Wearable Technology to Monitor Movement and Optimize Stroke Rehabilitation and Recovery

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CRIR Centre de recherche interdisciplinaire

IURDPM

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Affiliations:
I have no relationships with for-profit or not-for-profit organizations

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Evaluation

For the **Provincial Stroke Rounds Planning Committee**:

- To plan future programs
- For quality assurance and improvement

- For **You**: Reflecting on what you've learned and how you plan to apply it can help you enact change as you return to your professional duties

- For **Speakers**: The responses help understand participant learning needs, teaching outcomes and opportunities for improvement.

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Please take 2 minutes to fill the evaluation form out. Thank you!

Objectives

Upon completion participants will be able to:

1. Identify the potential benefits of using wearable technology to assess stroke survivors' participation in activity outside clinical settings.
2. Describe various factors that influence mobility and upper limb use in daily activities and affect recovery.

OUTLINE

1. Disparity between capacity and performance
2. Possibilities offered by wearable technology
3. Insights from wearable technology on stroke recovery
4. Interventions leveraging wearable technology
5. Perspectives of experts on the future of wearables

Disparity between capacity and performance

Capacity:
What one can do?

VS.

Performance:
What one chooses to do in the home and community

Andrews & Stewart. *Stroke recovery*. 1979;18(1):43-48; Hidaka et al., *PLoS Comput Biol*. 2012;8(2); Stewart & Cramer. *Stroke*. 2013;44(4):1111-1116; Winstein & Varghese. *NeuroRehabilitation*. 2018;43(1):3-18.

Insights on the learned/acquired non-use phenomenon

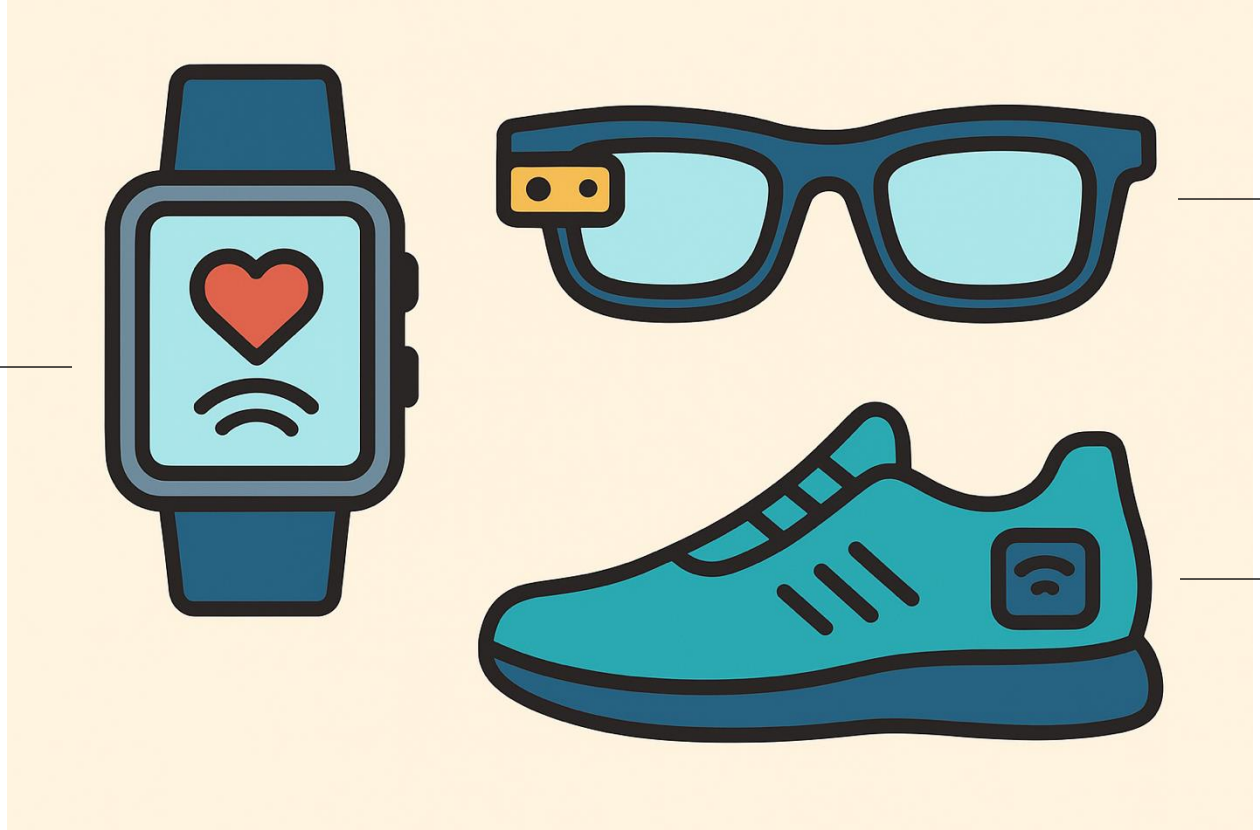
Learned non-use:

A discrepancy between a retained motor capacity, which can be retrieved when requested, and the spontaneous use of this motor capacity in daily life, a discrepancy that develops due to experience in inept or nonproductive perceived attempts to use that capacity.

Hirsch et al., *Neurorehabil Neural Repair.* 2021; 35(5).

Wearable technology for rehabilitation

Mobile devices and apps



Smart Glasses

Smart clothing

Source: ChatGPT, 5.0

Possibilities offered by wearable technology

Assessment

- Provides information about functional movement skills
  - Mobility
  - Arm and hand object interaction
- Offers insight on daily functioning and real-life experiences
- Complements clinical assessment

Treatment

- Offers direct, real-time feedback on activity
- Encourages health-promoting behaviors

Torriani-Passin et al. *Disabil Rehabil*. 2021

Challenges with wearable technology

Consumer-grade

- Diminished accuracy for severely impaired individuals
- Black box algorithms, inaccessible raw data
- Lack of customization and limited output variables

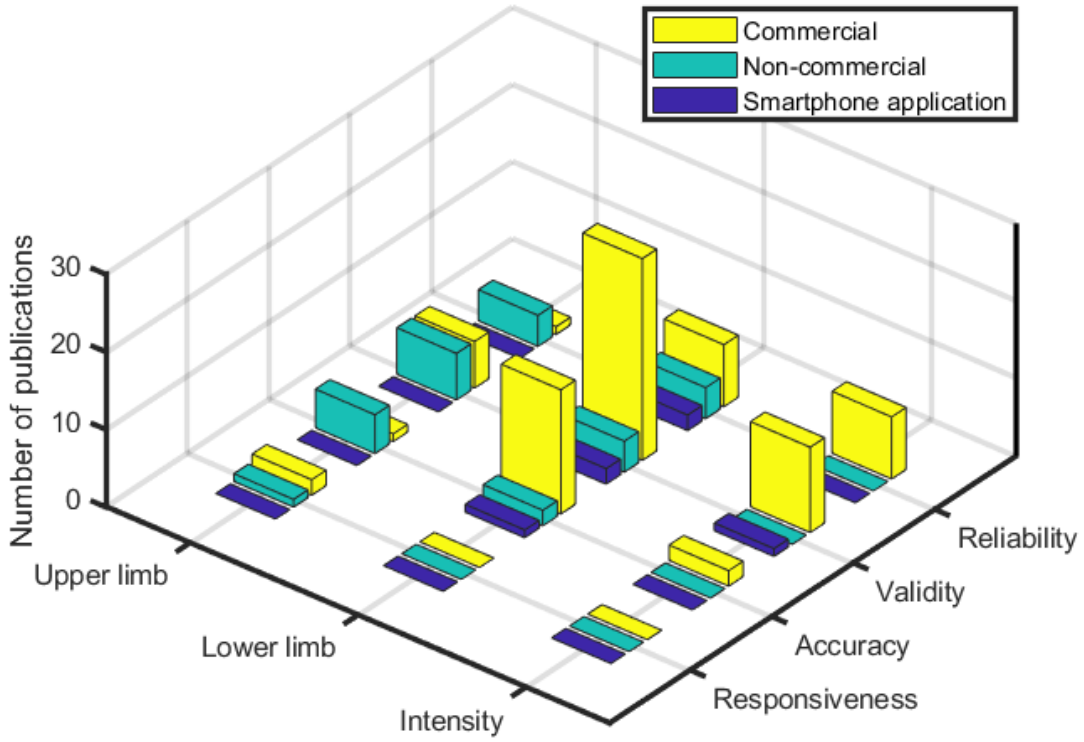
Research-grade

- Expensive
- Excessive time to process data
- Long setup time
- Need multiple sensors

Image source: FitBit, Actigraph

Lang et al. *Sensors*. 2020; Torriani-Passin et al. *Disabil Rehabil*. 2021

Measurement properties of wearable technology



Torriani-Pasin et al. *Disabil Rehabil*. 2021

weaRablEs for STroke functiOn in the natuRal Environment

In collaboration with

- Justin Rowe and Daniel Zondervan, Flint Rehabilitation Devices
- Lauri Bishop, Amelia Cain and Carolee Winstein, University of Southern California

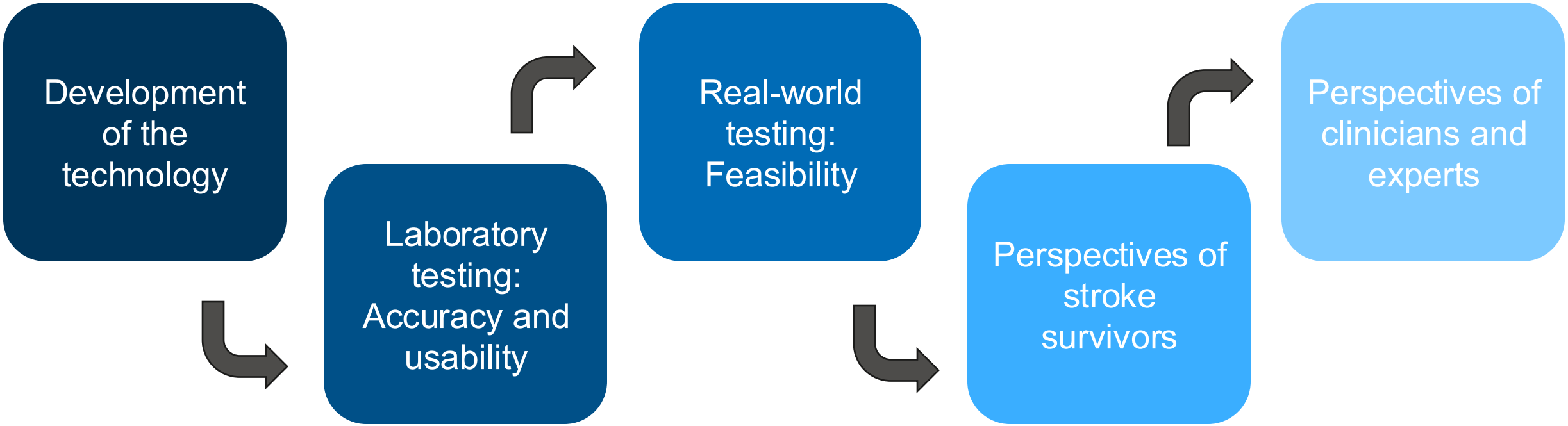
USC Division of Biokinesiology and Physical Therapy

FlintRehab Tools to spark recovery

SC CTSI Translating Science into Solutions for Better Health

NIH Eunice Kennedy Shriver National Institute of Child Health and Human Development

Steps the refinement of wearable technology



Wearable sensors metrics

Smart watch

- Upper limb time in active movement
- Use ratio

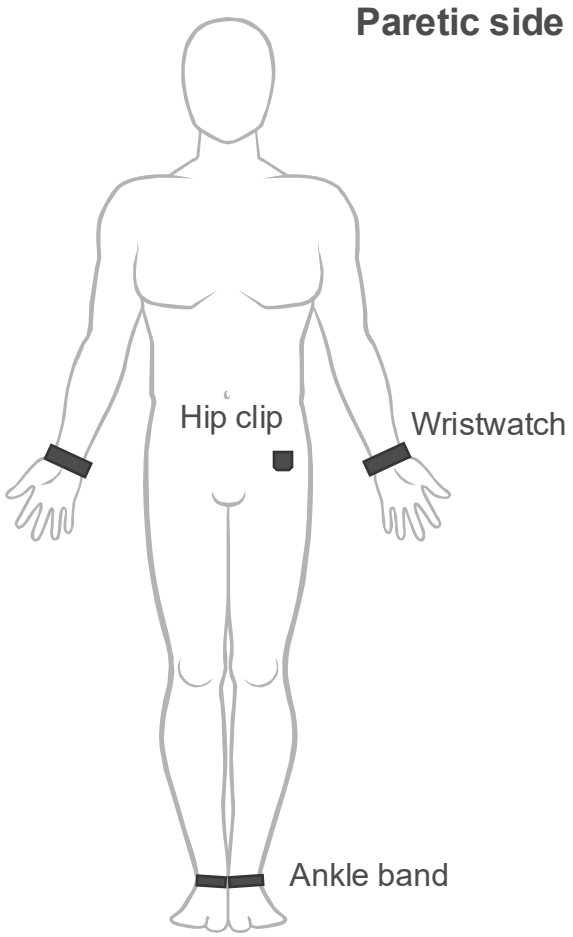
Ankle sensor

- Step counts
- Stance time symmetry

Accuracy and usability testing

1) Maximize the accuracy of a commercial grade wearable sensor system to measure arm activity and mobility across a range of motor impairments.
    - Gold-standard comparison: video annotation and APDM (only for mobility)

2) Optimize usability of the wearable sensor system for stroke survivors.
    - Time to don/doff
    - Utility cost survey
    - Alternative bracelets



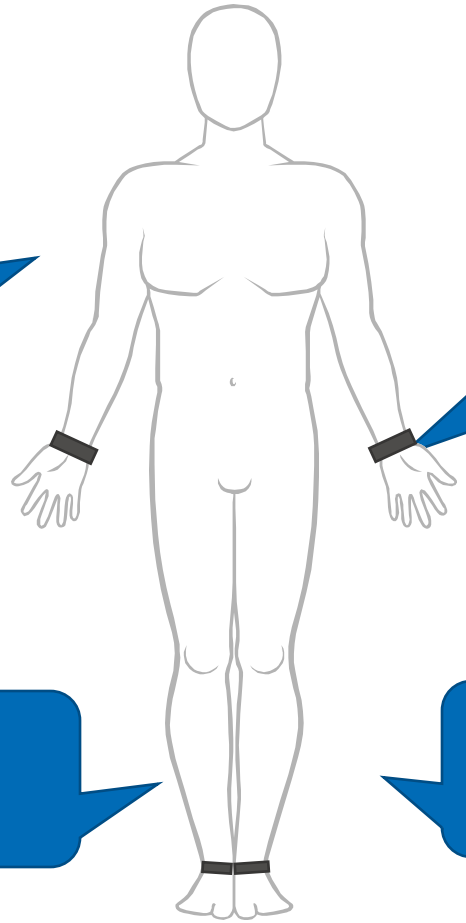
Demers, Bishop et al. *Arch Phys Rehabil Med*. 2024

Accuracy of a wearable sensor system capturing upper limb and mobility

Less affected side

Paretic side

Time in active movement (UL)
88.0 ± 4.7%



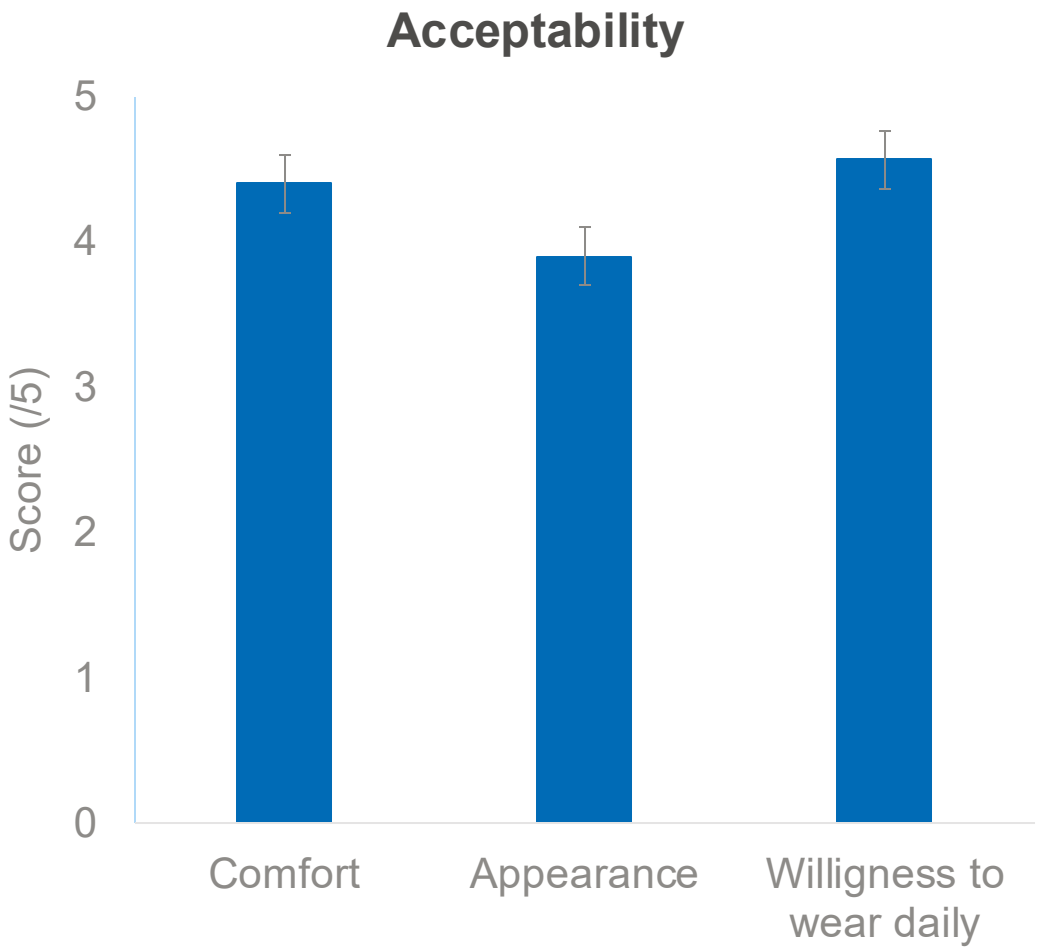
Time in active movement (UL)
85.2 ± 5.1%

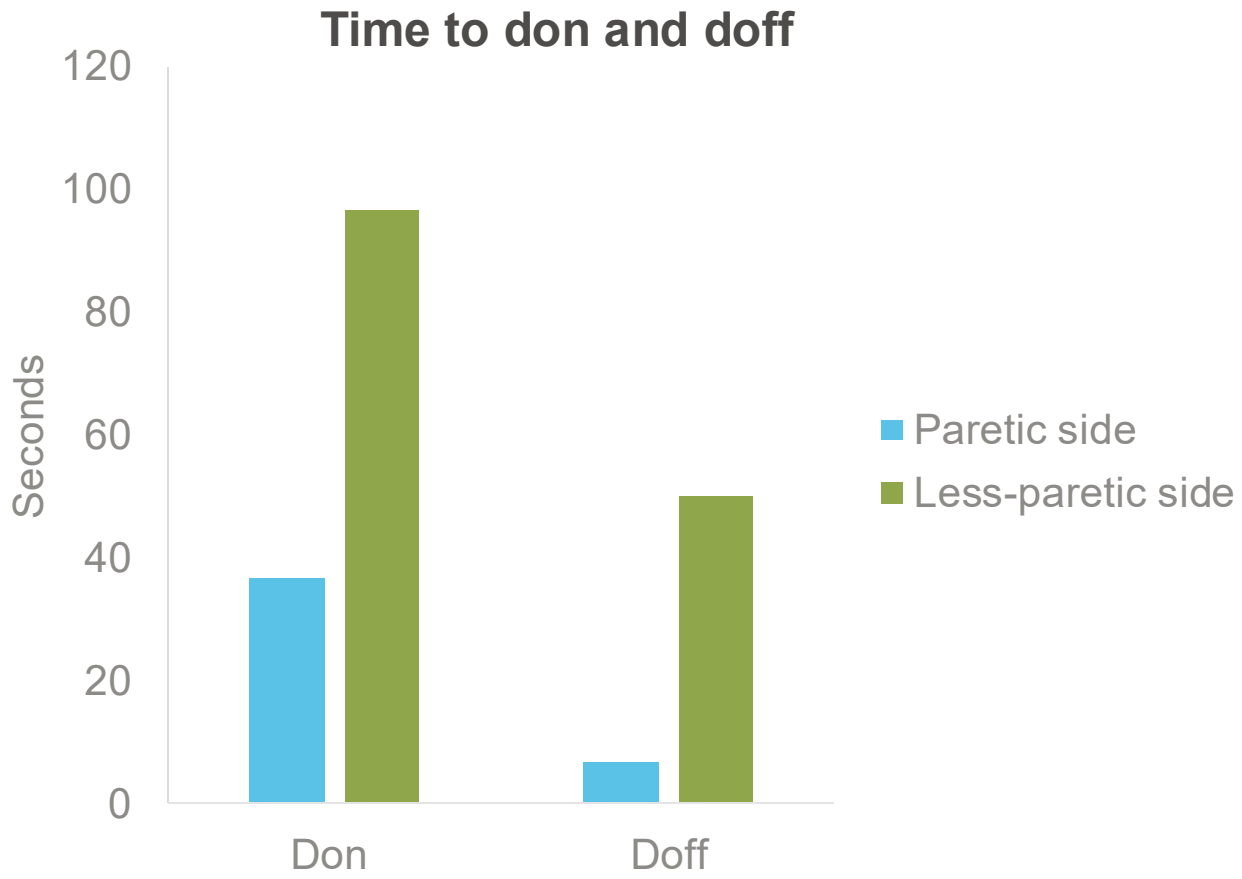
Step counts
96.0 ± 0.8%

Stance time symmetry
90.0 ± 4.8%

Bishop et al. *Arch Phys Rehabil Med*, 2024

Usability of the wearable sensor system





Demers, Bishop et al. *Arch Phys Rehabil Med*. 2024

Alternative wristbands

Magnetic band

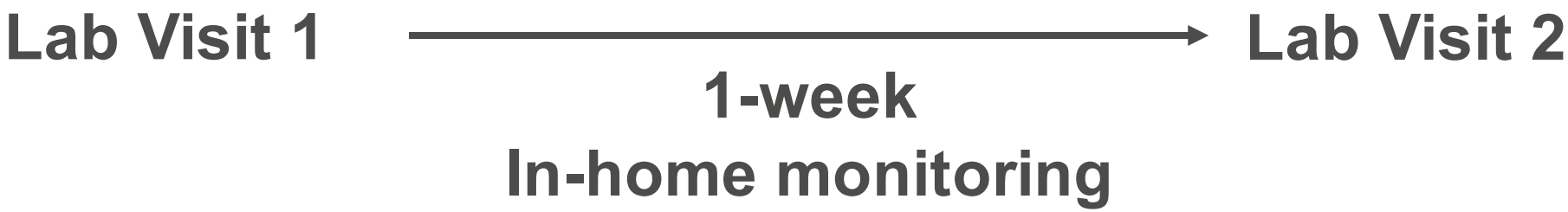
Silicone band

Elastic band

Velcro band

Demers, Bishop et al. *Arch Phys Rehabil Med*. 2024

Home monitoring



- Administer clinical tests
- Provide sensors and wearing instructions

- Administer clinical tests
- Orient participants to the Movement report
- Gather data about feedback preferences

Demers et al. *PTJ.* 2024.

Feasibility

Safety

- Discomfort with silicone band: n=3
- Unrelated adverse events: n=4

Usability

- System Usability Scale: mean: 85.0/100

Adherence and technical issues

- 87.9% of valid data

"It was wonderful. I didn't mind one day doing it."

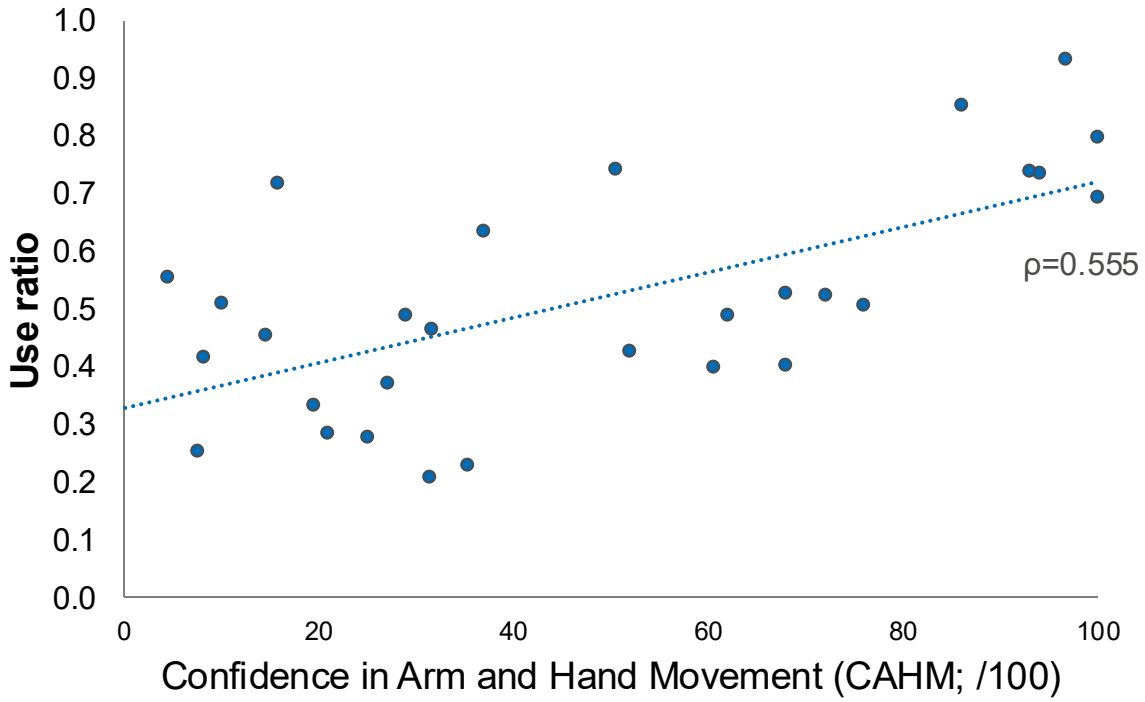
"Having to understand that [I was being monitored] kept me motivated. I am more aware of my movement. My affected side, I noticed it more so than last week."

Demers et al. *PTJ.* 2024.

What insight can we learn about real-world performance from wearable technology?

Source: AI generated image, DeepAI

Relationship between wearable sensors and clinical measures



Clinical measures	ρ	p-value
Fugl-Meyer Assessment	0.671	<0.001
Chedoke Arm and Hand Activity Inventory (CAHAI)	0.713	<0.001
REACH scale	0.597	<0.001
Motor Activity Log-Quantity	0.655	<0.001
Motor Activity Log-Quality	0.683	<0.001
Confidence in Arm and Hand Movement	0.555	0.01

Demers et al. *PTJ.* 2024.

Factors influencing stroke recovery

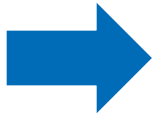
- Social interactions and self-efficacy were associated with paretic upper limb use in the daily context
- Mood was not significantly predictive of paretic upper limb movement

Chen et al., *APRM*, 2023;104: 390−402

Biomarkers for recovery

Acute stage of recovery

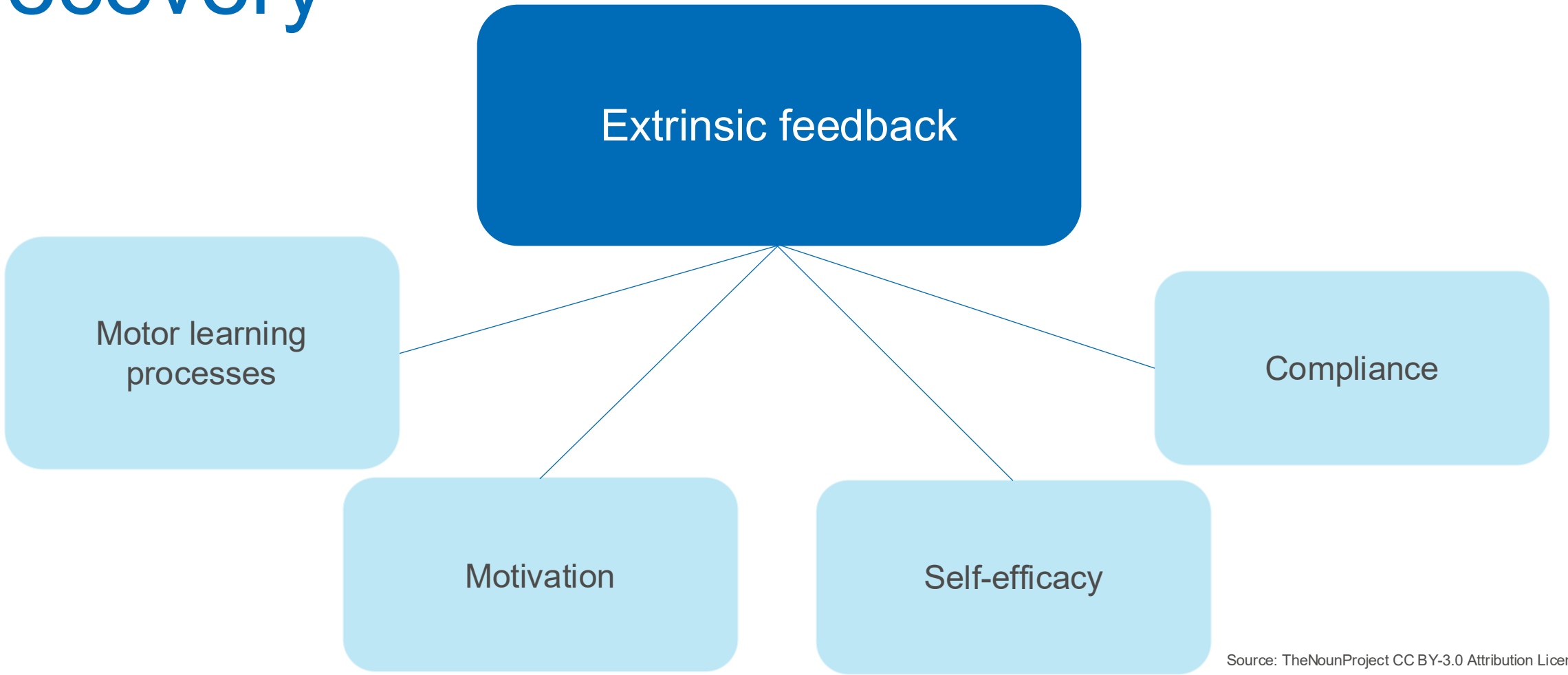
3 months post-stroke

Spontaneous upper limb use  Predictor of motor recovery

Seitz et al., *J Neurol,* 2021; 258:457–463.

Interventions using wearable technology

Role of feedback for sensorimotor recovery

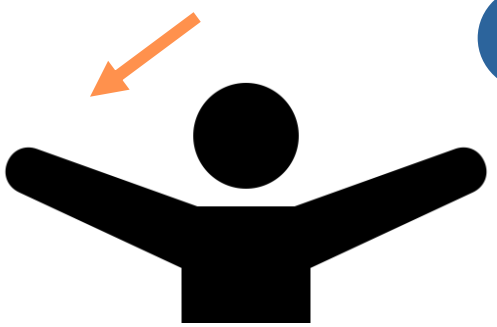


Annesi JJ. *Percept Mot Skills*. 1998 Oct 1;87(2):723–30. Subramanian et al. *Neurorehabil Neural Repair*. 2010;24(2):113–24. van Vliet et al. Disabil Rehabil. 2006;28(13–14):831–40.

Feedback from wearable technology for upper limb rehabilitation

Wang et al. *Journal NeuroEng Rehabil. 2017; 14:20*

Example of Movement Report



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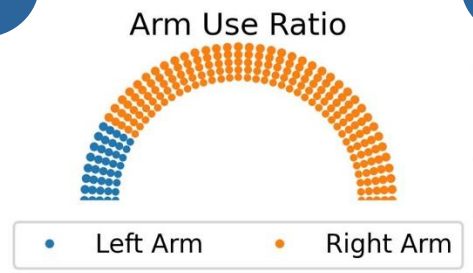

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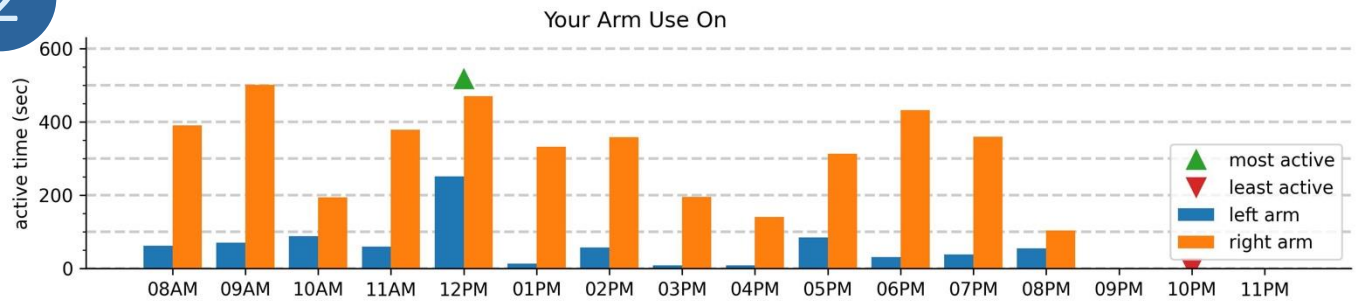

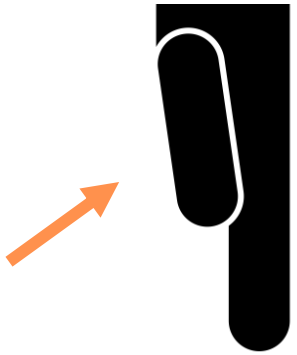

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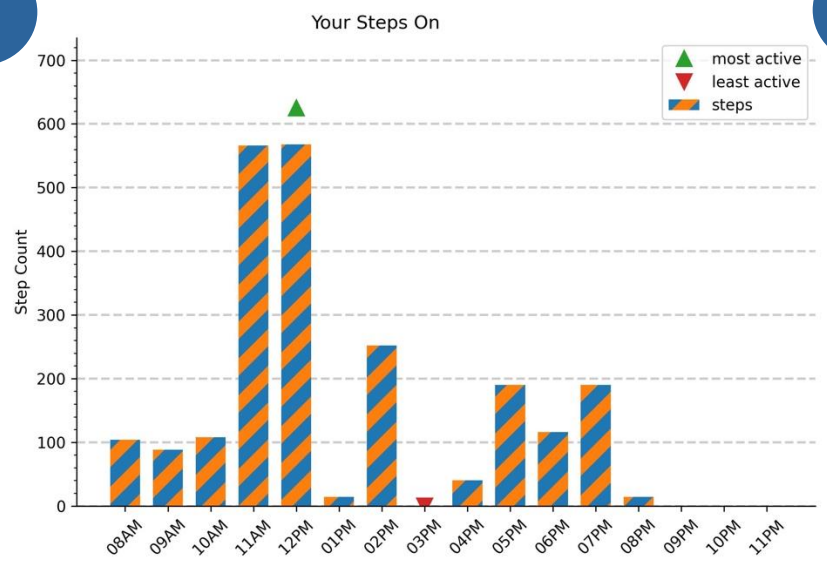

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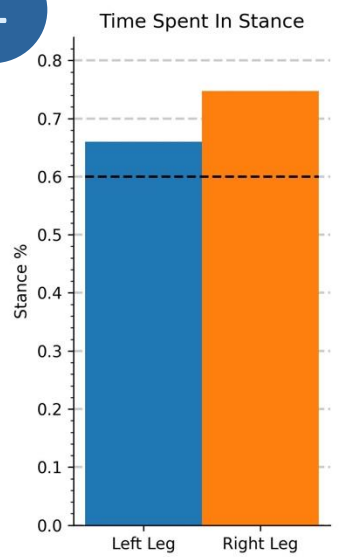
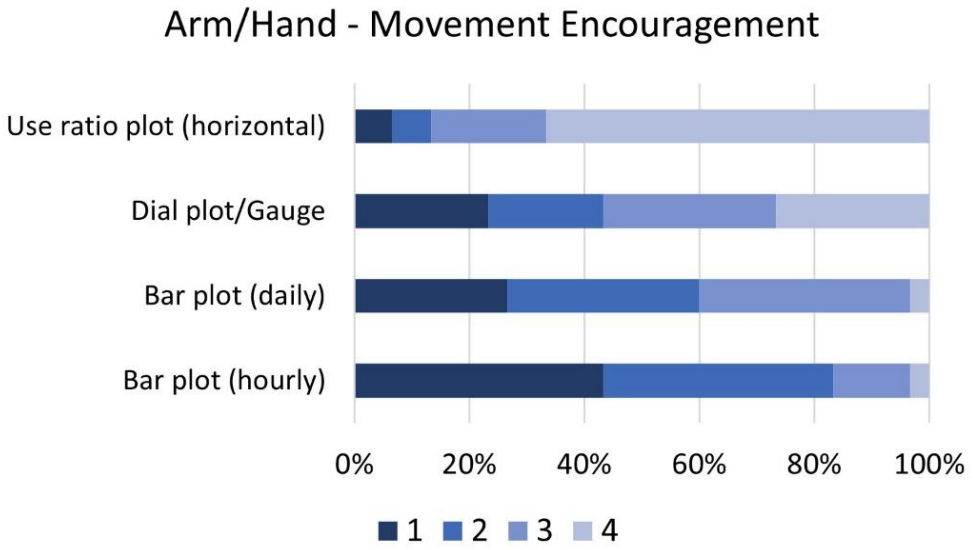
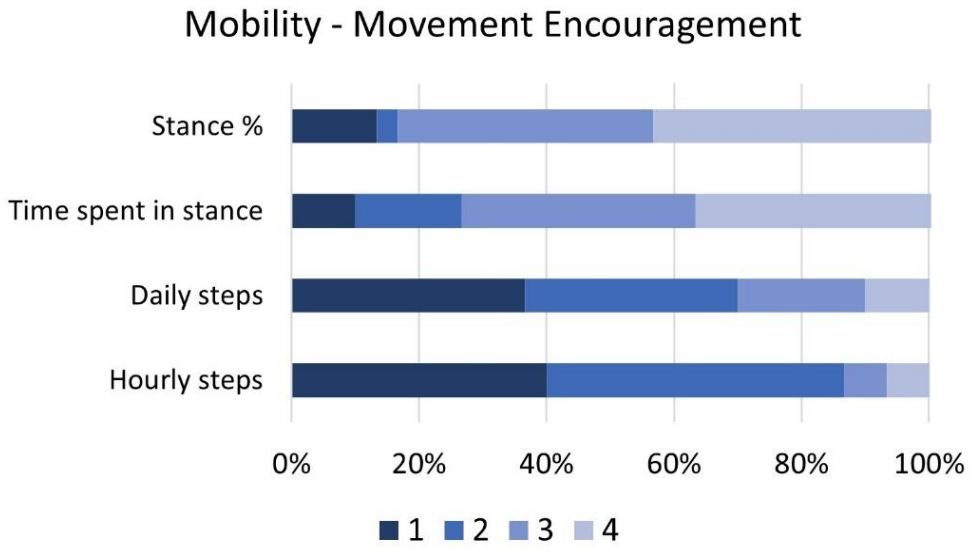


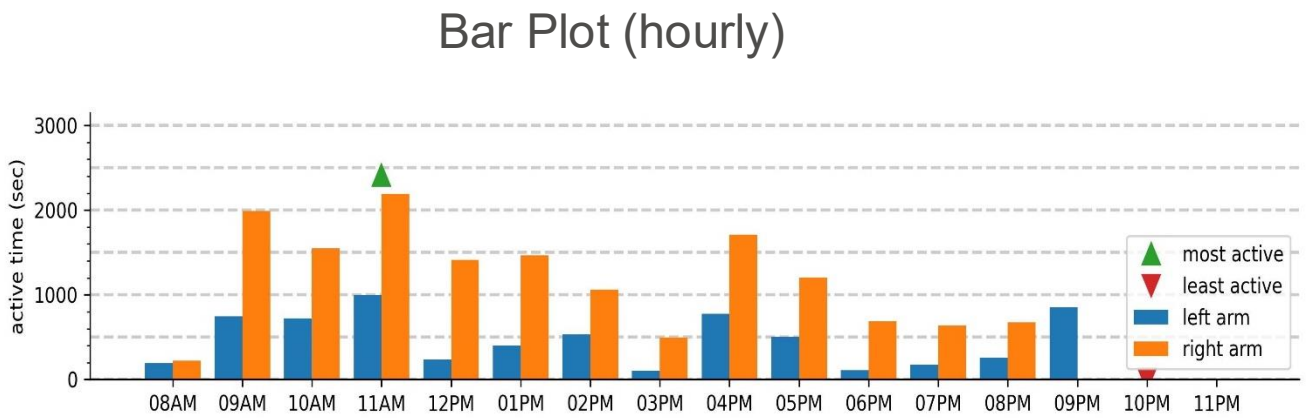
1. Use ratio for the left and right arm
2. Mean hourly time in active movement for the left and right arm
3. Hourly step counts
4. Time spent in stance for the left and right leg

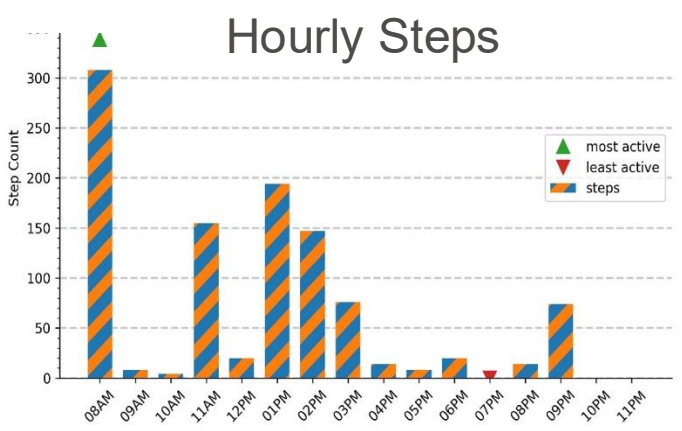
Demers et al. *J NeuroEng Rehabil.* 2023

Preferences for movement encouragement









Demers et al. *J NeuroEng Rehabil.* 2023

Results from qualitative analysis

Perceived benefits of the wearable sensors to motivate behavior change

- Caveat for those with severe motor impairments: Limited usefulness of feedback due to lack of function of paretic arm/hand

P39, Man, 61 y.o: "*Oh, the report was very helpful. These graphs and these scales help you with your movement and your motivation because it inspires me to try even more – to do better than this. […] I am impressed with myself, you know. I can't wait to share this with my family*."

P17, Man, 65 y.o.: "*I wasn't using [my paretic arm and hand] at all. After you started recording, I think I kind of -- something turned on and said, "You know what, it's time to move that hand, move the arm." […] It encouraged me to use more [my paretic arm/hand].*"

P33, Woman, 61 y.o.: "*For me, [the graphs are] not telling me anything, so my arm being what it is [...] That's hard to motivate somebody.*"

Demers et al. *J NeuroEng Rehabil.* 2023

Results from qualitative analysis

- Need for real-time feedback based on individual goals
- Value of experienced clinicians for prescription and accountability

P22, Woman, 66 y.o.: "*If we're using the sensors, and I would assume maybe you're using [personalized feedback] in conjunction with your PT to set up this week's goal.*"

P35, Woman, 78 y.o.: "*Because of who I am, I like to do well. I like to be obedient to what the professionals are [saying].*"

P06, Transman, 53 y.o.: "*I would like to meet with a therapist to review overall what just I'm doing, what I'm doing. Because I like encouragement.*"

Demers et al. *J NeuroEng Rehabil.* 2023

Perspectives of clinicians

1. Usefulness and clinical relevance of sensor-derived data
2. Importance of personalization
3. Therapeutic value of real-time feedback

Recommendations:
Mobile app for clinicians (remote monitoring)
Customization features

Perron, Asli et al. (in preparation)

Perspective of experts

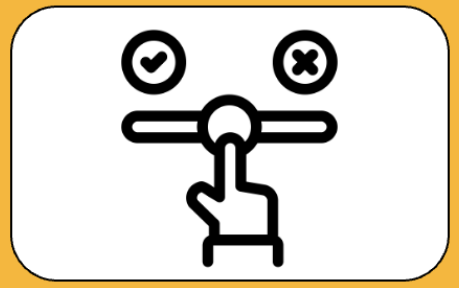
Theme 1

Activity performance is critical to understand patient behavior

Wearable technology:
- Offers relevant data
- Is useful to inform care
- Complements traditional outcome measures

Theme 2

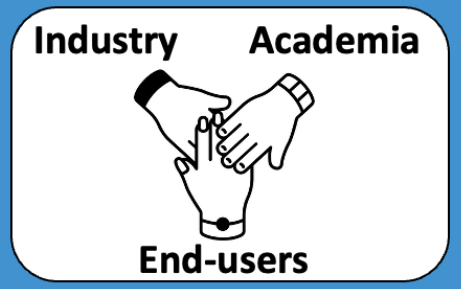
Benefits < Added hassle



- Clinical workflow
- Device usability
- Technological maturity
- Medical record integration
- Data storage
- Privacy

Theme 3

Call for action for enhanced collaboration



- Relationship between industry and academia
- Interdisciplinary collaboration for development, adoption and maintenance
- Training and education

USC Division of Biokinesiology and Physical Therapy

Cain et al., *Disabil Rehabil Assist Dev*, 2025 (in press)

Which wearable technology should I use?

Clinical considerations

Behaviour to be monitored

Upper limb
Gait & mobility
Physical activity
Sleep, heart rate, etc.

Measurement properties

Valid for people with stroke
Accurate for severe motor impairments
Responsive
Reliable

Clinical purpose & feedback

Customizable?
Remote monitoring possible?

Usability

Ease of use for people with stroke
Cost

Gait and mobility

Smartphone apps

- Pacer
  - iOS: Good*
  - Android: Mod*
- GoogleFit
  - Mod-good*
- X Sensor Pro
  - Good*

VS

Smartwatches (Good accuracy)

- ActiGraph GT3X*✤
- ActiPAL
- Actical
- FitBit One* (for >0.8m/s)
- FitBit ULTRA*✤
- FitBit ZIP✤ (for >0.5m/s)
- Garmin VivoFit✤ (for >0.8m/s)
- ONStep 400 Pedometer
- SmartShoe*
- StepWatch Activity Monitor*✤
- XSens MTx sensors

*Validity in stroke survivors, ✤ Reliability

Upper limb

Smartphone apps

VS

Smartwatches

- Actical: Mod*
- Crossbow MO2: Good✤ Mod*
- ActiGraph: Good ✤*
- Actiwatch AW7: Mod*
- Micro mini motion logger activity monitor: Mod*

*Validity in stroke survivors, ✤ Reliability

Summary

- Activity performance is essential to understand stroke survivors' behaviour
- Importance of a close collaboration between key stakeholders, academia and industry
- Sensor-derived metrics offer intuitive and actionable feedback to stroke survivors

  Need to:
  - Be consistent with personalized goals
  - Be used in conjunction with therapy
  - Be integrated in clinical workflow

Future research directions

- Factors contributing to the disparity between motor capacity and performance for activity
- Interventions leveraging wearable technology grounded in strong theoretical foundations
- Development of wearable technology meeting benchmarks for clinical implementation
- Education and integration in healthcare professional's curriculum

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Camila Torriani-Pasin
Joseph Saba
Eric Wade
Carolee Winstein
Daniel Zondervan

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Questions

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