Development of an Exosuit to Support the Back During Lifting

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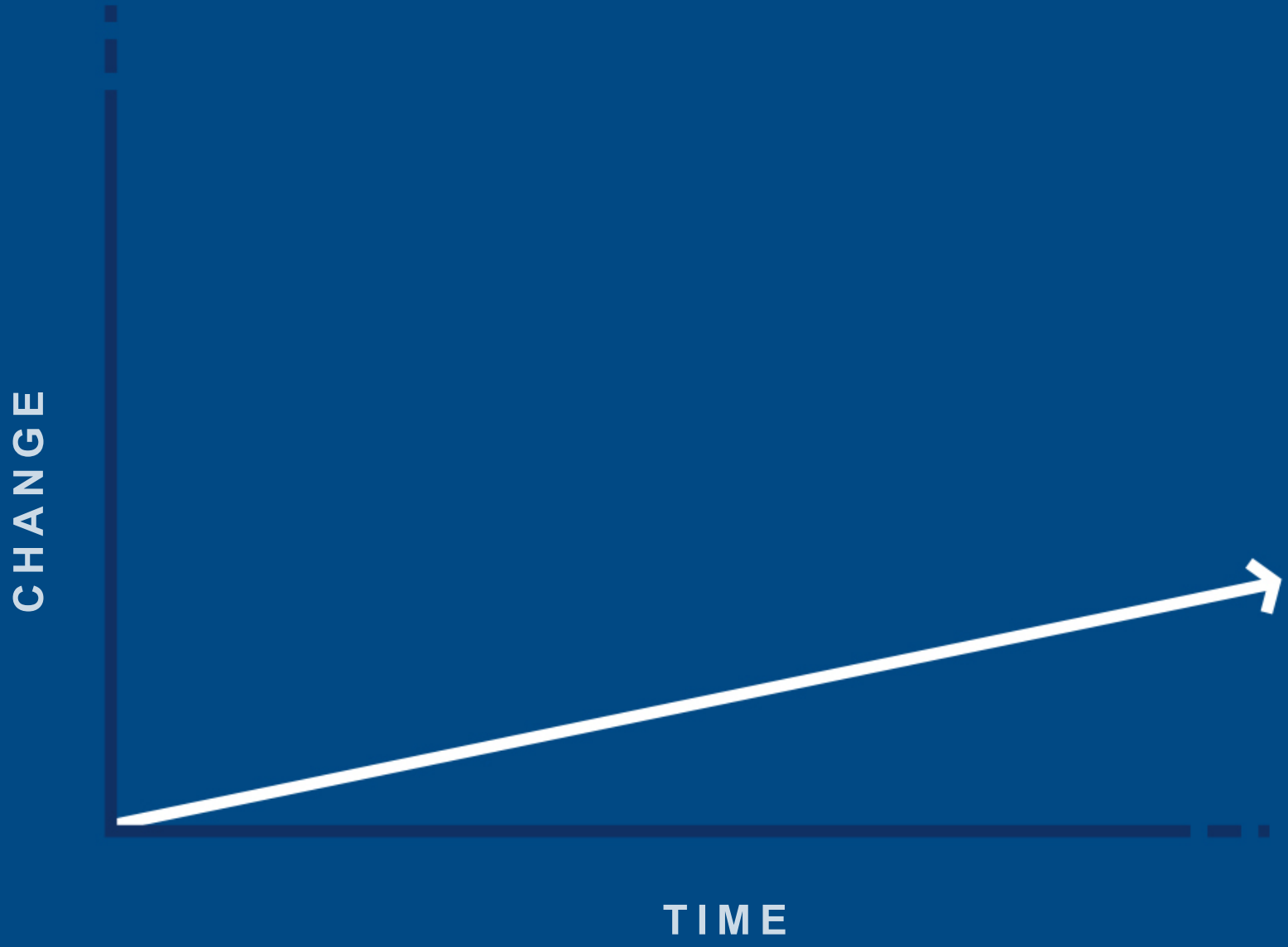
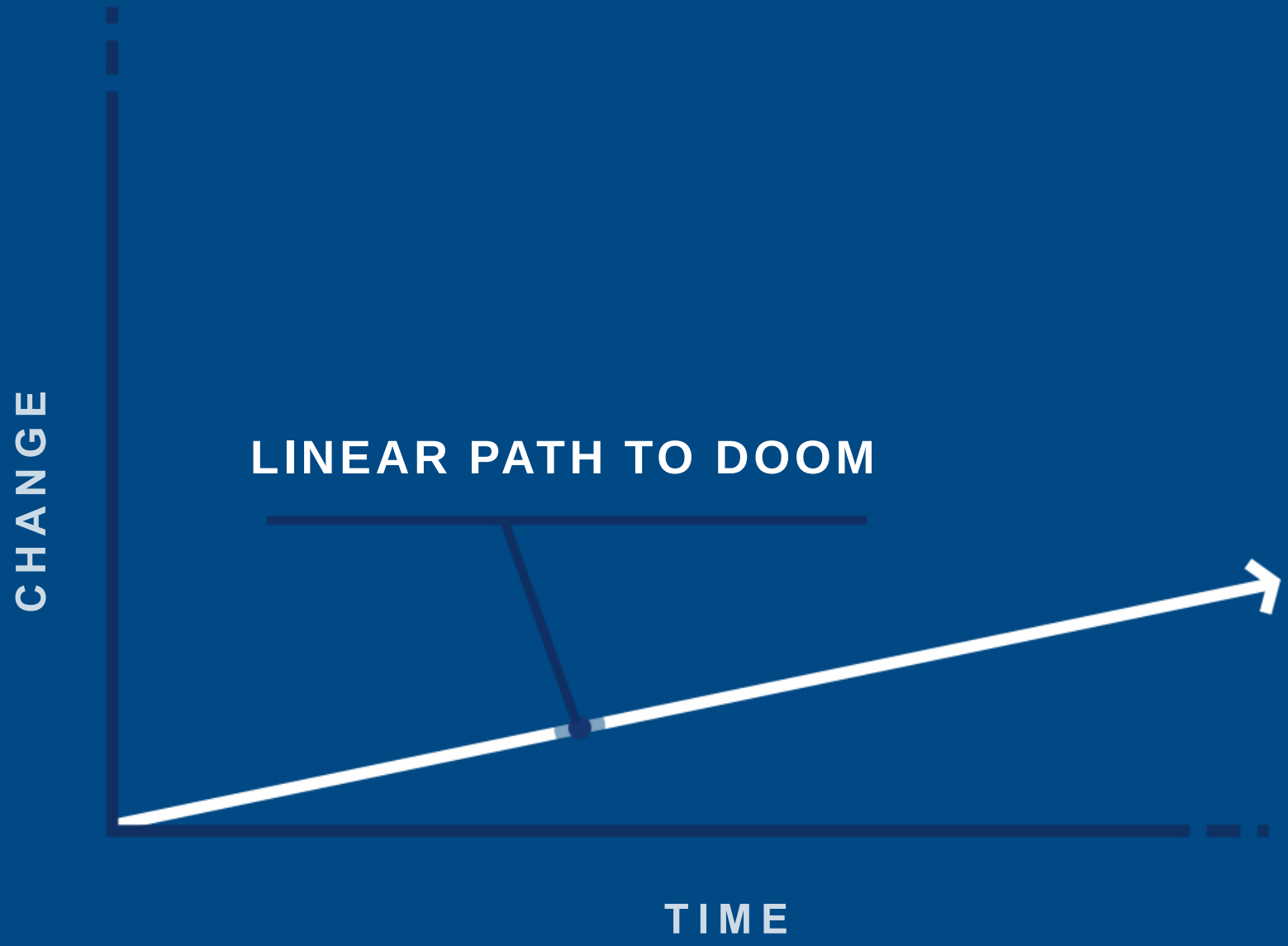
to help people love
where they live


to help people love
where they live
by seeding the future


CHANGE
TIME


CHANGE
TIME


CHANGE
LINEAR PATH TO DOOM
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

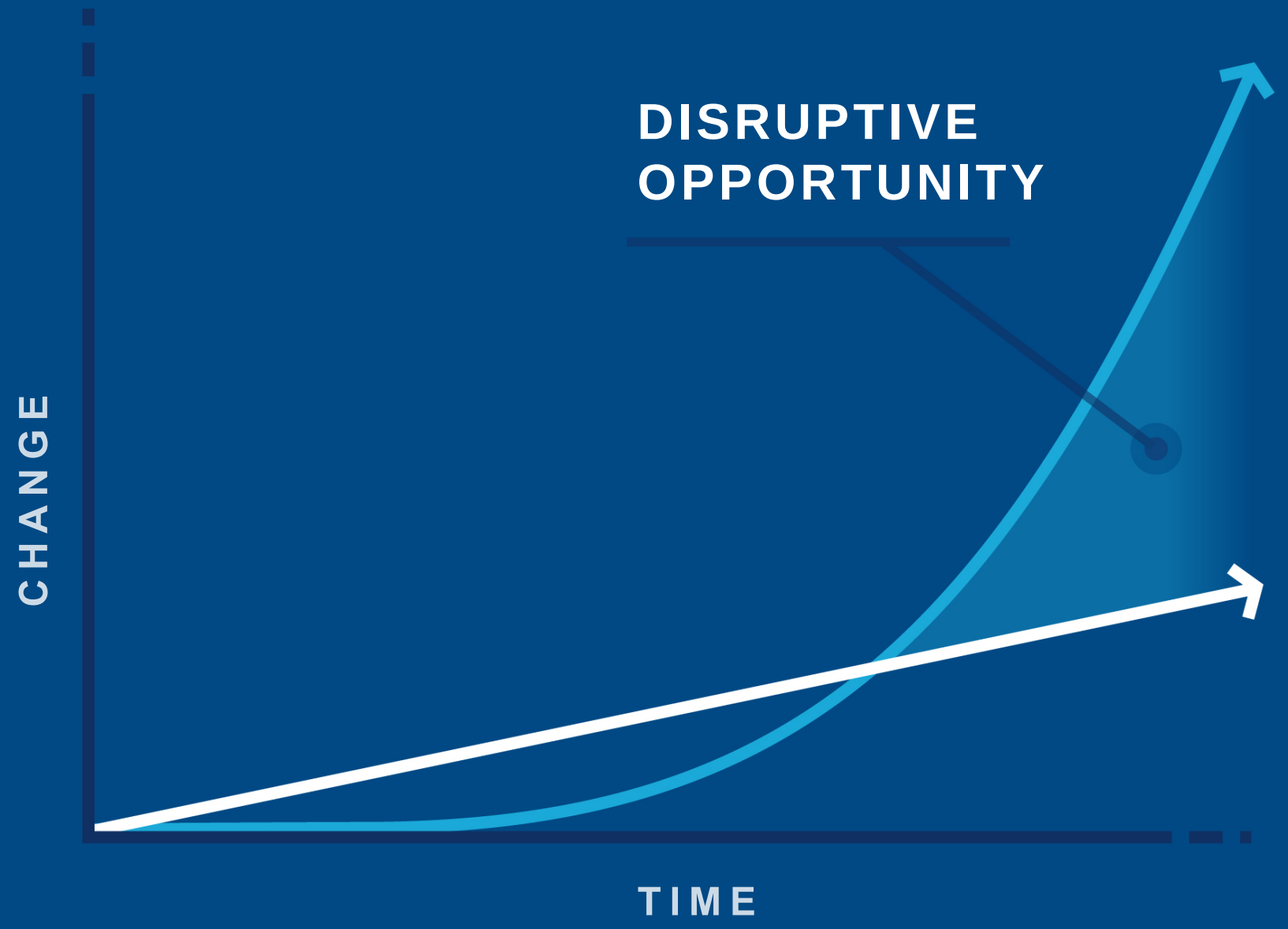
What caused the retail apocalypse?

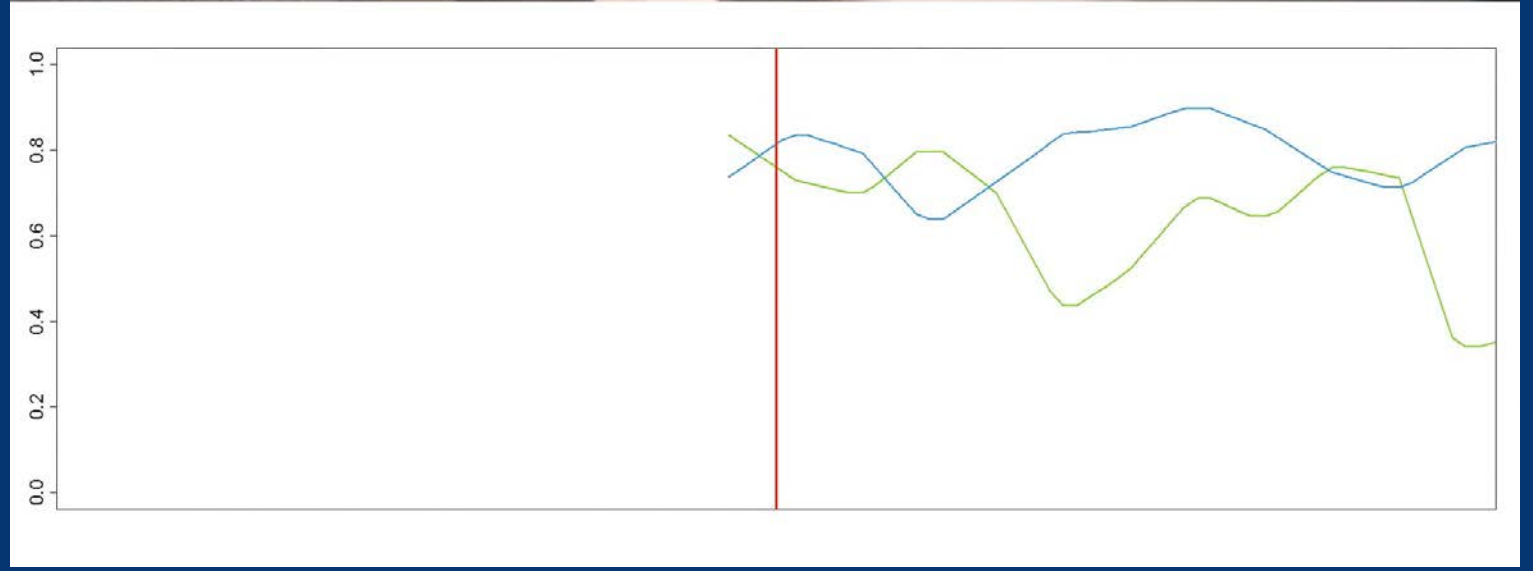
What in the World Is Causing the Retail Meltdown of 2017?


CEL robox


DECEPTIVE
DISAPPOINTMENT
CHANGE
TIME


CHANGE
YOU ARE HERE
TIME


DISRUPTIVE
OPPORTUNITY
CHANGE
TIME


1.0
0.8
0.6
0.4
0.2
0.0

2013

HOLOROOM 1

2014/
2015

HOLOROOM 2

2016

**OCULUS +
CARDBOARD**

2016

TANGO

2016

HOLOLENS

2016

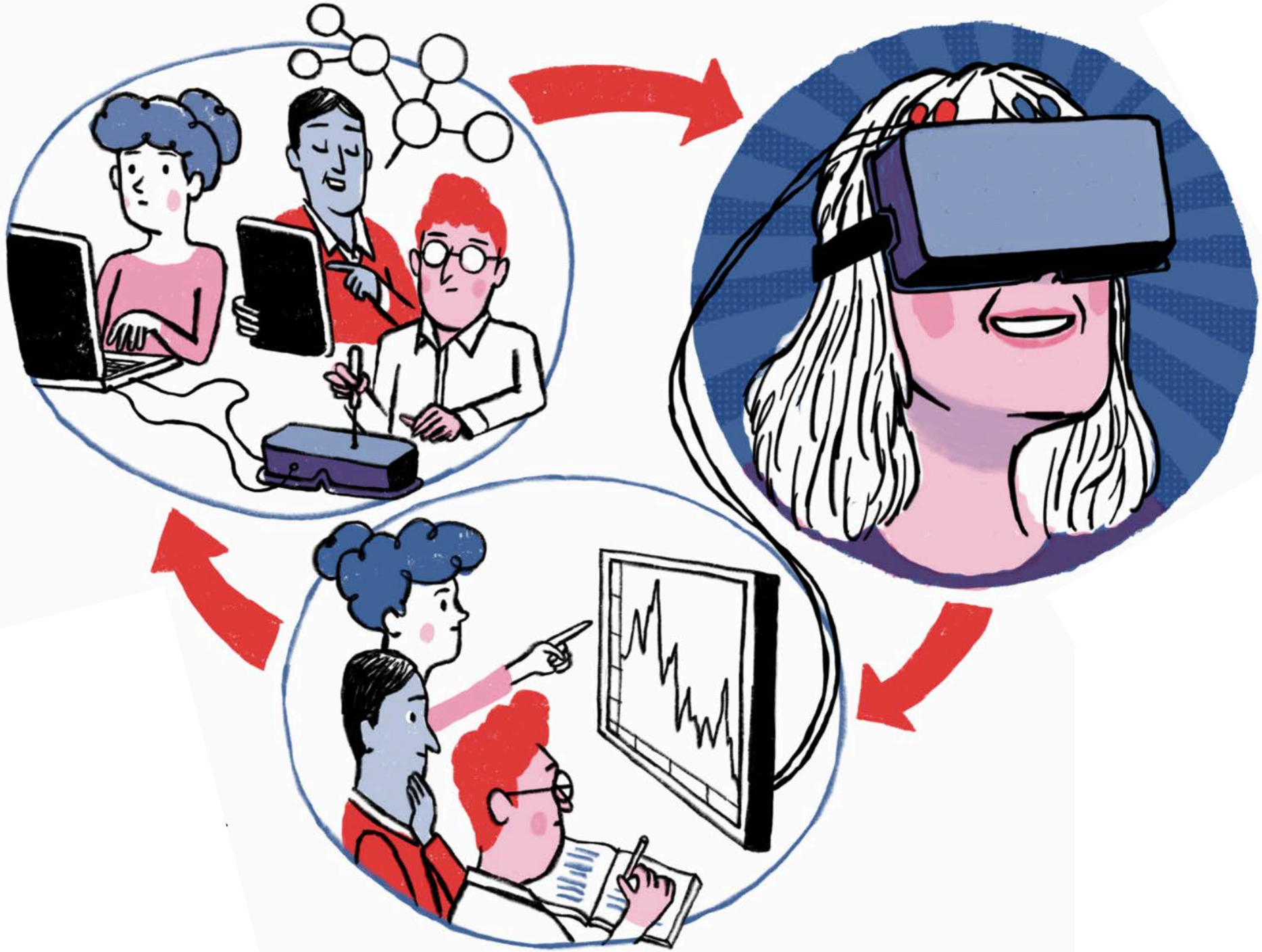
TANGO 2

2017

**HOLOROOM
HOW TO**

2017

LOWE'S VISION



LOWEBOT


Tool World
LOWE'S
Customer Service
NAVII
POWERED BY fellow ROBOTS
INVENTORY
SCANNING
IN PROGRESS
NAVII


LET'S REBUILD IT.
LOWE'S


LET'S SEE WHAT THIS SUIT CAN DO!
COME ON #8!
GGGRRRRRR
...IT'S NOT MOVING...
LIKE HELL, IT ISN'T!
TH..THAT'S IT!
NOW!
GET THEM OUT NOW!


THANK YOU.
THANK YOU, SAM.
...HOW WELL DO YOU KNOW THIS AREA?
LOWE'S
IT'S MY HOME.

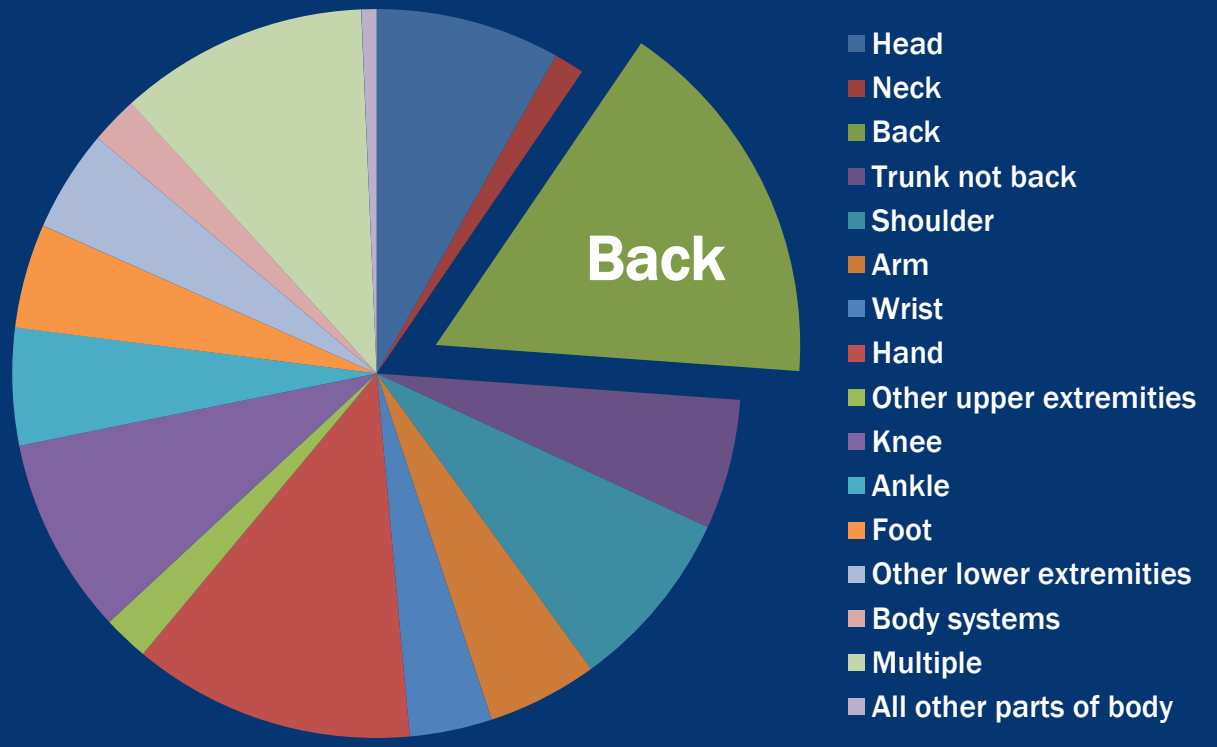
The Problem

- 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]


[3]

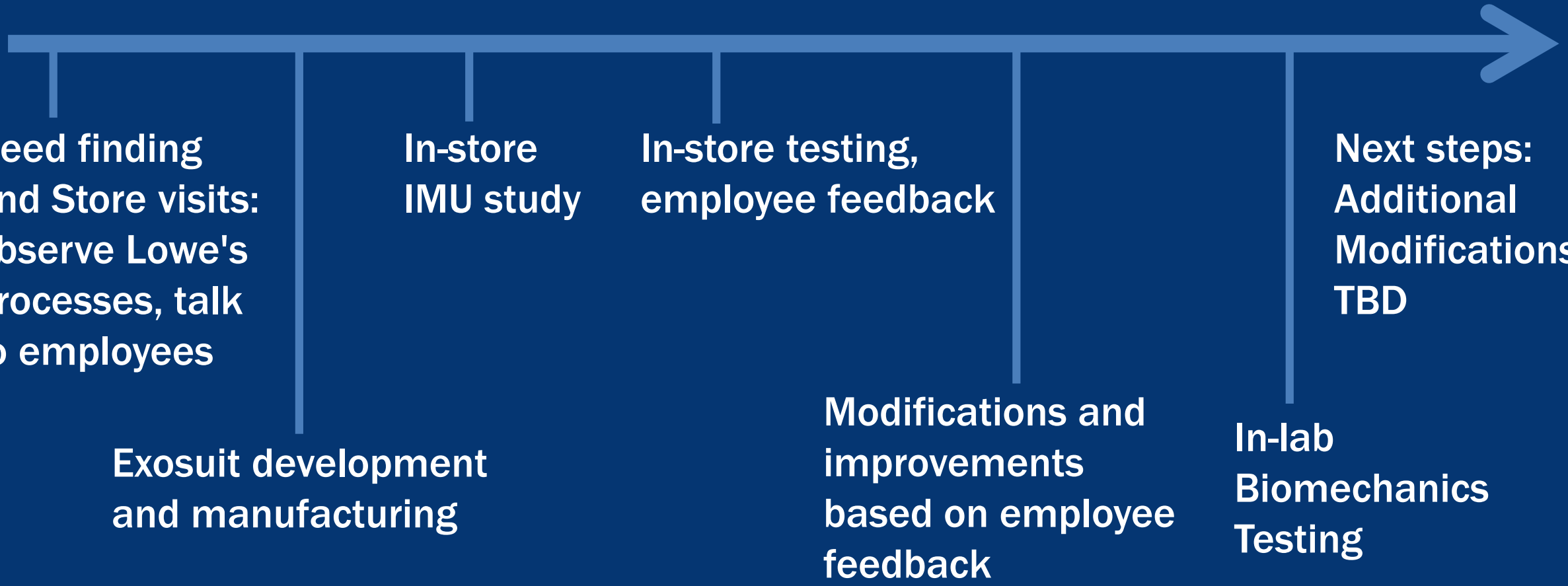
Why the back?

- 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



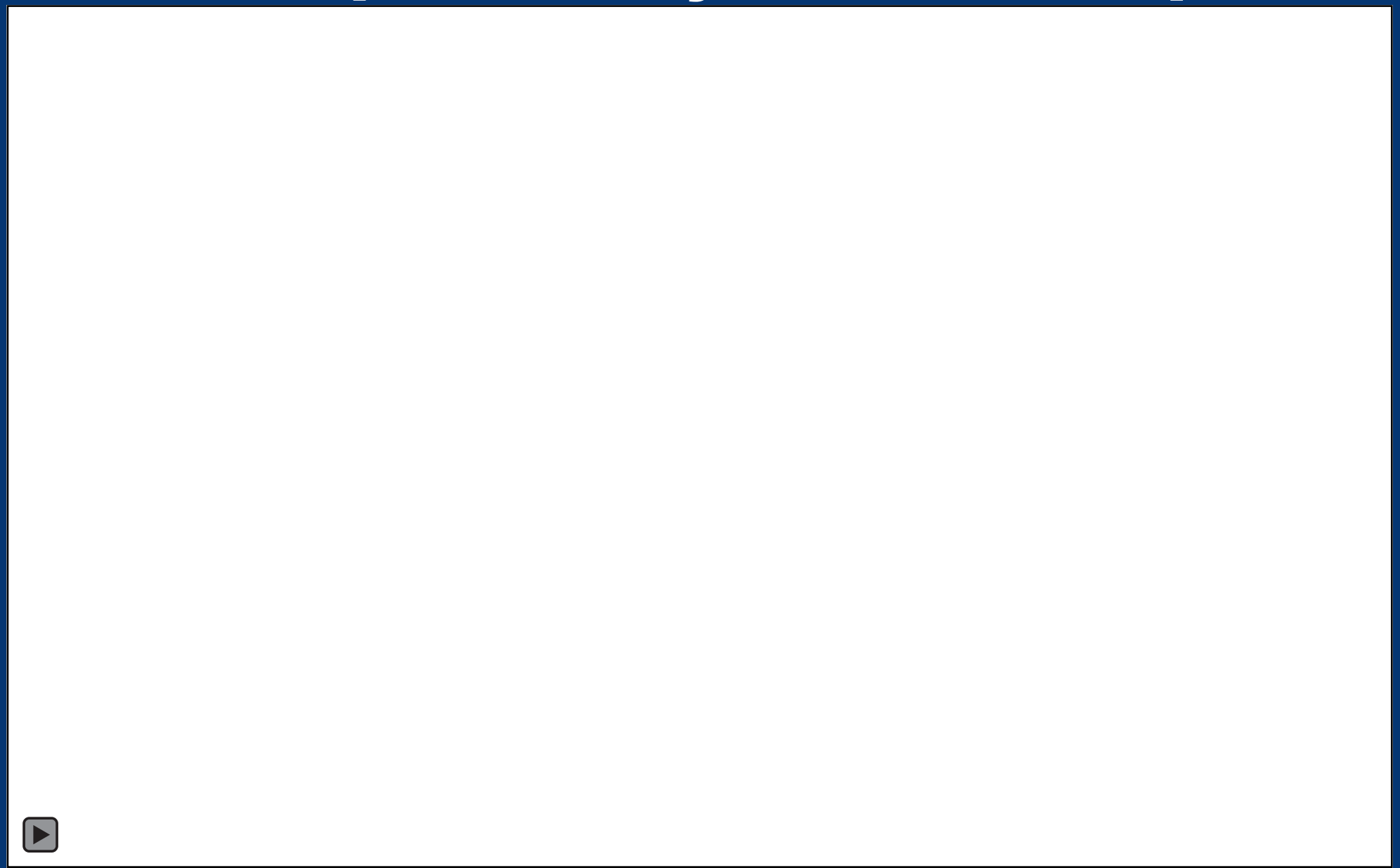
Rapid Feedback

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

IMU Study

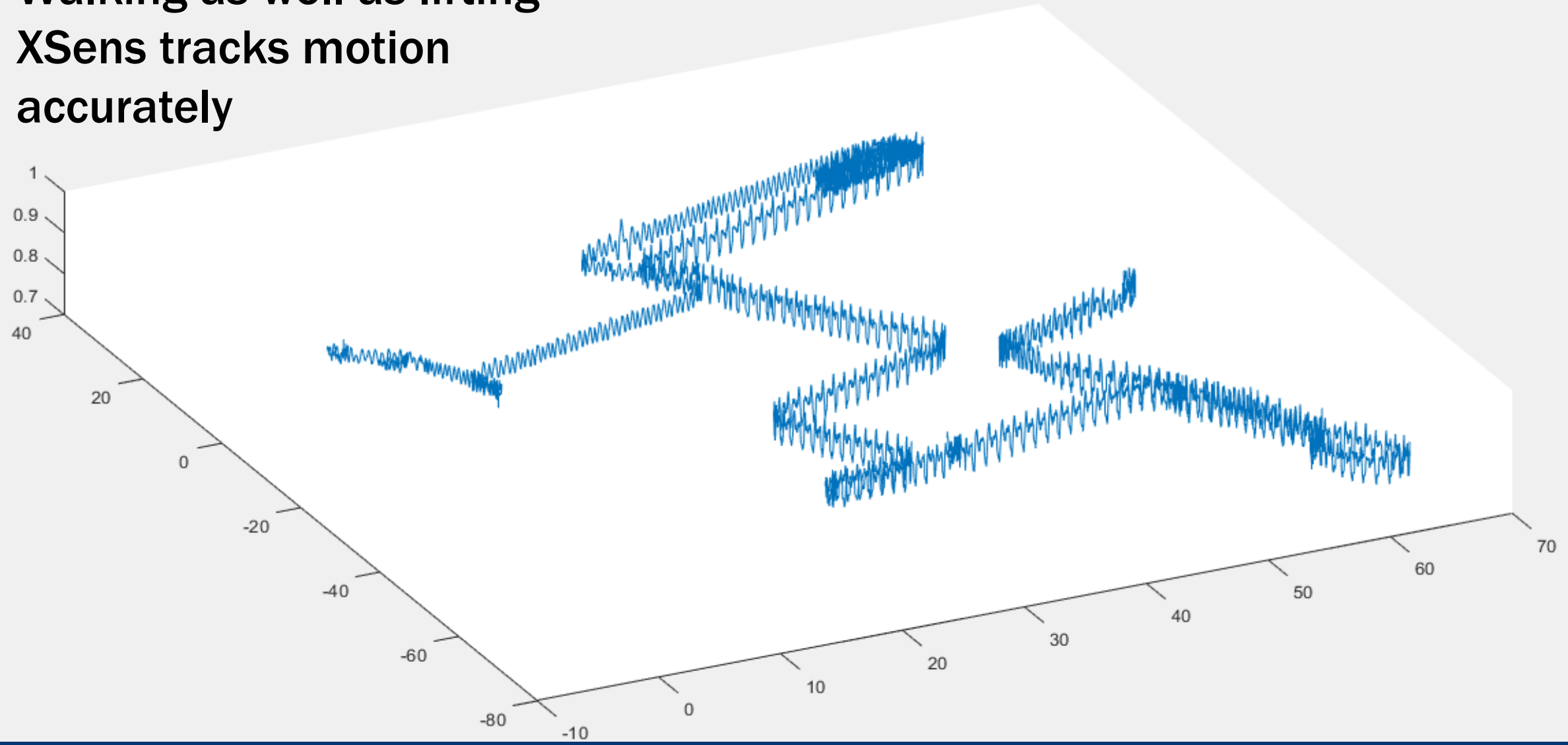
- Goal: Understand lifting and motion in a real-world environment
- XSens MVN Link IMU-based motion capture system
- 4 subjects, ~20 hours of data
- XSens does on-body recording
- Normal store activities

Motion Capture System Output



Motion in the store

- Walking as well as lifting
- XSens tracks motion accurately

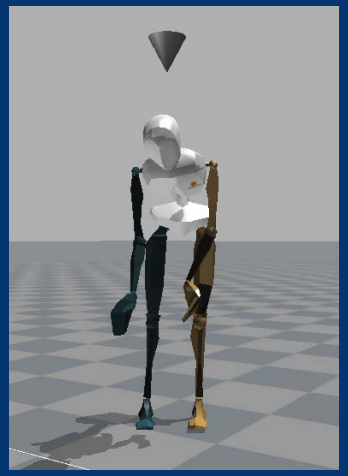


Different Lifting Style Tradeoffs

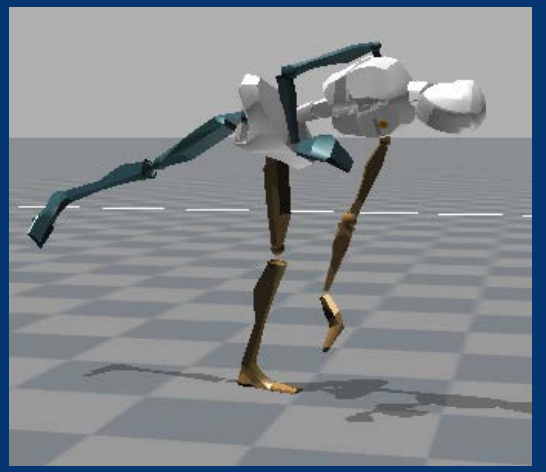
Squat ⟷ Stoop

Symmetric ⟷ Asymmetric

Legs together ⟷ Legs apart sideways

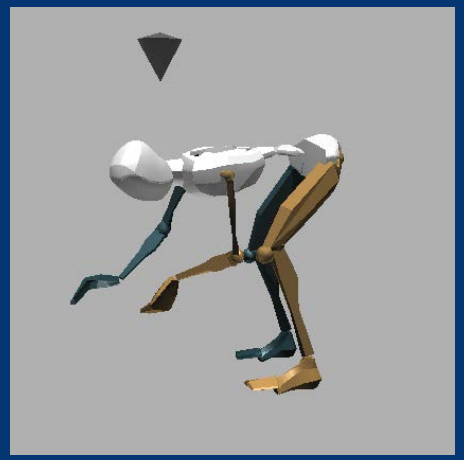


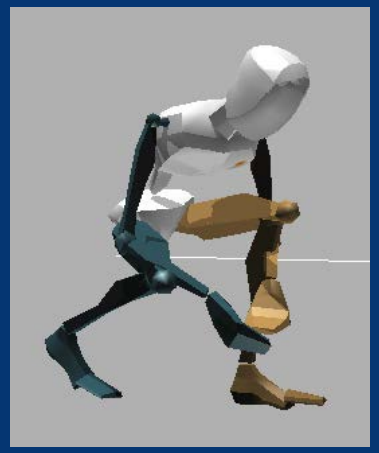
Both legs grounded ⟷ One leg in air



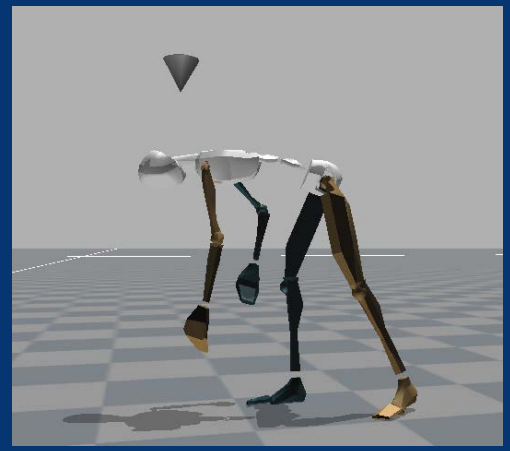
Different Lifting Style Tradeoffs

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

Whole Body Center of Mass

- 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

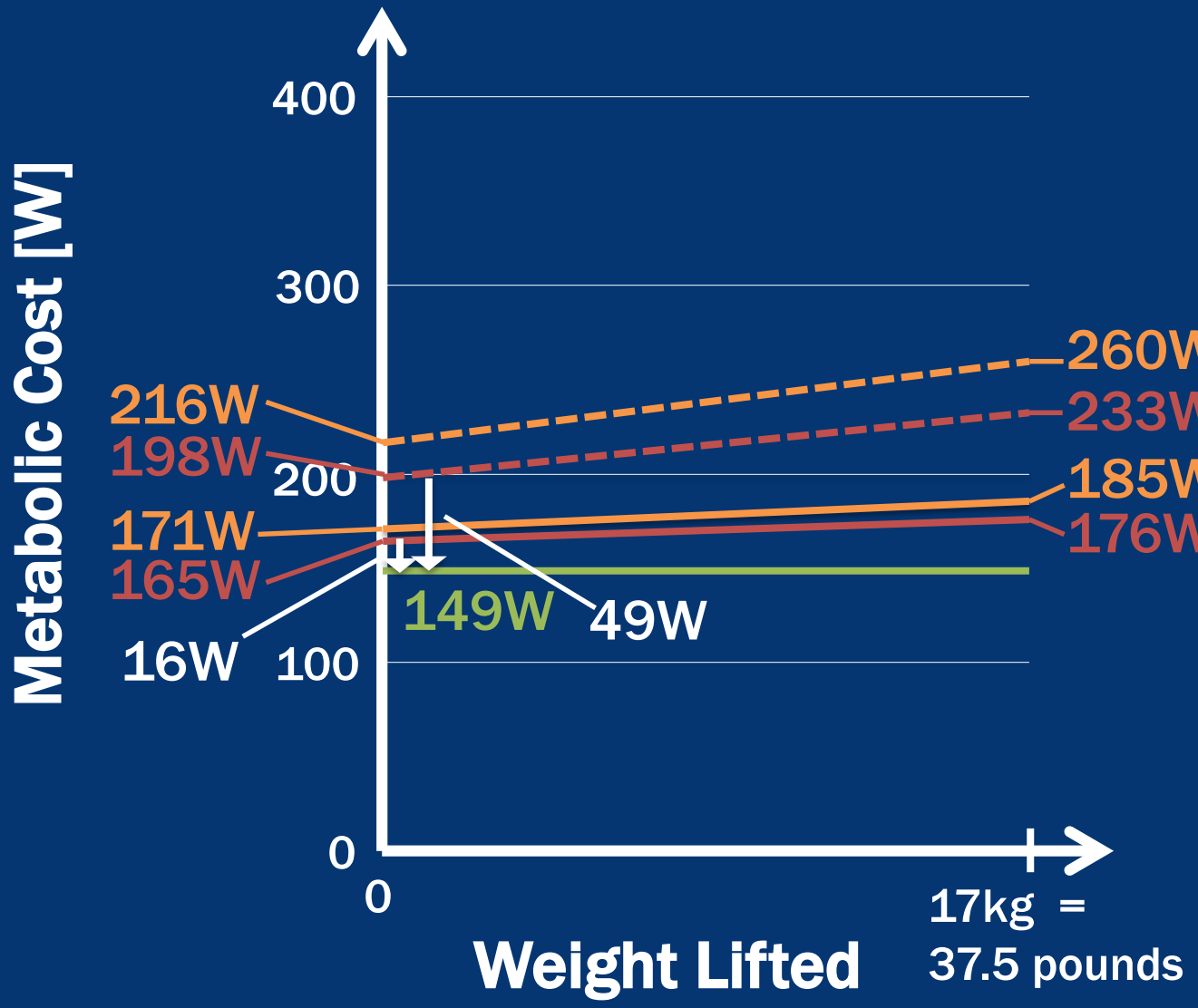
  ➔ ~3.33W Mechanical

- 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

Squat lifting

Stoop lifting

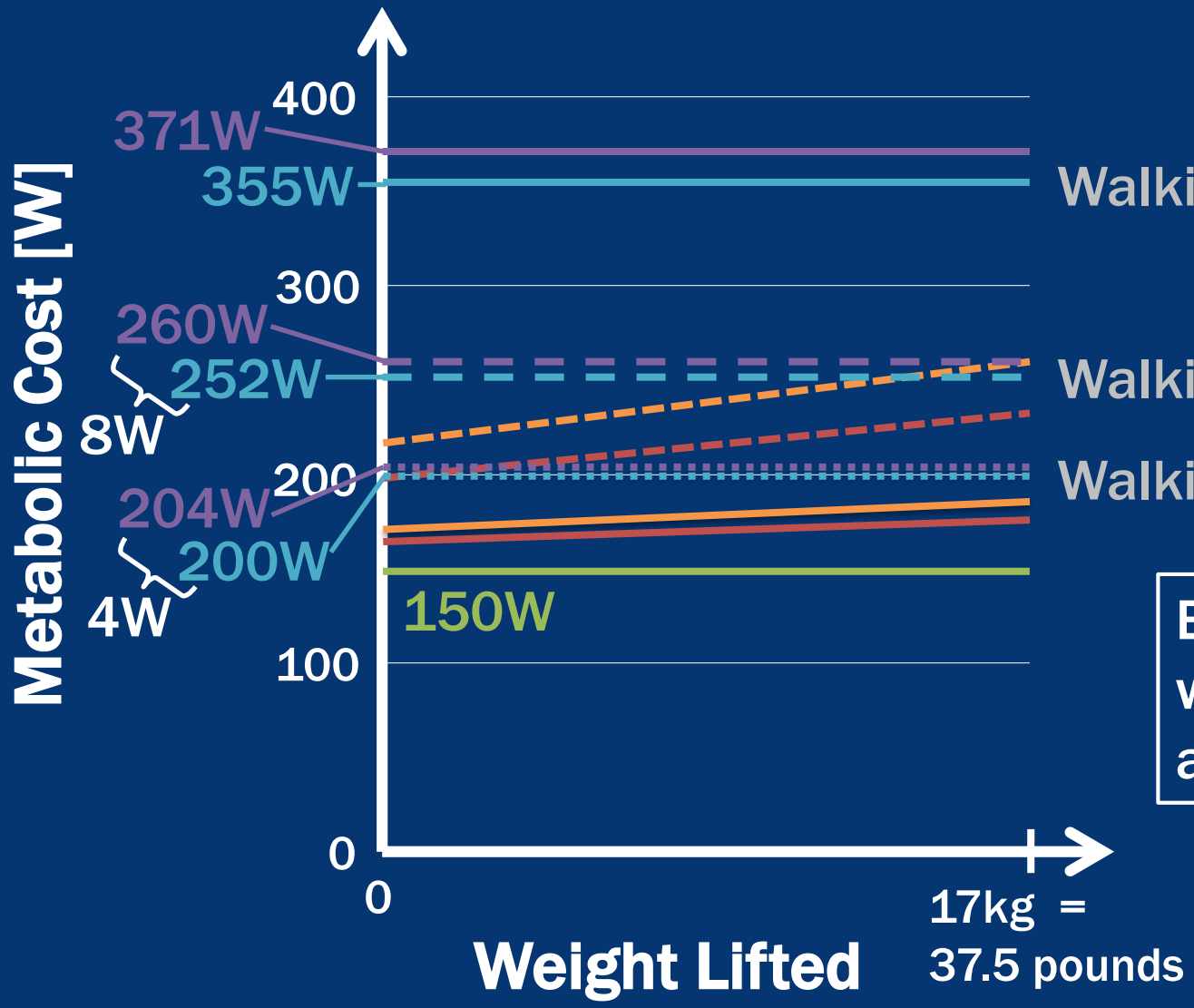
Standing still

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

Stoop lifting

Standing still

Walking

Walking with a 4kg load

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

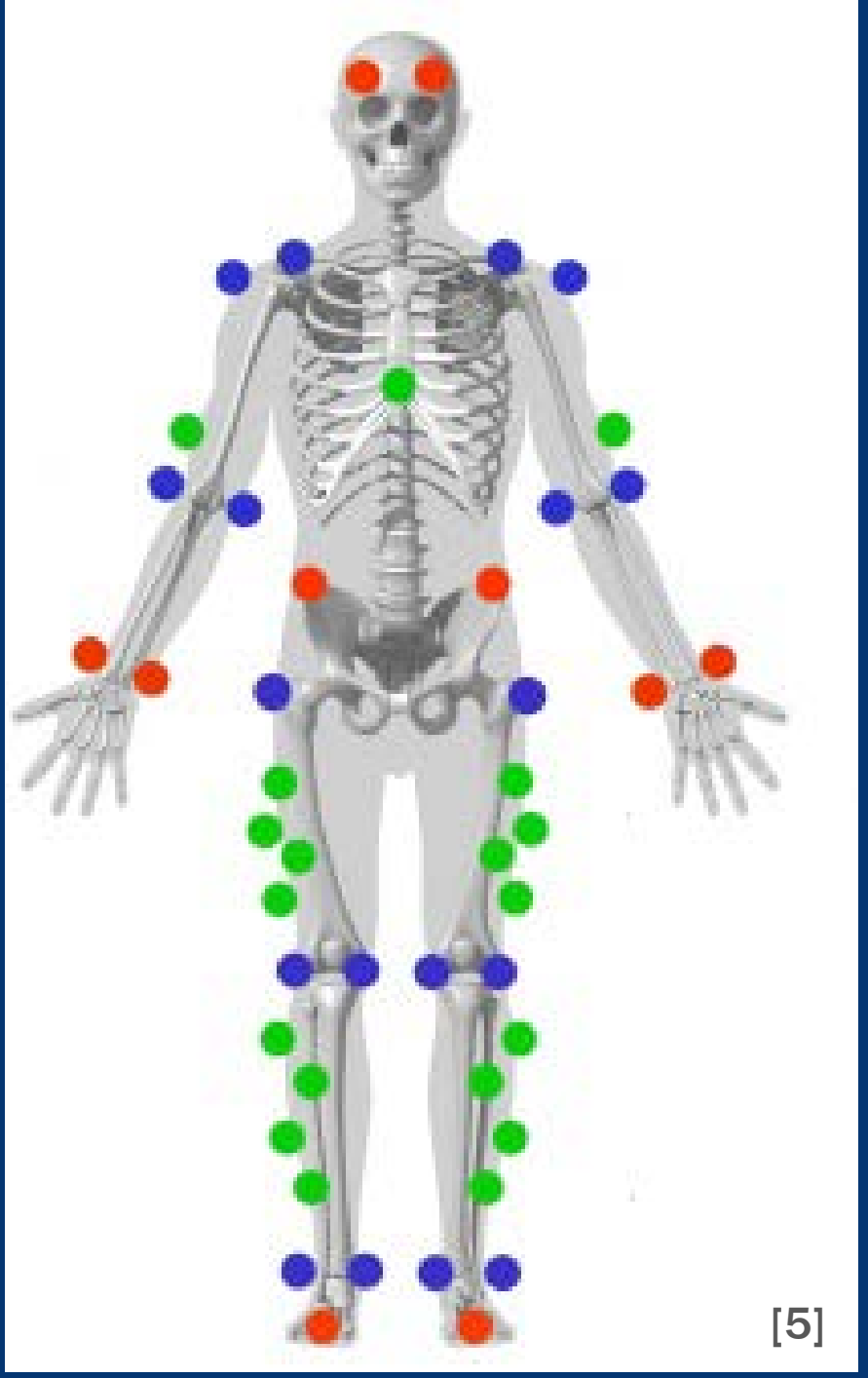
Pads

Webbing straps

Leg sliders

Next Steps

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



[5]

Acknowledgements

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David Weisbrodt

Chris Loll

Bonham Ekleberry

References

[1] = 2016 Liberty Mutual Workplace Safety Index

[2] = BLS Nonfatal Occupational Injuries and Illnesses Requiring Days Away from Work, 2015

[3] = DHHS (NIOSH) Publication No. 2007-131 - Ergonomic Guidelines for Manual Material Handling

[4] = DHHS (NIOSH) Publication No. 2013-111 - Simple Solutions for Home Building Workers Manual Material Handling Injuries, 2013

[5] = https://www.c-motion.com/v3dwiki/index.php?title=Marker_Set_Guidelines