




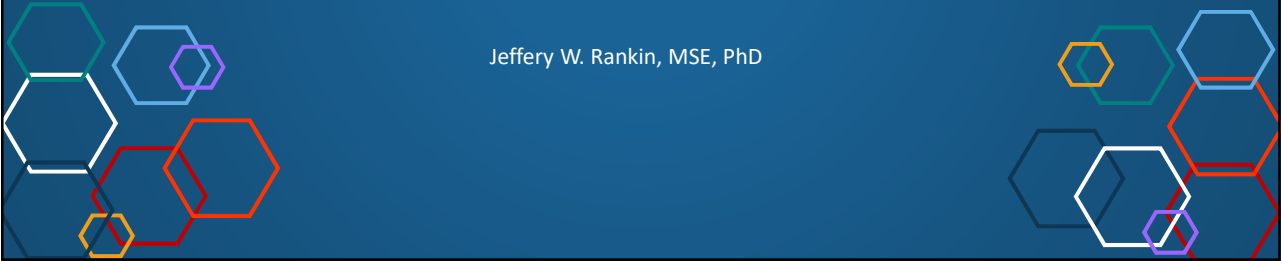
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Emerging Uses of Wearable Technologies to Support the Long-term Health and Wellness of Individuals Living with Spinal Cord Injury

23 March 2024

Jeffery W. Rankin, MSE, PhD



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## Emerging Wearable Technologies

### Learning Objectives

At the conclusion of this activity, the participant will be able to:

1. Understand how commercially available wearable technologies might be used to support exercise programs and goal setting for individuals living with SCI.
2. Understand how technologies can be used to support pressure injury prevention efforts in manual wheelchair users.
3. Understand how wheelchair fitting technologies can be used to help preserve shoulder health.



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## Wearable Sensors and Exercise:

### WODAA versus PACE

#### Background

- Physical Activity (PA) is critical to preventing major chronic health conditions (e.g., Type II Diabetes; Cardiovascular Diseases)
- PA Guidelines for persons with SCI:
  - Muscle Strength Training (2x/week)
  - Moderate to vigorous intensity aerobic exercise (≥20-30 min, 2-3x/week)

- Reduced PA after SCI contributes to:
  - Abnormal carbohydrate & lipid metabolism
  - Higher prevalence of diabetes mellitus
  - Earlier occurrence of coronary heart disease & stroke
  - Development of pressure ulcers, osteoporosis & UTIs





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## Wearable Sensors and Exercise: WOODA versus PACE

### The Challenge

*Individuals with SCI engage in less Physical Activity (particularly recommended moderate & vigorous levels) relative to the general population.*

- Increased time in sedentary activities (independent risk factor for poor health)
- **Contributes to secondary health challenges**
  - Abnormal carbohydrate & lipid metabolism
  - Higher prevalence of diabetes mellitus
  - Earlier occurrence of coronary heart disease & stroke
  - Development of pressure ulcers, osteoporosis & UTIs
- **Small activity increases benefit least active individuals**





## Wearable Sensors and Exercise: WODAA versus PACE

### Goal





*Evaluate New Approach to Increase PA in Manual Wheelchair Users.*

#### Whole of Day Activity Accumulation (WODAA)

- Activity accumulation, incorporated into daily activities
- Offers flexibility & personal choices for long-term sustainability
- Avoids PA barriers: (cost, transportation, & lack of time)

#### Planned Arm-Crank Exercise Program (PACE)

- Traditional Exercise Approach
- Portable Arm-Crank for Home Use
- Training Log



*Hypotheses: Improved PA, Satisfaction with Life, and Cardiometabolic Measures in WODAA group vs. PACE group.*

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# Wearable Sensors and Exercise: WODAA versus PACE

## Approach

- Randomized Clinical Trial
  - 16-Week Intervention
  - Included STOMPS (Shoulder Pain Prevention)

## • Participants

- + C7 SCI & below (AIS A-D)
- +  $\geq 18$  y/o & SCI  $\geq 1$  year
- + Use manual WC in community
- + Participating in aerobic exercise < 3 days/wk x 30 min/day
- + Desire to increase PA
- UE surgery in past year
- Shoulder Pain limiting WCP (WUSPI  $\geq 12$ ) &/or RC tear
- Cardiac abnormalities on ECG &/or physician instruction to limit PA
- Pregnant (or planning to become)

## Whole of Day Activity Accumulation vs Planned Arm-Crank Ergometry

Baseline  
N=100 Sedentary MWC Users

 → 

Subjects  
Randomized into 2  
RX groups

 → 

16 – Week Implementation  
of WODAA or PACE Programs

| ASSESSMENT                | ASSESSMENT                                      | INTERVENTION  | INTERIM<br>ASSESSMENT<br>4- WEEKS | FINAL<br>OUTCOMES<br>16- WEEKS |
|---------------------------|---|---|-----------------------------------|--------------------------------|
| Baseline (in clinic)      | Baseline (home and community)                   | (in clinic)   | (in clinic)                       | (in clinic)                    |
| Shoulder strength         | 7-day PA/HR monitoring with electronic PA diary | WODAA or PACE<br>Intervention/goal setting<br>Instruction in Shoulder Program | Reassess PA and goals             | Shoulder strength              |
| Metabolic parameters      |   |   | Reassess Shoulder Program         | Metabolic parameters           |
| Maximal exercise capacity |   |   |                                   | Max exercise capacity          |
| Shoulder pain             |   |   |                                   | Shoulder pain                  |
| Participation/SQOL        |   |   |                                   | Participation/SQOL             |


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# Wearable Sensors and Exercise: WODAA versus PACE

## Approach

- **WODAA**
  - Use commercial activity monitor
  - Increase PA as measured in daily “steps”
  - Reduce sedentary time (<250 steps/hour)
  - Increase light + moderate intensity (heart rate)
- **PACE**
  - Weeks 1-5: Increase exercise duration from 15-33 min
  - Weeks 5-16: Increase intensity (85% max heart rate )
- **Daily Activity Monitoring**
  - Fitbit Blaze/Versa



Whole of Day Activity Accumulation vs Planned Arm-Crank Ergometry


| Baseline<br>N=100 Sedentary MWC Users |   | Subjects<br>Randomized into 2<br>RX groups | 16 – Week Implementation<br>of WODAA or PACE Programs |                                |
|---------------------------------------|---|--|---|--------------------------------|
| ASSESSMENT                            | ASSESSMENT                                      | INTERVENTION                               | INTERIM<br>ASSESSMENT<br>4- WEEKS                     | FINAL<br>OUTCOMES<br>16- WEEKS |
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| Shoulder strength                     | 7-day PA/HR monitoring with electronic PA diary | WODAA or PACE Intervention/goal setting    | (in clinic)   | (in clinic)                    |
| Metabolic parameters                  |   | Instruction in Shoulder Program            | Reassess PA and goals                                 | Shoulder strength              |
| Maximal exercise capacity             |   |  | Reassess Shoulder Program                             | Metabolic parameters           |
| Shoulder pain                         |   |  |   | Max exercise capacity          |
| Participation/SQOL                    |   |  |   | Shoulder pain                  |
|                                       |   |  |   | Participation/SQOL             |

Goal Setting (Brief Action Planning)

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## Wearable Sensors and Exercise: WOODA versus PACE

**Results**

- 55 Participants (complete data sets)
- Completion Rate
  - WODAA 29/32 (90.6%)
  - PACE 34/36 (94.4%)
- Sedentary Time
- Overall Activity Levels (“Daily Steps”)
- Very Active Time (>6 METs = jumping jacks, aerobic dancing)

|   | WODAA<br>(n= 24) | PACE<br>(n=31) | Total<br>(n=55)            |
|---|------------------|----------------|----------------------------|
| Age at baseline, years  | 40.4             | 41.0           | 40.7 years                 |
| Duration of injury, years   | 14.4             | 16.3           | 17.9                       |
| Paraplegia (vs tetraplegia)   | 91.6%            | 93.5%          | 92.7% (51/55)              |
| High Paraplegia (T2-T7) (vs. Low T8-L3)   | 45% (10/22)      | 34% (10/29)    | 39% (20/51)                |
| Gender, % female (national average 22%)   | 21% (5/24)       | 16% (5/31)     | 18% (10/55)                |
| Race  |                  |                |                            |
| Asian/Pacific Islander  |                  |                | 5%                         |
| Black   |                  |                | 20%                        |
| White   |                  |                | 56%                        |
| Unknown/Declined  |                  |                | 2%                         |
| More than one race  |                  |                | 15%                        |
| Ethnicity, % Hispanic   | 58% (14/24)      | 65% (20/31)    | 61% Hispanic (2% declined) |
| Self Described Exerciser, % Yes   | 54% (13/24)      | 48% (15/31)    | 51%                        |
| Baseline Wheelchair User’s Shoulder Pain Index Score (Shoulder Pain: WUSPI≥12) (%Participants w shoulder pain at entry) | 0.1 (0/24)=0%    | 1.6 (1/31)=3%  | 0.9 1/55=2%                |

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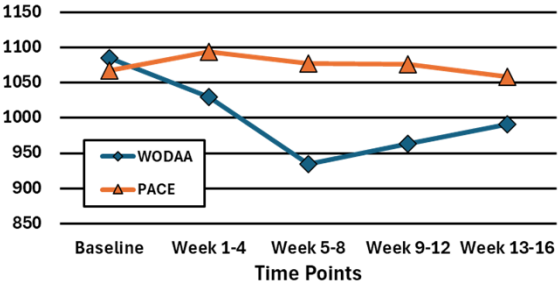
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## Wearable Sensors and Exercise: WOODA versus PACE

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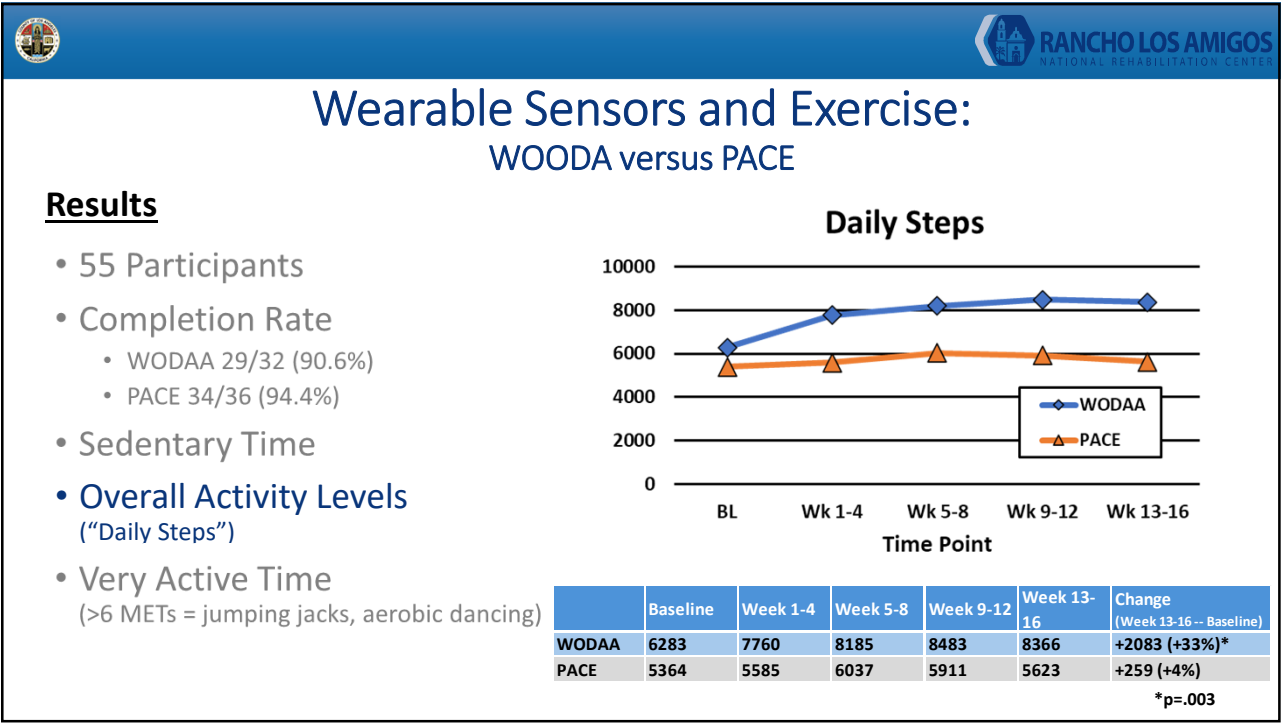
### Daily Sedentary Minutes



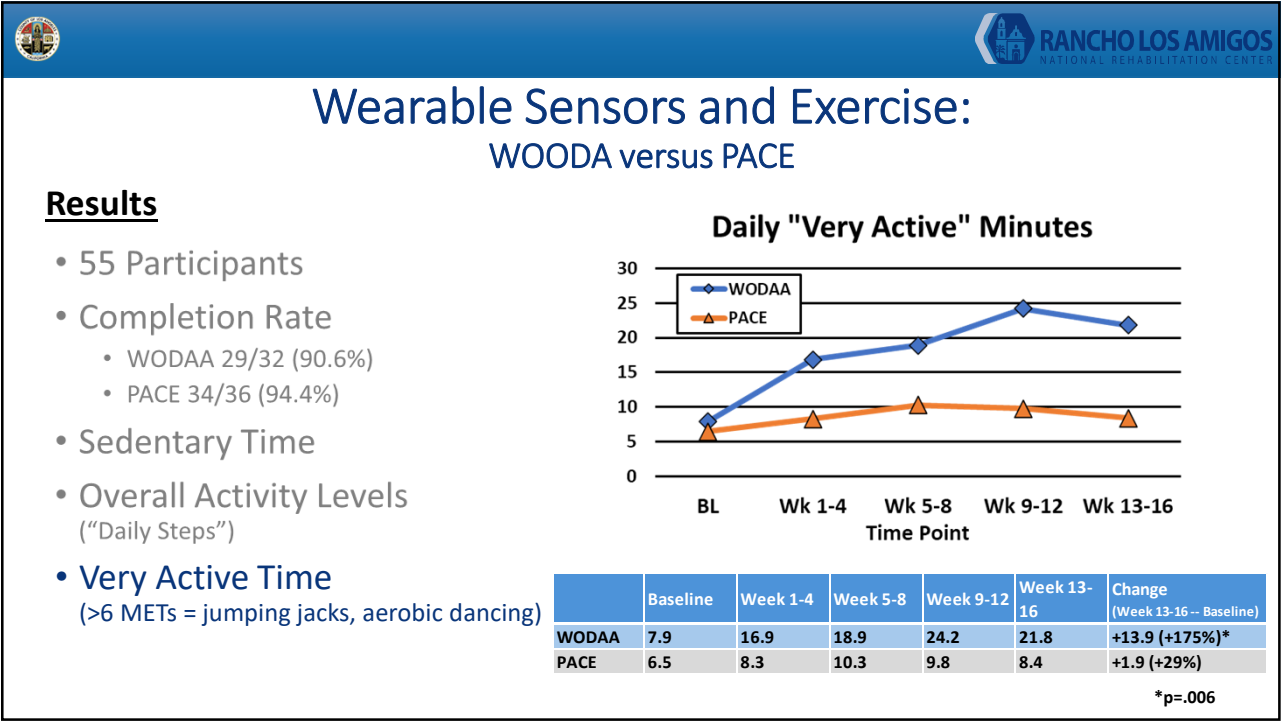
|       | Baseline | Week 1-4 | Week 5-8 | Week 9-12 | Week 13-16 | Change (Week 13-16 -- Baseline) |
|-------|----------|----------|----------|-----------|------------|---------------------------------|
| WODAA | 1085     | 1030     | 935      | 963       | 991        | -94 (-9%)                       |
| PACE  | 1068     | 1094     | 1078     | 1077      | 1059       | -9 (-1%)                        |

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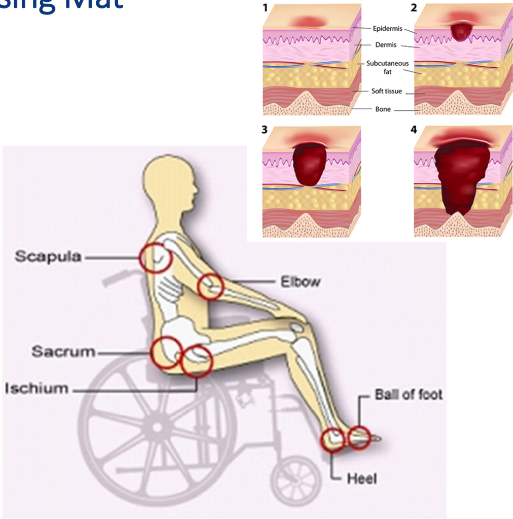
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## Wearable Sensors and Pressure Injury Prevention : Pressure Sensing Mat

### Background

- >1.5 million manual wheelchair (MWC) users in the USA (Kaye et al. 2000).
- 31-85% Pressure Injury (Ulcer) Incidence
  - Risk Factors
    - Muscle Atrophy
    - Nutrition
    - Inability to Sense the Need to Move
    - Inadequate Performance of Pressure Relieve Activities
    - Mechanical Pressure on Skin
- High Financial and Psychosocial Costs



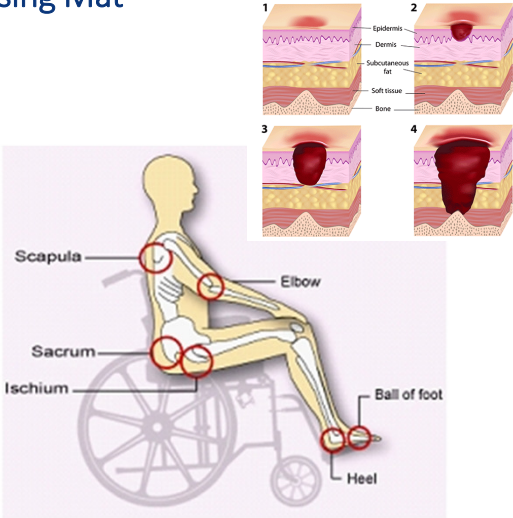







## Wearable Sensors and Pressure Injury Prevention : Pressure Sensing Mat

### Background

- >1.5 million manual wheelchair (MWC) users in the USA (Kaye et al. 2000).
- 31-85% Pressure Injury (Ulcer) Incidence
  - Prevention is Best Approach
    - Muscle Atrophy
    - Nutrition
    - Inability to Sense the Need to Move
    - Inadequate Performance of Pressure Relieve Activities
    - Mechanical Pressure on Skin
- High Financial and Psychosocial Costs









# Wearable Sensors and Pressure Injury Prevention :

## Pressure Sensing Mat

### Prevention through Offloading


#### Cushions



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#### Pressure Relief Exercises

Depression  
Raise  
(Pushup)



Forward  
Lean

Right  
Lean



Left  
Lean

Furumasu J, Buckner R, Mata C, Requejo P. OFF-LOADING PRESSURE RELIEF WITH FOAM CUT OUT CUSHIONS: EXPERIENCES FROM RANCHO LOS AMIGOS NATIONAL REHABILITATION CENTER. J Rehabil Med Clin Commun. 2023 Nov 14;6:18706. doi: 10.2340/jrmcc.v6.18706. PMID: 38025663; PMCID: PMC10658289.



# Wearable Sensors and Wheelchair Fitting:

## Pressure Sensing Mat

### The Challenge

Manual wheelchair users do not regularly meet recommended pressure offloading goals (quantity) and/or do not perform activities at a high level of precision (quality).

- Inability to Sense the Need to Move
- Inadequate Performance of Pressure Relieve Activities
- Mechanical Pressure on Skin



### Depression Raise



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## Wearable Sensors and Wheelchair Fitting: Pressure Sensing Mat

### The Challenge



- Patient 1
  - T7 Complete
  - Car Accident
  - Time Since Injury: < 2years
  - 28 Year Old National Park Traveler
  - Pressure Injury History: None
- Patient 2
  - T8 Complete
  - Gun Shot Wound
  - 36 Year Old Basketball Player
  - Time Since Injury: 15 years
  - Pressure Injury History: Multiple

I'm a newbie...want to see how much I can learn how to do a pressure injury better

I'm doing all I can to keep from having another pressure injury.



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## Wearable Sensors and Wheelchair Fitting: Pressure Sensing Mat

### Goal

*Develop and test an easy to use, portable system to support pressure injury prevention efforts by manual wheelchairs with Spinal Cord Injury*




**Focus Groups**  
(Paraplegia; 3-30 years post injury)






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## Wearable Sensors and Wheelchair Fitting: Pressure Sensing Mat




### Our Solution

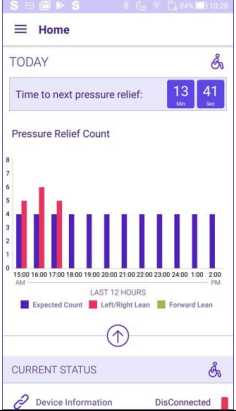
Mat with Textile-Based Pressure Sensors




Microprocessor with Bluetooth Connection




Phone App with Biofeedback




Cloud-based Clinician Dashboard





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## Wearable Sensors and Wheelchair Fitting: Pressure Sensing Mat

### Testing (ongoing)

Accuracy

Jay J2 (Gel)  
Jay Fusion (Air)  
Jay Fusion (Gel)  
Meridian (Air)  
Java Ride Designs (Foam)  
Axiom XP  
Roho Contour (Air)  
Varilite

Baseline Period

Measurement Only

Intervention Period

Initial Group: Initial Prototype System

Control Group: Measurement Only

Final Group: Fully Developed System

Initial Visit  
Consent & System Install

2-Week Visit  
Education & Goal Setting

6-Week Visit  
Education & Goal Setting

6-Month Survey


12-Month Survey

18-Month Survey

24-Month Survey

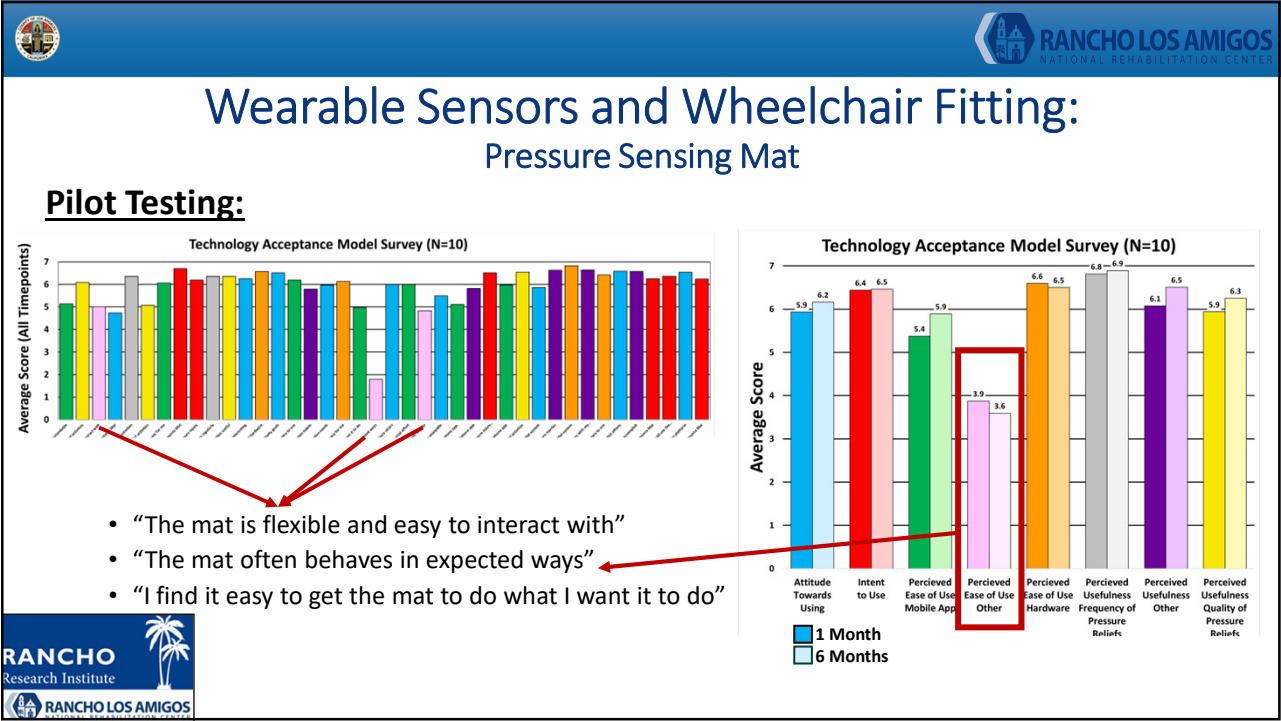
### Clinical Testing (N=10)

- Manual Wheelchair Users
- Able to Perform Pressure Relief Exercises w/out Assistance
- >6 months post-injury

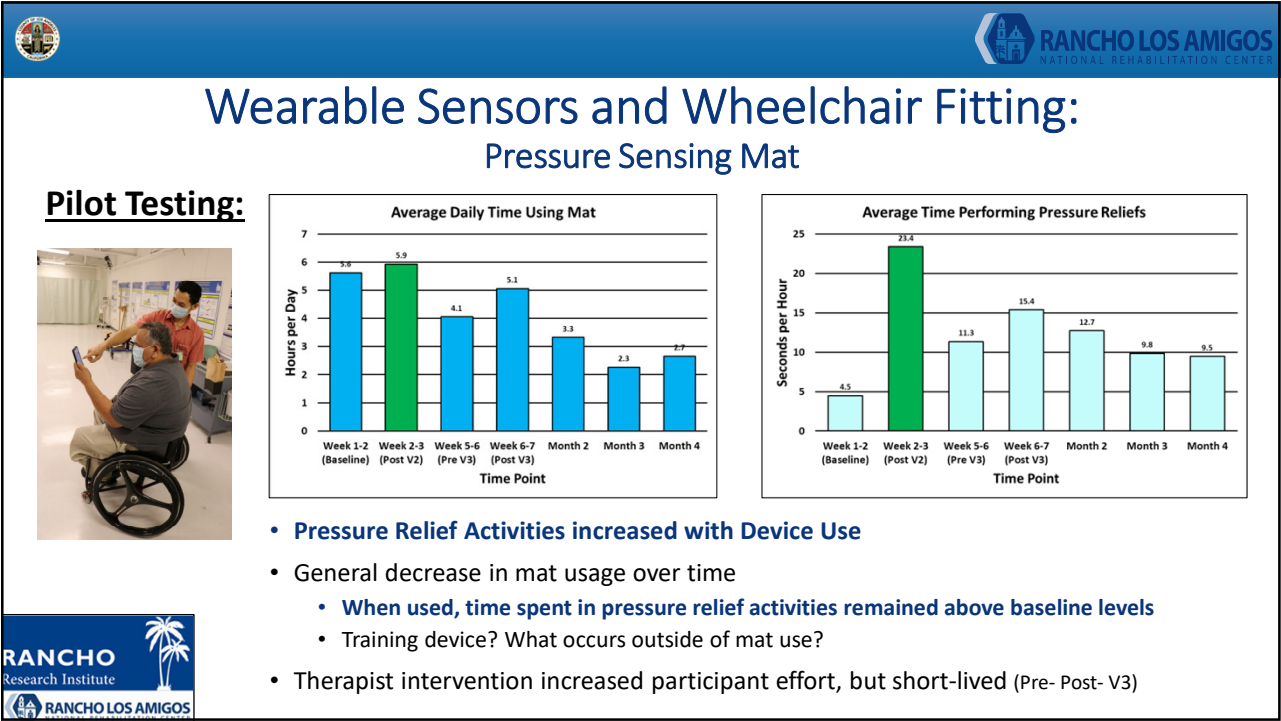


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**Wearable Sensors and Wheelchair Fitting:**  
Propulsion in the Community

**Acknowledgments**


- Jill McNitt-Gray, PhD
- Ian M. Russell, PhD
- Leslie Porter, PT ATP
- Jan Furumaso, PT ATP
- Philip S. Requejo, PhD





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**Wearable Sensors and Wheelchair Fitting:**  
Propulsion in the Community

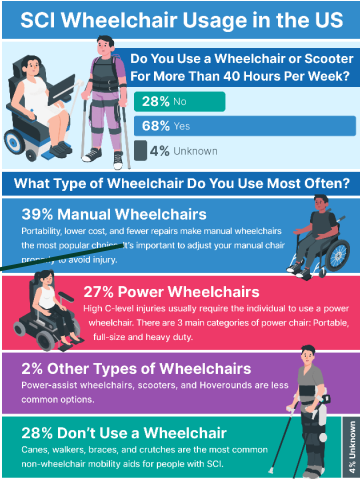
**Background**

- >1.5 million manual wheelchair (MWC) users in the USA (Kaye et al. 2000).
- MWC users are dependent on their upper extremities for both mobility and routine daily activities.
- **Benefits to MWC use**
  - Preserve upper body strength
  - Cardiovascular conditioning
  - Independence
  - Community Participation



**“It’s important to adjust your manual chair properly to avoid injury”**

**SCI Wheelchair Usage in the US**



**Do You Use a Wheelchair or Scooter For More Than 40 Hours Per Week?**

28% No

68% Yes

4% Unknown

**What Type of Wheelchair Do You Use Most Often?**

39% Manual Wheelchairs

27% Power Wheelchairs

2% Other Types of Wheelchairs

28% Don't Use a Wheelchair

4% Unknown





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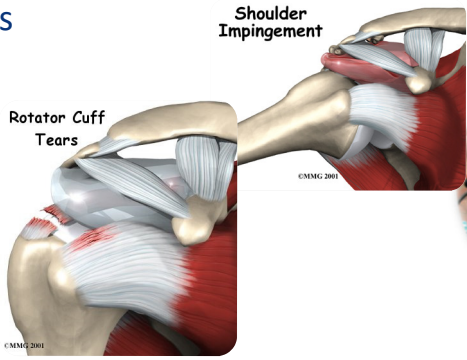



## Wearable Sensors and Wheelchair Fitting: Propulsion in the Community



### The Problem

*The mechanical demand imposed on the shoulders during manual wheelchair propulsion exceeds ergonomic recommendations.*

- Shoulder Overuse Injuries
  - Chronic Pain
  - Impingement
  - Rotator Cuff Tears








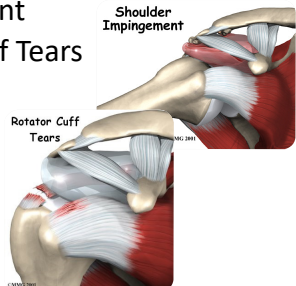
## Wearable Sensors and Wheelchair Fitting: Propulsion in the Community


### The Problem

*The mechanical demand imposed on the shoulders during manual wheelchair propulsion exceeds ergonomic recommendations.*


- Shoulder Overuse Injuries
  - Chronic Pain
  - Impingement
  - Rotator Cuff Tears

- Care Approaches
  - Strength/Conditioning (STOMPS)
  - Propulsion Technique (Rankin et al 2010, 2011)
  - Modify Wheelchair Fit
    - Axle, Seat Slope, Seatback










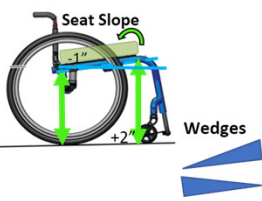
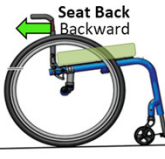

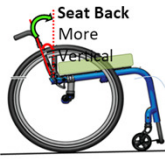
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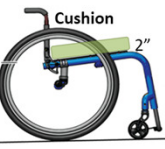
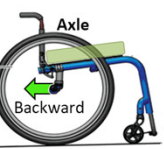
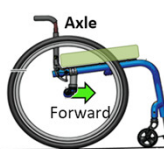
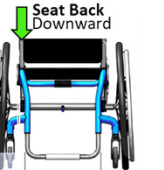

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## Wearable Sensors and Wheelchair Fitting: Propulsion in the Community


### K5 Chairs are Adjustable




Wedges



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## Wearable Sensors and Wheelchair Fitting: Propulsion in the Community

### An Example

Static





Propulsion



Are adjustments being made to address static posture or propulsion posture?

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## Wearable Sensors and Wheelchair Fitting: Propulsion in the Community

### Intervention Approach

1. Measure Current Wheelchair Configuration
2. Record Propulsion Data *In a Community Environment*
  - Overground, Slopes
  - 3 Wearable Sensors (IMUs)
    - Forearm, Shoulder, Trunk
3. Determine Demand
4. Adjust Wheelchair Fit
5. Verify Fit *In a Community Environment* (IMUs)





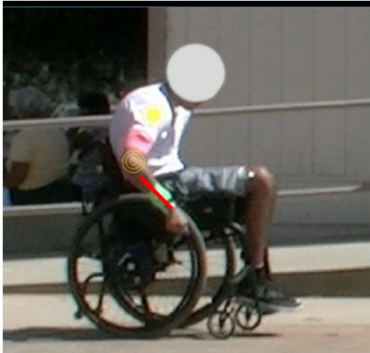


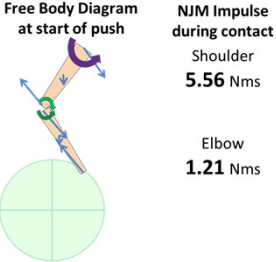
## Wearable Sensors and Wheelchair Fitting: Propulsion in the Community

### An Example

#### Complaints

- Wants to improve slouched posture
- Pushing bothers his right shoulder





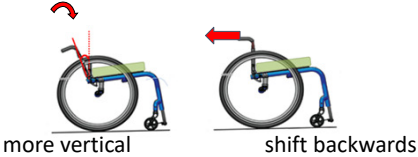
Free Body Diagram  
at start of push

NJM Impulse  
during contact

Shoulder  
5.56 Nms

Elbow  
1.21 Nms



#### WC Modifications: seatback





more vertical

shift backwards

<https://www.ranchoptlab.org/wheelchairfitting>







# Wearable Sensors and Wheelchair Fitting: Propulsion in the Community

## An Example




Baseline



Follow-Up



40% reduction in shoulder demand during push!

<https://www.ranchopklab.org/wheelchairfitting>





# Wearable Sensors and Wheelchair Fitting: Propulsion in the Community



## MWC Fit

Impairment

Function




★


Wearable Sensors  
Biomechanics



### Considerations

- Static vs Dynamic
- Clinic vs Community
- Posture
- Pressure
- Stability
- Limb Demand



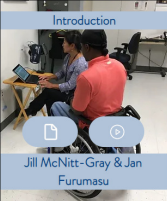


## Wearable Sensors and Wheelchair Fitting: Propulsion in the Community

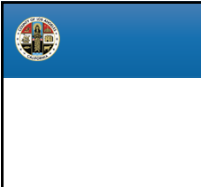

### Additional Resources



Get the Right Fit!



<https://www.ranchopklab.org/wheelchairfitting>



## Emerging Wearable Technologies

### Learning Objectives

At the conclusion of this activity, the participant will be able to:

1. Understand how commercially available wearable technologies might be used to support exercise programs and goal setting for individuals living with SCI.
2. Understand how technologies can be used to support pressure injury prevention efforts in manual wheelchair users.
3. Understand how wheelchair fitting technologies can be used to help preserve shoulder health.

