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FHS MSK-IF

Co-Design of Wearable Devices

BUILDING IMPACTFUL MSK HEALTH RESEARCH:
KNOWLEDGE MOBILIZATION SUMMER SCHOOL

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About MSK-IF

A research incubator in Western's Faculty of Health Sciences that brings researchers, clinicians, and patients together to co-develop and test innovative solutions for musculoskeletal (MSK) conditions

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What are wearable devices?

Body-worn devices with sensors that track data during daily life **ranging from consumer gadgets to purpose-built clinical tools.**

Consumer & commercial

Smartwatches, fitness trackers, smart rings — general wellness for everyone.

Clinical & research

Purpose-built for a specific project or study

Over the past decade, wearables have gone mainstream and become one of the most popular ways to monitor health outside the clinic

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The clinical data gap

A lot of recovery happens *outside* the clinic — at home, over days and weeks, between appointments.

A clinician sees a patient for a short visit every few weeks. What happens in between is largely unseen, and often filled in by self-report.

Wearable devices can help answer many questions stemming from this gap.

Example 1: Adherence

Is the patient actually using their prescribed device?

Example 2: Movement

How is the patient moving at home, not in a clinical environment?

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Why the gap matters

Wrong assumptions change treatment plans

If you believe a patient is wearing their splint and they aren't, you might escalate to surgery or a different treatment when the real fix is addressing why they stopped wearing it.

Hidden compensation goes unseen

A patient may report good shoulder function while compensating with trunk rotation at home, a pattern that can lead to secondary problems you didn't observe in clinic.

Research conclusions get muddied

Poor data makes treatment efficacy hard to evaluate, and single-time-point measures can miss the real-world variability that matters most to patients.

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What is co-design?

Designing a device together with the people who'll use it — clinicians, patients, and engineers — involved throughout, from defining the problem to testing in the real world.

WHAT EACH PERSPECTIVE BRINGS

Clinicians

What question actually needs answering, what data would change a decision, and how it fits real clinical workflows.

Patients

What's comfortable to wear, what feels acceptable day to day, and what they'll realistically keep using at home.

Engineers

What's technically possible, what each design choice costs, and how to turn the shared goal into a working device.

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Common design requirements & specifications

What to sense

What sensing is needed to answer the question? More sensors mean more size, power, and complexity.

Sampling & duration

How often to read, and for how long? Resolution trades directly against battery life.

Form factor & placement

What footprint will patients accept while having a good sensor placement?

Store vs. Stream

Streaming can give flexibility in storage but costs more power and adds failure points.

Raw vs. processed

Keep raw data for flexibility, or process onboard for simple outputs?

Portability & battery life

Why prioritize this?

If the device is bulky or obvious, patients stop wearing it. For long, everyday wear, small and forgettable wins.

Example: *A splint worn under a sleeve, all day, for weeks at a time.*

Design decisions

BATTERY	Small & thin (e.g. Coin cell battery)
SAMPLING	Low frequency
CONNECTIVITY	None; download at the clinic
SENSORS	Low-power sensors

Result: Coin-sized, multi-week life, simple data.

Trade-off: no real-time feedback, low resolution data.

Rich, detailed data

Why prioritize this?

Some questions need data with fine detail to answer.

Example: *Tracking shoulder motion through daily activities after surgery.*

Design decisions

BATTERY	Rechargeable LiPo
SAMPLING	Fast (e.g., ~50 Hz kinematics)
CONNECTIVITY	Bluetooth for periodic sync
SENSORS	Multiple motion sensors

Result: Larger device, detailed kinematics.

Trade-off: shorter battery life, patient setup.

Real-time monitoring

Why prioritize this?

The value is in instant detection, knowing the change in state as soon as it occurs.

Example: *Collect data at a higher frequency when user is active*

Design decisions

BATTERY	Large battery
SAMPLING	Moderate, event-triggered bursts
CONNECTIVITY	Bluetooth or WiFi
SENSORS	Multiple sensors

Result: Larger device, responsive algorithms.

Trade-off: more failure points & patient setup.

How are design choices made?

Whether portability beats data richness, or real-time monitoring justify the added burden, they need the whole team to answer.

Clinician

Knows what data is useful for a clinical decision.

Patient

Knows what they'll realistically tolerate wearing.

Engineer

Knows what's technically feasible and what each choice costs.

Different stakeholders can have varying responses to the same question

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CASE STUDY

Upper limb splint Adherence monitoring

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All in.

Background

The clinical setting

Wrist and hand splints are a common treatment in upper-limb rehabilitation, to let fractures and other soft tissues to heal and decrease pain and inflammation.

Currently, splint wearing is tracked mostly through self-report and diaries, which are easy to misremember and tend to overstate real use. Clinicians are left making treatment decisions without a reliable picture of what actually happened between visits.

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Define the objective

The goal: reliably tell whether a splint is being worn, across weeks of ordinary daily life, without relying on the patient to report it.

Runs for weeks

The data collection needs to last until next monthly clinical visit.

Small and unobtrusive

It has to be embeddable into the splint, or patients stop wearing it.

Simple, targeted sensing

We are looking to answer a yes/no question: "*Was the splint worn during this time?*"

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First iteration: temperature-based detection

Given the specifications, temperature is the intuitive signal to collect.

Simple detection condition

Skin **(~30–34°C)** is warmer than a room **(~20–22°C)**. Warm = worn, cool = not worn.

Why it fit the design choices

- One low-power sensor: easy on the battery
- Tiny data footprint: one number per reading
- Kept the device small and simple

In early testing, this version worked.

- The temperature signal increased & decreased as expected.
- Clean, simple, and cheap on power and storage.

First iteration: stress testing & failure analysis

Once we pushed past short tests into longer, more realistic use, temperature alone turned out to have the following drawbacks.

Slow to time events

It can take several minutes to warm up or cool down. Short wear sessions blurred together or were missed entirely.

Affected by the environment

A warm room, a heating vent, or a sunny windowsill produced false readings.

The fix: add a second signal

A proximity sensor was added for reading, which measures the distance between the sensor and an object. When the user wears the splint, the sensor will measure this distance to be 0.

Proximity

Distance is a non-lagging variable; when there is a change in value, that is when an event occurred.

Temperature

Confirms the contact is a warm body, not a random object.

The trade-off

What it cost

More power draw

Shorter battery life (6 weeks to 5 weeks).

More data to store

Larger files resulting from storing additional values.

What it bought

Improvement in accuracy

Margin of error from ±10 min to ±5 min

Robust to false positives

Both signals must meet their condition before wear is registered

This trade-off was a shared decision as part of the co-design process, agreed by the whole team

Co-design Iteration

Design iterations (earliest → latest)

Design 1

Battery holder integrated
into case to minimize
thickness.
Temperature only.

Design 2

Separate space for battery
holder (safer circuitry).
Screw tabs for mounting
to splint. Temperature only.

Design 3

Adds plexiglass window
for proximity sensor.
Puck / screw-lid style
clamps window tight to sensor.

Design 4

Reshaped to shrink contact
area, but did not apply
enough pressure or narrow
the surface enough.

Design 5 (latest)

Components stacked (not
side-by-side): narrow contact
area, window held to sensor.
Taller but smaller footprint.

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Designed wearable overview

Microcontroller + coin-cell battery

About the size of a stick of gum, powered by a coin cell battery

Two sensors

One for proximity (physical contact), one for temperature (body heat).

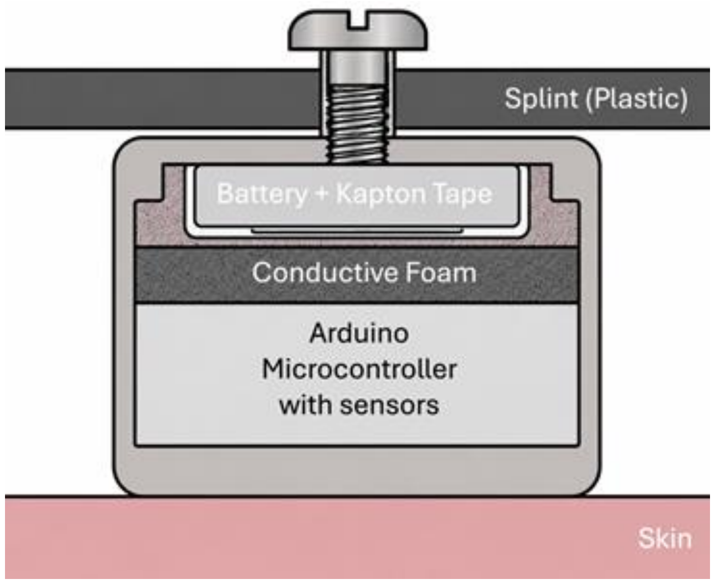
Records for weeks

A reading every few minutes, data stored onboard, running at low power mode.

Unobtrusive to the patient

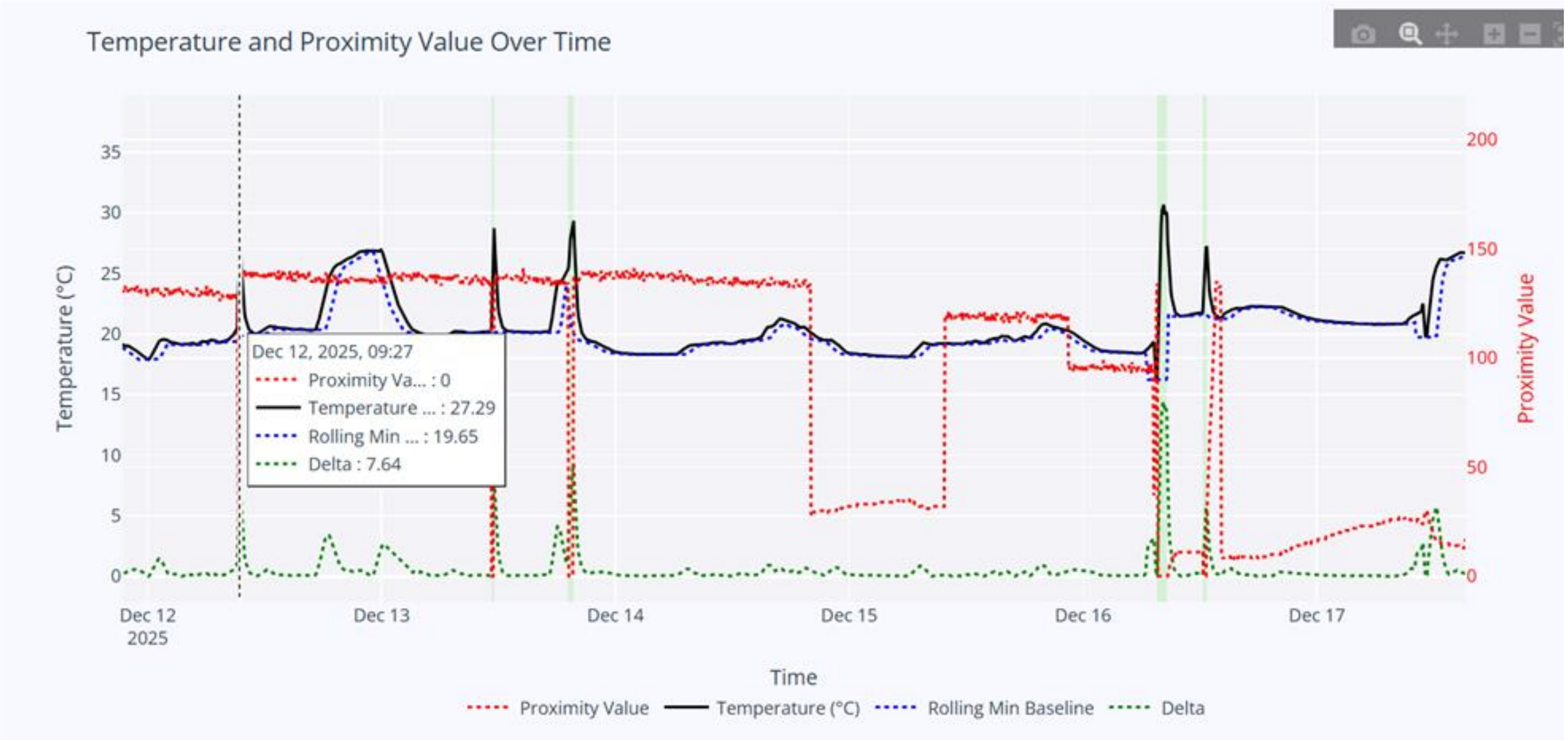
Patients can just wear the splint as prescribed.

How it layers against the skin



Reading the signals together

When a temperature rise lines up with a proximity drop, the splint is worn; when the temperature drops with proximity rising, the splint is off.



**Above graph is generated from a test dataset*

What objective data could enable

Possibilities that open up when you can close the gap between clinic and daily life.

Link adherence to outcomes

A quantifiable way to understand the relationship between splint wear and patient recovery.

Personalize rehabilitation

The prescription can adapt based on the observed data and the patient's recovery trajectory.

Key takeaways from case study

01 Design starts with the clinical question

The objective drove every hardware and sensing decision that followed.

02 Real-world testing reveals what the lab can't

Temperature alone looked fine in short tests; only extended, realistic use exposed its drift and false positives.

03 The best designs are made together

Clinicians frame the question, patients define what is usable in daily living, engineers weigh what is feasible.

LET'S DISCUSS

A patient is prescribed a knee brace after ACL surgery. What one thing would you most want to measure at home? What would be the design requirements?

Thank you!

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