EFFECTS OF GLOVE AND LADDER RUNG DESIGN ON PREVENTION OF LADDER FALL

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Introduction

- Falls from a ladder/scaffold are the leading cause of disabling injuries (BLS 2009)
- Every year, more than 20,000 American workers get injured by ladder falls (Christensen and Cooper, 1986)
- The direct compensation and medical treatments cost $5.3 billion/year (LibertyMutual, 2010)

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Introduction

- Hands are the only interface to arrest the body once a fall has been initiated

- Quantification and understanding of a person's breakaway strength (maximum hand force to hold onto a ladder rung) are needed to develop measures to prevent ladder fall injuries

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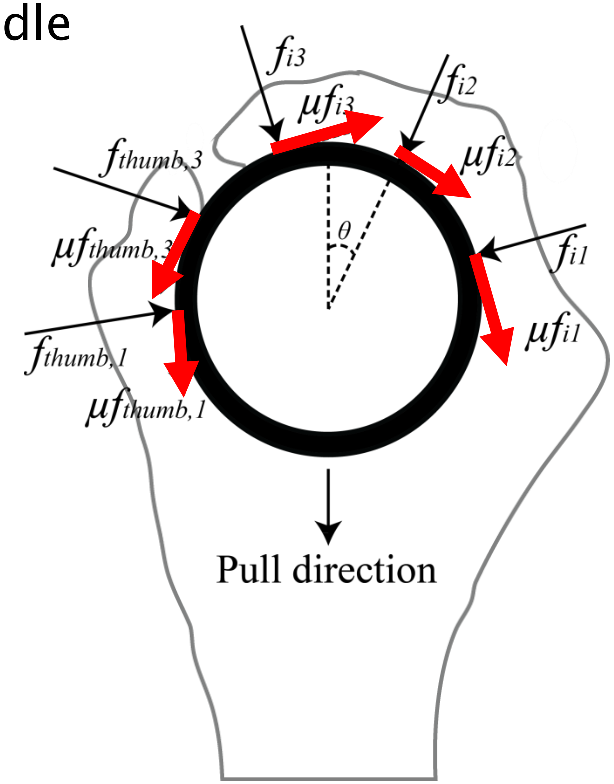
Introduction

- Frictional coupling is important for breakaway strength
  - Power grip strengths do not reflect whole aspects of breakaway strength
    → Power grip strengths do not account for the influence of frictional coupling between a hand and a handle



- Possible factors for breakaway strength
  - Frictional coupling
  - Handle shapes

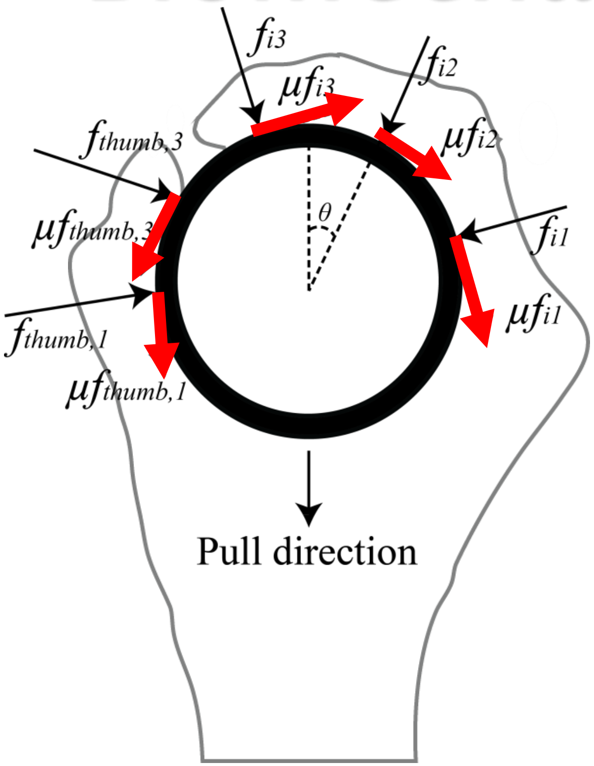
Introduction

- Knowledge gap
  - Previous studies are primarily empirical
  - Previous studies do not provide biomechanical description of how both finger flexion and frictional coupling contribute to breakaway strength
  - This gap imposes an obstacle in improving handle and ladder designs to increase breakaway strength and reduce ladder fall-related injuries and fatalities

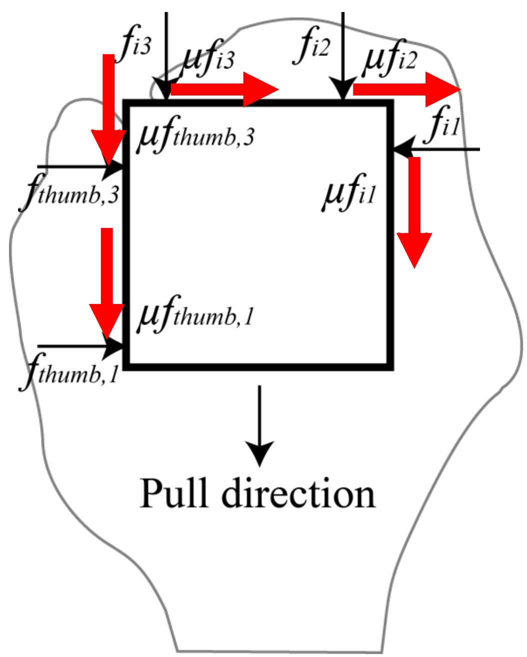
Objective

- To develop and evaluate biomechanical models for two handle shapes (circular vs. rectangular) that take into account both finger flexion strength and frictional coupling for predicting breakaway strength

Biomechanical models



$$\textit{Breakaway strength} = \sum_{i=2}^{5}\sum_{j=1}^{3} f_{ij}\left(\cos\theta_{ij} + \boxed{\mu\sin\theta_{ij}}\right) + \sum_{j=1,3} f_{1j}\left(\cos\theta_{1j} - \boxed{\mu\sin\theta_{1j}}\right)$$



$$\textit{Breakaway strength} = \sum_{i=2}^{5}\left(f_{i,2} + f_{i,3} + \mu f_{i,1}\right) + \boxed{\mu\left(f_{11} + f_{13}\right)}$$

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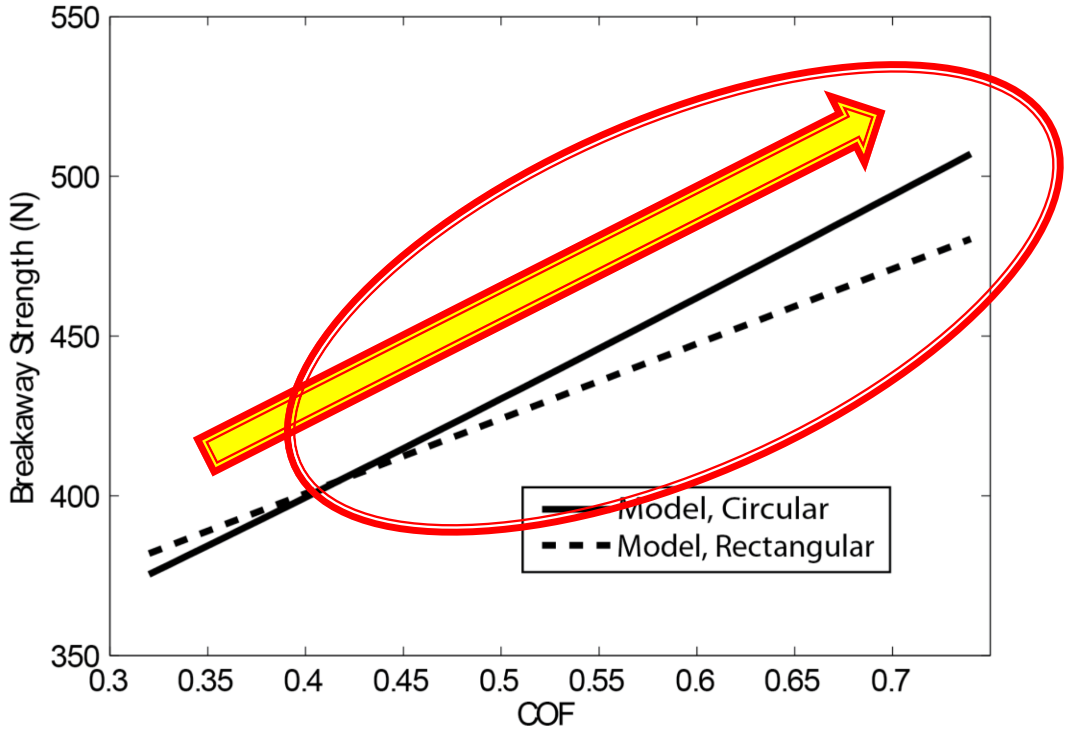
Model prediction



1. Breakaway strength increases with increasing COF
2. Breakaway strength for the circular handle is greater than that for the rectangular handle when COF>0.42

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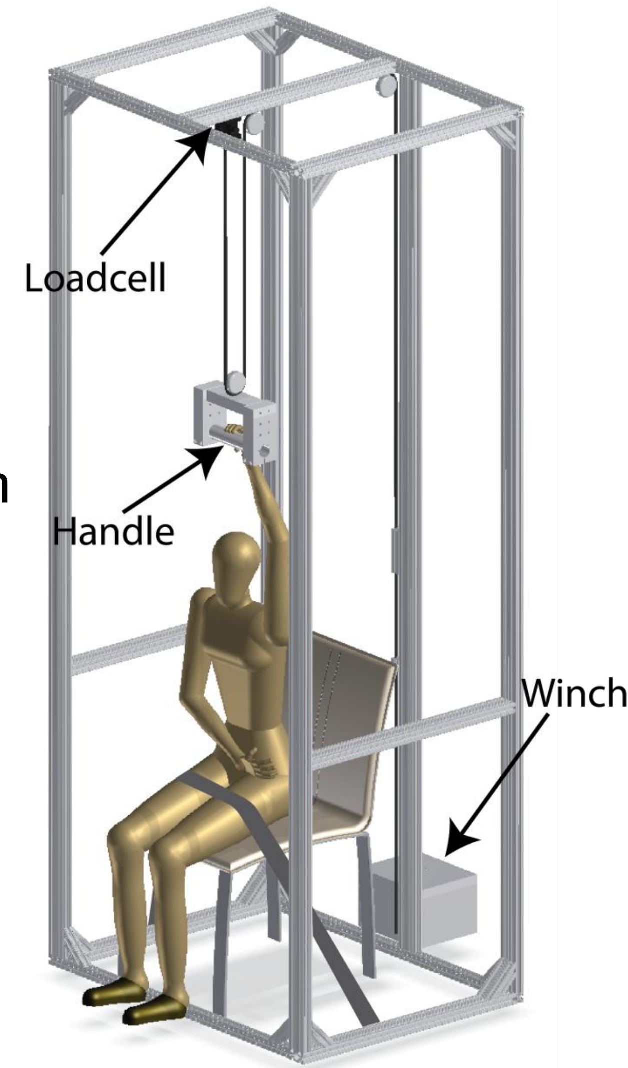
* The model used 50th percentile hand size data (Wickens et al., 2004) and maximum normal force data (Amis, 1989) for each phalanx available from the literature

Protocol

- Subjects
  - 13 healthy young adults (25±4 years)
- Procedure
  - Subjects were seated and strapped down
  - Subjects were instructed to hold onto a handle as long as they could while the handle was being lifted up (7cm/s)
  - Force was recorded by a loadcell

Breakaway strength $\stackrel{\text{def}}{=}$ Max (Force)



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Conditions

Polyester glove

Bare hand

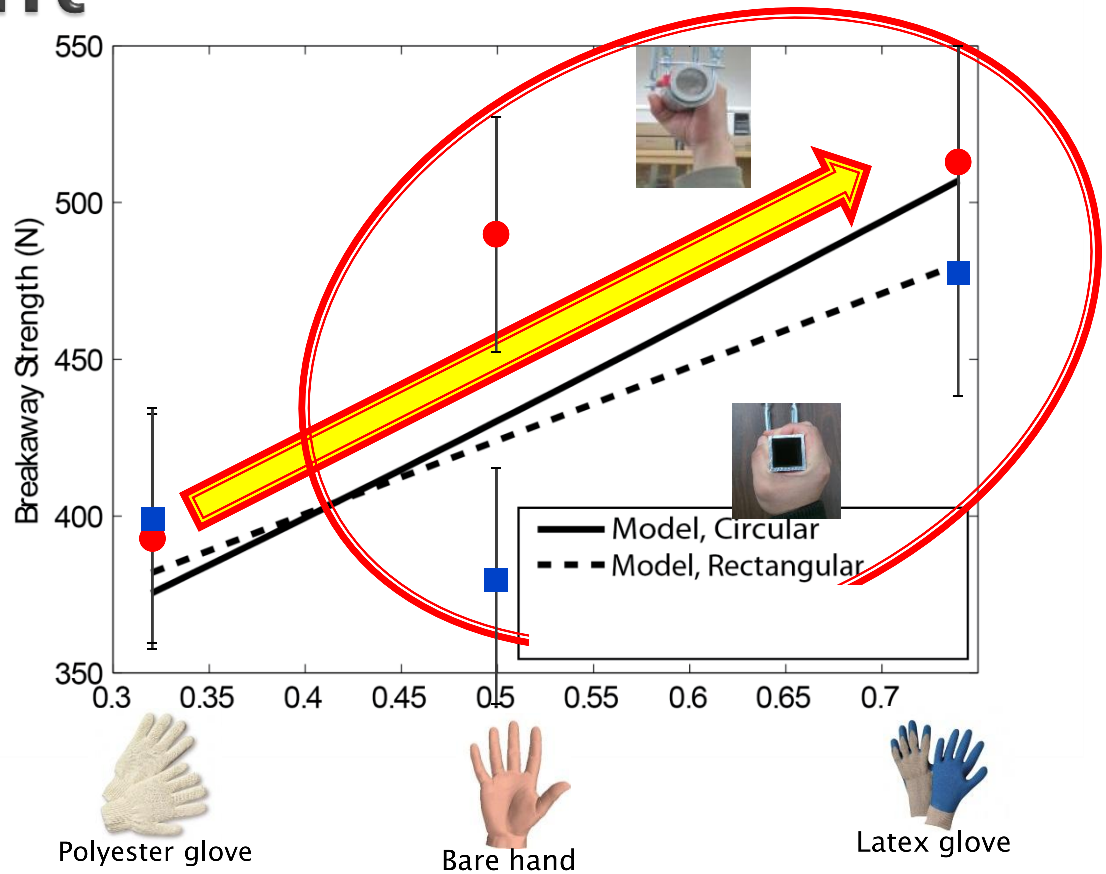
Latex glove

- 3 Glove conditions
  - Polyester glove (COF*=0.32)
  - Bare hand (COF=0.50)
  - Latex glove (COF=0.74)

- Handle shapes
  - Circular handle (diameter=50.8 mm)
  - Rectangular handle (cross-section of 38.1 mm by 38.1 mm)
- Note that all of these conditions are frequently encountered in workplaces.

* COF: Coefficient of Friction against aluminum handle

Result



1. Breakaway strength increased with increasing COF

2. Breakaway strength for the circular handle was greater than that for the rectangular handle for COF>0.42

- Experiment supported the two model predictions

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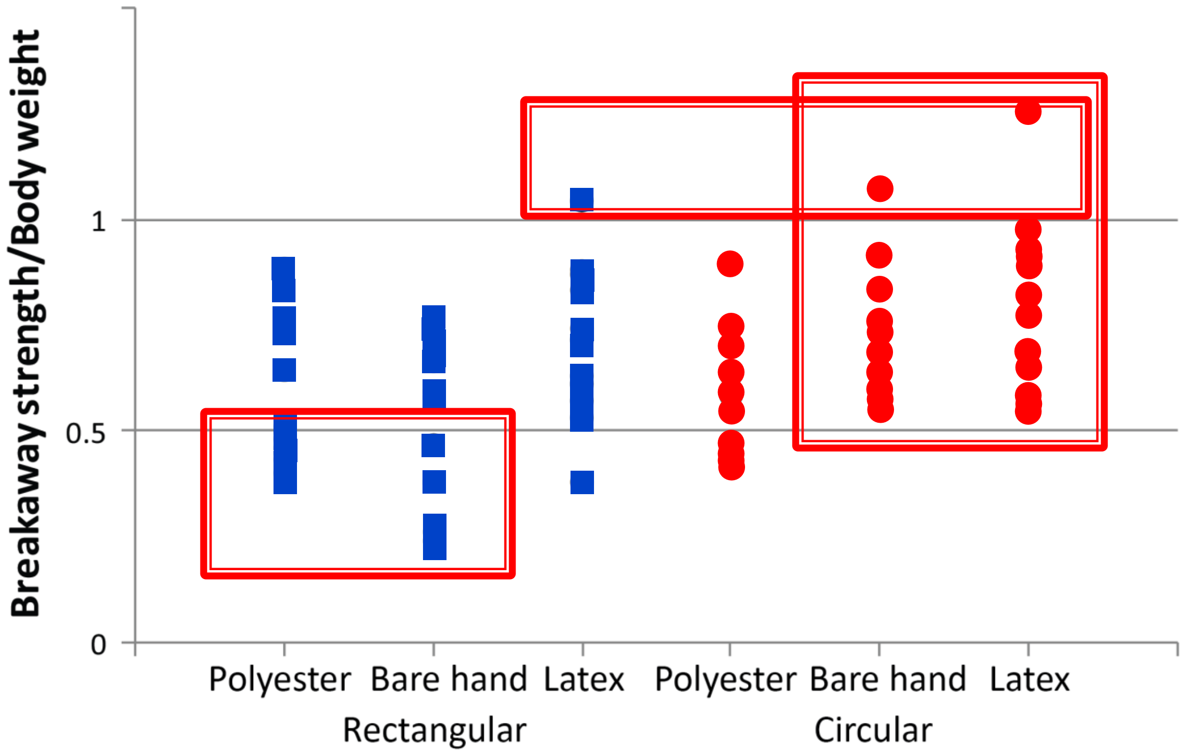
Result



- Half of subjects would not be able to support their body weights with two hands for the polyester glove and bare hand with the rectangular handle
- If subjects use the bare hand and the latex glove with the circular handle, they would be able to support their body weights with two hands
- Even the strongest subject would not be able to hold his body by one hand for 3 out of 6 conditions.

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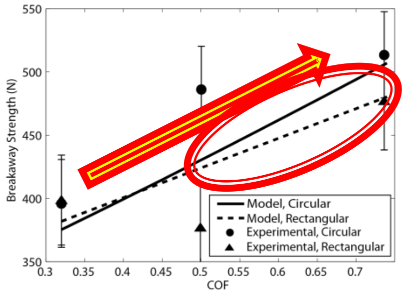
Discussion

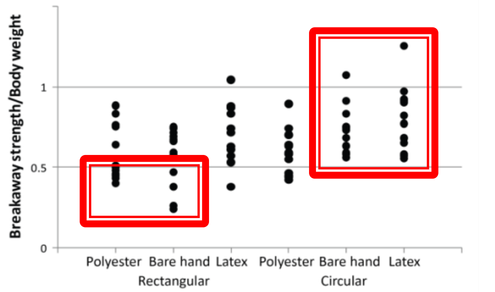


- Experimental results supported the biomechanical models

1. Breakaway strength increases with increasing COF
   - Frictional coupling accounts for only 21% of breakaway strength for the polyester glove, whereas frictional coupling accounts for 39% of breakaway strength for the latex glove

2. Breakaway strength is greater for the circular handle than for the rectangular handle for the bare hand and the latex glove

Implication



- Using greater COF and the circular handle may reduce fall-related injuries from ladders/scaffolds
- The model can be used as a platform to predict breakaway strength for various handles and COF conditions
- Biomechanical models can help improve design of ladder/scaffold handles to reduce injuries due to fall from elevation

Acknowledgment

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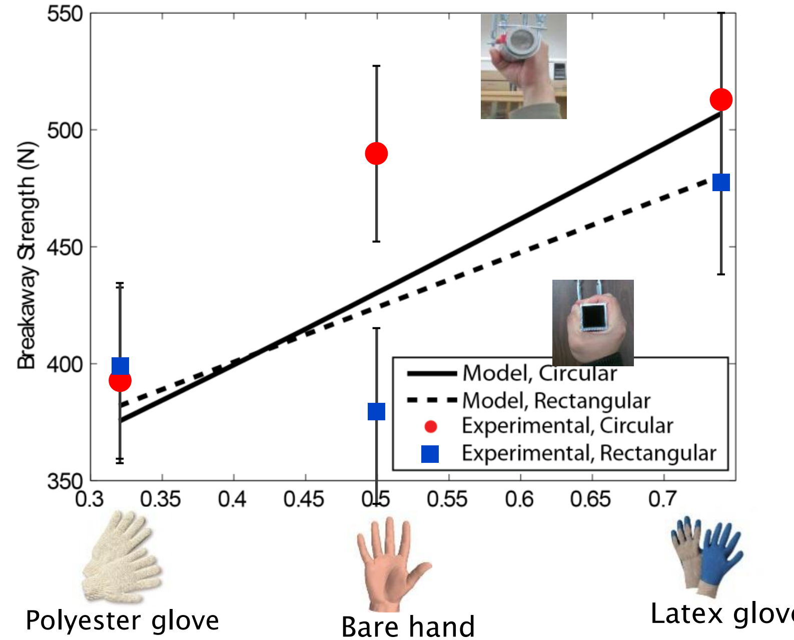
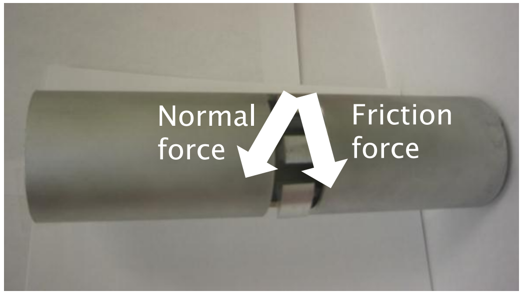
Other factors for breakaway strength

- Tactile sensation may have resulted in greater breakaway strength for the bare hand and the circular handle (add refs)
- Pain due to pinching may have resulted in reduced breakaway strength for the bare hand and the rectangular handle



Further evaluation

- Additional evaluation for circular handle model was performed
  - Subjects performed an isometric pull exertion with 50% of breakaway strength on the dynamometer for 5 sec
  - The dynamometer can measure both normal force and friction force on each phalanx
  - Friction force relative to normal force was measured using a custom-made dynamometer



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Result

- Further evaluation for circular handle
  - Friction force relative to normal force tended to increase with increasing COF