).

- Cole Ward and Carson Davis presented the preliminary ACOF and RCOF findings at the National American Society of Biomechanics Conference in Pittsburgh, PA.





- Cole Ward received the NextGen Award from the American Society of Biomechanics. News link.

- Tanner Simeon created a physics-based model of the RCOF during ladder climbing to assess ladder slip risk across various user-environmental conditions.

- Erika Pliner submitted a Federal Grant application to the National Institute of General Medical Sciences (NIGMS) to build off the findings of this work (see Future Work).

- Erika Pliner is advising a team of students to initiate the commercialization of the ACOF testing methods from this study (see Future Work).

vii. Setbacks in this Project

- Laboratory move (uncommon)
- IRB approval timeline
- Dismissal of student
- Recruitment

g. Deliverables

- Final report.
- 3 conference abstracts.
- 3 conference posters.
- 4 explicit instructional videos on ladder setup.
  - A YouTube channel with these videos and closed captioning can provided via a link.
- Supplementary material on a model of ladder slip risk

h. Future Work

- Carson Davis is continuing in our lab as a master's thesis student. For his master's thesis research, he will continue to collect participants to address the effects of ground condition on ladder setup accuracy and slip risk. In addition, he will continue to investigate worker level tool preferences. We will continue to acknowledge JSI and Little Giant Ladder Systems on Carson Davis' thesis work.

- Carson Davis is working on a manuscript that validates our ACOF methods for outside the laboratory environment.

- Cole Ward is working on a manuscript that characterize the ACOF across surface conditions under dry and muddy conditions.

- This work will be disseminated in peer-reviewed academic journals upon data collection and analysis completion.

- Erika Pliner is seeking additional funding that builds on the findings of this work. Specifically, she has submitted a research proposal to the National Institute of General Medical Sciences on the following specific aims:

  Aim 1: Develop a new tool to estimate the required friction of ladder climbing across users.

  Aim 1a: Model the required coefficient of friction [RCOF] of climbing a straight ladder from user characteristics and knowledge. We will record the biomechanics of straight ladder climbing across ladder user characteristics, which include age groups (18-35, 36-55, and 56-75 years of age) and ladder use experience (occupational and domestic); and training knowledge (none, general use, and ladder set up-specific). We will extract the RCOF from the kinetic data recorded below the ladder base. Hypothesis 1: The highest Akaike Information Criterion [**AIC**] value for predicting the RCOF will be obtained in a model with age group, ladder use experience, and training knowledge.

  Aim 1b: Predictive validation of the RCOF model with actual ladder slipping. We will mechanically replicate the vertical and horizontal climbing loads for a subset of participants. Specifically, we will add the participant's vertical load to the ladder and apply a horizontal load until the ladder slips. If the ladder slips before the participant's horizontal load is reached, the actual outcome will be classified as a slip. If the modeled RCOF exceeds the ACOF in this experiment, the predicted outcome will be classified as a slip. We will report the sensitivity and specificity to assess the validity of the RCOF model.

  Aim 2: Develop a portable instrument that captures the available coefficient of friction [ACOF] between real-world ground conditions and ladder shoes. We will extract ACOF values from a custom-built, portable friction testing instrument in parallel with laboratory equipment. Hypothesis 2: The ACOF values obtained using the portable instrument will be highly correlated with laboratory equipment.

- Erika Pliner is advising a mechanical engineering senior-design team on the commercialization of the ACOF testing methods in this study to a portable device.

References

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