Development of an Exosuit to Support the Back During Lifting

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to help people love where they live
to help people love where they live by seeding the future
LINEAR PATH TO DOOM

CHANGE

TIME
CHANGE TODAY IS EXPONENTIAL
Wall Street is expecting the worst of the retail apocalypse this week

Retail funk: Stores face biggest challenges since recession

What caused the retail apocalypse?

What in the World Is Causing the Retail Meltdown of 2017?
DECEPTIVE DISAPPOINTMENT
DISRUPTIVE OPPORTUNITY
LET'S REBUILD IT.
LET'S SEE WHAT THIS SUIT CAN DO!

COME ON #8!

GRRRRRR!

...IT'S NOT MOVING...

LIKE HELL, IT ISN'T!

TH..THAT'S IT!

NOW!

GET THEM OUT NOW!

THANK YOU.

THANK YOU, SAM

...HOW WILL YOU KNOW THIS AREA?

IT'S MY HOME.

LOWE'S
The Problem

• People get injured at work

• $15 billion in 2016 in direct costs for injuries related to lifting, pushing, pulling, holding, carrying or throwing objects [1]

• Incidence rate of ~3% per year for laborers and freight, stock, and material movers (private industry) – around 59,000 injuries [2]
Why the back?

• Back injuries are 17.3% of all injuries in 2016 [2]
• Workers’ compensation costs for an average lost-time back injury are $25,000 [4]
• Average lost time is 7-8 days for a back injury [2]
The Solution: Build an Exosuit
Project Progression

Need finding and Store visits: observe Lowe's processes, talk to employees

Exosuit development and manufacturing

In-store IMU study

In-store testing, employee feedback

Modifications and improvements based on employee feedback

Next steps: Additional Modifications, TBD

In-lab Biomechanics Testing
Rapid Feedback

• Christiansburg Lowe's is 10 minutes from Virginia Tech
• Informal verbal feedback
• Paper surveys
• Focused discussions
• Ongoing feedback as changes are made
IMU Study

- Goal: Understand lifting and motion in a real-world environment
- XSens MVN Link IMU-based motion capture system
- 4 subjects, ~20 hours of data
- XSens does on-body recording
- Normal store activities
Motion Capture System Output
Motion in the store

- Walking as well as lifting
- XSens tracks motion accurately
Different Lifting Style Tradeoffs

- Squat ↔ Stoop
- Symmetric ↔ Asymmetric
- Legs together ↔ Legs apart sideways
- Both legs grounded ↔ One leg in air
Different Lifting Style Tradeoffs

Legs together ↔ One leg behind ↔ One-handed ↔ Two-handed

Lift ↔ Tilt
Other activities

• Walking
• Pushing, pulling
• Kneeling
• Crawling
• Climbing stairs
• Driving a forklift
• Using a lift
• Using pens, box cutters
• ...

• ...
Summary of Back Support Exoskeleton Requirements

• Support the weight of the torso during stoop lifting
• Unrestrictive: easily permit walking, sitting, stair climbing, kneeling, crawling
• Light-weight
• Low-profile
• High energy return
Goal

• Build an exosuit that offsets the weight of the torso (during stoop lifting)

→ Picking up a ~50 pound box feels like picking up nothing to the back muscles

• Start simple and learn!
Stoop vs. Squat

- Center of Mass moves further down with a squat lift, requiring more energy.
Rough Calculations

Round numbers:

• 200 pound (90 kg) person

• Torso weighs around half of the body's mass: 100 pounds (45 kg)

• Moves down around 1.5 feet (45cm) – around 25% of body height

→ Requires around 200 Joules of energy
How much energy does it take to lift?

Rough calculations:

• Suppose one stoop bend per minute, not lifting anything
  ➔ ~3.33W Mechanical

• Metabolic efficiency ~ 0.25
  ➔ ~13.33W Metabolic

• Actual number: 16W
How much energy does it take to lift?

• Data replotted from Hagen et al, 1994 "Influence of lifting technique on perceptual and cardiovascular responses to submaximal repetitive lifting"

• Scaled to 90kg person

<table>
<thead>
<tr>
<th>Weight Lifted</th>
<th>Metabolic Cost [W]</th>
</tr>
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<tbody>
<tr>
<td>17kg</td>
<td>37.5 pounds</td>
</tr>
<tr>
<td>165W</td>
<td>16W</td>
</tr>
<tr>
<td>171W</td>
<td>198W</td>
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<tr>
<td>176W</td>
<td>216W</td>
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<tr>
<td>185W</td>
<td>233W</td>
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<tr>
<td>260W</td>
<td>260W</td>
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- 3 Lifts/minute
- 1 Lift/minute

Squat lifting
Stoop lifting
Standing still

17kg = 37.5 pounds
How much energy does it take to walk?

- Data from Weyand et al. 2009 "Assessing the metabolic cost of walking: the influence of baseline subtractions"
How much does the weight of the exoskeleton matter?

- Data from Browning et al. 2007, "The Effects of Adding Mass to the Legs on the Energetics and Biomechanics of Walking"

Each kg at the waist adds 4W for a 90kg person

Squat lifting
Standing still
Walking
Walking with a 4kg load

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<th>Metabolic Cost [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing still</td>
<td>17kg = 37.5 pounds</td>
</tr>
<tr>
<td>Squat lifting</td>
<td>200W</td>
</tr>
<tr>
<td>Stoop lifting</td>
<td>204W</td>
</tr>
<tr>
<td>Walking 25%</td>
<td>252W</td>
</tr>
<tr>
<td>Walking 50%</td>
<td>355W</td>
</tr>
<tr>
<td>Walking 100%</td>
<td>400W</td>
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</table>

8W for 150W
4W for 200W
2W for 252W
8W for 260W
12W for 204W
20W for 252W
32W for 355W
40W for 400W

Summary of energetic calculations

• Walking uses a lot more energy (~2x) than lifting at low frequencies

• An exosuit/exoskeleton will ideally offset around 16-50W depending on the lift frequency
  – 10-20% of total energy expenditure
    • Assuming the exosuit/exoskeleton offloads 100% of torso weight; in reality it will be less than this

• Exoskeleton weight matters primarily during walking
  – affects energy use comparatively less

• More important effect: exosuit reduces muscle strain
Our Exosuit

- Chest harness
- Chest harness buckle
- Waist belt
- Waist belt buckle
- Thigh pad supports
- Thigh pads
- Back carbon fiber leaf springs
- Back of chest harness
- Support blocks
- Leg carbon fiber leaf springs
- Pads
- Webbing straps
- Leg sliders
Next Steps

• In-lab biomechanics experiments
• Improved exosuit design
• Additional in-store testing
References

[1] = 2016 Liberty Mutual Workplace Safety Index