Smartphones and wearables for clinical care and research (and where we need statisticians)

Will Dixon

Professor of Digital Epidemiology & Honorary Consultant Rheumatologist

The University of Manchester & Salford Royal Hospital

QuanTIM webinar

Fri 20Mar2026

Outline

- My background and interests
- Opportunities from smartphones and wearables
- Case studies, with focus on analysis challenges
  - Remote Monitoring of Rheumatoid Arthritis — RA
  - Cloudy with a Chance of Pain — Chronic pain
  - PAPrKA — Knee Replacement

Rheumatologist & Epidemiologist

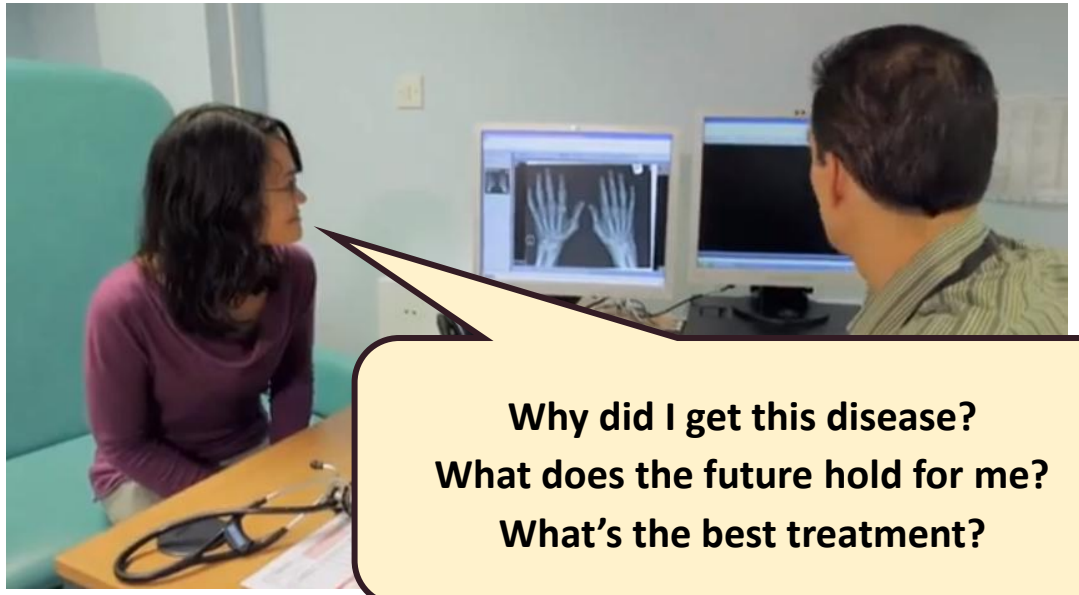
Salford Royal NHS
NHS Foundation Trust

MANCHESTER 1824
The University of Manchester

CENTRE FOR EPIDEMIOLOGY VERSUS ARTHRITIS

Rheumatologist & Epidemiologist

Questions important to patients and carers



Why did I get this disease?
What does the future hold for me?
What's the best treatment?

Answers from population health research

Salford Royal NHS
NHS Foundation Trust

MANCHESTER 1824
The University of Manchester

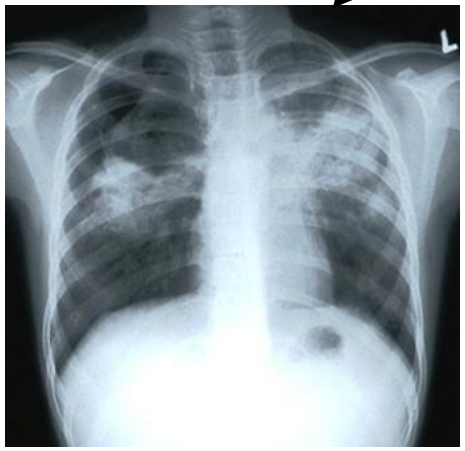
CENTRE FOR EPIDEMIOLOGY VERSUS ARTHRITIS

Rheumatologist since 2002

Rheumatoid arthritis

Anti-TNF therapy

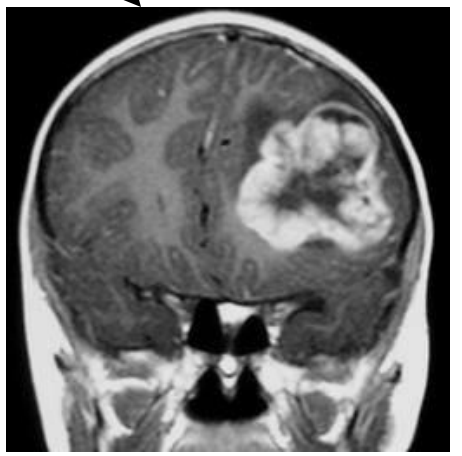
2000



Infection

?

Malignancy



Pharmacoepidemiology

Disease severity

Confounder

Exposure → **Outcome**

Medication

Side effect

Pharmacoepidemiology

Disease severity

Confounder

Exposure → **Outcome**

Medication

Side effect

Disease severity

Confounder

Exposure → **Outcome**

Medication

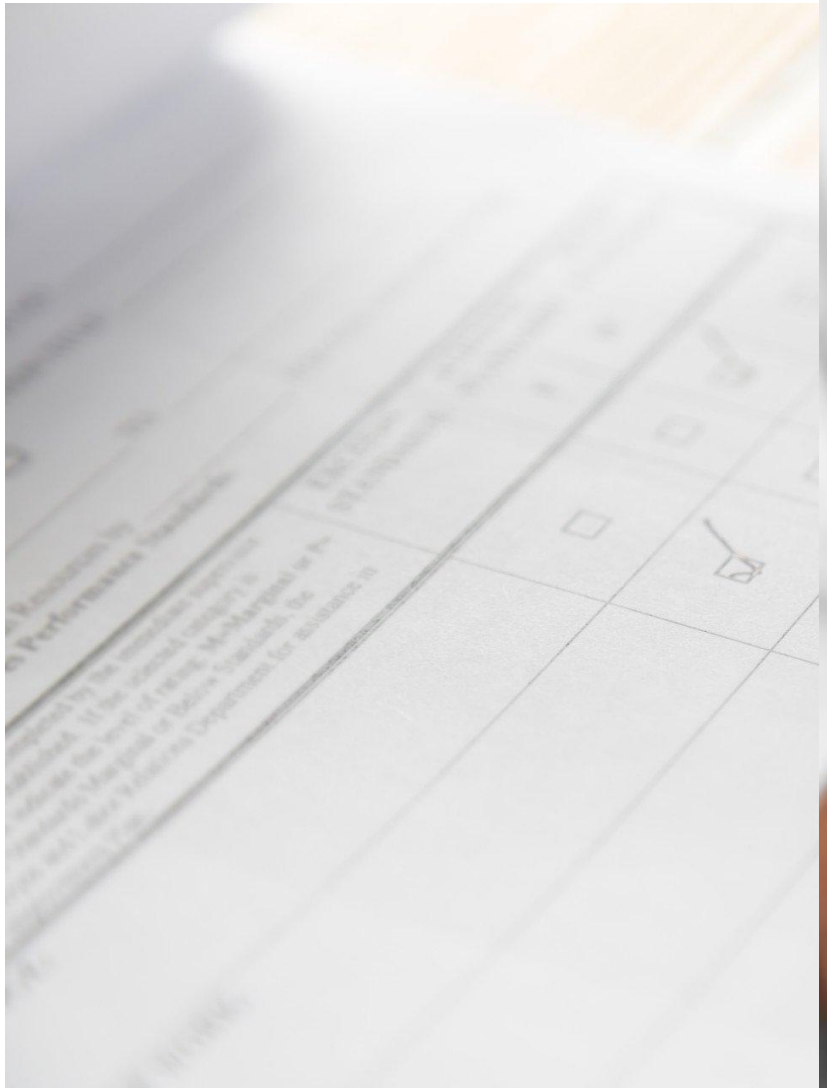
Side effect

Patient- (or Person-)Generated Health Data

*"Health-related **data recorded, collected or generated from a patient** or a patient's designees, **outside of a clinical setting** without the interaction or interference from a clinician or a member of the patient's medical team"*

The Office of the National Coordinator for Health Information Technology (ONC)

20th Century

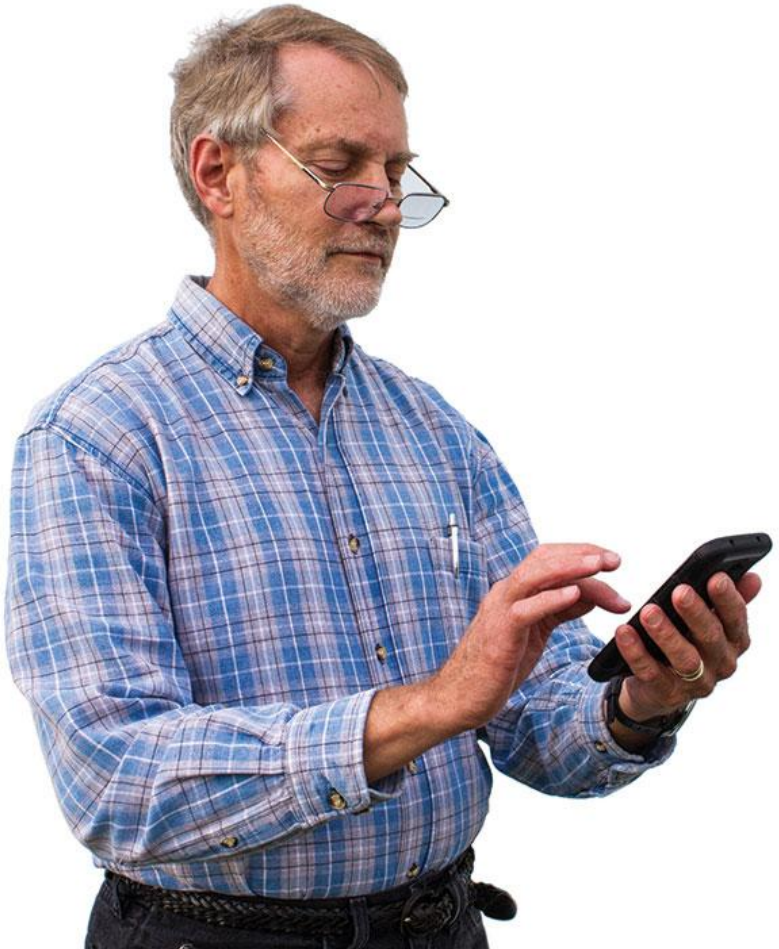


20th Century

21st Century

Clinical care

Self-management

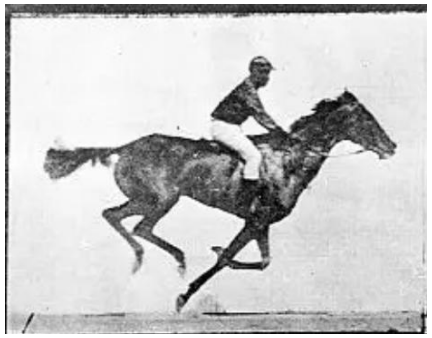


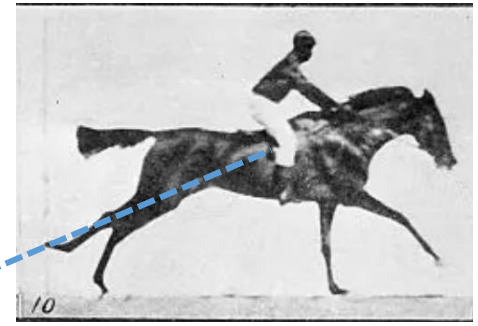
Population health research

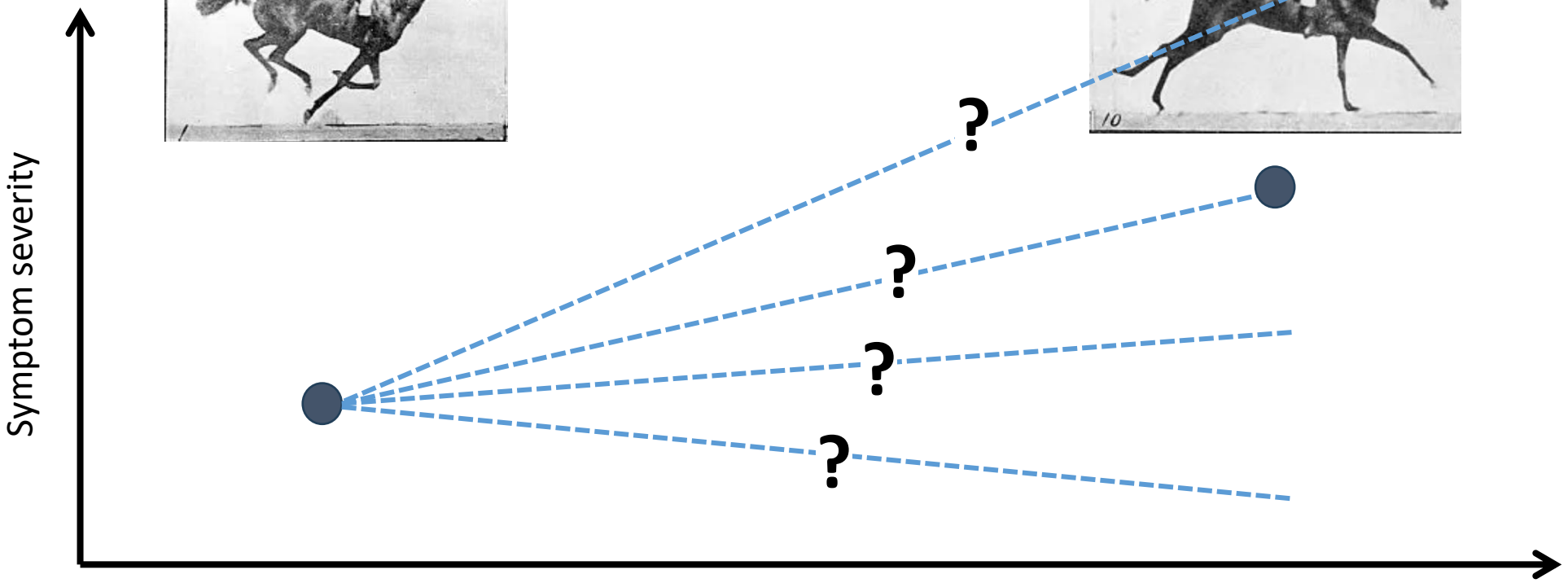
1. Novel data collection

- **Touch screen**
  - Questionnaires
  - Smartphone interactions
- **Accelerometer + gyroscope**
  - Physical activity
- **Camera**
  - Heart rate, respiratory rate
  - Video selfies
- **Microphone**
  - Voice commands
  - Cough, snore, tremor
- **GPS**
  - Geolocation

2. Frequent measurement



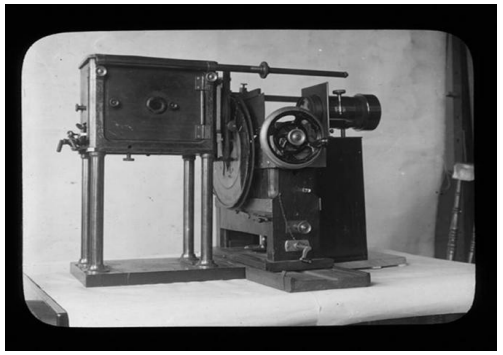


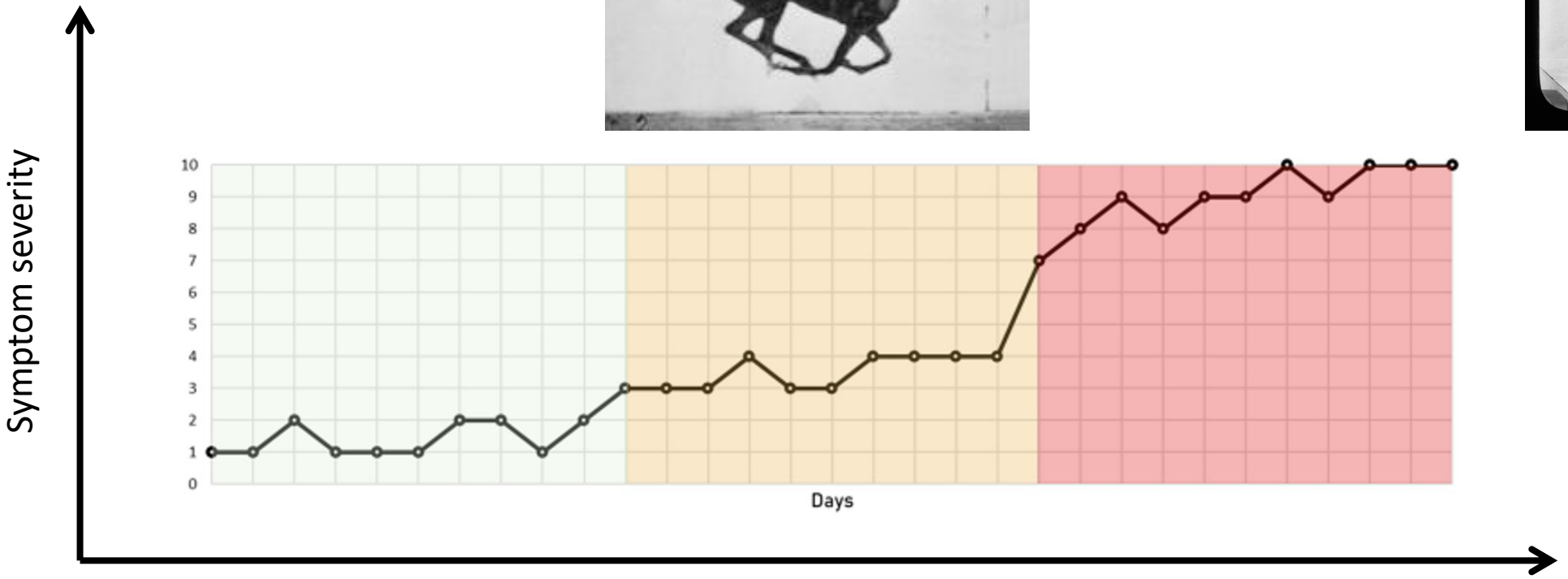


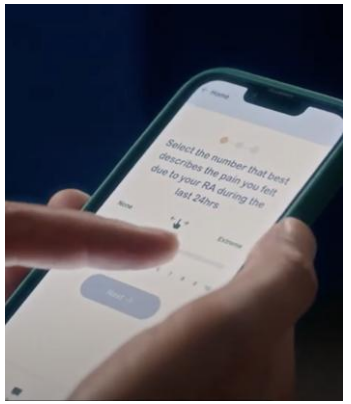
2. Frequent measurement

With technology

Eadweard Muybridge







Baseline visit

Six month follow-up visit

3. Widespread use

- **Clearer picture of disease**
  for better shared decision making
- **Right care at the right time**
  for better and earlier treatment

- Descriptive
- Aetiological
- Predictive

Clinical care

- **Improved understanding of disease,**
  including triggers
- **Timely support and coaching**
  including digital interventions

Advancing understanding of:
- Disease progression and how to measure it
- Causes and consequences of disease
- Early detection and prediction

Development & testing of digital interventions

Self-management

Population health research

Outline

- Descriptive
- Aetiological
- Predictive

- My background and interests

- Opportunities from smartphones and wearables

- Case studies, with focus on **analysis challenges**
  - Remote Monitoring of Rheumatoid Arthritis — RA
  - Cloudy with a Chance of Pain — Chronic pain
  - PAPrKA — Knee Replacement

2008: End of PhD

Licensed 2001

Licensed 1954


“At your age, the chances of side effects are low.
“Okaaay….
but just how high is the risk of diabetes*?”
*substitute with favourite steroid side effect

EXTENDED REPORT

EULAR evidence-based recommendations on the management of systemic glucocorticoid therapy in rheumatic diseases

J N Hoes, J W G Jacobs, M Boers, D Boumpas, F Buttgereit, N Caeyers, E H Choy, M Cutolo, J A P Da Silva, G Esselens, L Guillevin, I Hafstrom, J R Kirwan, J Rovensky, A Russell, K G Saag, B Svensson, R Westhovens, H Zeidler, J W J Bijlsma

Ann Rheum Dis 2007;**66**:1560–1567. doi: 10.1136/ard.2007.072157

Recommendation 1:

The adverse effects of glucocorticoid therapy should be considered and discussed with the patient before glucocorticoid therapy is started

2009-2010

MRC Medical Research Council Clinician Scientist Award

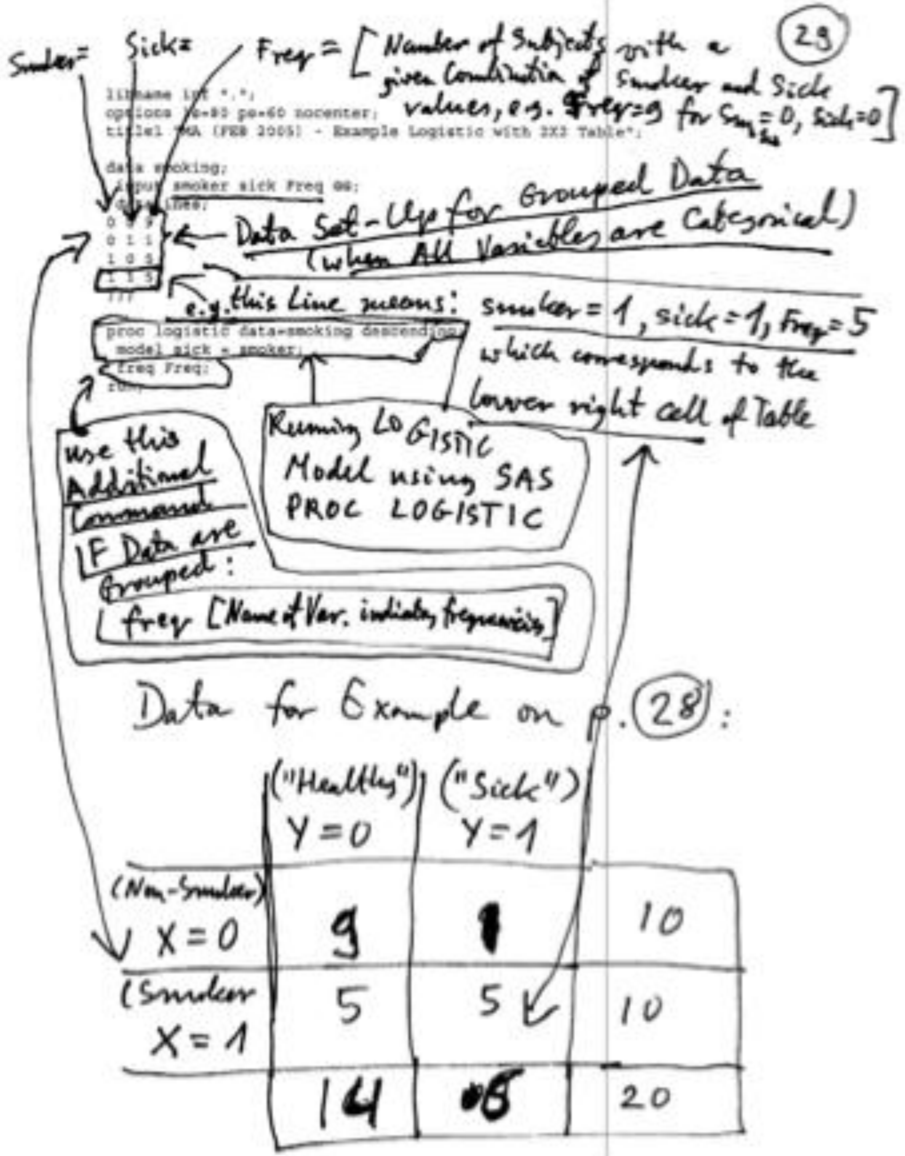
The safety of glucocorticoid therapy in patients with inflammatory musculoskeletal conditions

− Fall 2013

Timetable [.pdf]

- + EPIB 507 Biostatistics for Health Professionals
- + EPIB 525 Health Care Systems in Comparative Perspective
- + EPIB 527 Economics for Health Services Research and Policy - Not offered in 2013/2014
- + EPIB 528 Economic Evaluation of Health Programmes - Not offered in 2013/2014
- + EPIB 591 Regression Analysis for Health Professionals
- + EPIB 601 Fundamentals of Epidemiology
- + EPIB 602 Foundations of Population Health
- + EPIB 604 Epidemiologic Analysis
- + EPIB 607 Inferential Statistics
- + EPIB 609 Seminar on Advanced Methods in Epidemiology - Not offered in 2013/2014
- + EPIB 613 Introduction to Statistical Software - Not offered in 2013/2014
- + EPIB 623 Research Design in Health Sciences
- + EPIB 624 Public Health Ethics and Policy
- + EPIB 628 Measurement in Epidemiology
- + EPIB 630 Public Health Project
- + EPIB 641 Principles in Study Design
- + EPIB 648 Methods in Social Epidemiology
- + EPIB 676 Advanced Modeling of Survival and Other Multivariable Data
- + EPIB 677 Knowledge Synthesis - NEW COURSE
- + EPIB 682 Introduction to Bayesian Analysis in Health Sciences - NEW COURSE


Michal Abrahamowicz


29
Freq = [Number of Subjects with a given Combination of Smoker and Sick values, e.g. Freq=9 for Smoker=0, Sick=0]
data smoking;
input smoker sick Freq @@;
Data Set-Up for Grouped Data (when All Variables are Categorical)
e.g. this Line means: smoker = 1, sick = 1, Freq = 5 which corresponds to the lower right cell of Table
proc logistic data=smoking descending;
model sick = smoker;
freq Freq;
Running LOGISTIC Model using SAS PROC LOGISTIC
use this Additional Command IF Data are Grouped:
freq [Name of Var. indicating frequencies]
Data for Example on p. 28:
("Healthy") Y=0
("Sick") Y=1
(Non-Smoker) X=0
(Smoker) X=1
9
1
10
5
5
10
14
6
20

Weighted Cumulative Exposure (WCE)

We propose:

Recency-Weighted Cumulative Exposure (WCE) model, where the Cumulative Effect of Exposure History is modeled as a Weighted Sum (**) of all Past Doses, (**) with Weights representing the Relative Importance of Doses (Exposures) as a function of the Time Elapsed since the Exposure

$$WCE(u) = \sum_{t \le u} w(u-t) * X(t) \quad (1)$$

where:

u = current time (when Risk is being assessed)

$WCE(u)$= Weighted Cumulative Effect of the Past Doses on Risk at time u

$X(t)$ = Dose at time t ($t \le u$)

$u-t$ = Time elapsed since Dose $X(t)$ was received

$w(u-t)$ = Weight (Relative Importance) assigned to Dose $X(t)$ as a function of Time Elapsed ($u-t$)

Abrahamowicz et al. (2006), Breslow et al. (1983), Hauptmann et al. (2000), Thomas (1988), Vacek (1997)

McGill


"Around 14 people in every 1000 with RA get diabetes per year. If all 1000 took 30mg for one month, there would be an additional 26 cases of diabetes"
"Okaaay....
but just how high is the risk of diabetes*?"
*substitute with favourite steroid side effect

Outline

- My background and motivation for mobile
- Opportunities from smartphones and wearables
- Case studies, with focus on analysis challenges
  - **Remote Monitoring of Rheumatoid Arthritis** **RA**
  - Cloudy with a Chance of Pain Chronic pain
  - PAPrKA Knee Replacement


“How have you been in the last six months?”


Rooms 1 - 11
Rooms 12 - 24
Waiting Area B
Waiting Area C

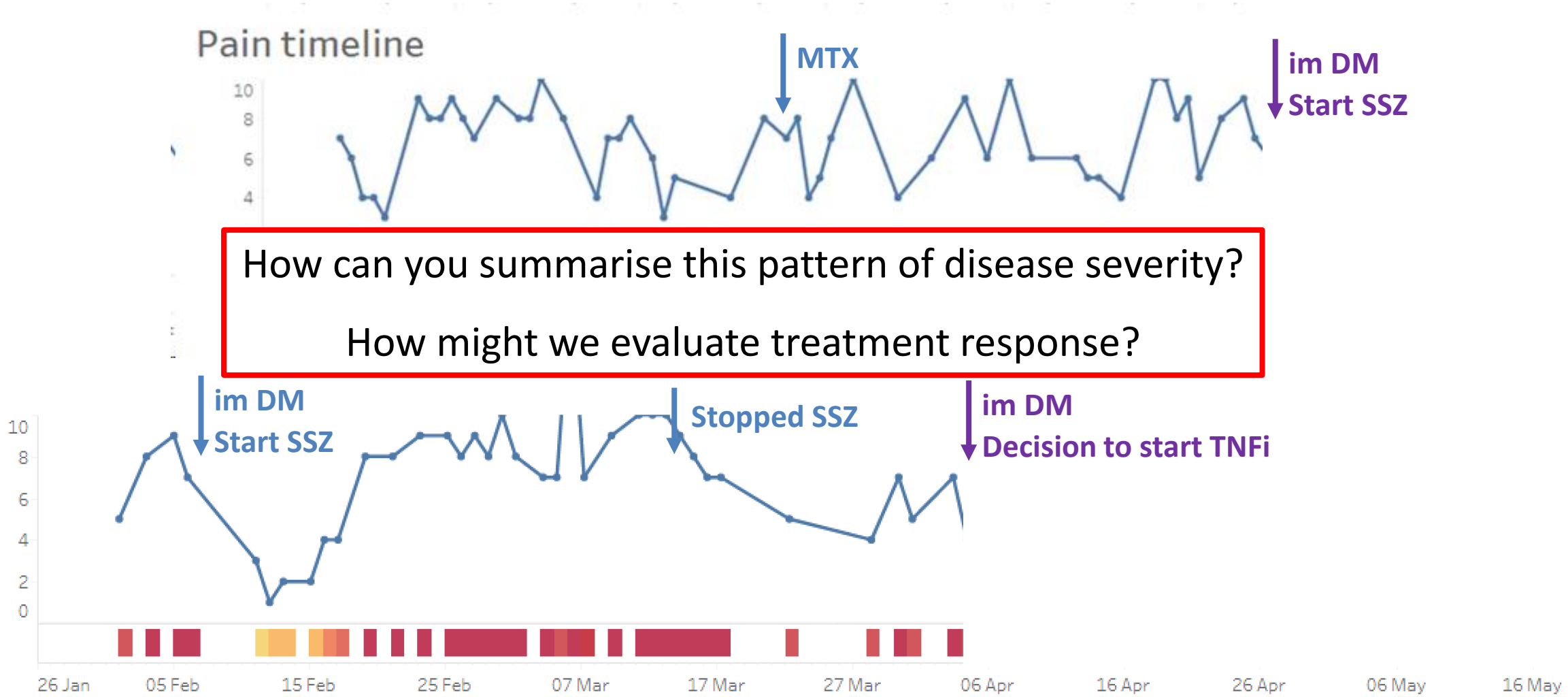
Analysis challenges

- Descriptive
  - Can we summarise a patient's time series data and treatment response?
  - Summarising treatment response across a population

- Predictive
  - Predicting treatment response for early interventions

Male, 30-39

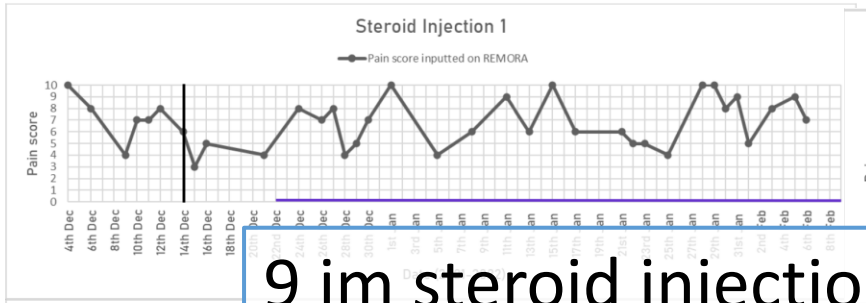
- First symptoms Summer 21
- November: mild synovitis on examination. Joined REMORA. To start methotrexate

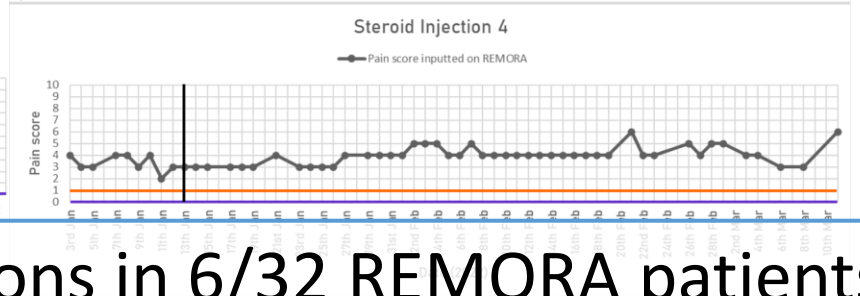


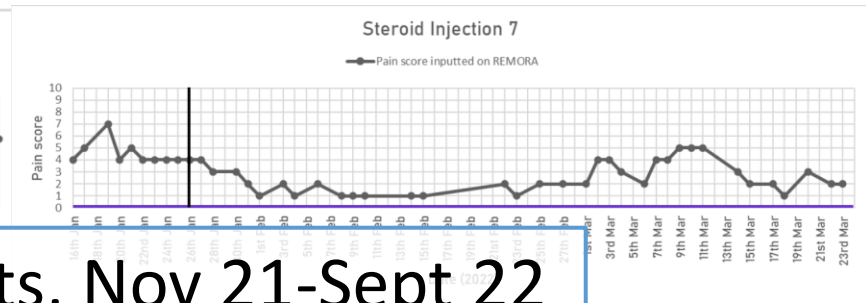
Evaluating treatment response

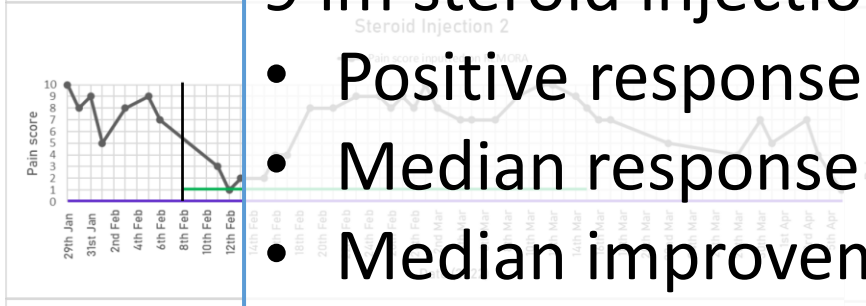
Intramuscular steroids

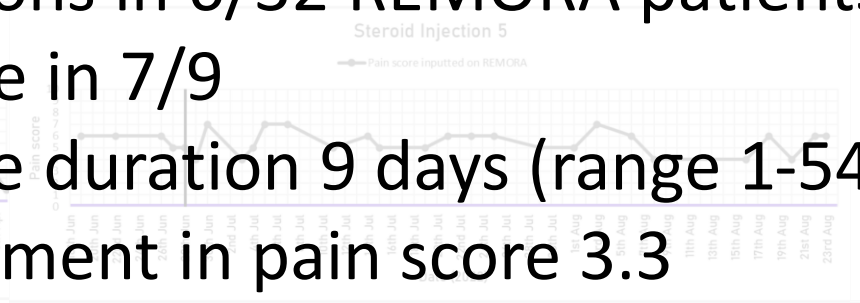
- **Descriptive**
- Aetiological
- Predictive





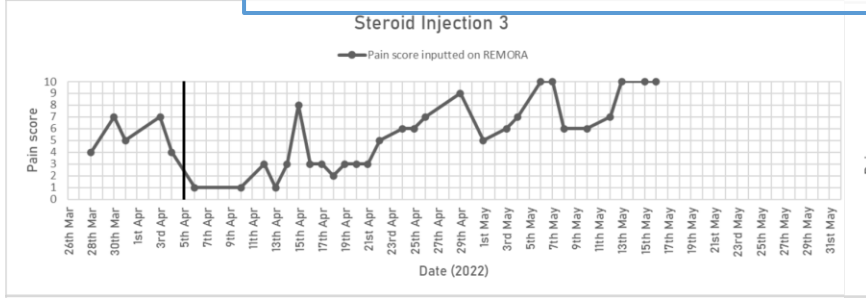


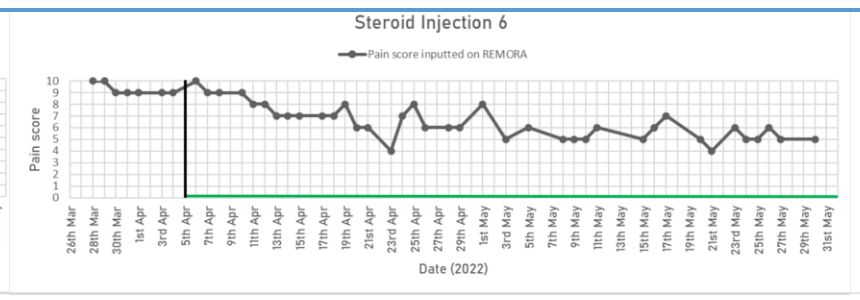


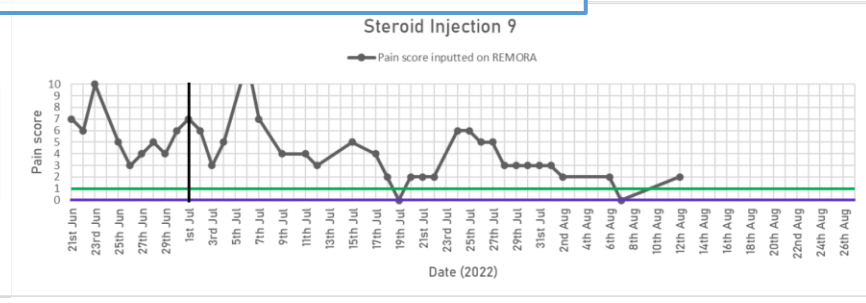


9 im steroid injections in 6/32 REMORA patients, Nov 21-Sept 22

- Positive response in 7/9
- Median response duration 9 days (range 1-54)
- Median improvement in pain score 3.3



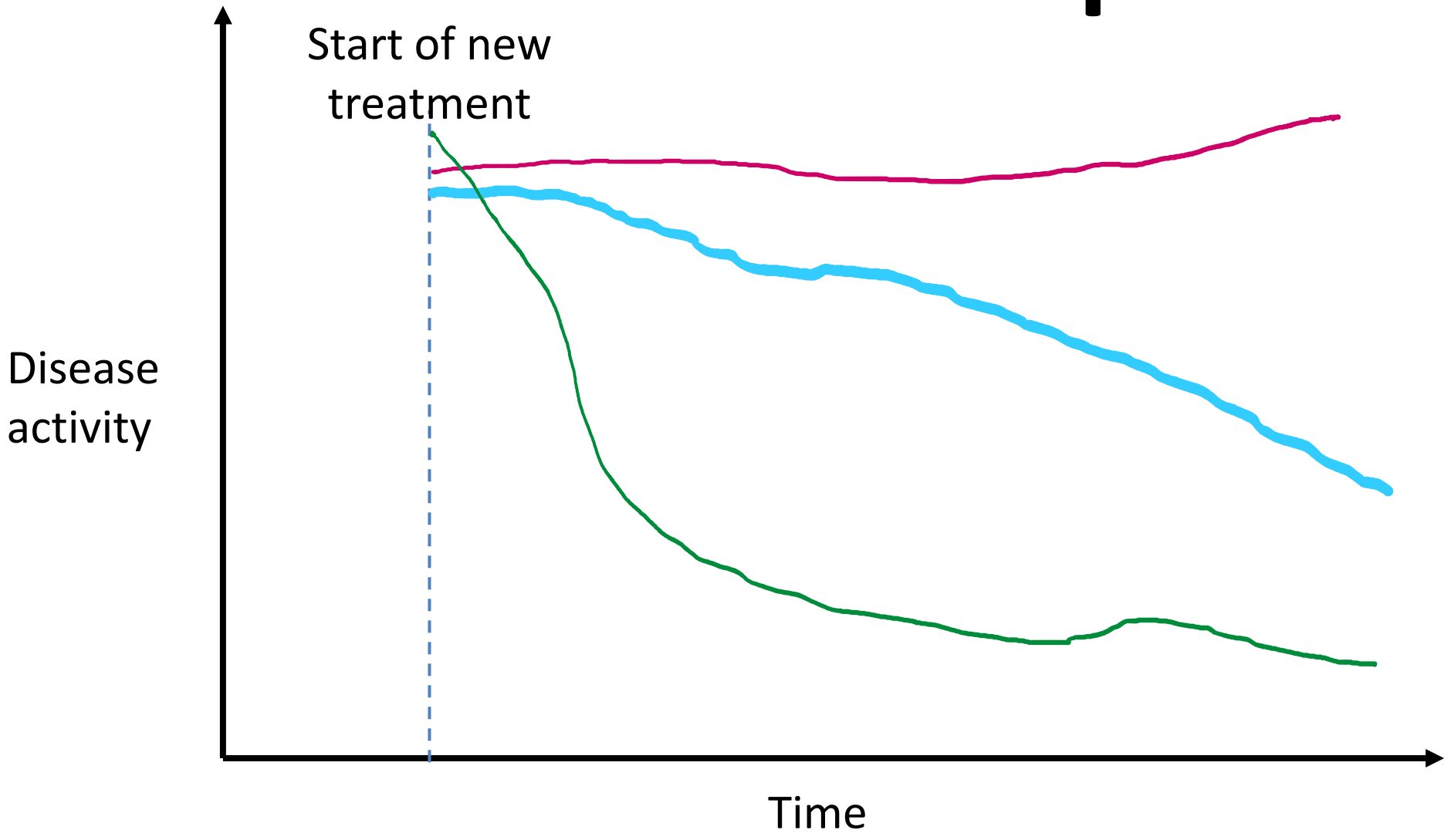




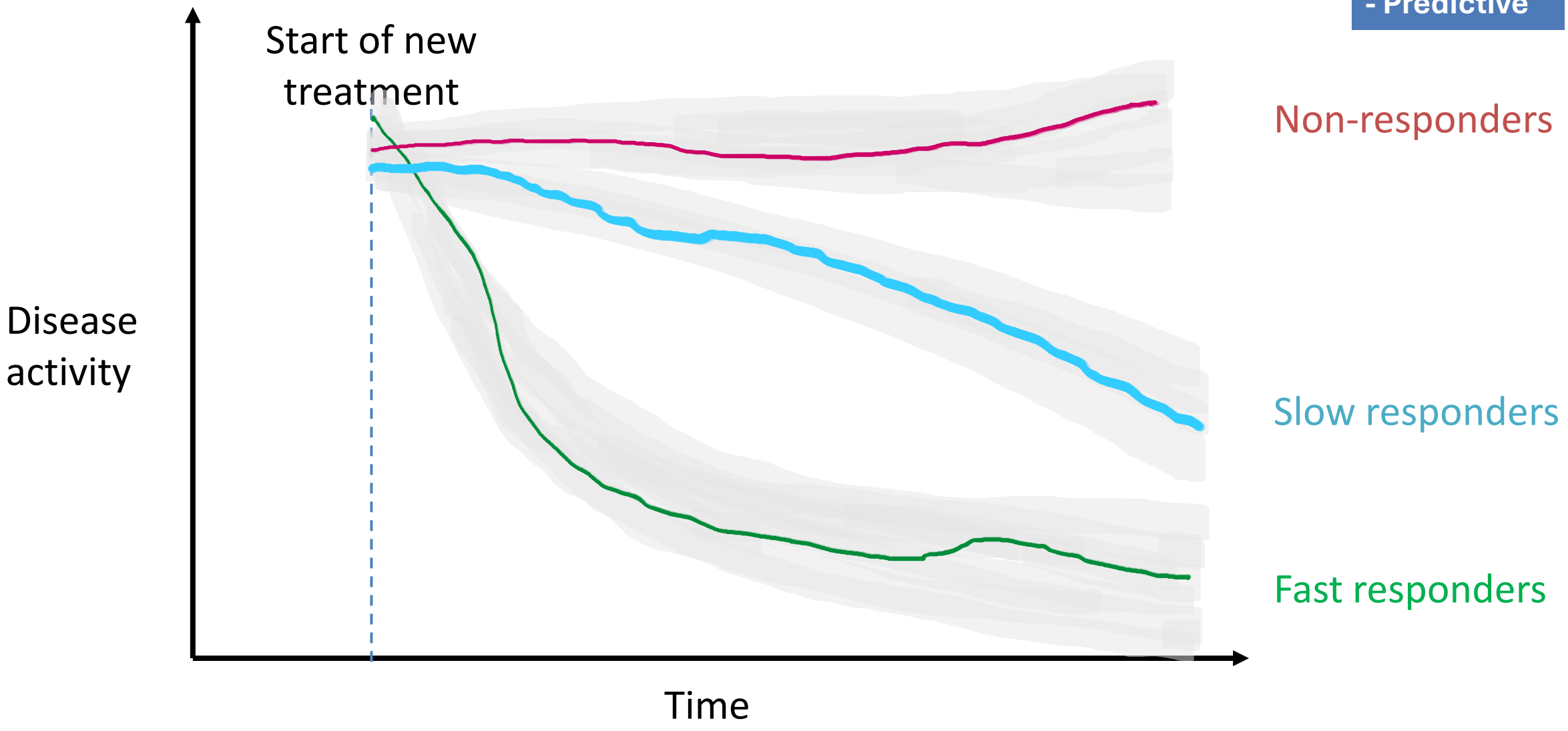
Mariam Al-Attar

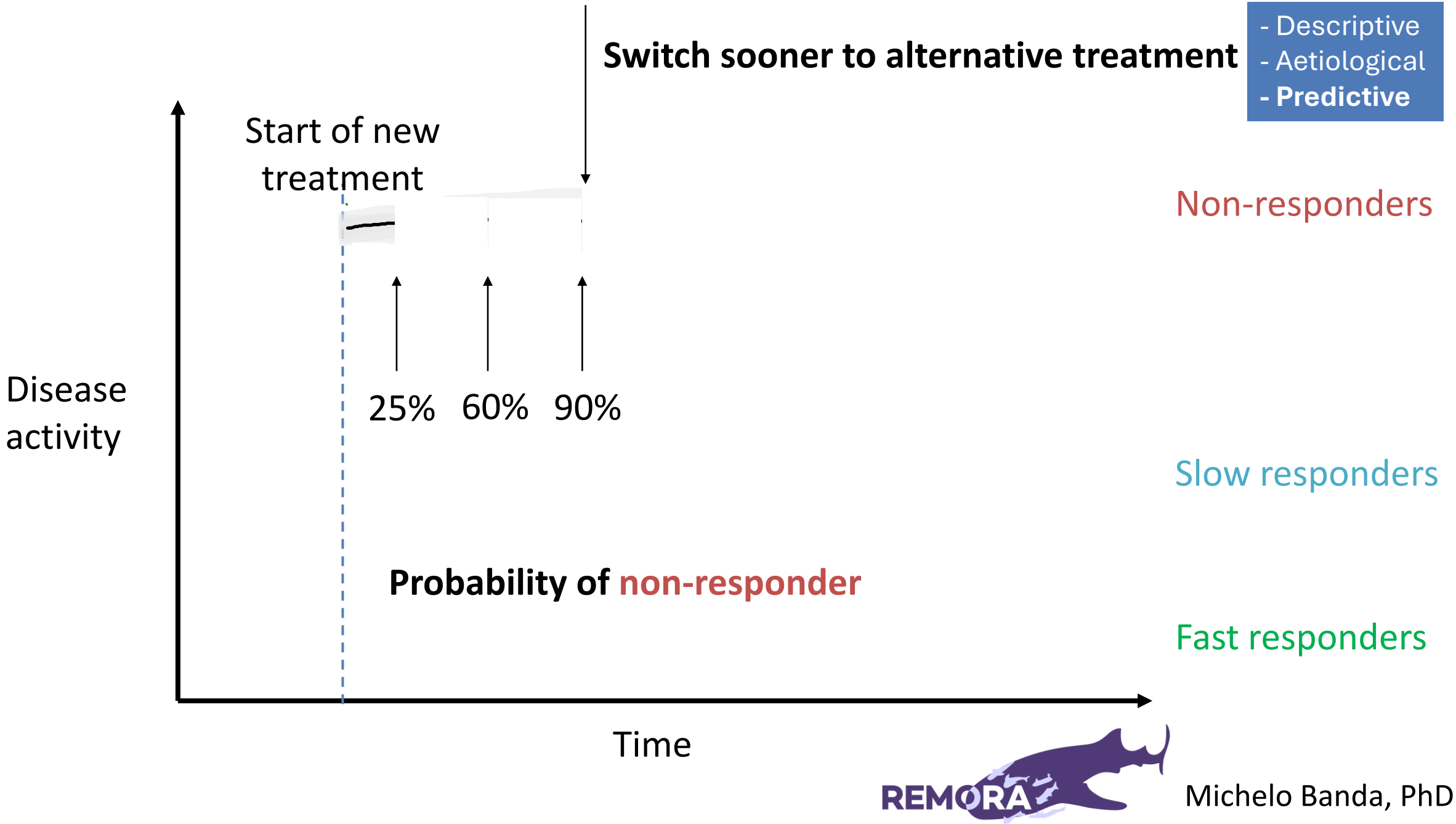
Treatment response

- Descriptive
- Aetiological
- **Predictive**



- Descriptive
- Aetiological
- **Predictive**





Michelo Banda, PhD

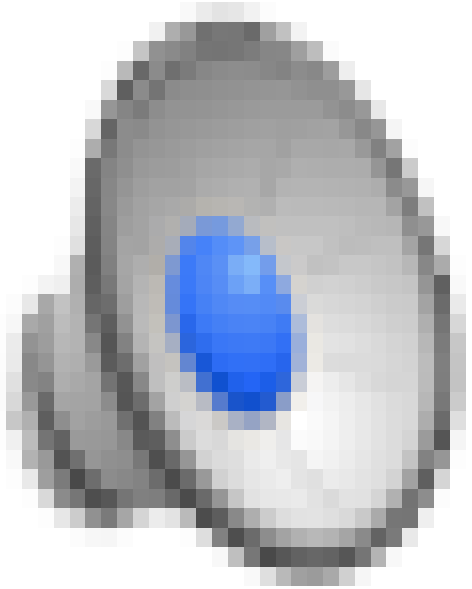
Outline

- My background and motivation for mobile health research

- Opportunities from smartphones and wearables

- Case studies, with focus on analysis challenges
  - Remote Monitoring of Rheumatoid Arthritis — RA
  - **Cloudy with a Chance of Pain** — **Chronic pain**
  - PAPrKA — Knee Replacement

Cloudy with a Chance of Pain



Cloudy with a Chance of Pain

- Recruitment in 12 months

  13,207

- Postcode areas

  124/124

- Symptom scores

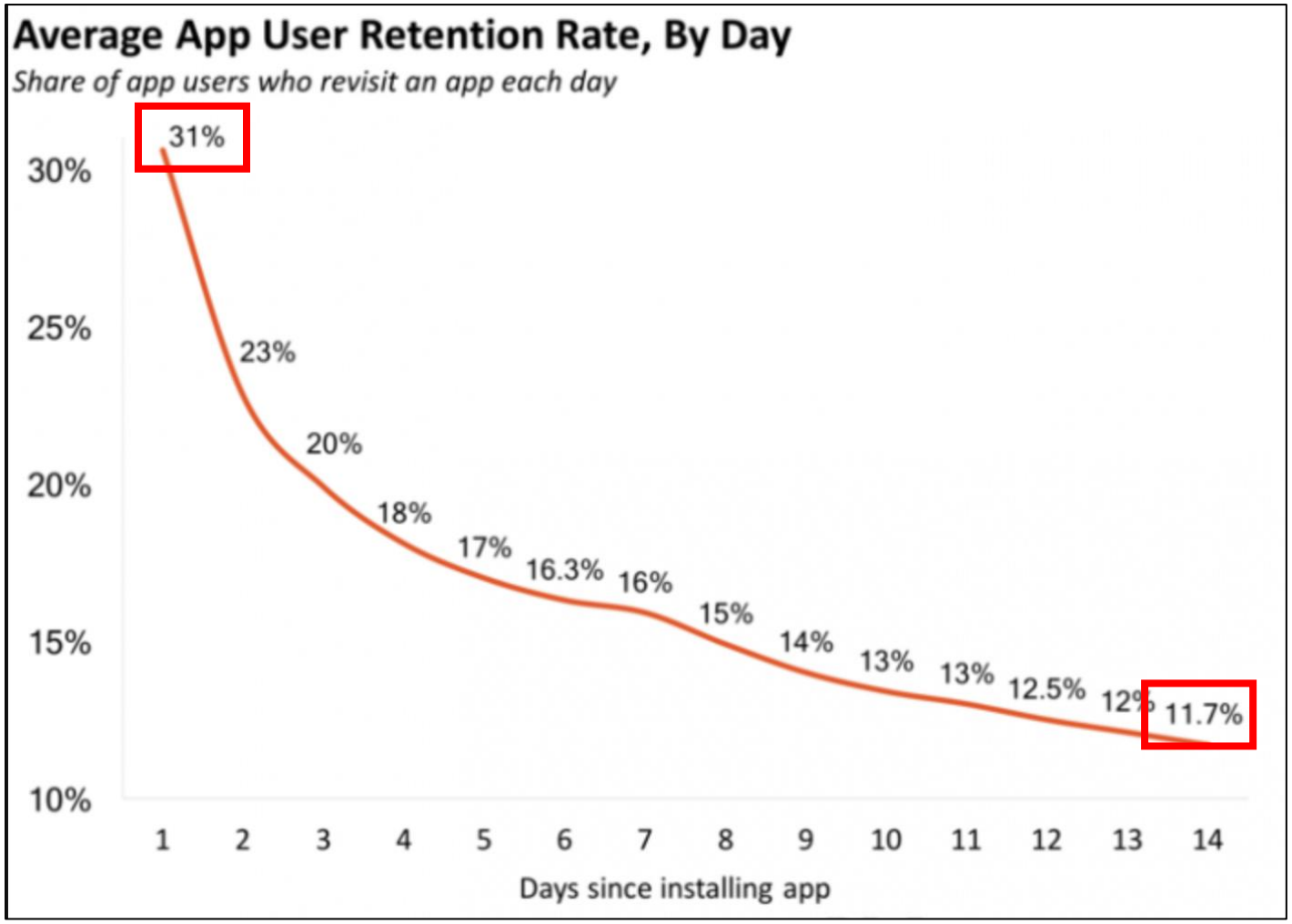
  5.1 million

CLOUDY

WITH A CHANCE OF

PAIN

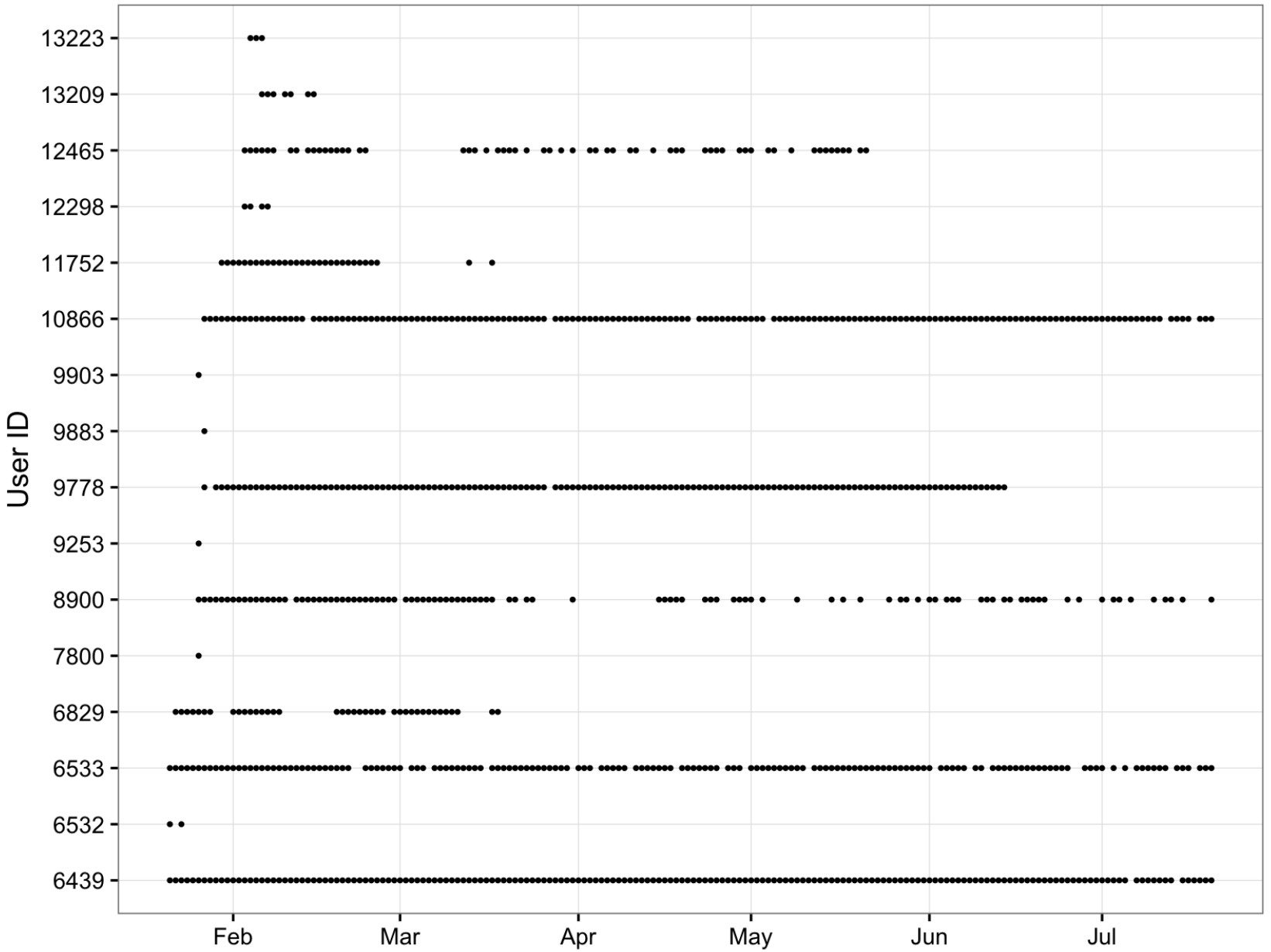
App ‘churn’ rates



Source: Business Insider: http://tinyurl.com/y5hmez8d

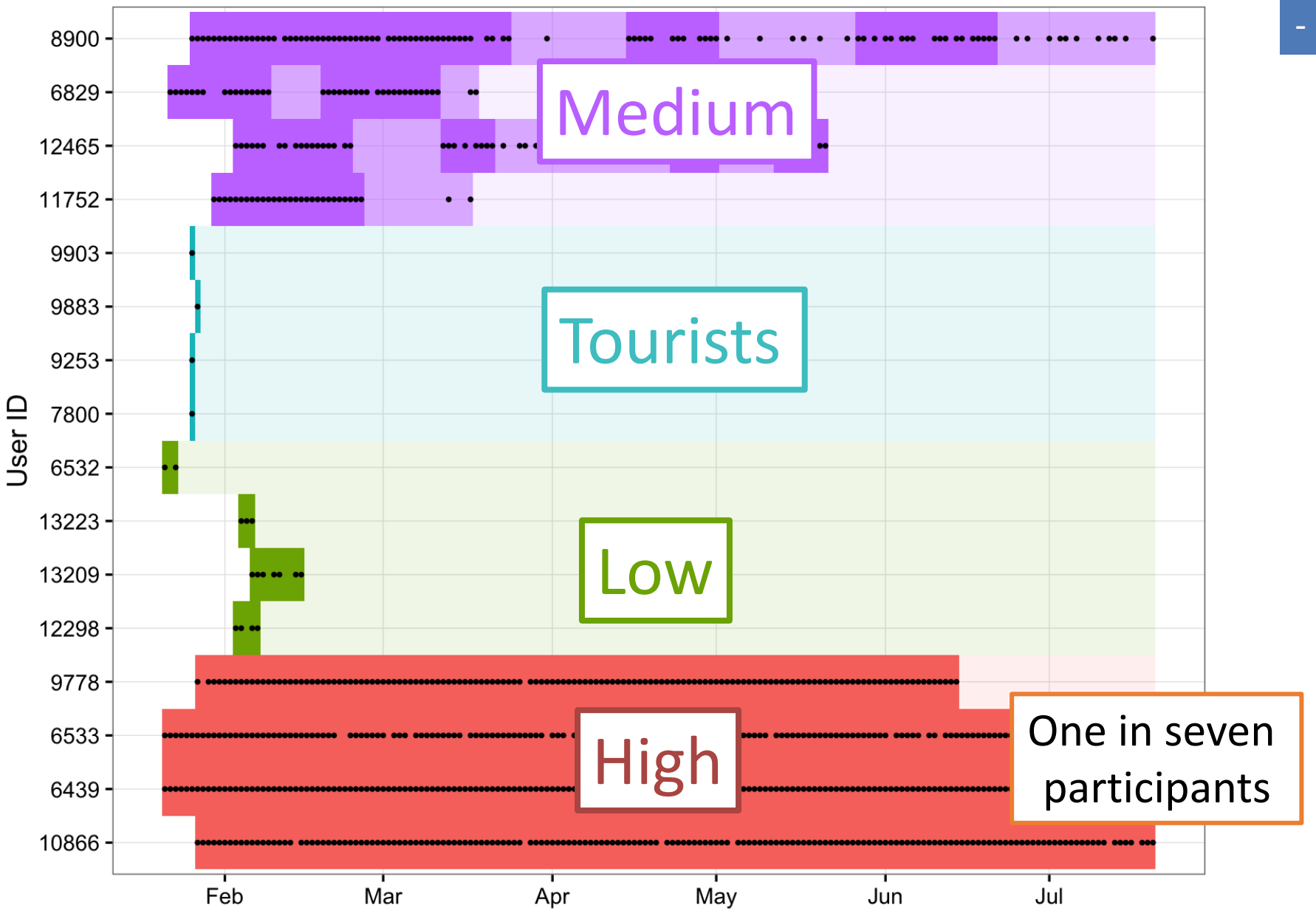
Patterns of engagement

- **Descriptive**
- Aetiological
- Predictive



Patterns of engagement

- **Descriptive**
- Aetiological
- Predictive



Who is in each cluster?

- **Descriptive**
- Aetiological
- Predictive

Engagement Cluster	Age	% male	Belief (0-10)
High			
Medium			
Low			
Tourists			

Data to July 31st 2016

Druce et al. JMIR 2017

Cloudy with a Chance of Pain

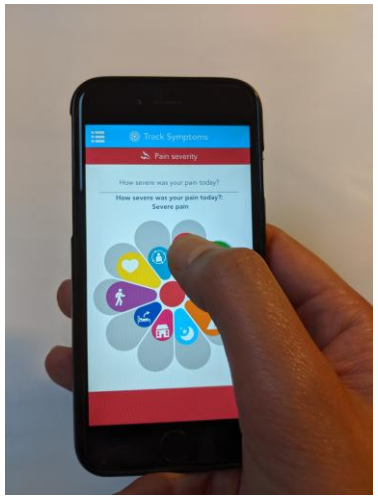
- National UK smartphone study investigating the association between weather and pain
  - Daily symptoms tracked using smartphone app; GPS links to local weather data
  - Recruited >13,000 participants
  - 124/124 UK postcode areas represented
  - One in seven participants tracking data every day for 6 months or more

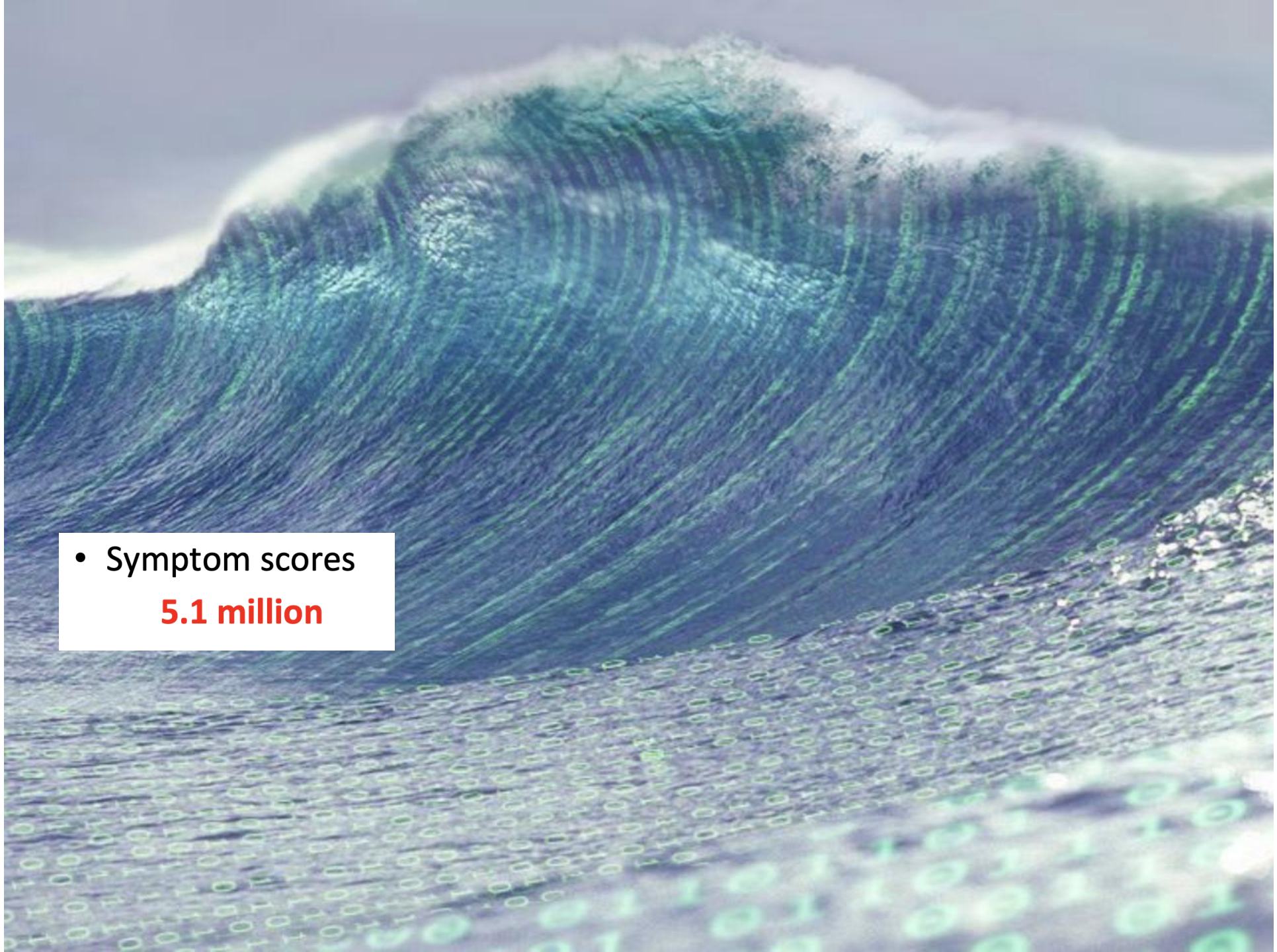
CLOUDY WITH A CHANCE OF PAIN

- Showed pain association with high humidity and low pressure

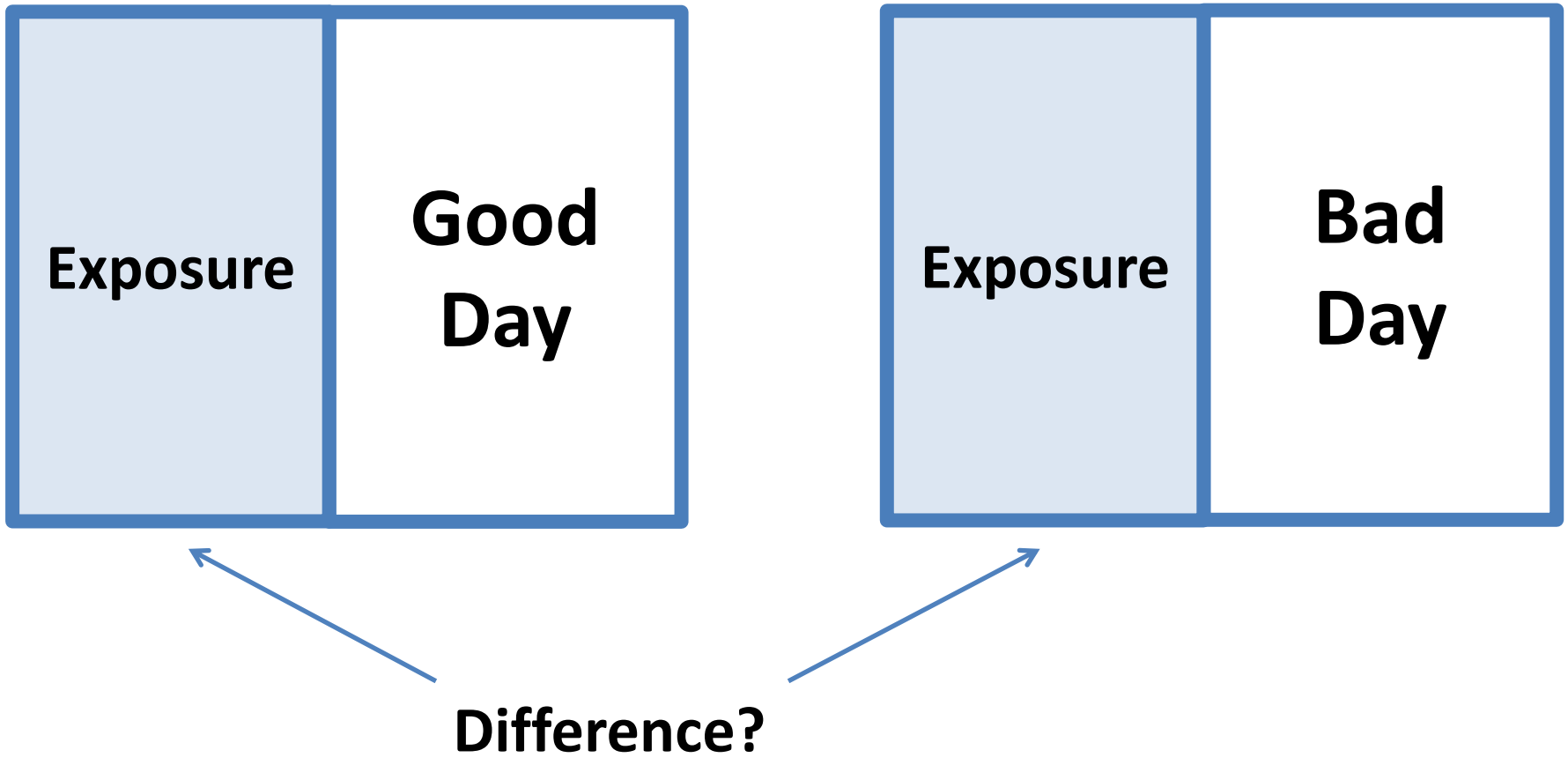
Dixon WG et al, npj Digital Medicine 2019

www.cloudywithachanceofpain.com




• Symptom scores
5.1 million

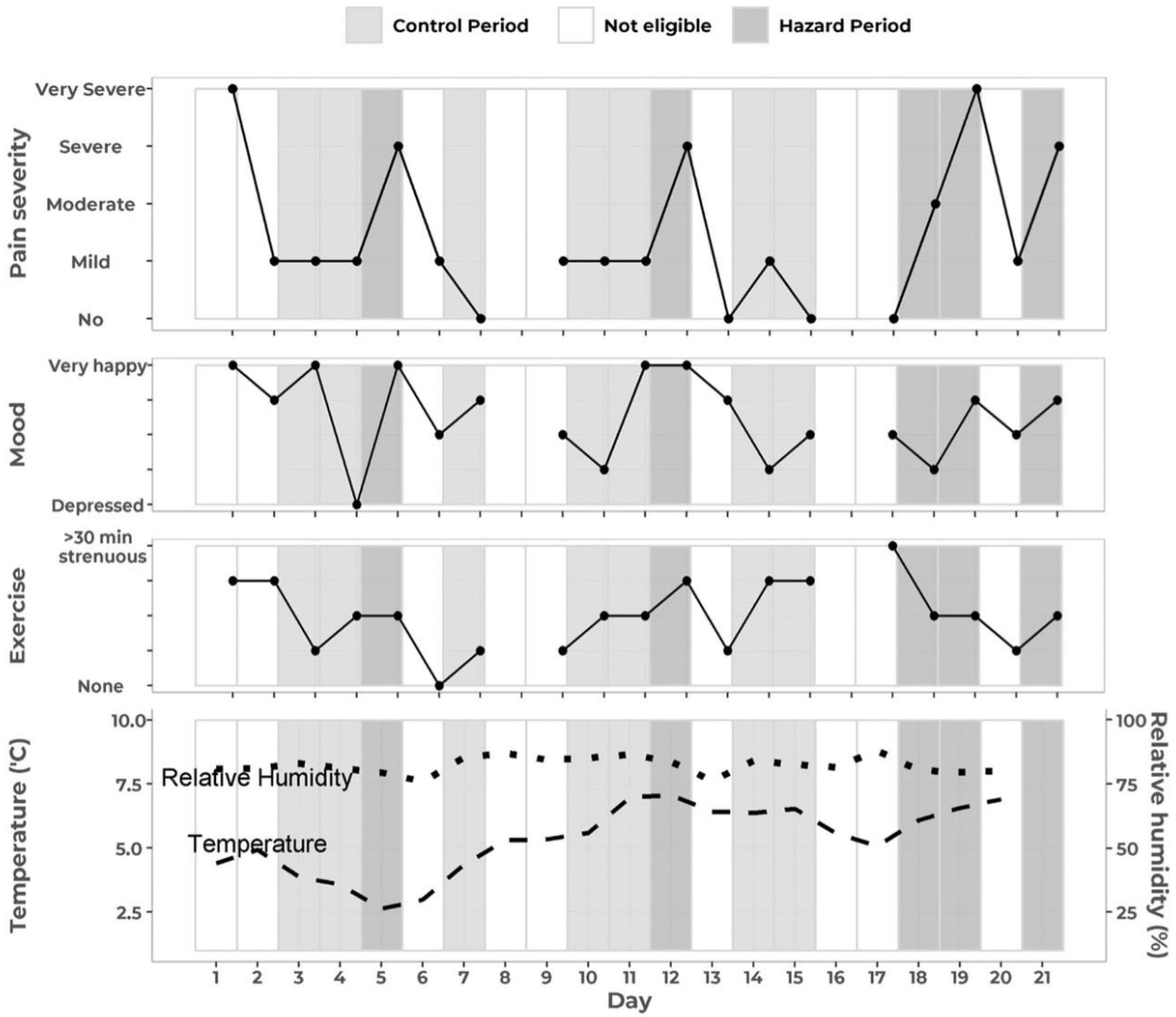
Case crossover design



Case crossover analysis

- Identify ‘pain events’
- Two-or-more category increase in pain from previous day
  - None
  - Mild
  - Moderate
  - Severe
  - Very Severe
- Weather using GPS

Case crossover analysis



Outline

- My background and motivation for mobile health research

- Opportunities from smartphones and wearables

- Case studies, with focus on analysis challenges
  - Remote Monitoring of Rheumatoid Arthritis — RA
  - Cloudy with a Chance of Pain — Chronic pain
  - **PAPrKA** — **Knee Replacement**

MANCHESTER 1824
The University of Manchester

PAPrKA

Physical Activity Patterns after Knee Arthroplasty

PAPrKA: How active are people after knee replacement surgery?

The **P**hysical **A**ctivity **P**atterns after **K**nee **A**rthroplasty (**PAPrKA**) study seeks to learn more about people's recovery after knee replacement. With your help, and through our research, we can support patients and doctors in the future make better informed decisions about knee replacement surgery.

FAQs Join Study

About the study

To learn more about recovery after knee replacement, we will bring together with your consent 3 bits of information:

1. Information you provide in a survey.
2. A one-time collection of your physical activity information from either iPhone, Fitbit, Apple Watch or Oura Ring. Physical activity can include things such as steps you take daily, walking, numbers of flights of stairs you climb etc.
3. Access to your knee replacement surgery information (from the UK National Joint Registry).

The University of Manchester is leading the PAPrKA research study in collaboration with King's College London and with support from the National Joint Registry.

What You Need to Complete PAPrKA Study Tasks

To take part you will need to complete Tasks 1, 2 and 3. Task 4 'Give us your feedback' is optional.
Please note, when you start a task, you must answer all the questions in one go and press "submit" or you will lose your answers

3 / 3

TASK 1: About my knee replacement
Eight quick questions.
Tip: You will need the month and year of your knee replacement surgery

Done

TASK 2: About You
Four quick questions.
Tip: You will need your NHS number

Done

TASK 3: Connect my devices
Connect one or more devices
Tip (for Fitbit & Oura ring): You will need login details for your device
Tip (for Apple): You need to enter the study name PAPrKA; use the email and password from your PAPrKA account; best completed using WiFi

Done

TASK 4: Give us your feedback
Seven quick questions about joining

It’s not all roses

Selection bias and representativeness

- Not everyone has devices
- Uncertain participation rates
- Digital literacy to participate; ability to successfully onboard

Data quality and completeness

- Different metrics across devices, and changes within devices
- Different carry and wear times
- How to handle missing data

Analysis and other concerns

- Analysis methods for time series data
- Public concerns about privacy and security
- … and many more!

Aim to study this in PAPrKA

It’s not all roses

Selection bias and representativeness

- Not everyone has devices
- Uncertain participation rates
- Digital literacy to participate; ability to successfully onboard

Data quality and completeness

- Different metrics across devices, and changes within devices
- Different carry and wear times
- How to handle missing data – **Doing simulations for ability to identify trajectories**

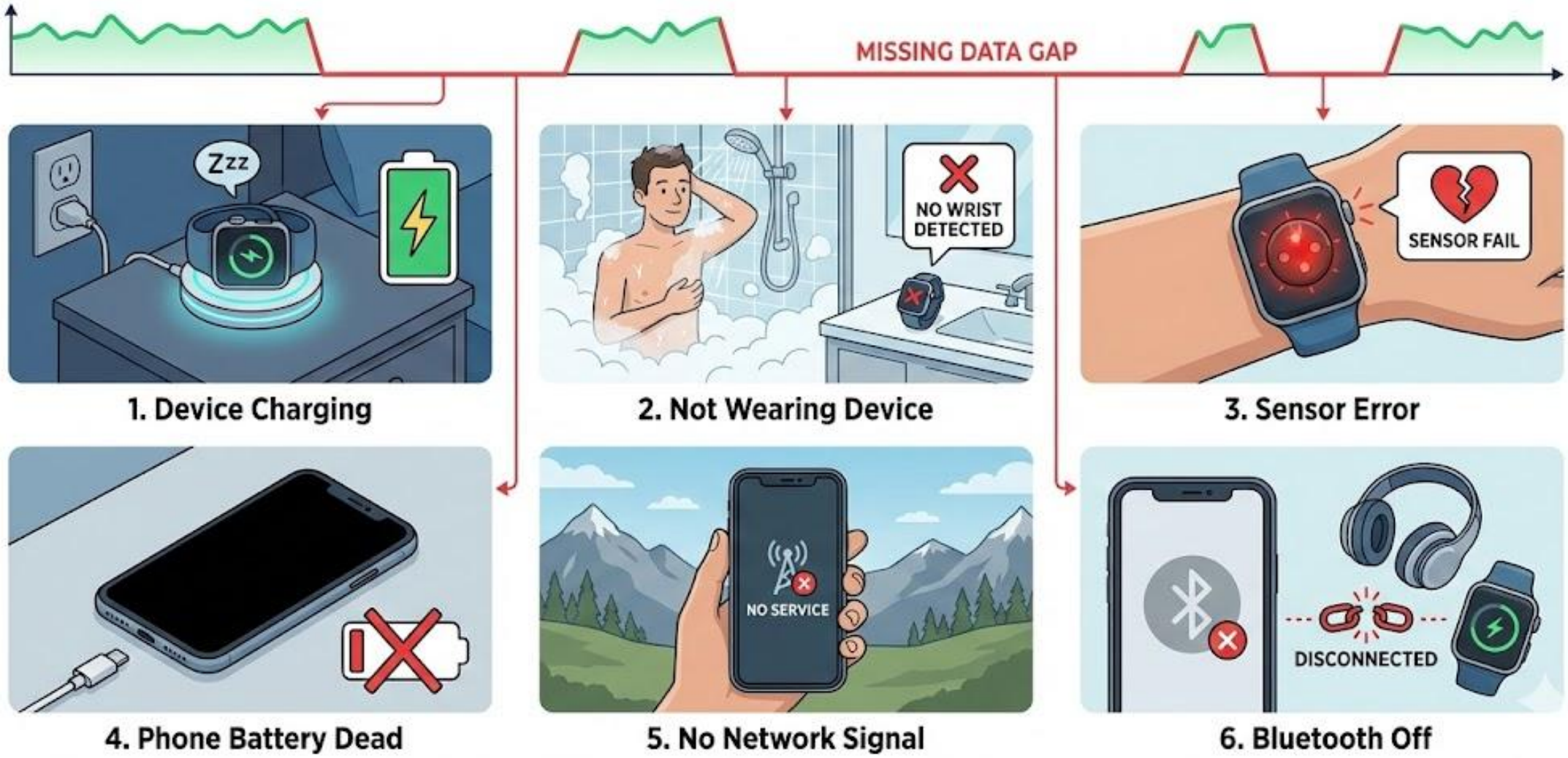
Analysis and other concerns

- Analysis methods for time series data
- Public concerns about privacy and security
- … and many more!

Aim to study this in PAPrKA

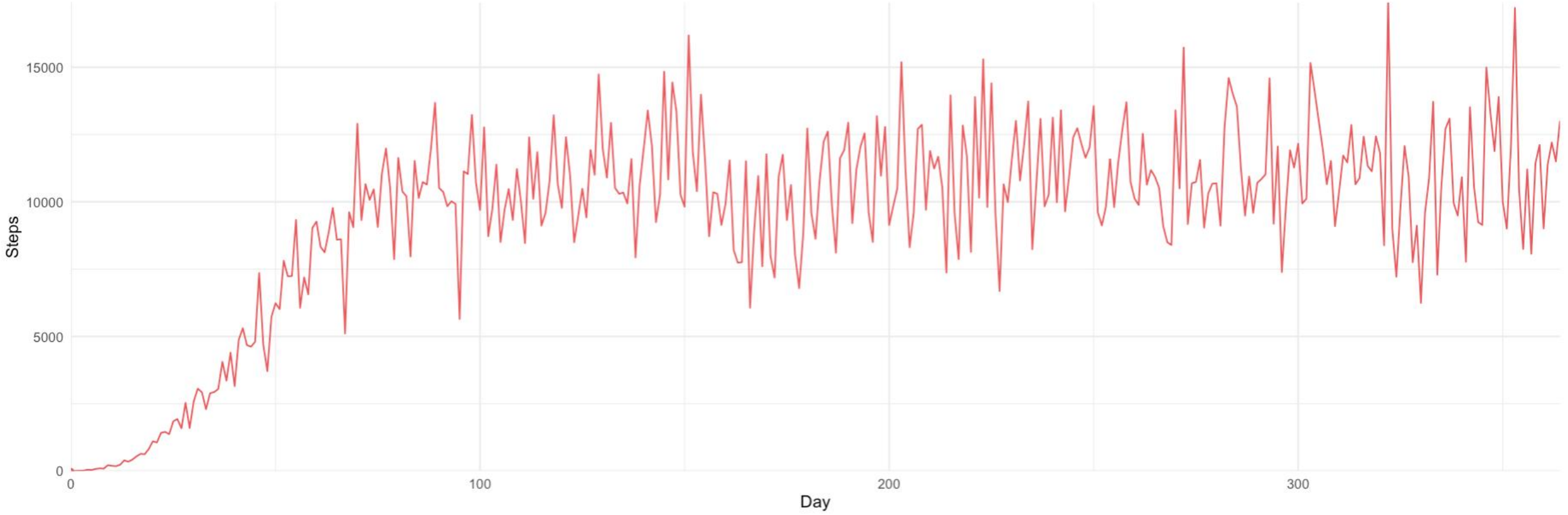
WHERE DID THE DATA GO?

Common Scenarios for Missing Information in Wearables & Smartphones

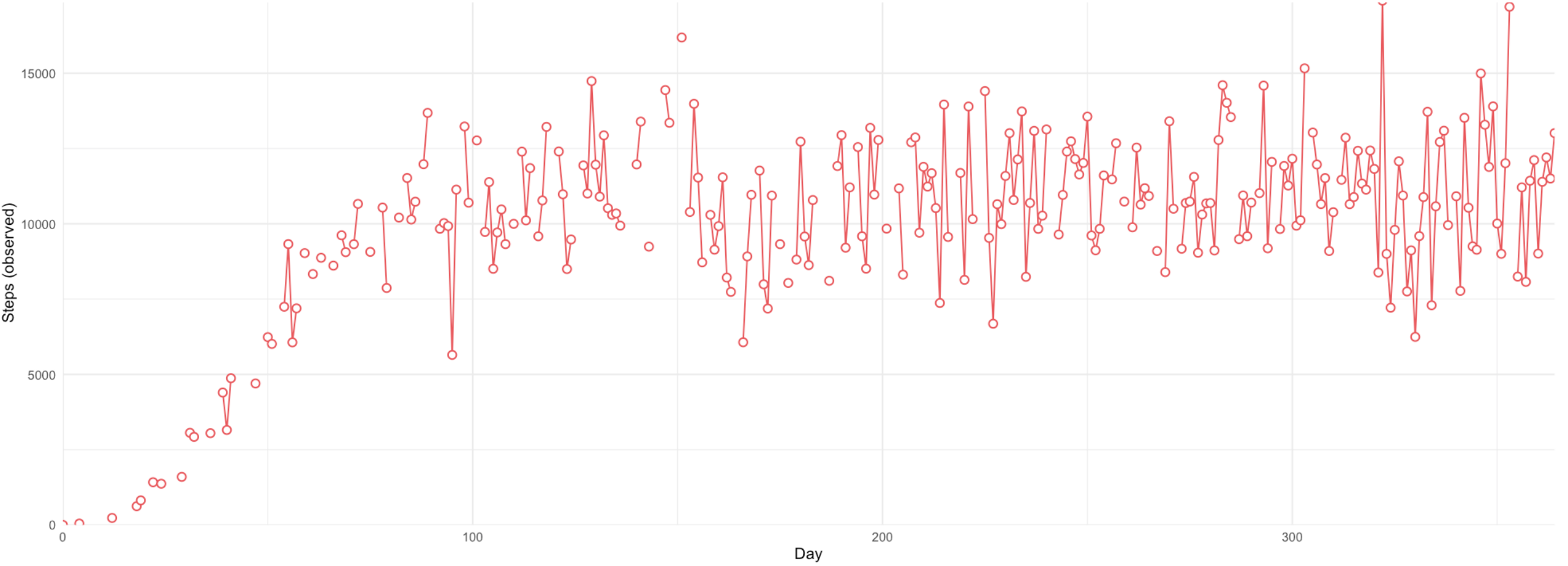


1. Device Charging
2. Not Wearing Device
3. Sensor Error
4. Phone Battery Dead
5. No Network Signal
6. Bluetooth Off

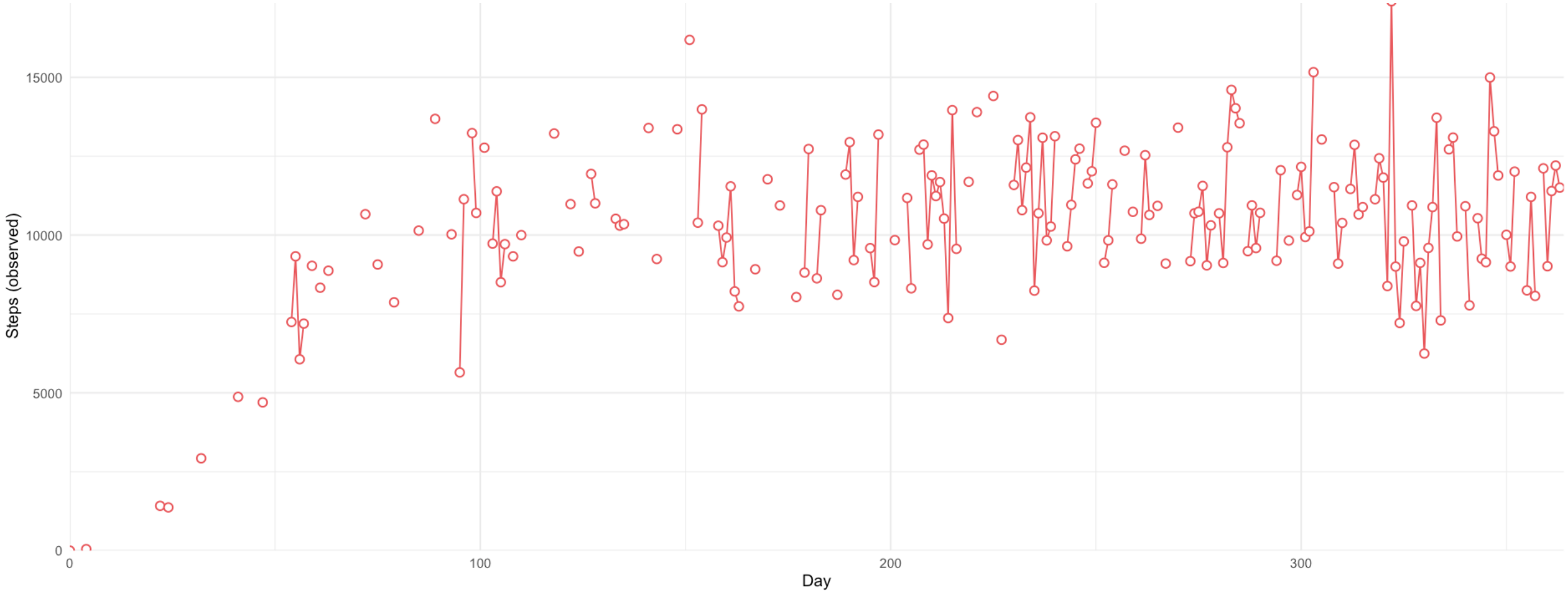
Simulated activity recovery following knee replacement surgery



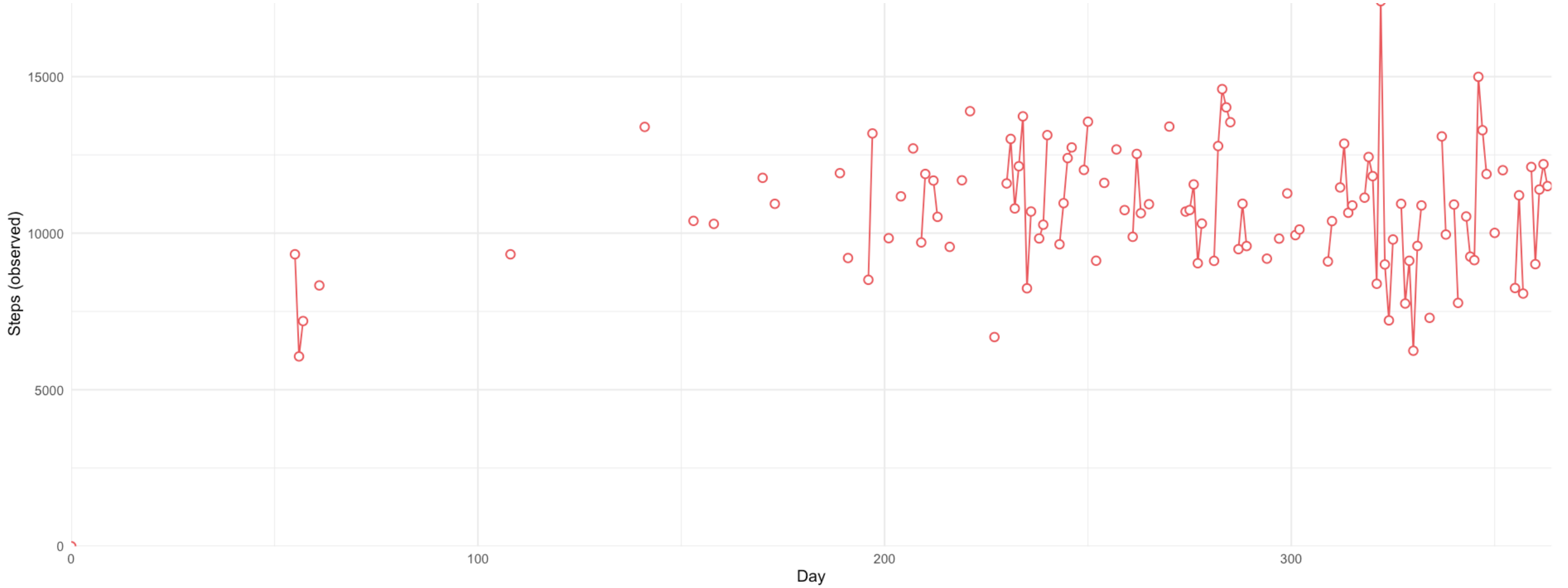
Data with 30% missingness



Data with 50% missingness



Data with 70% missingness



Add Shuai slides

Outline

- My background and interests
- Opportunities from smartphones and wearables
- Case studies, with focus on analysis challenges
  - Remote Monitoring of Rheumatoid Arthritis — RA
  - Cloudy with a Chance of Pain — Chronic pain
  - PAPrKA — Knee Replacement