



Quality of Life Technologies Lab  
University of Copenhagen & University of Geneva  
[qualityoflifetechnologies.org](http://qualityoflifetechnologies.org)



# Quantifying Quality of Life of Smartphone-Centric Humans via Human-Centric Methods

Prof. Katarzyna Wac

2020



UNIVERSITÉ  
DE GENÈVE

UNIVERSITY OF  
COPENHAGEN



STANFORD  
SCHOOL OF MEDICINE

Stanford University Medical Center



Schweizerische Eidgenossenschaft  
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SCHWEIZERISCHER NATIONALFONDS  
FONDO NAZIONALE SVIZZERO  
SWISS NATIONAL SCIENCE FOUNDATION



Research  
at Google



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Research  
at Google

# A Patient (female, 69)

Type 2 Diabetes (1992)

Heart attack (2014)

Hip fracture & replacement (2016)

Loves cooking

Much (too much) food (carbs)



# Not the Only One

**Genetic**

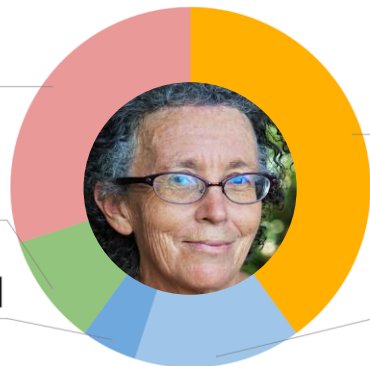
30.0%

**Health care**

10.0%

**Environmental**

5.0%



**Behavioral**

40.0%

**Social**

15.0%

Behavioural patterns Deaths

Tobacco intake 18.1%

Poor diet  
Physical inactivity 16.6%

Alcohol consumption 3.5%

...

THE  
LANCET **JAMA**

Naghavi, M., Abajobir, A. A., Abbafati, C., Abbas, K. M., Abd-Allah, F., Abera, S. F., ... & Ahmadi, A. (2017). *Global, Regional, And National Age-Sex Specific Mortality For 264 Causes Of Death, 1980–2016: A Systematic Analysis For The Global Burden Of Disease Study 2016*. *The Lancet*, 390 (10100), 1151-1210.

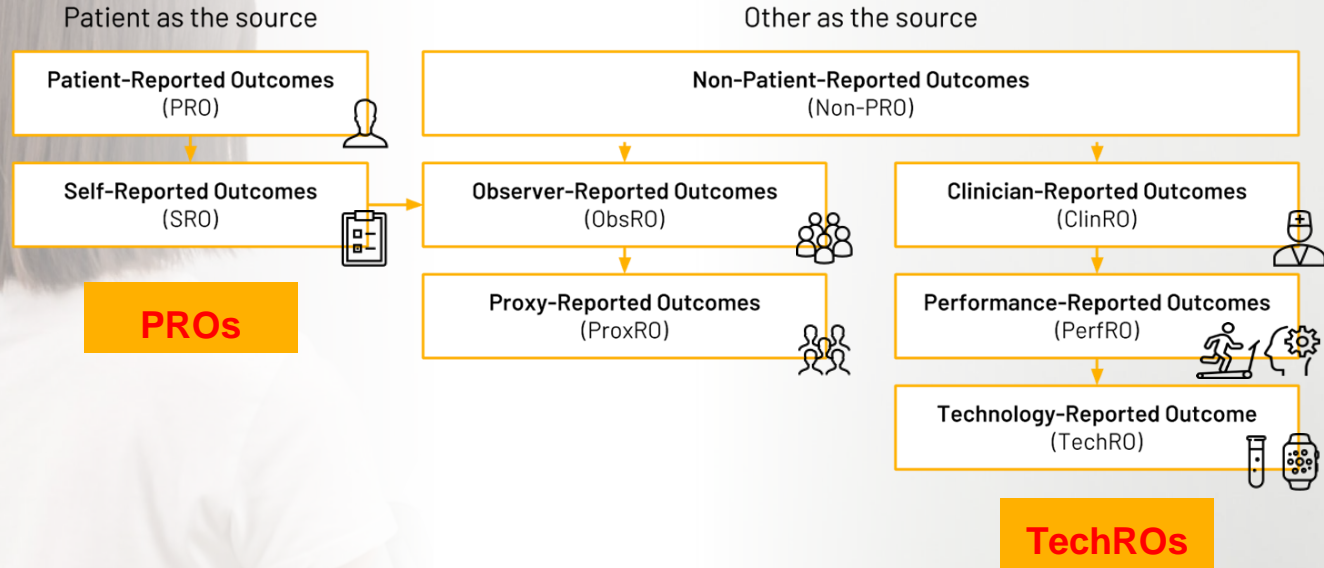
Mokdad, A. H., Marks, J. S., Stroup, D. F., & Gerberding, J. L. (2004). *Actual Causes of Death in the United States, 2000*. *Jama*, 291 (10), 1238-1245.

'Behaviour marker', 'Behaviome',

*If you can't measure it,  
you can't improve it.*



# At the Doctor's Office



# Sleep

*“During the past month,  
How often have you had  
trouble sleeping because you*

Wake up in the middle  
of the night or early  
In the morning?



**PITTSBURGH SLEEP QUALITY INDEX (PSQI)**

**INSTRUCTIONS:** The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of days and nights in the past month. Please answer all questions.

---

1. During the past month, when have you usually gone to bed at night?  
USUAL BED TIME \_\_\_\_\_

---

2. During the past month, how long (in minutes) has it usually take you to fall asleep each night?  
NUMBER OF MINUTES \_\_\_\_\_

---

3. During the past month, when have you usually gotten up in the morning?  
USUAL GETTING UP TIME \_\_\_\_\_

---

4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spend in bed.)  
HOURS OF SLEEP PER NIGHT \_\_\_\_\_

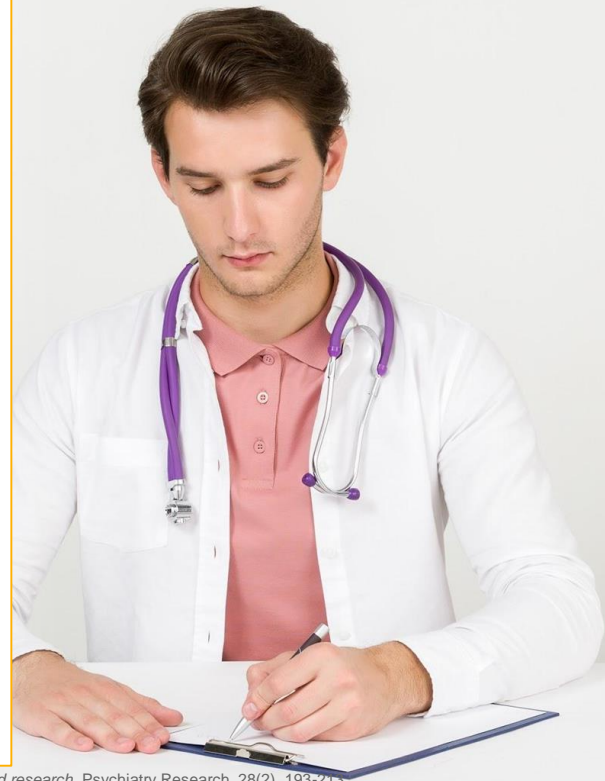
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**INSTRUCTIONS:** For each of the remaining questions, check the one best response. Please answer all questions.

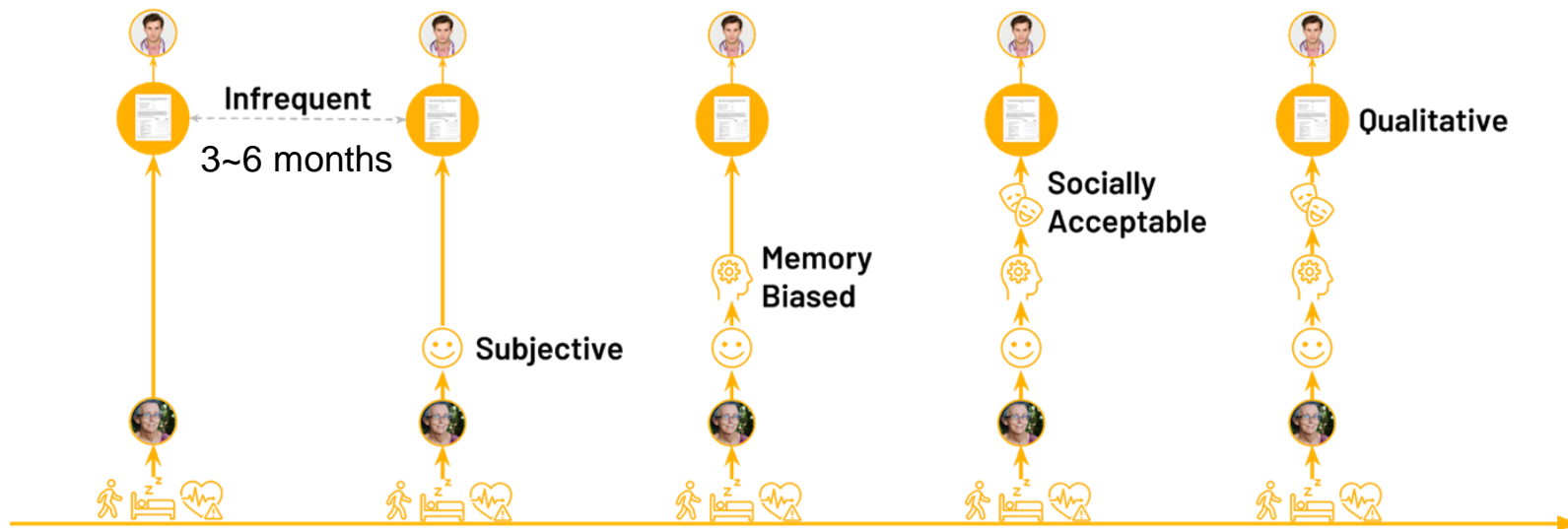
---

5. During the past month, how often have you had trouble sleeping because you...

	Not during the past month	Less than once a week	Once or twice a week	Three or more times a week
(a) ...cannot get to sleep within 30 minutes	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(b) ...wake up in the middle of the night or early morning	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(c) ...have to get up to use the bathroom	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(d) ...cannot breathe comfortably	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(e) ...cough or snore loudly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(f) ...feel too cold	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(g) ...feel too hot	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(h) ...had bad dreams	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(i) ...have pain	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
(j) Other reason(s), please describe _____ _____				
How often during the past month have you had trouble sleeping because of this?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



# Self-Reported Outcomes





# The Big Picture



# Smartphone

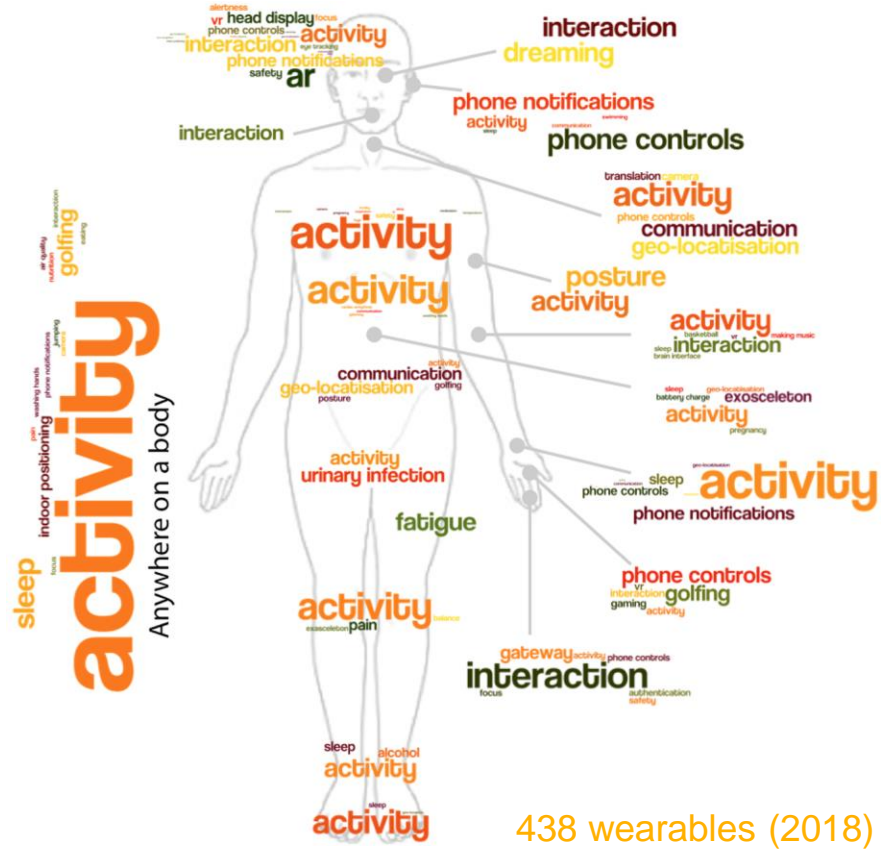


88%

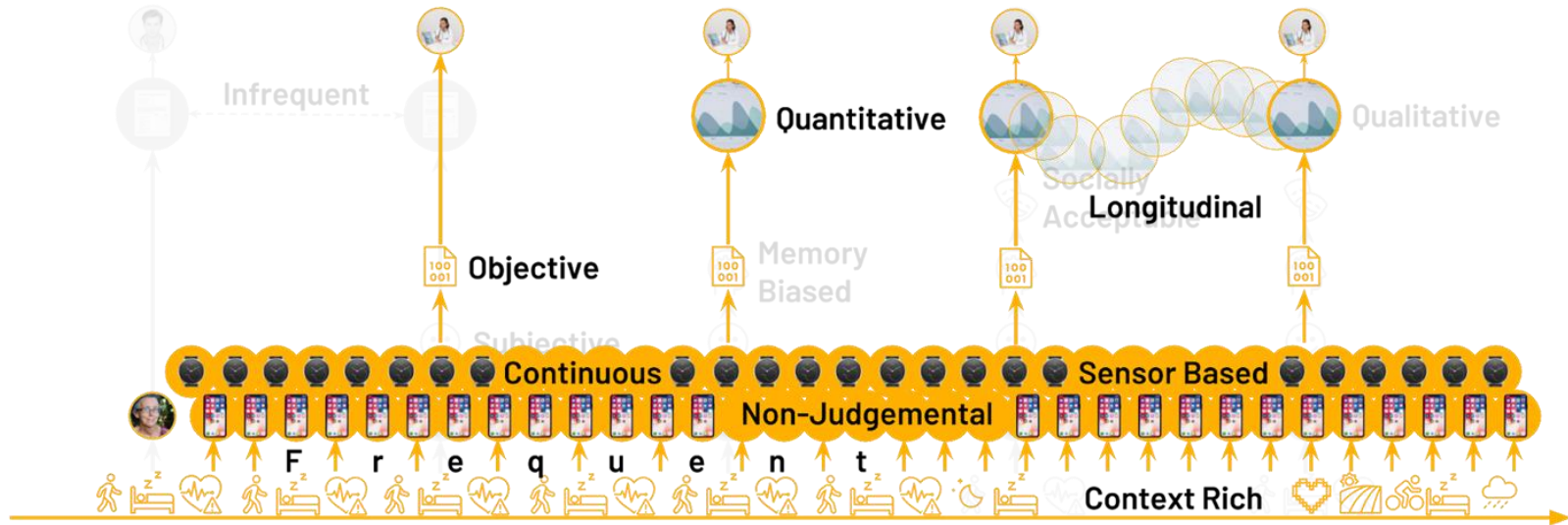
of the time  
next to us



# Smartphone & Wearables



# \*-Reported Outcomes: A New Paradigm





## QoL Domains

## QoL Facets



# Quality of Life

### Physical health

- Activities of daily living
- Dependence on medicinal substances and medical aids
- Energy and fatigue
- Mobility
- Pain and discomfort
- Sleep and rest
- Work capacity

### Psychological

- Bodily image and appearance
- Negative feelings
- Positive feelings
- Self-esteem
- Spirituality / Religion / Personal beliefs
- Thinking, learning, memory, and concentration

### Social relationships

- Personal relationships
- Social support
- Sexual activity

### Environment

- Financial resources
- Freedom, physical safety, and security
- Health and social care: accessibility, and quality
- Home environment
- Opportunities for acquiring new information and skills
- Participation in and opportunities for recreation / leisure activities
- Physical environment (pollution / noise / traffic / climate)
- Transport





## QoL Domains

## QoL Facets



# Quality of Life

### Physical health

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- Transport

***Individuals' perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards, and concerns.***





## Health

*A state of complete physical, mental and social well-being and not merely the absence of disease or infirmity.*





# Redefining Health

***The ability to adapt  
and self manage in the  
face of social,  
physical, and  
emotional challenges.***

BMJ

Huber, M., Knottnerus, J. A., Green, L., van der Horst, H., Jadad, A. R., Kromhout, D., ... & Schnabel, P. (2011). How should we define health?. *Bmj*, 343, d4163.



QoL Domains

QoL Facets (13/24)

# Bending the Curve

Physical health

- Activities of daily living ✓
- Dependence on medicinal substances and medical aids
- Energy and fatigue ✓
- Mobility ✓
- Pain and discomfort ✓
- Sleep and rest ✓
- Work capacity

Psychological

- Bodily image and appearance
- Negative feelings ✓
- Positive feelings ✓
- Self-esteem
- Spirituality / Religion / Personal beliefs ✓
- Thinking, learning, memory, and concentration

Social relationships

- Personal relationships ✓
- Social support ✓
- Sexual activity

Environment

- Financial resources
- Freedom, physical safety, and security ✓
- Health and social care: accessibility, and quality
- Home environment
- Opportunities for acquiring new information and skills
- Participation in and opportunities for recreation / leisure activities
- Physical environment (pollution / noise / traffic / climate) ✓
- Transport ✓

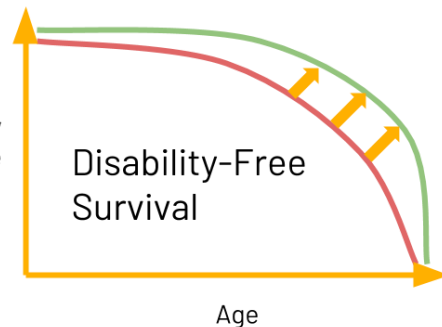
Self-management & Behaviour Change Facilitation



Computational Models



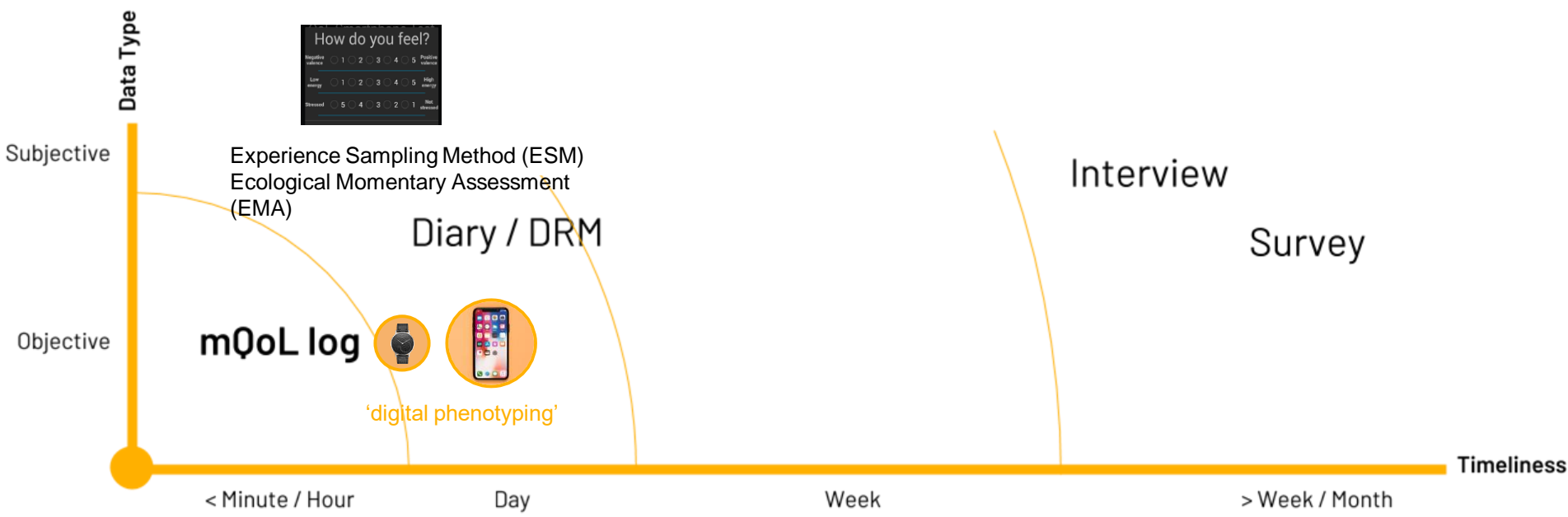
Quality of Life



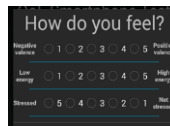
1000+ Participants  
(mQoL Living Lab)



# Reproducible Methodology (Explorative, Inductive & Hypothetico-Deductive Approach)



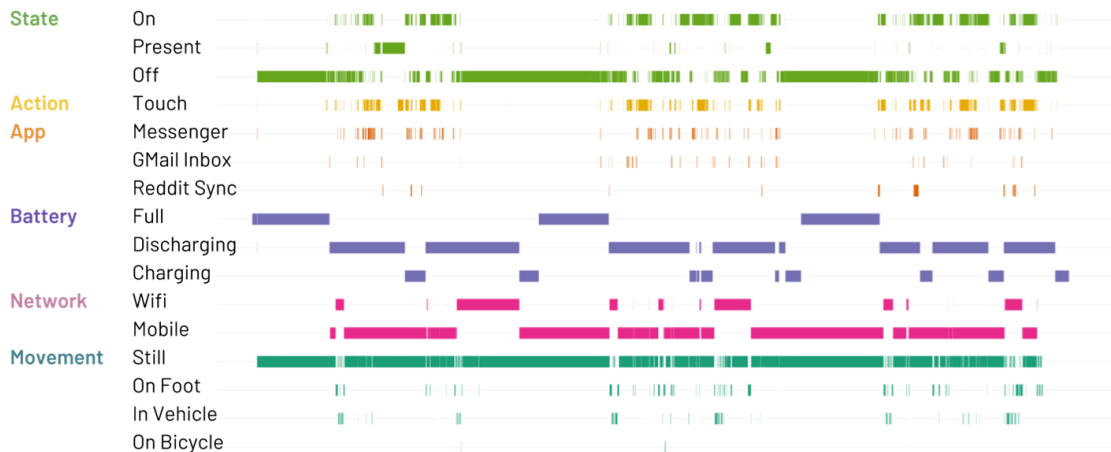
De Masi, A., Berrocal, A., ..., & Wac, K., *Mixed-Methods Research Methodology Enabling Identification, Modelling and Predicting Human Aspects of Mobile Interaction "In the Wild"*. User Modelling and User-Adapted Interaction (under evaluation)



## mQoL Log



6.6+ billion  
data points



# Research Infrastructure



Physical health



Psychological



Social relationships



Environment



Physical health



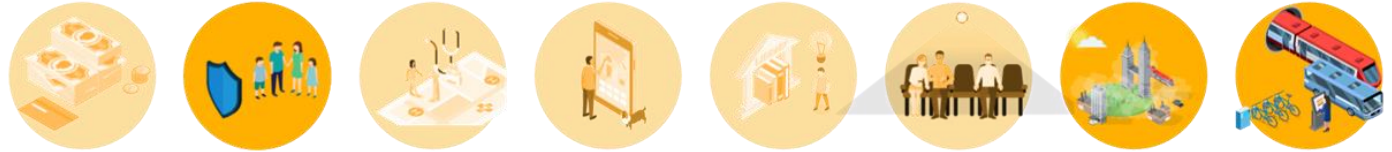
Psychological



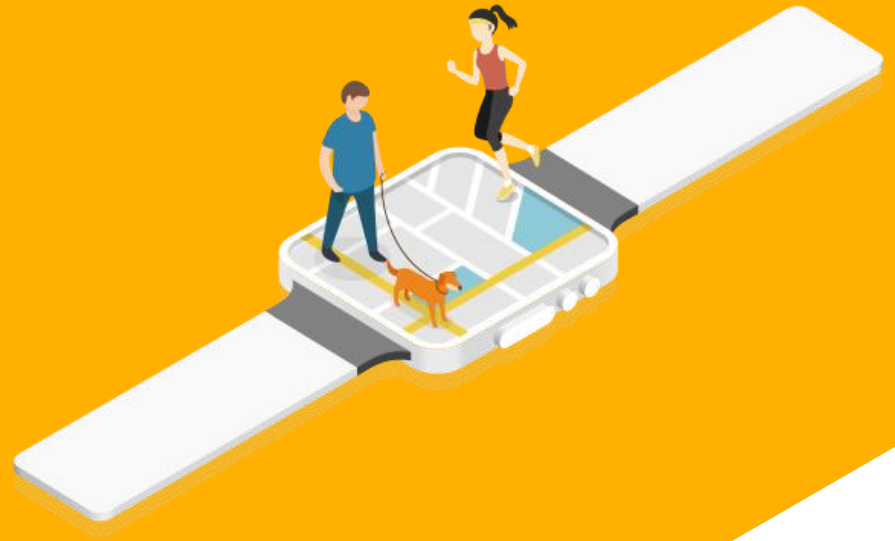
Social relationships



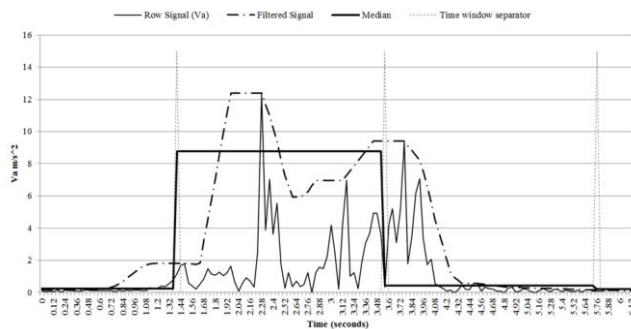
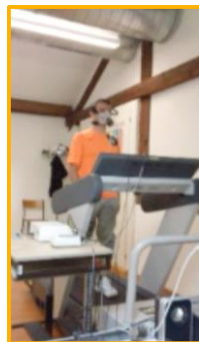
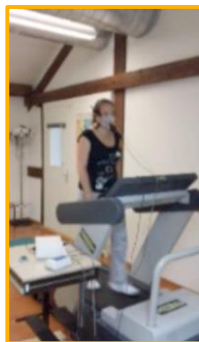
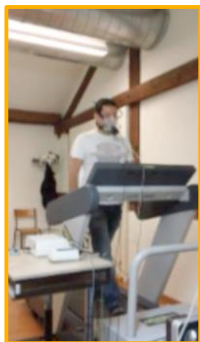
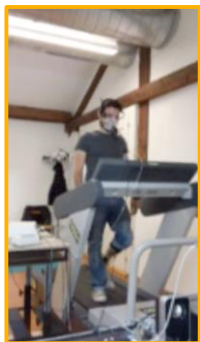
Environment



# Physical Health: Mobility



# From a Phone Accelerometer...



## Study details

N = 7 participants, up to a week each (CH)

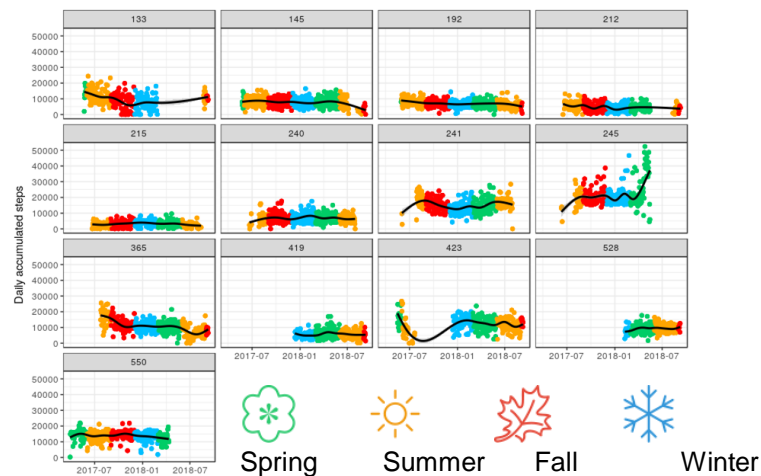
Walking accuracy of 85.7%

Activities of daily life accuracy of 76.6%





# Via a Wearable & Risk Assessment



UserID	Daily accumulates steps									
	3x/Week percentage				Statistics					
	10000	7000	5000	3000	Mean	STD	Min	Max	Mode	
133	54.55	88.64	93.18	95.45	9382.58	4922.44	15	24420	8585	
145	20.31	81.25	92.19	93.75	7828.04	2943.57	133	16483	9350	
192	1.49	62.69	97.01	98.51	7032.82	2219.07	10	14426	6905	
212	0.00	9.43	50.94	92.45	4629.41	2369.36	44	13188	6281	
215	0.00	0.00	6.67	65.00	3184.44	1778.24	7	9626	4105	
240	10.71	58.93	91.07	92.86	6835.83	2931.79	5	17649	11298	
241	94.55	94.55	96.36	96.36	15197.89	4177.19	22	28430	19062	
245	93.18	93.18	93.18	93.18	21469.72	7660.42	4588	52384	16762	
365	72.88	88.14	94.92	96.61	10749.82	4268.13	17	25556	11694	
419	2.56	23.08	82.05	97.44	5656.12	2571.62	204	16983	6943	
423	81.25	93.75	93.75	93.75	12499.01	4545.75	15	26696	17076	
528	48.39	96.77	100.0	100.0	9220.48	2519.64	1694	17668	8948	
550	94.55	100.0	100.0	100.0	13841.25	3078.23	291	21982	17134	

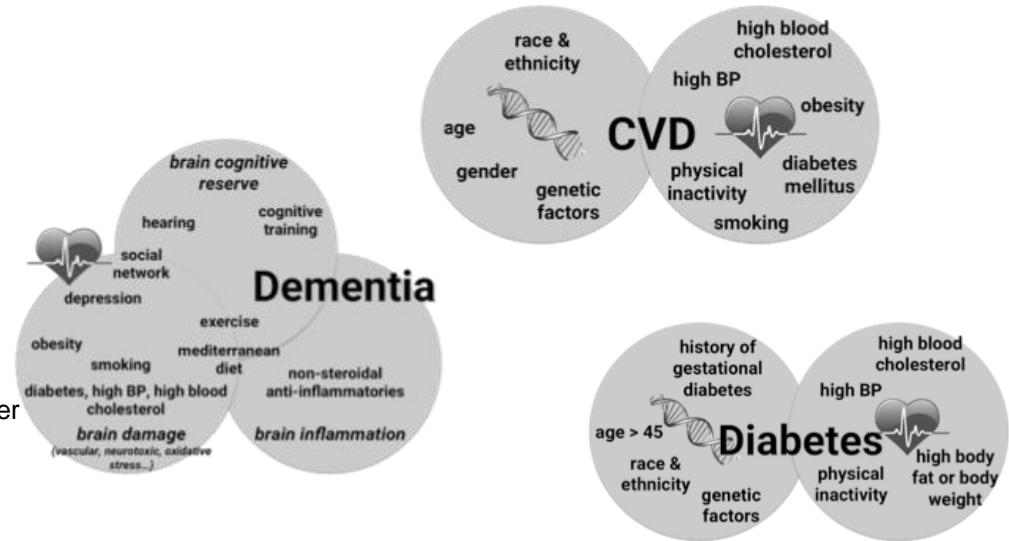
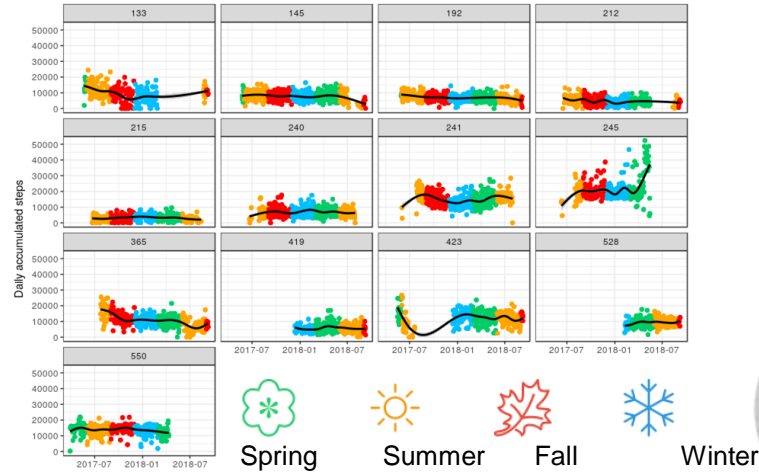
## Study details

N = 42 seniors over 65 (HU, ES)

Enrolled since January 2017 for at least 6 months



# Via a Wearable & Risk Assessment



## Study details

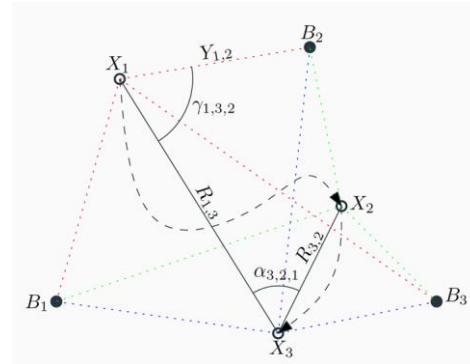
N = 42 seniors over 65 (HU, ES)

Enrolled since January 2017 for at least 6 months

Currently: multivariable logistic regression models for IPAQ (PRO) vs. wearable dataset (TechRO)



# To Phone-Based Mobility



## Study details

N = 191 participants, 6-12 months (CH)

Entropy-based recognition of (new) significant places within a week of data logging (no GPS)



Physical Health:

# Sleep



# From a Wearable...



Q: How do you sleep? What influences your sleep?



## Exercise

I need to wait an hour or two before I go to bed



## Alcohol

I dream more when I have alcohol



## Light

My husband watched TV



## Pregnancy



## Stress



## Temperature

Hard to sleep when the room is too hot



## Noise

Get used to the noise from the street



## Not Discussed

Going to bed when not sleepy (all tired)  
Late food / parties  
Late caffeine



## Family



## Not Own Bed



## No Control



## Social Pressure



## Time to Bed



## Pets

## Study details

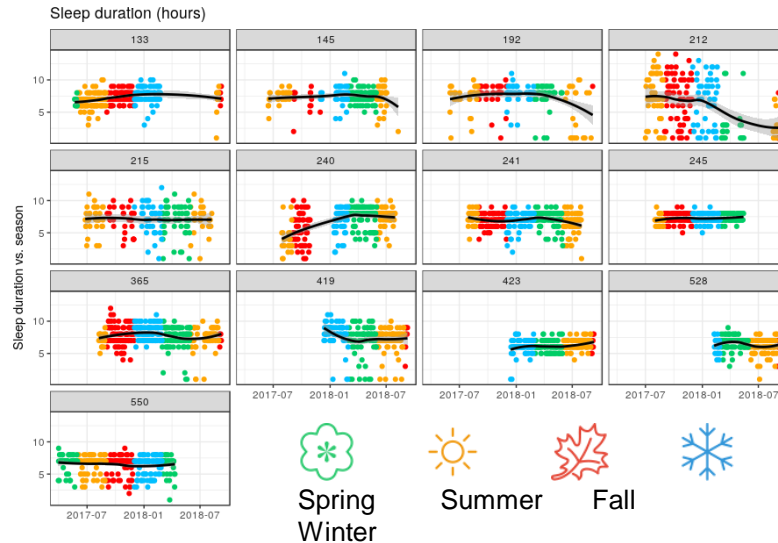
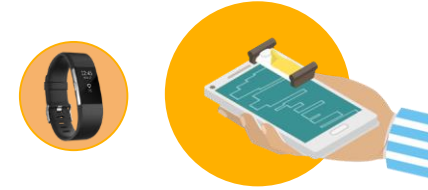
N = 6 working mothers (DK)

Up to 6 months each

User ID	Hours of sleep		User ID	Hours of sleep	
	Weekday	Weekend		Weekday	Weekend
2	5.5 +/- 13 min.	6 +/- 20 min.	5	6 +/- 18 min.	8.25 +/- 15 min.
3	7 +/- 17 min.	7.3 +/- 23 min.	7	7 +/- 15 min.	8 +/- 15 min.
4	8 +/- 10 min.	6.25 +/- 30 min.	10	6 +/- 10 min.	5.75 +/- 10 min.



# Via a Wearable & Risk Assessment



UserID	Sleep statistics			
	Mean	Standard deviation	Min	Max
133	7.26	1.20	1.0	10.0
145	7.47	1.30	2.0	11.0
192	7.45	2.18	1.0	11.0
212	6.23	3.77	1.0	14.0
215	7.11	2.09	1.0	12.0
240	6.81	2.18	1.0	10.0
241	6.94	1.26	1.0	9.0
245	7.24	0.66	5.0	9.0
365	7.76	1.53	1.0	12.0
419	7.37	2.06	1.0	11.0
423	6.16	0.94	1.0	8.0
528	6.38	1.17	1.0	9.0
550	6.47	1.38	1.0	9.0

## Study details

N = 75 seniors over 65 (HU, ES)

Enrolled since January 2017 for at least 6 months

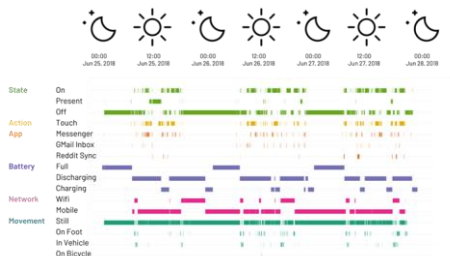
Currently: multivariable logistic regression models for PSQI (PRO) vs. wearable dataset (TechRO)



# ...Back to Phone (ON-OFF 'Sensor')



## mQoL Log



User ID	Sleep duration	Phone ON-OFF	Remark
	BASIS watch [avg±std]	Estimate [avg±std] * significantly diff	
2 (mothers)	393 +/- 10 min.	418 +/- 14 min.	
3	402 +/- 15 min.	507 +/- 16 min.*	Over
4	455 +/- 13 min.	377 +/- 34 min.*	Under
5	446 +/- 15 min.	444 +/- 25 min.	
11 (students)	429 +/- 15 min.	481 +/- 23 min.*	Over
12	473 +/- 16 min.	478 +/- 25 min.	
13	377 +/- 22 min.	377 +/- 24 min.	
14	450 +/- 15 min.	454 +/- 35 min.	
15	482 +/- 14 min.	459 +/- 24 min.	
16	478 +/- 16 min.	446 +/- 36 min.	
17	409 +/- 19 min.	378 +/- 45 min.*	Under
18	417 +/- 24 min.	374 +/- 16 min.	
19	462 +/- 16 min.	346 +/- 25 min.*	Under
20	452 +/- 29 min.	426 +/- 39 min.*	Under

## Study details



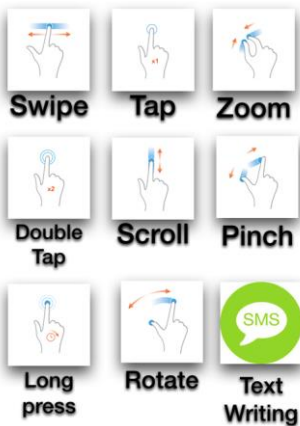
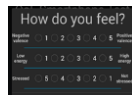
N = 14: working mothers (S2-S5) and students (S11-S20), up to 6 months each (DK)

Psychological:  
**Negative  
Feelings,  
Stress**

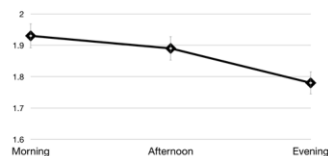




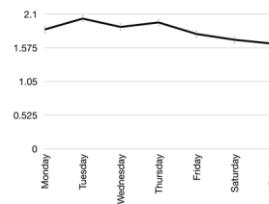
# Phone Use



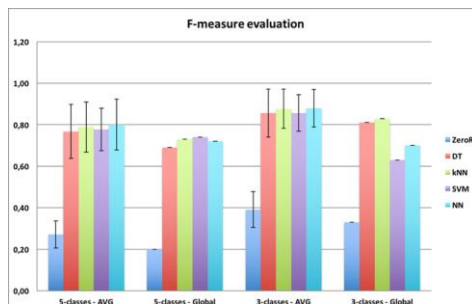
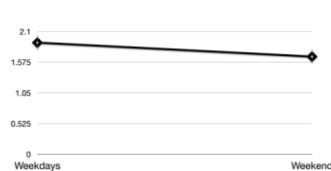
Stress - Along a Day



Stress - Per Day



Stress - Weekdays or Weekend



'Scroll' and 'Swipe' Features Ranks (*Information Gain*)

Rank	'Scroll' Features	'Swipe' Features
1	Average Size	Average Size
2	Time length	Mean distance top-left
3	Average pressure	Swipe interaction length
4	Scroll delta speed	Average touch pressure
5	Linearity as sum every point	Time length

Most Significant Features for the Classification

Rank	five-class problem	three-class problem
1	'Casual' Influence	'Word' Influence
2	'Casual' Timing Influence	Score sum activity
3	'Puzzle' Influence	'Music & Audio' Timing Influence
4	'Word' Influence	'Word' Timing Influence
5	'Word' Timing Influence	'Music & Audio' Influence

## Study details

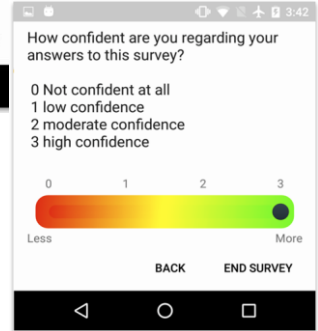
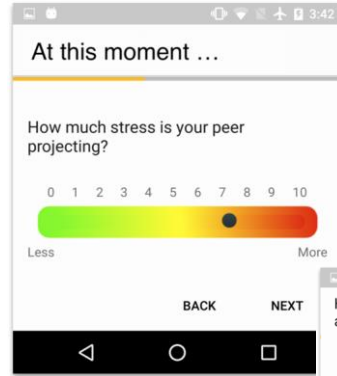
N = 38 participants, 1 month (CH)



Social Relationships:  
Personal  
Relationships  
as 'Sensors'



# Phone Self-Reports: EMA & Peer-M



		Statistics					
Participants →		S1			S5		
Peers →		S1-P1		S1-P2	S5-P1		S5-P2
Quality Metrics	recall	27	75	10	89	32	100
	gaps	15			34		
	voids		90	13		35	41
	halts	3	4	7	2	4	11
	validity	3	2	1	1	4	6
	pace	3	1	2	5	3	2
	lapse		12	2		35	26



Berocal, A., Concepcion, W., De Dominicis, S., Wac, K. (2019), *Complementing Human Behavior Assessment By Leveraging Personal Ubiquitous Devices and Social Links: Evaluation of the PeerMA Method*, JMIR mhealth and uhealth (forthcoming)

Berocal, A., Wac, K., (2018). *Peer-vasive Computing: Leveraging Peers to Enhance the Accuracy of Self-Reports in Mobile Human Studies*, Mobile Human Contributions: Workshop in conjunction with ACM UBICOMP, Singapore, October 2018.

Human Factors:

What about  
the  
Individual?



# Human Factors

'I just want my life back' (S111)



What is your current experience of Quality of Life?



What applications do you use, that support your Quality of Life?



# Human Factors

Q: Do you use technologies (smartphone/wearable) for your own health/care?

## I don't!

I don't mix my smartphone with my health [visibly angry]  
It's all in here [indicating own head]  
I do not want a phone reminds me about my disease  
I have got a [fitbit as a] gift and I dropped it

## I would...

Privacy is an issue  
It's complicated, I don't know how to use it, I am not a techie  
It's inaccurate: I have compared [fitbit] to my husband's Garmin  
and I was disappointed\* [and have dropped it]

## Study details

N = 200 participants (US)

Affinity clustering of significant factors

## I do...



### Interface design

Too complex!  
Passwords  
Notifications



### Performance

Slow!  
No sync  
Malfunctioning  
Internet is touchy



### Battery

Too short  
Carry 2 batteries  
Walked for free!



### Social Sharing

I have enough people  
judging me offline  
Doctor won't trust it



### Accuracy

Not a medical accuracy  
Accurate enough to  
recognize my efforts



### Emotions

Keeps me entertained  
I hate it when gained weight  
I get addicted



### Cost

Smartphone is a basis  
Wearables: Too Costly!



### Self-Efficacy

I like to see my progress  
I try harder  
I can always walk tomorrow



### Routines

For me when I need it  
Non-routine events most  
critical



Back to

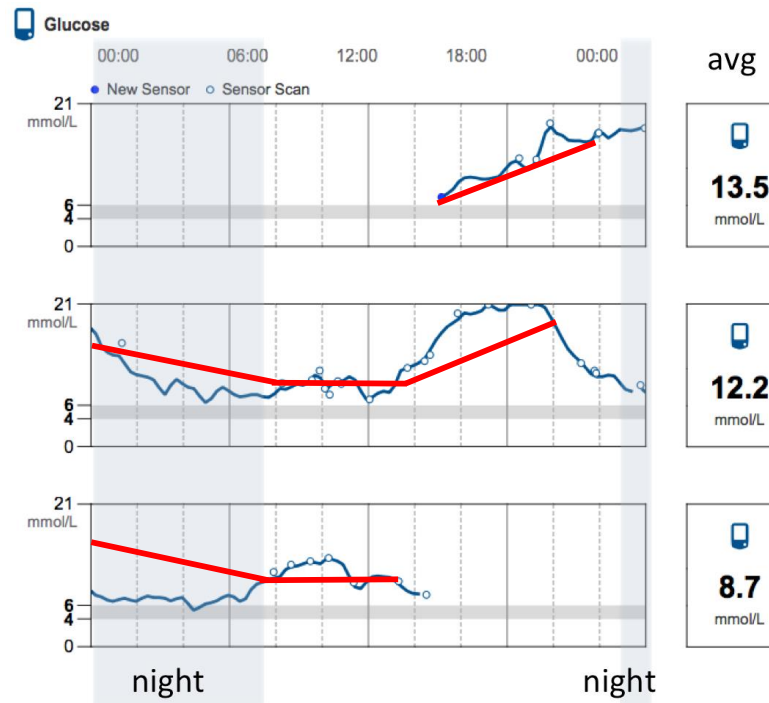
# The Big Picture



# What about my Mom?



Freestyle Libre



Red: infrequent finger pricks, 3 / day



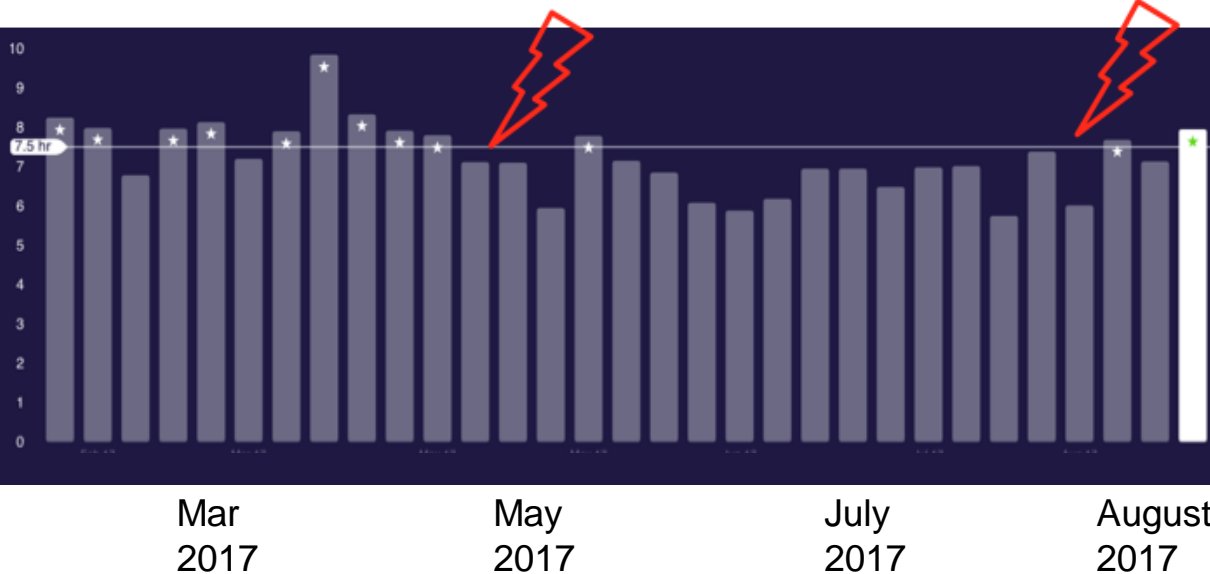
# What about my Mom?

PROs

New medication → worse sleep...

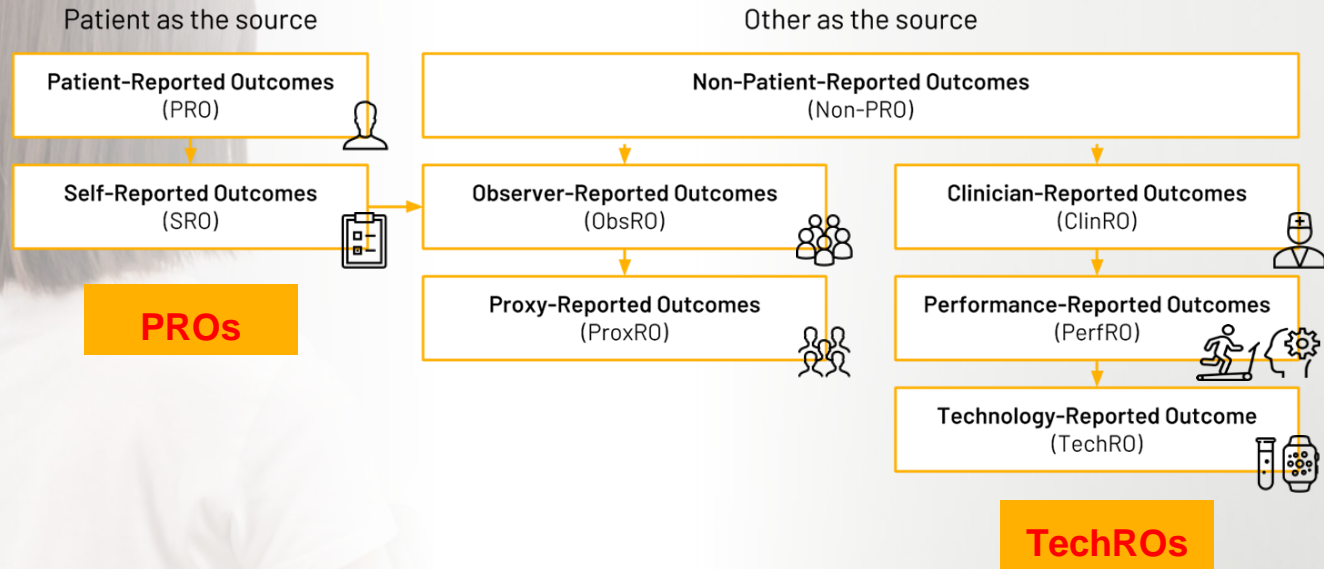


Change back to old meds



TechROs

# At the Doctor's Office



# How Can Our Research Help Others?

## ↘ Challenges

- Human factors & behaviour change
  - “I just want my life back” (S111)
  - effectiveness of feedback
- Data quality, accuracy, reliability
  - Meaningful data analysis
  - Safety & Quality of care
  - → Evidence
- Data privacy, security
  - Trust in service providers
  - Data ownership
  - EPR integration

## ↗ Opportunities

- Meaningful, actionable, high resolution (if needed) knowledge
- From routine check-up, prevention to treatment decisions, medication change, and treatment follow-up
- Future: better (self-) care and long-term QoL

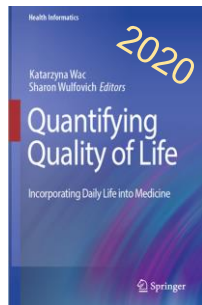


Current Research

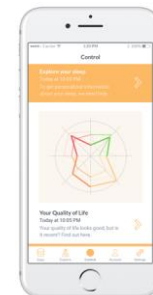
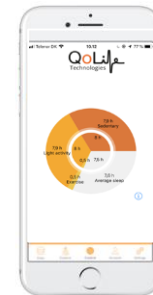
# Can it Work?

Yes.

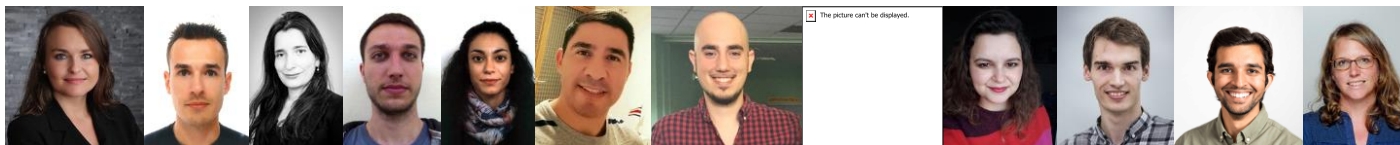




Quality of Life Technologies Lab  
qualityoflifetechnologies.org



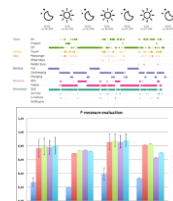
# Thank You



## Prof. Katarzyna Wac and the QoL Team

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