A Decade of Ubiquitous Computing Research in Mental Health

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Co-founder and Chief Scientific Officer

Monsenso

Research interests

- Ubiquitous Computing
- Pervasive Health
- Human-Computer Interaction
- Software Architecture

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DET SUNDHEDSVIDENSKABELIGE FAKULTET
KØBENHAVNS UNIVERSITET

MONSENSO

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2007

2009


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69° H: 75°
L: 58°
Market
Voicemail
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Browser
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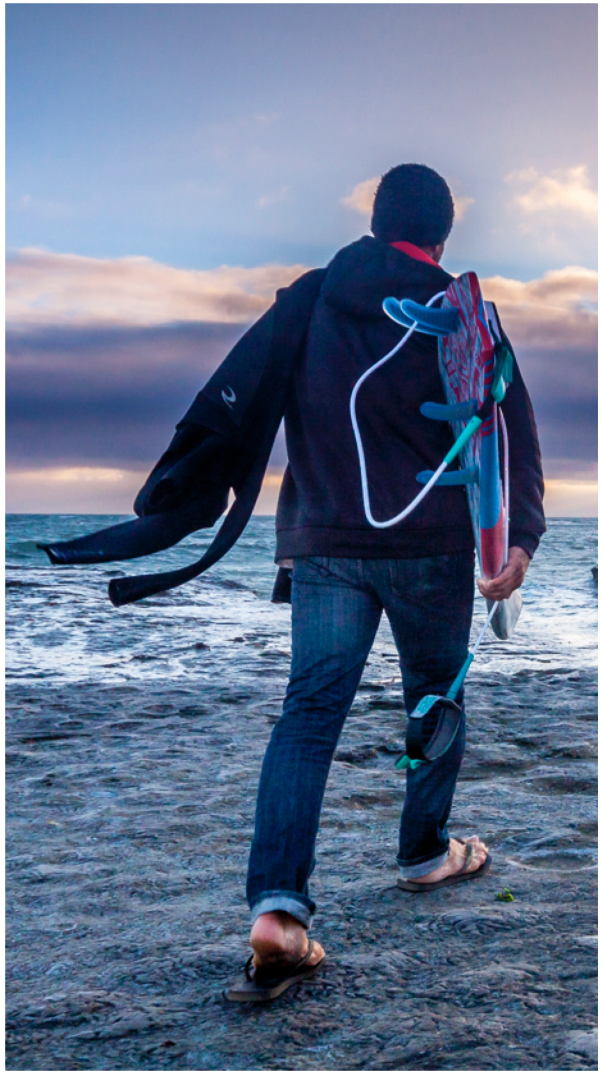
OUTLINE OF TALK

- **MONARCA** – an adventure in ubiquitous computing research in mental health

- Looking **back** at 10 years of research
  - technologies
  - technical evidence
  - clinical evidence

- Looking **ahead** at the next 10 years of research
  - from apps to platforms
  - from sensing to intervention
  - from pilot studies to clinical uptake

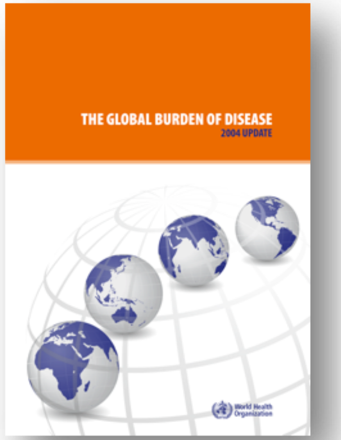



MONARCA
An adventure in ubiquitous computing research in mental health

Figure 27: Ten leading causes of burden of disease, world, 2004 and 2030

2004 Disease or injury	As % of total DALYs	Rank	Rank	As % of total DALYs	2030 Disease or injury
Lower respiratory infections	6.2	1	1	6.2	Unipolar depressive disorders
Diarrhoeal diseases	4.8	2	2	5.5	Ischaemic heart disease
Unipolar depressive disorders	4.3	3	3	4.9	Road traffic accidents
Ischaemic heart disease	4.1	4	4	4.3	Cerebrovascular disease
HIV/AIDS	3.8	5	5	3.8	COPD
Cerebrovascular disease	[illegible]	[illegible]	[illegible]	[illegible]	wer respiratory infections
Prematurity and low birth w	[illegible]	[illegible]	[illegible]	[illegible]	Hearing loss, adult onset
Birth asphyxia and birth trau	[illegible]	[illegible]	[illegible]	[illegible]	Refractive errors
Road traffic accidents	[illegible]	[illegible]	[illegible]	[illegible]	HIV/AIDS
Neonatal infections and othe	[illegible]	[illegible]	[illegible]	[illegible]	Diabetes mellitus
COPD	2.0	13	11	1.9	Neonatal infections and other[a]
Refractive errors	1.8	14	12	1.9	Prematurity and low birth weight
Hearing loss, adult onset	1.8	15	15	1.9	Birth asphyxia and birth trauma
Diabetes mellitus	1.3	19	18	1.6	Diarrhoeal diseases

"Mental health will be the largest burden for society in the 2020s" – WHO 2012



Opportunities for UbiComp in mental health?

- "A continuous multimodal monitoring is of particular importance for preventing mental disorders. A relevant example is prevention of clinical depression. An early assessment of risk factors or an early detection of negative vital signs could significantly reduce this cost through early prevention." (2010)

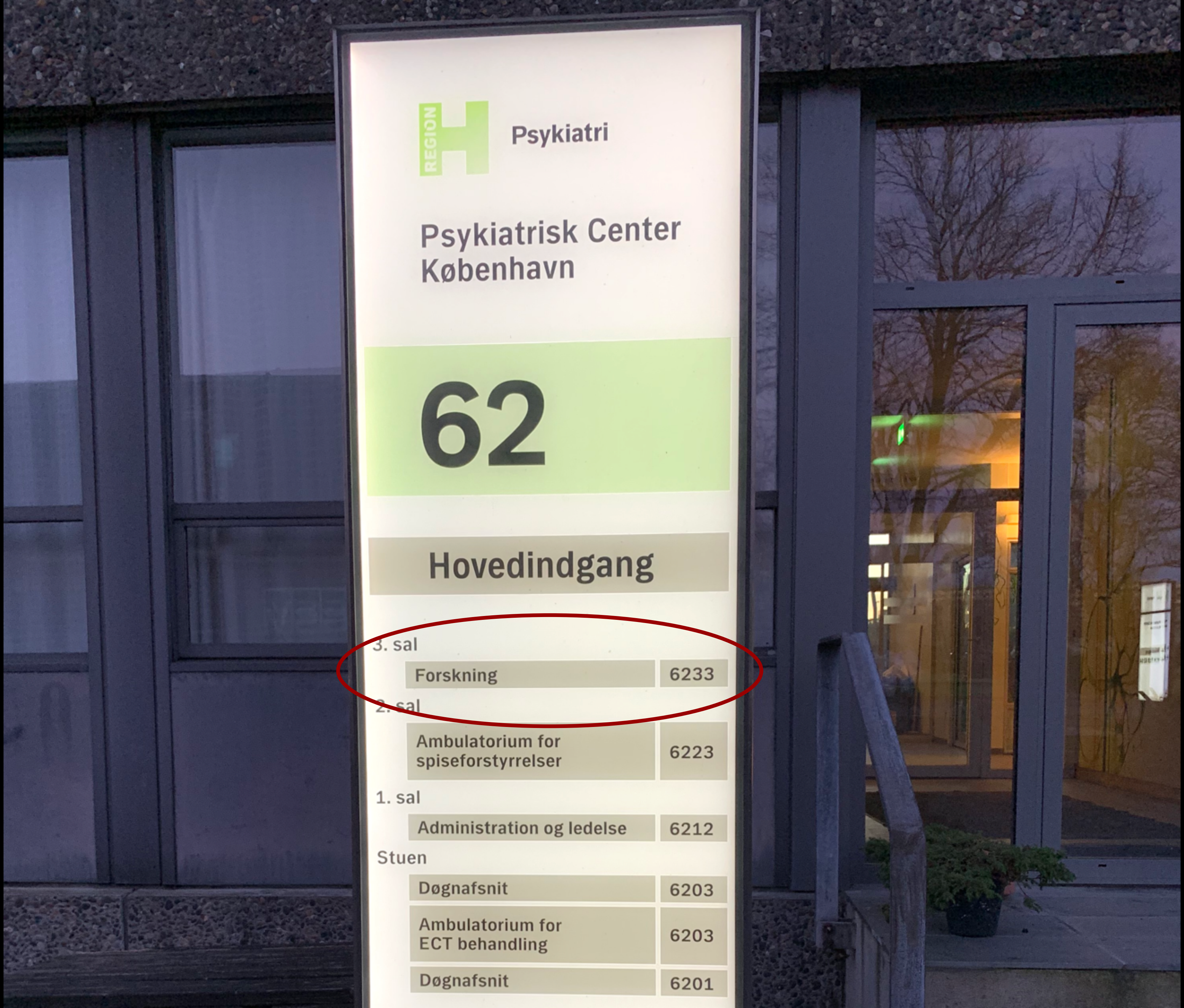
- Idea
  - mobile sensing
  - ecological momentary assessment
  - mood / episode prediction
  - psycho-education
  - clinical evaluation

Pervasive Healthcare

Paving the Way for a Pervasive, User-centered and Preventive Healthcare Model

B. Arnrich[1]; O. Mayora[2]; J. Bardram[3]; G. Tröster[1]
[1]ETH Zurich, Electronics Laboratory, Zurich, Switzerland;
[2]Create-Net, Trento, Italy;
[3]IT University of Copenhagen, Copenhagen, Denmark

Arnrich B, Mayora O, Bardram J, Tröster G. Pervasive healthcare: paving the way for a pervasive, user-centered and preventive healthcare model. *Methods Inf Med.* 2010;49(1):67-73.


REGION H
Psykiatri
Psykiatrisk Center
København
62
Hovedindgang
3. sal
Forskning 6233
2. sal
Ambulatorium for spiseforstyrrelser 6223
1. sal
Administration og ledelse 6212
Stuen
Døgnafsnit 6203
Ambulatorium for ECT behandling 6203
Døgnafsnit 6201

MONARCA

- MONARCA System
  - a personal health technology supporting the treatment of patients suffering from bipolar disorder (manio-depressive)
- EU STREP project w. 13 European partners
  - academic, industrial, clinical
  - **2010 – 2013**
- Copenhagen team
  - The Copenhagen Clinic for Affective Disorder, University Hospital of Copenhagen (”Rigshospitalet”)
  - IT University of Copenhagen

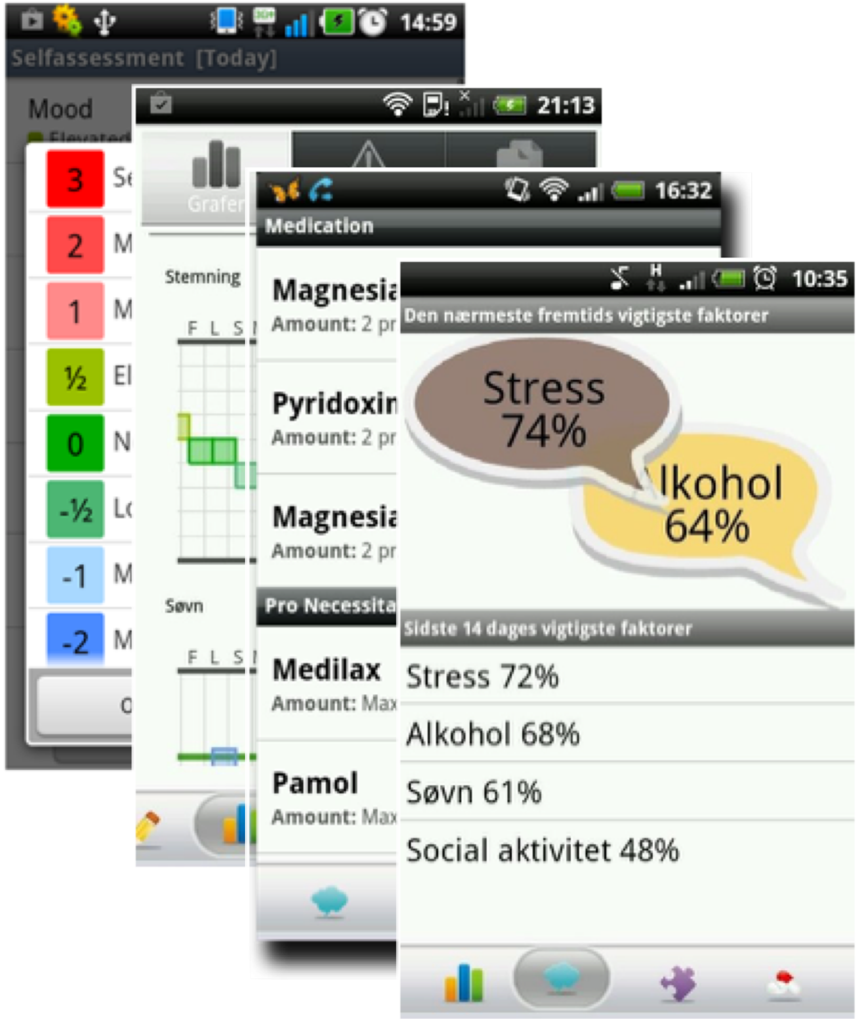
User-centered Design

- Patients and clinicians at the University Hospital of Copenhagen.
- Bi-weekly design sessions over 12 months, each with 3 hours duration
  - ~3 patients, ~3 clinicians and ~3 designers.
- Design session consisted of:
  - sketching and brainstorming
  - lengthy discussions about features
  - feedback on iterative prototyping

G Marcu, JE Bardram, S Gabrielli. A Framework for Overcoming Challenges in Designing Persuasive Monitoring Systems for Mental Illness. In *Proceedings of Pervasive Health* 2011, p.1-10, 2011

SYSTEM FEATURES

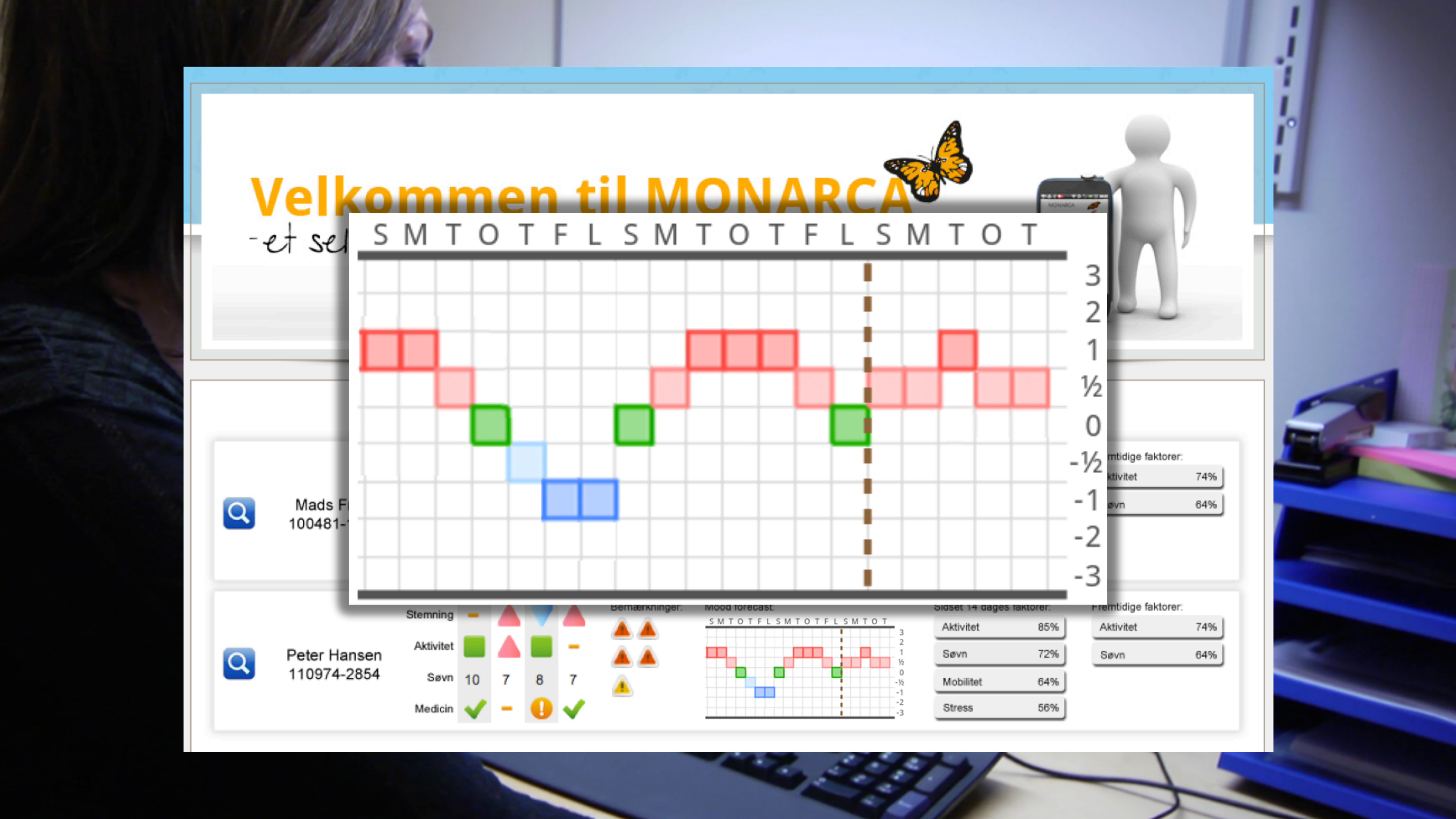
- Self-assessment (participatory sensing)
  - mood | sleep | stress | medicine | …
- Auto-assessment (opportunistic sensing)
  - physical activity | mobility | social activity | phone usage | voice
- Feedback
  - visualizations | medication | actions-to-take | triggers | early-warning-signs | impact factors
- Mood forecast
  - predict mood for next 5 days



Bardram JE, Frost M, Szanto K, Marcu G. The MONARCA self-assessment system: a persuasive personal monitoring system for bipolar patients. In: *Proceedings of the 2nd ACM SIGHIT International Health Informatics Symposium. IHI '12.* ACM; 2012:21-30.

DOUBLE LOOP

Bardram JE, Frost MM. Double-Loop health technology: Enabling socio-technical design of personal health technology in clinical practice. In: *Designing Healthcare That Works: A Sociotechnical Approach*. ; 2017.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Peter Hansen
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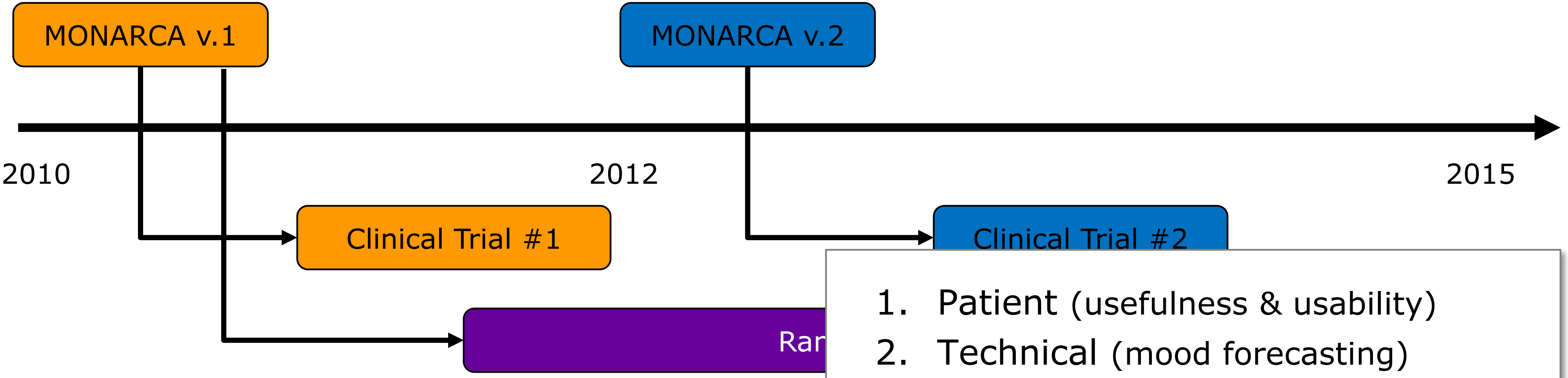
Bemærkninger:
Mood forecast:
Sidset 14 dages faktorer:
Aktivitet 85%
Søvn 72%
Mobilitet 64%
Stress 56%
Fremtidige faktorer:
Aktivitet 74%
Søvn 64%

Clinical Trials



1. Patient (usefulness & usability)
2. Technical (mood forecasting)
3. Diagnosis / Monitoring
(self-assessment vs. clinical rating)
4. Treatment (efficacy in treatment)

Usefulness & Usability

Clinical evaluations have shown that the MONARCA system

- have a very high compliance rate (87-95%)
- is considered very useful and very usable by patients and clinicians
- helps patients better manage their disease
- helps clinicians in better patient treatment

CSUQ item	*Description*	*avg.*	*sd.*
OVERALL	Overall satisfaction	2.60	1.01
SYSUSE	System usefulness	1.93	0.42
INFOQUAL	Information quality	3.32	1.10
INTERQUAL	Interface quality	2.71	0.93

Table 2. The CSUQ usability results on a Likert scale from 1–7: 1=Highly agree; 7=Highly disagree.

	System Usefulness		*Perceived Usefulness*	
	avg.	*sd.*	*avg.*	*sd.*
Disease Mgmt.	3.16	1.55	2.16	1.02
Self-assessment	2.21	1.06	1.73	0.72
Visualization	2.22	1.39	1.66	0.78
Alarms	2.34	1.44	2.13	1.88
Triggers	3.59	1.31	2.71	1.02
Early Warning Signs	3.44	1.18	2.36	0.78
Actions to take	3.25	1.52	2.34	0.88
Medication	4.30	1.50	3.17	1.51
Website	3.00	1.70	2.63	1.76

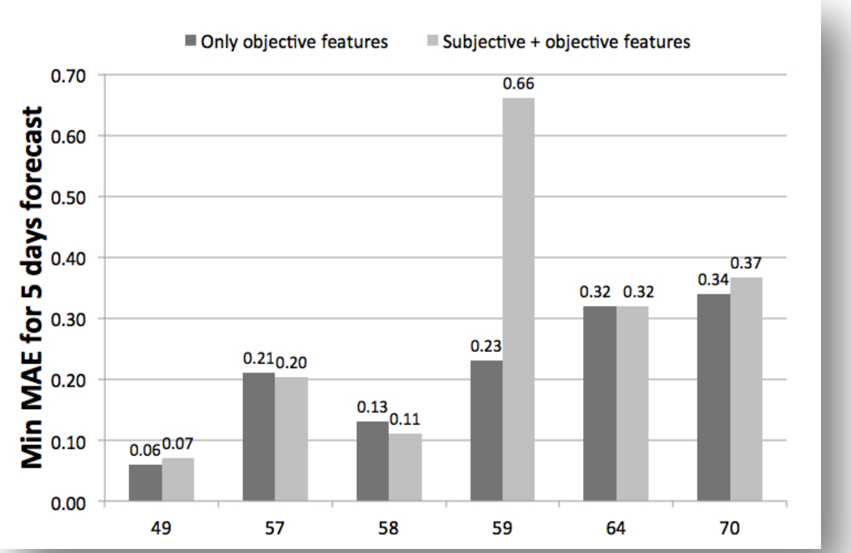
Table 3. Questionnaire results on 'System Usefulness' as used in the trial period and 'Perceived Usefulness' in the future. Users reported on a 1–7 point Liket scale on the question of "The MONARCA system is useful for ...": 1=Highly agree; 7=Highly disagree.

Bardram JE, Frost M, Szanto K, Faurholt-Jepsen M, Vinberg M, Kessing LV. Designing mobile health technology for bipolar disorder: a field trial of the monarca system. In: *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM; 2013.

Mood Forecasting

- Mood Forecasting
  - mean-absolute-error (MAE) is between 0.06 and 0.66 (±3 scale)
  - in 4 out of 6 cases, MAE is lower w. only objective data
  - i.e. mood forecasting can be done using only <u>objective data</u>

- Impact Factors – Top 5
  - Activity | Stress | Sleep
  - Phone Usage* | Social Activity*



Data features	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Activity	3	1	1	1	0	0	0	0	0	0	0	0	0	0
Stress	1	1	2	0	1	0	1	0	0	0	0	0	0	0
Sleep	0	1	0	3	2	0	0	0	0	0	0	0	0	0
Phone Usage*	1	0	3	0	0	0	1	0	0	0	0	1	0	0
Social Activity*	0	2	0	1	0	0	1	0	1	0	1	0	0	0
Irritability	0	0	0	0	2	2	0	1	1	0	0	0	0	0
Cognitive Problems	0	1	0	1	0	1	1	0	1	0	0	0	1	0
Physical Activity*	1	0	0	1	0	0	1	0	1	1	0	1	0	0
Alcohol	0	0	0	1	0	1	1	2	0	0	0	0	1	0
Warning Signs	0	0	0	0	1	1	0	1	1	1	0	0	1	0
Mobility*	0	0	0	0	0	1	0	2	0	1	1	1	0	0
Mixed Mood	0	0	0	0	0	0	1	1	1	0	0	0	0	3
Medicine Changed	0	0	0	0	0	0	0	1	0	0	2	1	1	1
Medicine Taken	0	0	0	0	0	0	0	0	0	0	0	2	2	2

Table 2. Ranking of the correlation between Impact Factors (features) and the mood score. The objective features are marked with *.

Frost M, Doryab A, Faurholt-Jepsen M, Kessing L, Bardram JE. Supporting disease insight through data analysis: Refinements of the MONARCA self-assessment system. In: *UbiComp 2013 - Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing.*

Clinical Correlations

- Clinical Study
  - N=61 | 6 m | 19 m
  - HDRS-17 (depression) and YMRS (manic)
  - 400+ clinical ratings
- Results
  - significant correlatio
    mood and HDRS &
  - significant correlatio
    activity and clinical ratings on both HDRS & YMRS
    - especially when grouping into 'affective states' (3 states)

"Smartphones provide an **easy** and **objective** way to monitor illness activity and could serve as an **electronic biomarker** for depressive and manic symptoms in patients with bipolar disorder."

Table 2. Correlations between self-monitored data[a] collected using smartphones and depressive and manic symptoms measured using the HDRS-17 and YMRS, respectively[b]

	Unadjusted			Adjusted[c]		
	Coefficient	95% CI	p-value	Coefficient	95% CI	p-value
Mood (scale: –3 to +3)						
HDRS-17	–0.055	–0.067 to –0.042	<0.001	–0.058	–0.071 to –0.045	<0.001
HDRS-17 sub-item 1 (mood)	–0.38	–0.45 to –0.30	<0.001	–0.38	–0.46 to –0.31	<0.001
YMRS	0.39	0.016–0.062	<0.001	0.039	0.017–0.062	<0.001
YMRS sub-item 1 (mood)	0.38	0.24–0.53	<0.001	0.38	0.24–0.53	<0.001
Sleep (hours/night)						
HDRS-17	–0.017	–0.048 to 0.014	0.28	–0.02	–0.052 to 0.011	0.21
YMRS	–0.047	–0.088 to –0.005	0.027	–0.047	–0.088 to –0.006	0.026
Activity (scale: –3 to +3)						
		–0.053 to –0.020	<0.001	–0.042	–0.059 to –0.025	<0.001
		0.022–0.072	<0.001	0.048	0.023–0.072	<0.001
		0.029–0.065	<0.001	0.046	0.027–0.064	<0.001
		–0.013 to 0.033	0.34	0.012	–0.013 to 0.037	0.35

epression Rating Scale–17 item; YMRS = Young Mania Rating Scale.
ed for the current day and three days before ratings with the HDRS-17 and YMRS, as
ast four days.

rated objective data [a] collected using smartphones and *affective states* according to the HDRS-17 and YMRS presented as categorical data [b], respectively[c]

	Unadjusted			Adjusted[d]		
	Coefficient	95% CI	p-value	Coefficient	95% CI	p-value
Incoming calls (no./day)						
Asymptomatic versus mania	0.95	0.076–1.82	0.033	0.97	0.10–1.84	0.029
Duration incoming calls (sec/day)						
Asymptomatic versus hypomania	729.51	334.87–1124.13	<0.001	768.10	374.34–1161.86	<0.001
Outgoing calls (no./day)						
Asymptomatic versus hypomania	2.09	0.38–3.80	0.016	2.08	0.37–3.80	0.017
Duration outgoing calls (sec/day)						
Asymptomatic versus moderate to severe depression	452.17	149.56–754.78	0.003	421.57	111.55–731.60	0.008
Asymptomatic versus hypomania	623.15	173.63–1072.67	0.007	641.53	190.41–1092.65	0.005
Outgoing text messages (no./day)						
Asymptomatic versus mania	4.14	–0.38 to 8.67	0.073	4.42	–0.10 to 8.95	0.055

CI = confidence interval; HDRS-17 = Hamilton Depression Rating Scale–17 item; YMRS = Young Mania Rating Scale.
[a]Averages of the smartphone data were analyzed for the current day and three days before ratings with the HDRS-17 and YMRS, as these rating scales address symptoms over the last four days.
[b]Scores on the HDRS-17 or YMRS ≤ 7 were defined as asymptomatic. Scores on the HDRS-17 or YMRS from 7 to 14 were defined as mild depression or hypomania. Scores on the HDRS-17 or YMRS ≥ 14 were defined as moderate to severe depression or mania.
[c]Analyses including all study participants; total N = 61.
[d]Adjusted for age and sex.

Faurholt-Jepsen M, Vinberg M, Frost M, Christensen EM, Bardram JE, Kessing LV. Smartphone data as an electronic biomarker of illness activity in bipolar disorder. *Bipolar Disorders*. 17(1): 2015

Voice Feature Analysis

- Collection of voice features in naturalistic setting
  - N=28 | 12 w
  - HDRS-17 (depression) and YMRS (manic)
  - 179 clinical ratings (fortnightly)
  - openSMILE (emolarge)
- Classification results (user-specific (s.d.)
  - depressive state : 70% (0.13)
  - manic state : 61% (0.04)
- Classification accuracy were not significantly increased when combining voice features with automatically generated objective data

"Voice features collected in naturalistic settings using smartphones may be used as objective state markers in patients with bipolar disorder."

Table 3. Classification of affective states based on voice features

	Accuracy (s.d.)[a]
User-dependent models[d]	
A depressive state[e] versus a euthymic state[f] ($n=13$)	0.70 (0.13)
A manic or mixed state[g] versus a euthymic state[f] ($n=3$)	0.61 (0.04)
User-independent models[d]	
A depressive state[e] versus a euthymic state[f]	0.68 (0.006)
A manic or mixed state[g] versus a euthymic state[f]	0.74 (0.005)

Abbreviations: HAMD, Hamilton Depression Rating Scale 17-item; YMRS, Young Mania Rating Scale. Data positive+true negative)/ (positive+negative). [b]Defined as sensitivity = true positive/positive. [c]Defined as speci models: building a model from each individual patient. User-independent models: building a common model and a YMRS score < 13. [f]Defined as HAMD < 13 and YMRS < 13. [g]Defined as a YMRS score ⩾ 13.

M Faurholt-Jepsen, J Busk, M Frost, M Vinberg, EM Christensen, O Winther, JE Bardram and LV Kessing. Voice analysis as an objective state marker in bipolar disorder. *Transl Psychiatry* (2016) 6

Randomized Clinical Trial

RCT Hypotheses

- "Daily electronic monitoring using an online interactive Smartphone […] reduces the severity of depressive and manic symptoms and stress, and increases social functioning, quality of life, adherence to medication and cognitive functioning."

78 patients, randomized 1:1

- N=78 | bipolar disorder | 18–60 years
- intervention group = phone w. "active" MONARCA app
- placebo group = phone w. "passive" MONARCA app
- 6 month period

Open Access — Protocol

BMJ Open

Daily electronic self-monitoring of subjective and objective symptoms in bipolar disorder—the MONARCA trial protocol (MONitoring, treAtment and pRediCtion of bipolAr disorder episodes): a randomised controlled single-blind trial

Maria Faurholt-Jepsen,[1] Maj Vinberg,[1] Ellen Margrethe Christensen,[1] Mads Frost,[2] Jakob Bardram,[2] Lars Vedel Kessing[1]

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ABSTRACT

Introduction: Electronic self-monitoring of affective symptoms using cell phones is suggested as a practical and inexpensive way to monitor illness activity and identify early signs of affective symptoms. It has never been tested in a randomised clinical trial whether electronic self-monitoring improves outcomes in bipolar disorder. We are conducting a trial testing the effect of using a Smartphone for self-monitoring in bipolar disorder.
Methods: We developed the MONARCA application for Android-based Smartphones, allowing patients suffering from bipolar disorder to do daily self-monitoring—including an interactive feedback loop between patients and clinicians through a web-based interface. The effect of the application was tested in a parallel-group, single-blind randomised controlled trial so far including 78 patients suffering from bipolar disorder in the age group 18–60 years who were given the use of a Smartphone with the MONARCA application (intervention group) or to the use of a cell phone without the application (placebo group) during a 6-month study period. The study was carried out from September 2011. The outcomes were changes in affective symptoms (primary), social functioning, perceived stress, self-rated depressive and manic symptoms, quality of life, adherence to medication, stress and cognitive functioning (secondary and tertiary).
Analysis: Recruitment is ongoing.
Ethics: Ethical permission has been obtained.
Dissemination: Positive, neutral and negative findings of the study will be published.
Registration details: The trial is approved by the Regional Ethics Committee in The Capital Region of Denmark (H-2-2011-056) and The Danish Data Protection Agency (2013-41-1710). The trial is registered at ClinicalTrials.gov as NCT01446406.

INTRODUCTION

Bipolar disorder is a common and complex mental disorder with a prevalence of 1–2%[1 2] and accounts as one of the most important causes of disability at age 15–44 years worldwide.[1] Bipolar disorder is a long-term and persistent illness with need for treatment over many years.[3] The disorder is associated with a high risk of relapse and hospitalisation and the risk of relapse increases along with the number of previous episodes.[4–6] Many patients do not recover from previous psychosocial function and the cognitive disturbances are also prevalent during remitted phases.[7] It is well documented from randomised clinical trials (RCT) that the risk of a new episode in bipolar disorder can be reduced significantly by treatment with lithium or other mood stabilisers.[8] Further, the prophylactic effect of medical treatment may be enhanced by psychoeducation or cognitive behavioural therapy.[9] However, results from naturalistic follow-up studies suggest that the progressive development of the disease is not prevented in clinical practice with the present treatments.[4–6 10] The major reasons for the decreased effect of interventions in clinical practice are delayed intervention for prodromal depressive and manic episodes[11 12] as well as decreased medical adherence.[13–15]

During the last decades, there has been an organisational shift in paradigm from inpatient to outpatient treatment in healthcare, and in bipolar disorder there is an emerging shift in illness paradigm from a

Faurholt-Jepsen M, Vinberg M, Christensen EM, *et al*. *BMJ Open* 2013;**3**:e003353. doi:10.1136/bmjopen-2013-003353 1

Faurholt-Jepsen M, Vinberg M, Christensen EM, Frost M, Bardram JE, Kessing LV. Daily electronic self-monitoring of subjective and objective symptoms in bipolar disorder - the MONARCA trial protocol (MONitoring, treAtment and pRediCtion of bipolAr disorder episodes): a randomised controlled single-blind trial. *BMJ Open*. 2013;3.

RCT Results

- Compliance = 93% (7% retrospective)
- Primary outcomes – changes in affective symptoms
  - no significant effects of using a smartphone for daily self-monitoring on depressive or manic symptoms
  - subgroup analysis show that patients in the intervention group experienced significantly more depressive symptoms but fewer manic symptoms
- Secondary outcome
  - increase in stress (but due to increase in depression)
  - no effect in psycho-social functioning, quality-of-life, or coping
- Tertiary outcome
  - no effect in medicine adherence

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ORIGINAL ARTICLE

Daily electronic self-monitoring in bipolar disorder using smartphones – the MONARCA I trial: a randomized, placebo-controlled, single-blind, parallel group trial

M. Faurholt-Jepsen[1]*, M. Frost[2], C. Ritz[3], E. M. Christensen[1], A. S. Jacoby[1], R. L. Mikkelsen[1], U. Knorr[1], J. E. Bardram[2], M. Vinberg[1] and L. V. Kessing[1]

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Background. The number of studies on electronic self-monitoring in affective disorder and other psychiatric disorders is increasing and indicates high patient acceptance and adherence. Nevertheless, the effect of electronic self-monitoring in patients with bipolar disorder has never been investigated in a randomized controlled trial (RCT). The objective of this trial was to investigate in a RCT whether the use of daily electronic self-monitoring using smartphones reduces depressive and manic symptoms in patients with bipolar disorder.

Method. A total of 78 patients with bipolar disorder according to ICD-10 criteria, aged 18–60 years, and with 17-item Hamilton Depression Rating Scale (HAMD-17) and Young Mania Rating Scale (YMRS) scores ≤17 were randomized to the use of a smartphone for daily self-monitoring including a clinical feedback loop (the intervention group) or to the use of a smartphone for normal communicative purposes (the control group) for 6 months. The primary outcomes were differences in depressive and manic symptoms measured using HAMD-17 and YMRS, respectively, between the intervention and control groups.

Results. Intention-to-treat analyses using linear mixed models showed no significant effects of daily self-monitoring using smartphones on depressive as well as manic symptoms. There was a tendency towards more sustained depressive symptoms in the intervention group ($B = 2.02$, 95% confidence interval −0.13 to 4.17, $p = 0.066$). Sub-group analysis among patients without mixed symptoms and patients with presence of depressive and manic symptoms showed significantly more depressive symptoms and fewer manic symptoms during the trial period in the intervention group.

Conclusions. These results highlight that electronic self-monitoring, although intuitive and appealing, needs critical consideration and further clarification before it is implemented as a clinical tool.

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Key words: Bipolar disorder, electronic self-monitoring, feedback loop, randomized controlled trial, smartphone, the MONARCA I trial.

Introduction

Bipolar disorder is a long-term and heterogeneous illness with a continued need for treatment and naturalistic follow-up studies suggest that the progressive development of bipolar disorder is not prevented with the present treatment options (Kessing *et al.* 2004; Baldessarini *et al.* 2010). Major reasons for the insufficient effect of present treatment options in clinical practice are delayed intervention for prodromal depressive and manic symptoms as well as decreased adherence to mood stabilizer treatment (Kessing *et al.* 2007; Morriss *et al.* 2007). During the last decade there has been an emerging shift in illness paradigm from a focus on affective episodes in bipolar disorder to an increasing focus on inter-episodic mood instability (MacQueen *et al.* 2003; Bonsall *et al.* 2012). Many patients with bipolar disorder continue to experience subsyndromal mood swings on a daily basis, with euthymic patients with bipolar disorder suffering more from mood instability than healthy subjects (Paykel *et al.* 2006; Henry *et al.* 2008; Bonsall *et al.* 2012). Mood instability at a subclinical level is reported to be associated with impaired global functioning and

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(Email: maria@faurholt-jepsen.dk)

Faurholt-Jepsen M, Frost M, et al. Daily electronic self-monitoring in bipolar disorder using smartphones - the MONARCA I trial: a randomized, placebo-controlled, single-blind, parallel group trial. *Psychological Medicine* Cambridge University Press; 2015;1–14.

Status

- ✓ High compliance, useful & usable
- ✓ Mood forecasting & clasification promising
- ✓ Correlations to clinical ratings
- ✗ Clinical evidence on treatment

Technical University of Denmark

LOOKING BACK AT A DECADE OF RESEARCH

Mental Health Tech is gaining a lot of momentum

- Quite a lot of technologies have been designed
  - in research projects
  - as commercial applications

- A number of clinical researchers are using and evaluating mental health tech
  - pilot studies
  - randomized clinical trials
  - meta-studies of RCTs

- Governmental and Regulatory bodies are picking up
  - US : National Institute of Mental Health (NIMH) / Federal Drug Administration (FDA)
  - UK : National Health Services (NHS)
  - DK : Danish Health Authority

Technology and the Future of Mental Health Treatment

Introduction

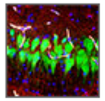
Technology has opened a new frontier in mental health support and data collection. Mobile devices like cell phones, smartphones, and tablets are giving the public, doctors, and researchers new ways to access help, monitor progress, and increase understanding of mental wellbeing.

Mobile mental health support can be very simple but effective. For example, anyone with the ability to send a text message can contact a crisis center. New technology can also be packaged into an extremely sophisticated app for smartphones or tablets. Such apps might use the device's built-in sensors to collect information on a user's typical behavior patterns. If the app detects a change in behavior, it may provide a signal that help is needed before a crisis occurs. Some apps are stand-alone programs that promise to improve memory or thinking skills. Others help the user connect to a peer counselor or to a health care professional.

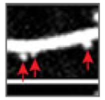
Join A Study

- Studies for Adults
- Studies for Children

Science News



Limited Brain Functions Preserved Postmortem



Ketamine Reverses Neural Changes Associated with Depression

Fifth Annual BRAIN Initiative Investigators Meeting

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Status

Recruitment:

- Not yet recruiting
- Recruiting
- Enrolling by invitation
- Active, not recruiting
- Suspended
- Terminated
- Completed
- Withdrawn
- Unknown status†

Expanded Access:

Eligibility Criteria

Age: years OR

Age Group:

- Child (birth–17)
- Adult (18–64)
- Older Adult (65+)

Sex:

- All
- Female
- Male

Showing: 1-10 of **227** studies 10 studies per page

Show/Hide Columns

Row	Saved	Status	Study Title	Conditions	Interventions	Locations
1		Recruiting	Addressing **Mental Health** of Cancer Patients and Caregivers Using a Mobile **App** Suite	• **Mental Health Wellness** 1 • Depression • Anxiety	• Behavioral: IntelliCare + Phone Coaching	• University of Virginia Charlottesville, Virginia, United States
2		Completed	Can **Mental Health Apps** Work in the Real World? A Feasibility Pilot Study.	• MDD	• Other: Problem Solving Therapy • Behavioral: Evolution • Behavioral: Basic **health** push **app**	• Web-based; log onto www.brightenstudy.com/spa for details San Francisco, California, United States
3		Completed	SME(Sharing, **Mind** & Enjoyment) **App** for Adolescents	• **Mental Health Wellness** 1	• Behavioral: SME **App**	• School of Public **Health**, The University of Hong Kong Hong Kong, Hong Kong
4		Not yet recruiting	Feasibility and Efficacy of a Digital **Mental Health** Intervention for Teen Wildfire Survivors	• Disaster • PTSD • Adolescent Behavior • (and 3 more...)	• Behavioral: Sonoma Rises	• Stanford University Palo Alto, California, United States
5		Not yet recruiting NEW	Examining the Feasibility of the Ask RoSE Mobile **Mental Health** Application	• **Mental Health Wellness** 1 • Anxiety	• Behavioral: Mobile **Mental Health App**	
6		Recruiting	Evaluating a Mobile **App** for Students Seeking Care for Depression and Anxiety at Harvard University **Health** Services	• Depression, Anxiety	• Behavioral: 7 Cups Mobile **App** • Behavioral: Bliss Mobile **App**	• Harvard University **Health** Services Cambridge, Massachusetts, United States
7		Recruiting	The Efficacy of Using a Smartphone **App** to Support Shared Decision Making in People With a Diagnosis of Schizophrenia	• Schizophrenia, Schizotypal and Delusional Disorders	• Device: Momentum **app**	• OPUS Amager Amager, Denmark • OPUS Ballerup Ballerup, Denmark • OPUS Glostrup Brøndby, Denmark • (and 2 more...)
8		Completed	The Efficacy of the Alcooquizz **App** to Reduce Hazardous Alcohol Consumption	• Alcohol Consumption	• Behavioral: Alcooquizz	• Centre for Addiction and **Mental Health** Toronto, Ontario, Canada
9		Not yet recruiting	PTSD Help - a Randomized Controlled Trial of a PTSD Mobile **Health App**	• PTSD • Post Traumatic Stress Disorder	• Device: mHealth intervention, PTSD Help **app**.	

What have been designed?

- Systematic review of technologies (not studies!)
  - as published in peer-reviewed literature
  - 2009-2019
  - mobile & wearable technologies (‘ubicomp’)
  - severe mental illness (SMI) as defined by ICD-10
- Results
  - 45 systems – 32 clinical | 13 non-clinical
- “Typology”
  - sensing
  - clinical assessment
  - predictive modelling
  - intervention models
  - user interaction

A Decade of Ubiquitous Computing Research in Mental Health

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I. Introduction

Mental health represents a huge disease and societal burden [62] and the episodic nature of traditional healthcare models is considered to be sub-optimal to improve chronic mental conditions [22]. ’Anytime and everywhere’ ubiquitous technology was seen early on as an opportunity for addressing continuous monitoring, diagnosis, and care of mental health conditions, thereby enabling an extension of care delivery beyond the reach of traditional healthcare. In particular, mobile and wearable technologies with their ability to track behavioral, physiological and contextual signals has been seen as a potential enabler of a continuous symptom monitoring and personalized intervention [2], [32].

This year it is ten years since smartphones[1] became widely available as an open platform and have since then been used for creating novel personalized health applications. The early mobile phones with sensing capabilities had already sparked the inspiration of some pioneering UbiComp researchers [35], [47] who saw the opportunity for improving mental healthcare. Subsequently, there was a growing interest in exploiting the advantages of mobile and wearable technologies to unobtrusively sense and analyze human behaviour, assess and predict mental health status, and to deliver feedback and intervention when needed in mental health [2].

In this paper, we look back on the last decade of Ubicomp research in mental health. We do this by focusing on the different technologies and systems, which have been built and evaluated. Hence focus is more on technical contributions rather than clinical studies. Initially, we present a review of 45 systems presented over the years and investigate which disease they are designed for, and their technical features in terms of sensing, prediction, intervention, and clinical assessment. Then we present the results of an interview with nine core researchers in the field asking for their retrospective and prospective view on the status of ubicomp research for mental health. Combining this input with our review helps us discuss current challenges in terms of technology, study reproducibility, and clinical evidence and adoption, as well as provide an outlook for future research for the next decade.

[1] The first iPhone appeared in 2007 and the first stable Android phone in 2009

II. Methods

In contrast to a traditional systematic literature review of published papers – which is the standard approach in medical sciences – this review focuses on research-based technologies and systems for mental health. Hence, the “unit” of the review is not a study but a technology or a system, which has been published in one or more papers.

We used a snowballing approach to the review. Snowballing refers to using the reference list of a paper and the citations to the paper to identify additional papers [67]. Using the references and the citations respectively is referred to as backward and forward snowballing. In this review, we identified an initial “seed” set of nine technologies to be the starting point (marked in bold in Table I). We also carefully reviewed other systematic review papers to look for systems to include [18], [17], [51], [49], [56]. Once we had a list of technologies, we contacted a set of core researchers (listed in the acknowledgement) in the field to ask for verification of the list and annotations.

The review was conducted by applying the following inclusion criteria: (i) research-based technologies published in scientific peer-reviewed papers; (ii) mobile and wearable technology; (iii) technologies for severe mental illness (SMI) as defined by ICD-10 on “Mental and behavioural disorders” [44] including schizophrenia, affective/mood disorders (incl. depression and bipolar disorder), neurotic and stress-related disorders (incl. stress, PTSD, phobia and anxiety), disorders of psychological development (incl. autism and ADHD), aging-related mental disorders (Alzheimer’s, dementia), and substance abuse. Technologies focusing on more general mental well-being and technologies only evaluated on healthy subjects were also included, but treated separately. An iterative coding process was then applied to label; (i) the year the system was first published, (ii) disease classification (according to ICD-10) and specific disorder(s), (iii) geographical region (US, EU, Asia, Australia); (iv) technology topic and type of technology (mobile, wearable), and (v) the size of the clinical study in terms of number of participants (N) and duration (T) in days. The review was done in late 2018 and early 2019.

III. Results

Table I shows the list of identified technologies represented as a) systems with a clear SMI focus (upper section of Table I) and b) systems focusing on general mental well-being and/or

TABLE I

UBIQUITOUS COMPUTING SYSTEMS AND TECHNOLOGIES IN MENTAL HEALTH. SYSTEMS USED AS SEED ARE MARKED IN BOLD.

System (N=42)	Year	ICD10 SMI	Disorder(s)	Region	Topics	Technology	Study (N/T)	References
Clinical focus (N=32)								
PsychLog	2010	NEU	Stress, PTSD	EU	SEN;INT	WEAR;MOB	100 / 270	[25]
LifeShirt	2010	SKIZ;MOOD	Skizophrenia, Bipolar	US	SEN	WEAR	28 / 1	[41]
Empath	2011	MOOD	Depression	US	SEN	MOB	1 / 14	[16]
Mobilyze!	2011	MOOD	Depression	US	SEN;PRE;CAS	MOB	7 / 56	[9]
A-CHESS	2011	SUB	Alcohol abuse	US	SEN;INT	MOB	280 / 365	[29]
MONARCA	2012	MOOD	Bipolar	EU	UI;SEN;PRE	MOB	12 / 98	[5], [4]
Moodbuster	2012	MOOD	Depression	EU	UI;INT;CAS	WEAR	52 / 30	[61]
MOSOCO	2012	DEV	Autism	US	INT;UI	MOB	12 / 49	[21]
AGATE	2012	SUB	Alcohol abuse	US	UI;INT	MOB	105 / 56	[59]
StudentLife	2013	MOOD	Depression	US	SEN;CAS	MOB	48 / 70	[66]
MoodRhythm	2013	MOOD	Bipolar	US	SEN;INT;UI	MOB	7 / 28	[63], [40]
MONARCA^2	2014	MOOD	Bipolar	EU	SEN;PRE	MOB	12 / 48	[26], [27]
BigBlackDog	2014	MOOD	Depression	US	SEN	MOB	3 / 120	[20]
ParentGuardian	2014	DEV	ADHD	US	SEN;UI	MOB	10 / 14	[45]
PSYCHE	2015	MOOD	Bipolar	EU	SEN	WEAR;MOB	26 / 1	[28]
PurpleRobot	2015	MOOD	Depression	US	SEN;UI;CAS	MOB	18 / 14	[50]
MoodTraces	2015	MOOD	Depression	EU	SEN;PRE;CAS	MOB	28 / 14	[10]
Dem@Care	2015	ORG	Dementia	EU	SEN;UI	WEA	n/a / n/a	[8]
Mindful Moods	2015	MOOD	Depression	US	CAS;SEN	MOB	13 / 30	[60]
LifeRhytm	2016	MOOD	Depression	US	SEN;PRE;CAS	MOB	79 / n/a	[23]
SIMBA	2016	MOOD	Bipolar	US	SEN;PRE;CAS	MOB	13 / 360	[7]
AMoSS	2016	MOOD	Bipolar	EU	SEN;CAS	MOB;WEAR	50 / n/a	[54]
NEVERMIND	2016	MOOD	Depression	EU	SEN;UI	WEAR;MOB	15 / n/a	[36]
MOOS	2016	MOOD	Depression	EU	SEN;INT;CAS	MOB	126 / 14	[64]
CrossCheck	2016	SKIZ	Schizophrenia	US	SEN;PRE	MOB	21 / 180	[65]
SleepSight	2016	SKIZ	Schizophrenia	EU	SEN	MOB;WEAR	16 / 56	[33]
MOBERO	2016	DEV	ADHD	EU	UI;CAS	MOB	13 / 14	[57]
DEMOS	2016	MOOD;NEU	Depression, Anxiety	US	SEN;CAS	MOB,WEAR	72 / n/a	[12]
MedLink	2016	MOOD	Depression	US	UI;CAS;INT	MOB	11 / 56	[14]
PocketSkill	2018	DEV;MOOD	Depression, Anxiety, B	US	UI;INT;CAS	MOB	73 / 28	[55]

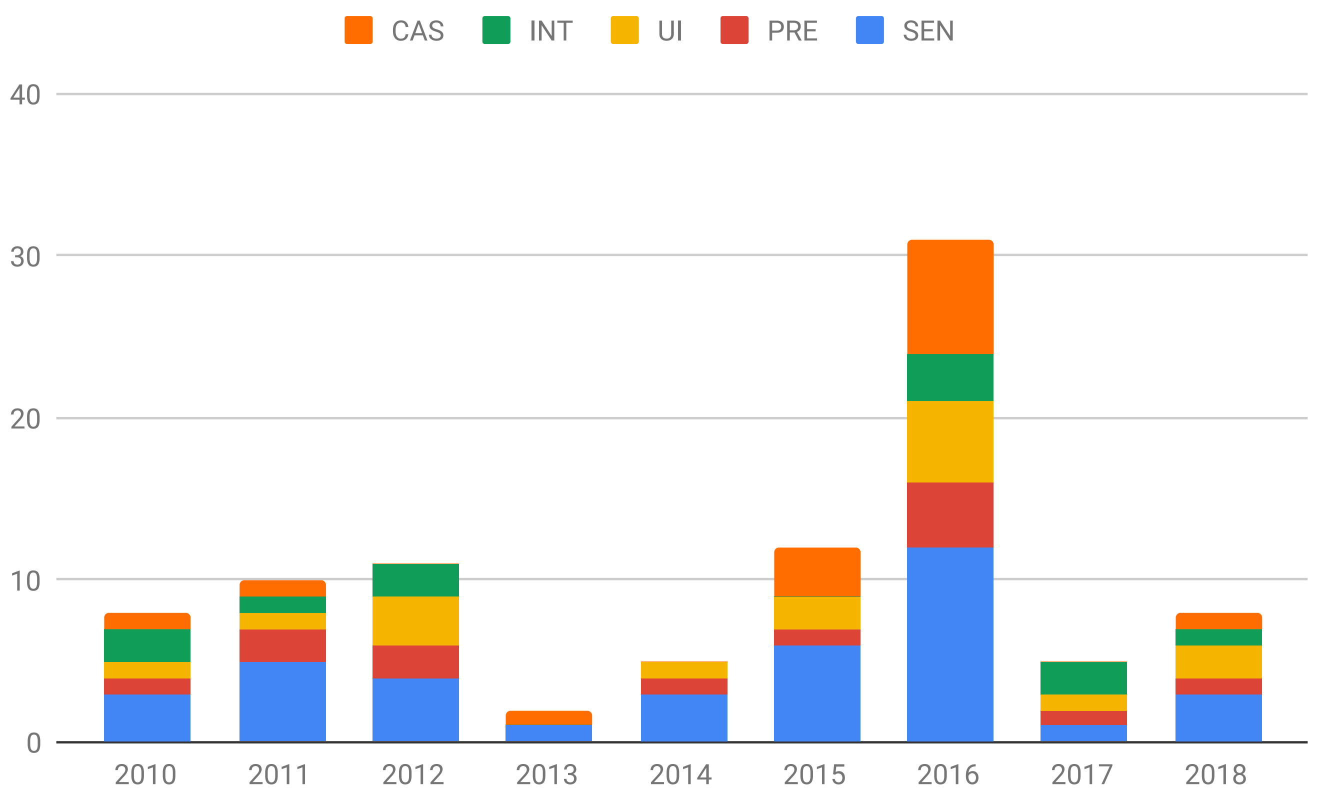


Fig. 2. Historical overview of the number of systems and their technology focus.

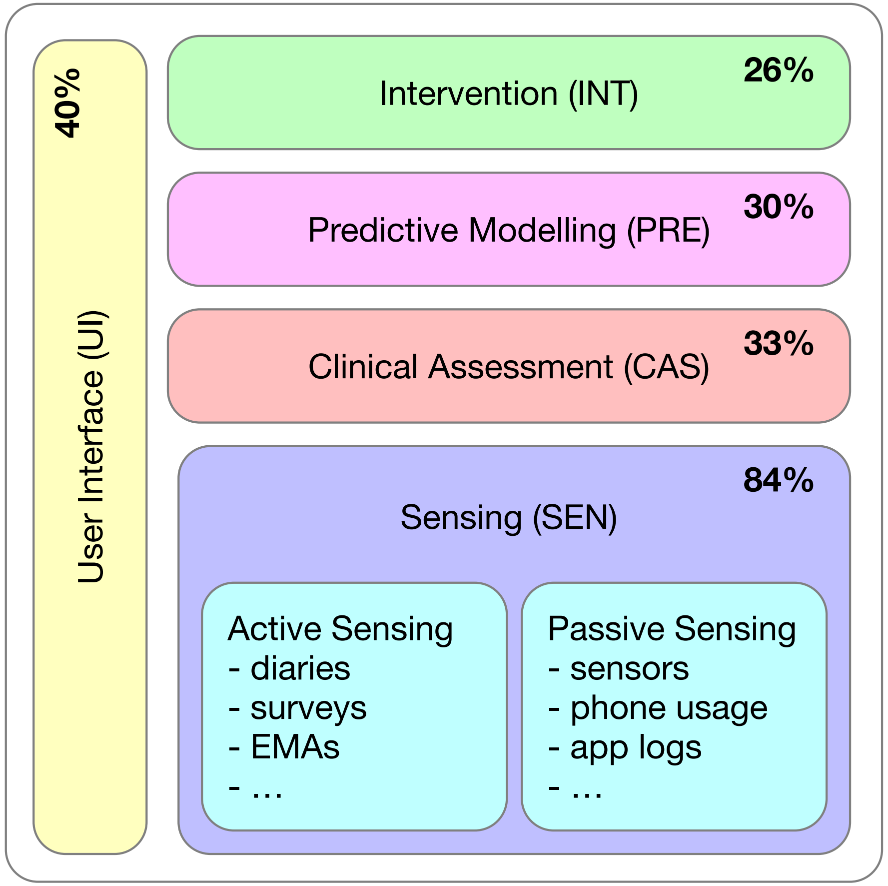


Fig. 1. Technology topics and the number of systems focusing on each technology in percentage. Since most systems focus on more than one technology, the sum is greater than 100%.

TABLE II
SMI FOCUS OF SYSTEMS ACCORDING TO ICD-10. SINCE SOME SYSTEMS SUPPORTS MORE THAN ONE ICD-10 CODE, THE SUM I GREATER THAN 100%.

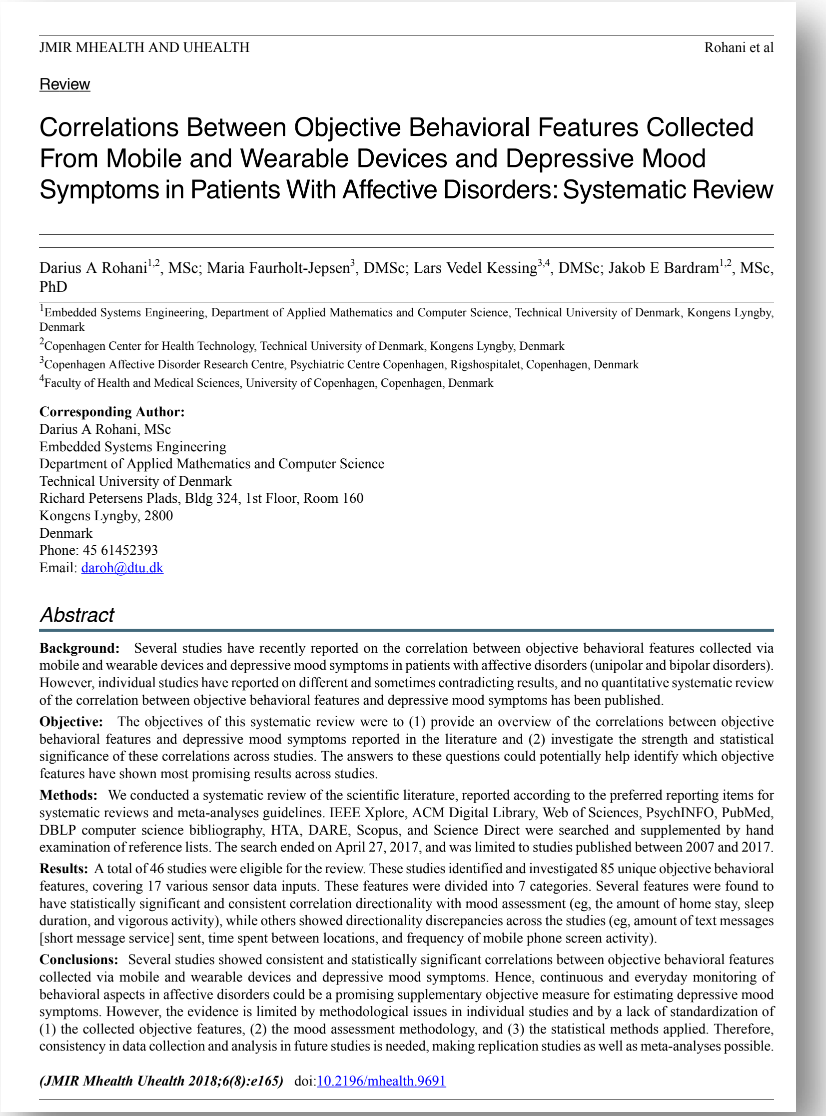
Label	ICD-10		N	%
ORG	F00-F09	Organic, including symptomatic, mental disorders	1	2%
SUB	F10-F19	Mental and behavioural disorders due to psychoactive substance use	2	4%
SKIZ	F20-F29	Schizophrenia, schizotypal and delusional disorders	4	9%
MOOD	F30-F39	Mood (affective) disorders	25	56%
NEU	F40-F48	Neurotic, stress-related and somatoform disorders	5	11%
BEH	F50-F59	Behavioural syndromes associated with physiological disturbances and physical factors	0	0%
PDIS	F60-F69	Disorders of adult personality and behaviour	1	2%
RETA	F70-F79	Mental retardation	0	0%
DEV	F80-F89	Disorders of psychological development	5	11%
CHLD	F90-F98	Behavioural and emotional disorders with onset in childhood and adolescence	0	0%
N/A		Unspecified mental disorder or healthy subjects	8	18%

Sensing & Mood Symptoms

- Systematic review
  - behavioral features
    - collected from mobile and wearable devices
  - depressive mood symptoms
  - patient w. affective disorders
    - major depression
    - bipolar disorder
- 2,644 unique papers identified
  - 929 full papers screened
  - 46 papers included

- Studies divided into
  - clinical (i.e. diagnosed)
  - non-clinical (”healthy individuals”)

Rohani AD, Faurholt-Jepsen M, Kessing VL, Bardram EJ. Correlations Between Objective Behavioral Features Collected From Mobile and Wearable Devices and Depressive Mood Symptoms in Patients With Affective Disorders: Systematic Review. *JMIR Mhealth Uhealth*. 2018;6(8):e165.



JMIR MHEALTH AND UHEALTH Rohani et al

Review

Correlations Between Objective Behavioral Features Collected From Mobile and Wearable Devices and Depressive Mood Symptoms in Patients With Affective Disorders: Systematic Review

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Abstract

Background: Several studies have recently reported on the correlation between objective behavioral features collected via mobile and wearable devices and depressive mood symptoms in patients with affective disorders (unipolar and bipolar disorders). However, individual studies have reported on different and sometimes contradicting results, and no quantitative systematic review of the correlation between objective behavioral features and depressive mood symptoms has been published.

Objective: The objectives of this systematic review were to (1) provide an overview of the correlations between objective behavioral features and depressive mood symptoms reported in the literature and (2) investigate the strength and statistical significance of these correlations across studies. The answers to these questions could potentially help identify which objective features have shown most promising results across studies.

Methods: We conducted a systematic review of the scientific literature, reported according to the preferred reporting items for systematic reviews and meta-analyses guidelines. IEEE Xplore, ACM Digital Library, Web of Sciences, PsychINFO, PubMed, DBLP computer science bibliography, HTA, DARE, Scopus, and Science Direct were searched and supplemented by hand examination of reference lists. The search ended on April 27, 2017, and was limited to studies published between 2007 and 2017.

Results: A total of 46 studies were eligible for the review. These studies identified and investigated 85 unique objective behavioral features, covering 17 various sensor data inputs. These features were divided into 7 categories. Several features were found to have statistically significant and consistent correlation directionality with mood assessment (eg, the amount of home stay, sleep duration, and vigorous activity), while others showed directionality discrepancies across the studies (eg, amount of text messages [short message service] sent, time spent between locations, and frequency of mobile phone screen activity).

Conclusions: Several studies showed consistent and statistically significant correlations between objective behavioral features collected via mobile and wearable devices and depressive mood symptoms. Hence, continuous and everyday monitoring of behavioral aspects in affective disorders could be a promising supplementary objective measure for estimating depressive mood symptoms. However, the evidence is limited by methodological issues in individual studies and by a lack of standardization of (1) the collected objective features, (2) the mood assessment methodology, and (3) the statistical methods applied. Therefore, consistency in data collection and analysis in future studies is needed, making replication studies as well as meta-analyses possible.

(JMIR Mhealth Uhealth 2018;6(8):e165) doi:10.2196/mhealth.9691

Table 1. Summary of the included studies with nonclinical samples of participants.

Reference	Technology used	Participants (N=1189), n		Participant age (years), mean (SD)	Study duration (days)	Mood scale
		Male	Female			
Asselbergs et al, 2016 [15]	Android; Funf	5	22	21.1 (2.2)	36	10p mood
Baras et al, 2016 [40]	Android; EmotionStore	9	1	N/A[a]	14	BRUMS[b]
Becker et al, 2016 [41]	Android; Funf	5	22	N/A	42	Mood
Ben-Zeev et al, 2015 [42]	Android	37	10	22.5	70	PHQ-9[c]
Berke et al, 2011 [43]	Multisensor (waist)	4	4	85.3 (4.1)	10	CES-D[d]
Canzian and Musolesi, 2015 [9]	Android; MoodTraces	15	13	31	71	PHQ-8[e]
Cho et al, 2016 [44]	Phone records	234	298	57	N/A	BDI-21[f]
Chow et al, 2017 [45]	Android	35	37	19.8 (2.4)	17	DASS-21[g]
DeMasi et al, 2016 [46]	Android	17	27	N/A	56	BDI-21
Edwards and Loprinzi, 2016 [47]	Digi-Walker Pedometer	16	23	21.82	7	PHQ-9
Farhan et al, 2016 [17]	Android or iOS; LifeRhythm	21	58	18-25[h]	N/A	PHQ-9
Mark et al, 2016 [48]	Fitbit flex	20	20	N/A	12	Affect balance
Matic et al, 2011 [16]	Windows M. 6.5; MyExperience	6	3	28.4 (2.8)	7	rPOMS[i]
Mehrotra et al, 2016 [49]	Android	25[j]	N/A	N/A	30	PHQ-8
Mestry et al, 2015 [14]	Android	1	1	22	34	DASS21
Pillai et al, 2014 [50]	Actigraph	10	29	19.55 (3.2)	7	BDI-21
Saeb et al, 2015 [7]	Android; Purple robot	8	20	28.9 (10.1)	14	PHQ-9
Saeb et al, 2016 [39]	Android; Studentlife	38	10	N/A	70	PHQ-9

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N=20

April 2019

Table 2. Summary of the included studies with clinical samples of participants diagnosed with unipolar (UD) or bipolar (BD) disorder.

Reference	Technology used	Participants (N=3094), n		Clinical diagnosis	Participant age (years), mean (SD)	Study duration (days)	Mood scale
		Male	Female				
Abdullah et al, 2016 [53]	Android; MoodRhythm	2	5	BD	25-64[a]	28	SRM II-5[b]
Alvarez-Lozano et al, 2014 [11]	Android; Monarca	18[c]	N/A[d]	BD	N/A	150	7p mood
Beiwinkel et al, 2016 [22]	Android; SIMBA	8	5	BD	47.2 (3.8)	365	HDRS[e]
Berle et al, 2010 [54]	Actigraph	10	13	UD	42.8 (11)	14	Group difference
Dickerson et al, 2011 [55]	iOS; Empath	0	1	UD	83	14	10p mood
Doryab et al, 2016 [18]	Android	3	3	UD	>18[f]	20	CES-D[g]
Faurholt-Jepsen et al, 2012 [56]	Actiheart	8	12	UD	45.2 (12)	3	Group difference
Faurholt-Jepsen et al, 2015 [57]	Actiheart	7	11	UD	45.6 (11.1)	3	HDRS-17
Faurholt-Jepsen et al, 2016 [58]	Android; Monarca	9	19	BD	30.3 (9.3)	84	HDRS-17
Faurholt-Jepsen et al 2014 [10]	Android; Monarca	5	12	BD	33.4 (9.5)	90	HDRS-17
Faurholt-Jepsen et al, 2015 [26]	Android; Monarca	20	41	BD	29.3 (8.4)	182	HDRS-17
Faurholt-Jepsen et al, 2016 [6]	Android; Monarca	11	18	BD	30.2 (8.8)	84	HDRS-17
Gershon et al, 2016 [59]	Actigraph	14	23	BD	34.4 (10.4)	46	Group difference
Gonzales et al, 2014 [60]	Actigraph	15	27	BD	41.0 (11.2)	7	IDS-C-30[h]
Grünerbl; 2015 [61]	Android	2	8	BD	33-48	84	7p mood
Guidi et al, 2015 [20]	Android	0	1	BD	36	98	mood state
Hauge et al, 2011 [62]	Actigraph	14	11	UD	42.9 (10.7)	14	Group difference
Krane-Gartiser et al, 2014 [63]	Actigraph	5	7	BD	39.9 (15.6)	1	Group difference
Loprinzi and Mahoney, 2014 [64]	Actigraph (hip)	1261	1313	UD	46.3	7	Group difference

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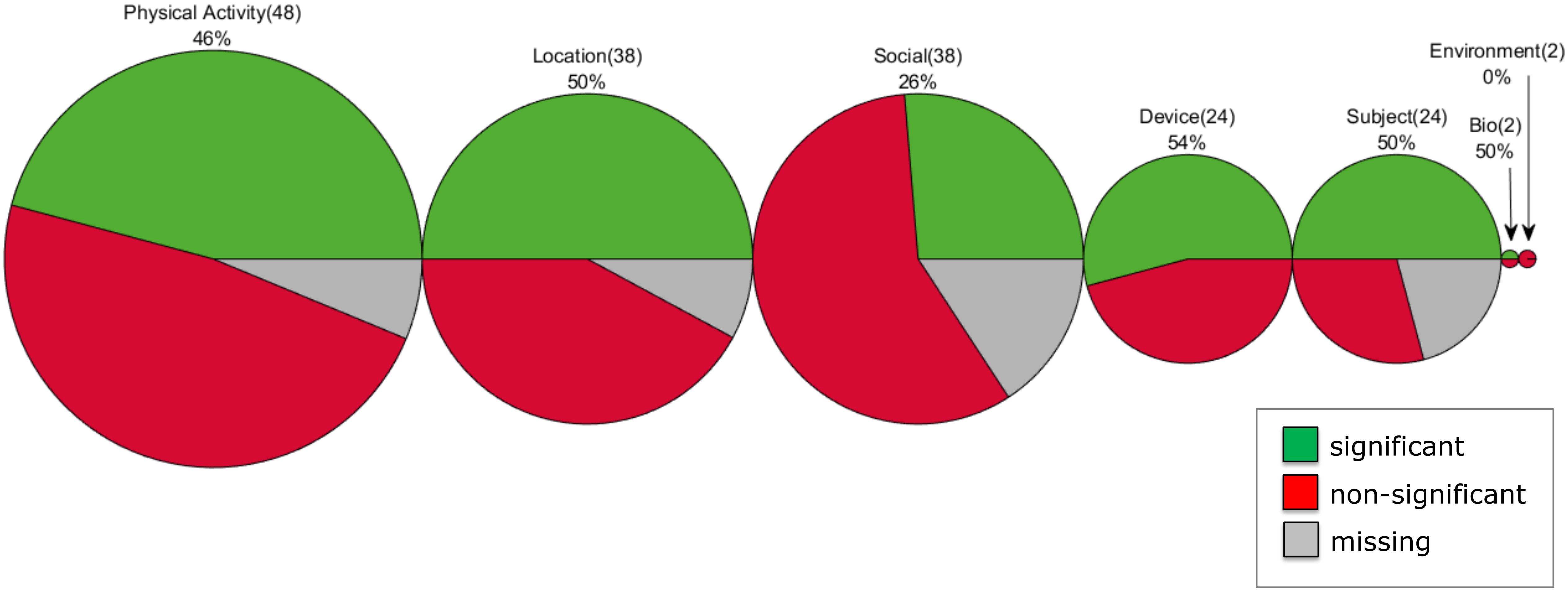
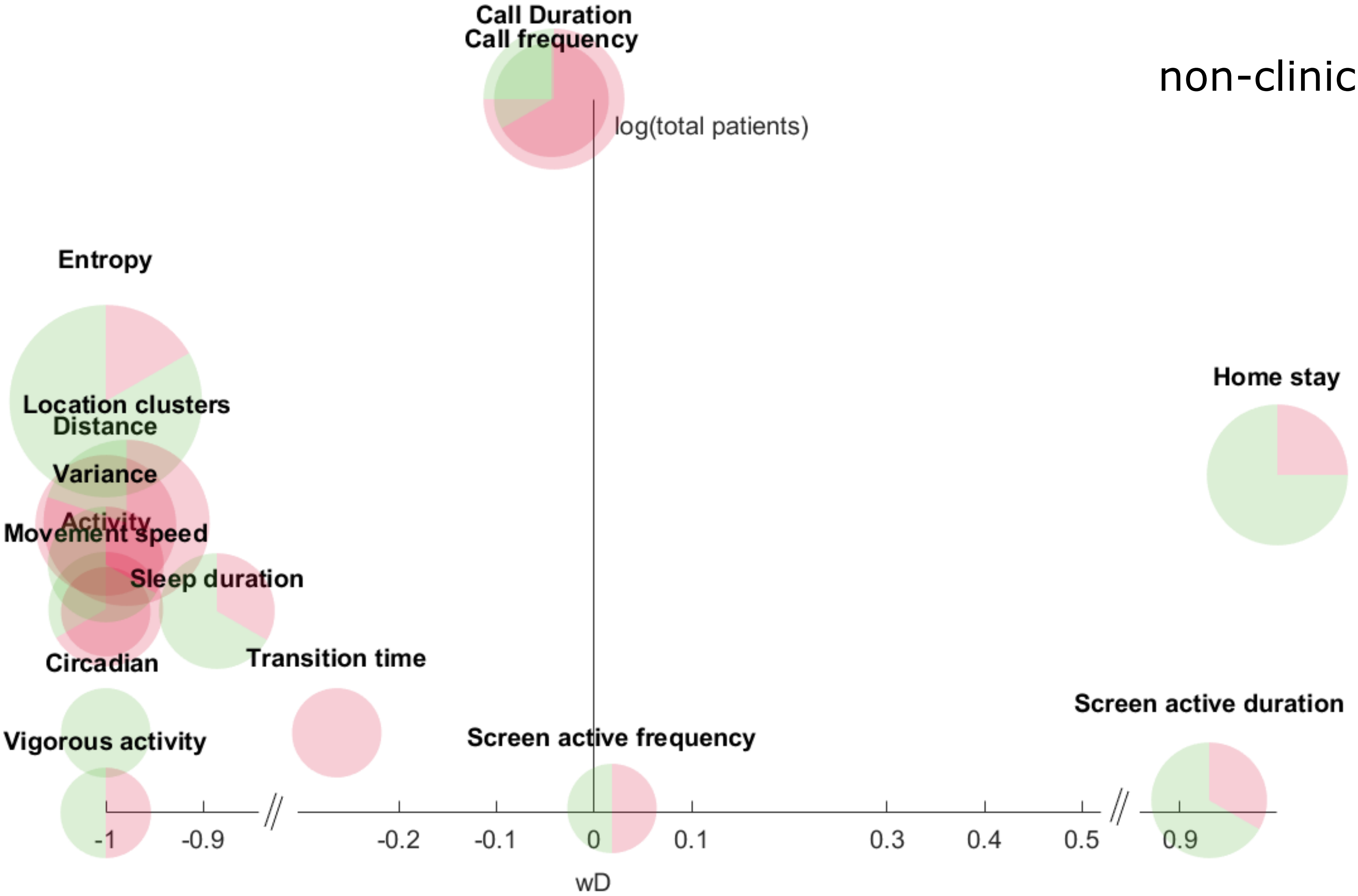
N=26

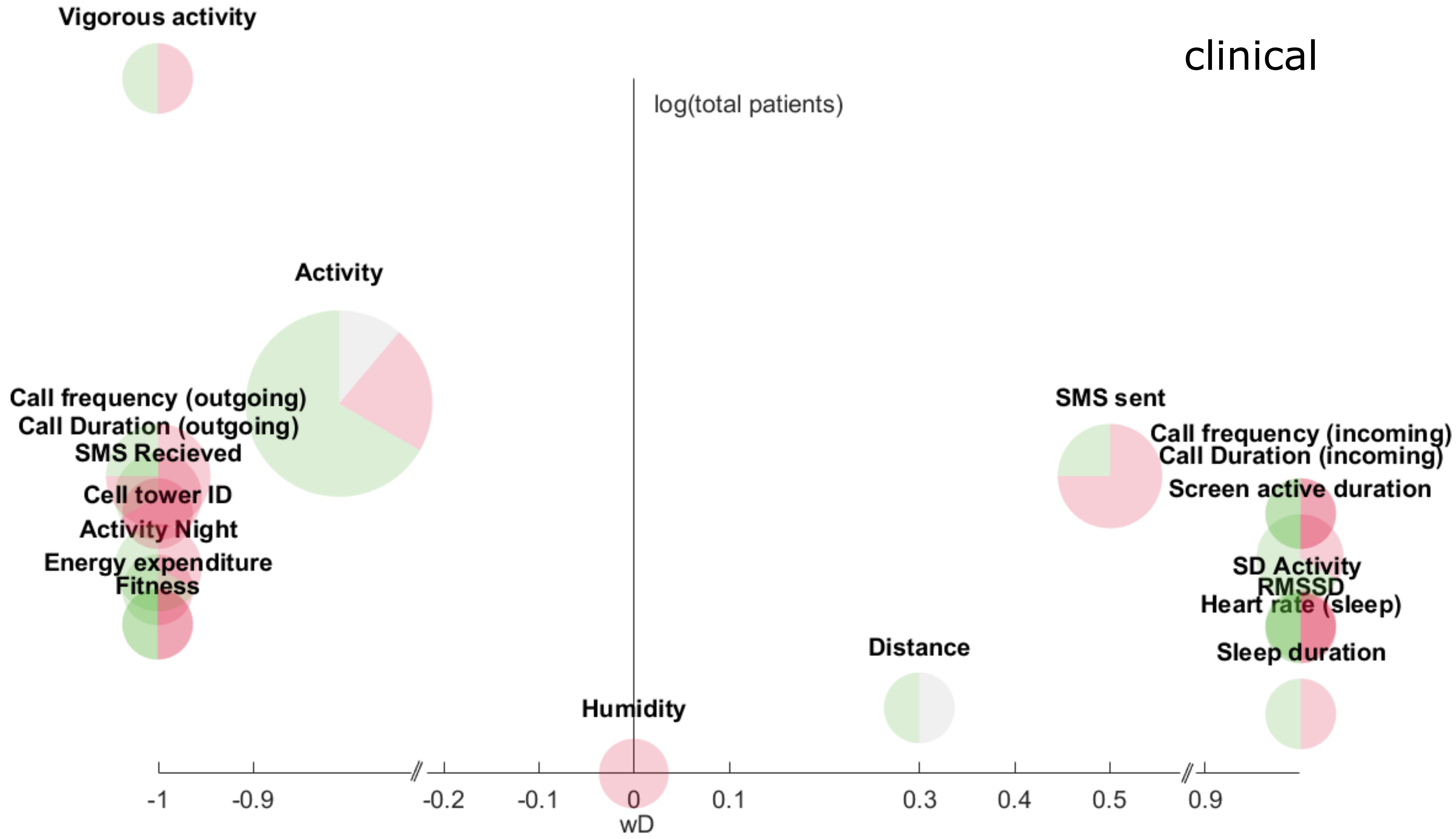
April 2019

Feature Categories



non-clinical




clinical
log(total patients)
Vigorous activity
Activity
Call frequency (outgoing)
Call Duration (outgoing)
SMS Recieved
Cell tower ID
Activity Night
Energy expenditure
Fitness
SMS sent
Call frequency (incoming)
Call Duration (incoming)
Screen active duration
SD Activity
RMSSD
Heart rate (sleep)
Sleep duration
Distance
Humidity
-1
-0.9
-0.2
-0.1
0
0.1
0.3
0.4
0.5
0.9
wD

However, …

1. Standardized **data collection** and **features extraction** methods
   – the way that physical activity, social activity, and mobility features based on accelerometer and GPS data are extracted should be standardized across studies.
2. Standardized **mood assessment** tools
   – a wide range of clinical (n=11) and nonclinical (n=9) mood rating scales were used
   – hard to compare correlations across studies when such different scales are used.
3. Standardized **statistical correlation** methodology
   – studies applied more than 11 different methods for correlation values, with different time windows.

?!

Meta-review of Efficacy

- 18 RCTs
- 22 apps
- 4-24 weeks intervention
- 7 different depression scales (!)


RESEARCH REPORT

The efficacy of smartphone-based mental health interventions for depressive symptoms: a meta-analysis of randomized controlled trials

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The rapid advances and adoption of smartphone technology presents a novel opportunity for delivering mental health interventions on a population scale. Despite multi-sector investment along with wide-scale advertising and availability to the general population, the evidence supporting the use of smartphone apps in the treatment of depression has not been empirically evaluated. Thus, we conducted the first meta-analysis of smartphone apps for depressive symptoms. An electronic database search in May 2017 identified 18 eligible randomized controlled trials of 22 smartphone apps, with outcome data from 3,414 participants. Depressive symptoms were reduced significantly more from smartphone apps than control conditions (g=0.38, 95% CI: 0.24-0.52, p<0.001), with no evidence of publication bias. Smartphone interventions had a moderate positive effect in comparison to inactive controls (g=0.56, 95% CI: 0.38-0.74), but only a small effect in comparison to active control conditions (g=0.22, 95% CI: 0.10-0.33). Effects from smartphone-only interventions were greater than from interventions which incorporated other human/computerized aspects along the smartphone component, although the difference was not statistically significant. The studies of cognitive training apps had a significantly smaller effect size on depression outcomes (p=0.004) than those of apps focusing on mental health. The use of mood monitoring softwares, or interventions based on cognitive behavioral therapy, or apps incorporating aspects of mindfulness training, did not affect significantly study effect sizes. Overall, these results indicate that smartphone devices are a promising self-management tool for depression. Future research should aim to distil which aspects of these technologies produce beneficial effects, and for which populations.

Key words: Smartphone technology, mental health interventions, depression, e-health, mhealth, apps, cognitive training, mood monitoring, cognitive behavioral therapy, mindfulness training

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Depression is now recognized as a leading cause of global disability, impacting over 300 million people around the world[1]. In countries like the US, 9% of the population may have depression at any one time[2]. Beyond the personal suffering, depression is associated with unemployment, poor physical health, impaired social functioning and, in its most severe forms, suicide[3]. Thus, the disorder carries a high cost for both the individual and the society, particularly when considering the economic burden incurred through clinical care and lost productivity[4].

Depression is a potentially treatable condition, with a range of available medications and psychological interventions that are supported by robust clinical evidence. While the choice of pharmacotherapy or psychotherapy depends on many factors, for most individuals with mild or moderate depression they may be nearly equivalent[5].

However, there are many barriers towards both of these treatment methods. For instance, access to mental health care remains limited, as almost half of the world's population lives in countries where there is less than one psychiatrist per 100,000 people[6], and continued shortage in mental health care staff is expected for both the near and long term future[7,8]. Additionally, medications and psychotherapies may carry some level of stigma (particularly among younger people), which further limits their effectiveness[9,10].

Furthermore, although these therapies demonstrate high clinical efficacy for reducing symptoms, they may not always bring about full and sustained remission in those treated. Finally, many people experience either subclinical depression or residual depressive symptoms even after achieving clinical response to treatment. Therefore, novel primary and/or adjunctive methods for reducing depression on a population scale are urgently needed.

Digital technologies may represent a novel and viable solution. Mobile phones are among the most rapidly adopted innovations in recent history, and smartphone ownership continues to increase in both developed and developing countries[11]. Through providing ubiquitous Internet connectivity, along with the capacity to download and run externally created applications ("apps"), smartphone technology presents an opportunity to transform mobile phones into devices which could provide global, cost-effective and evidence-based mental health services on demand and in real time[12].

This clear therapeutic potential has triggered a wave of interest and investment in mental health apps from governments, technology companies, advocacy groups, and research groups internationally[13,14]. But in the enthusiasm to realize the potential of apps for depression, it has become difficult to separate actual efficacy from overzealous aspirational claims[15]. With thousands of mental health apps readily available through Apple or Google marketplaces, finding a useful tool supported by robust evidence to manage one's depression is clearly a challenge for a lay person[16,17]. The increasing media promotion and accessibility of apps for mental health now presents a "duty of

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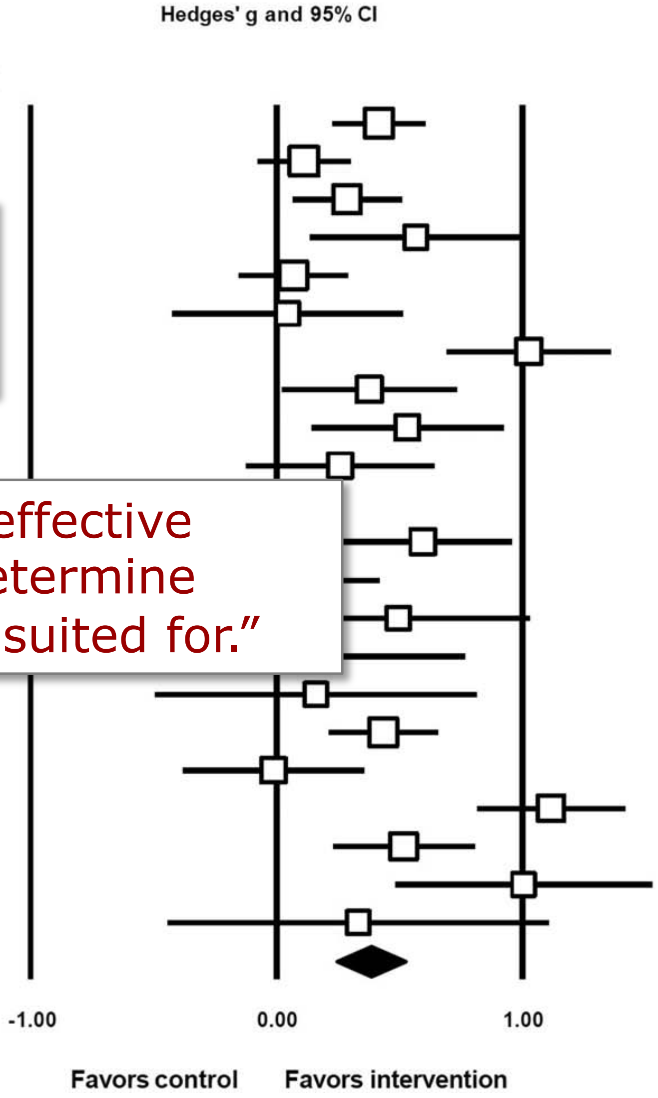
Study	App name	Statistics for each study							Sample size	
		Hedges' g	Standard error	Variance	Lower limit	Upper limit	Z	p	Smartphone	Control
Arean et al[26]	iPST	0.417	0.099	0.010	0.224	0.611	4.224	<0.001	211	206
Arean et al[26]	Project EVO	0.112	0.098	0.010	-0.080	0.304	1.142	0.253	209	206
Bi[illegible]	[illegible]									
D[illegible]										
E[illegible]										
F[illegible]										
H[illegible]										
Howells et al[illegible]	Headspace	[illegible]								
Ivanova et al[33]	ACTsmart - guided	0.533	0.201	0.040	0.139	0.927	2.652	0.008	50	51
Ivanova et al[33]	ACTsmart - unguided	0.259	0.197	0.039	-0.127	0.646	1.314	0.189	51	51
Kahn et al[34]										
Kuhn et al[35]										
Ly et al[36]										
Moell et al[37]										
Oh et al[38]										
Oh et al[38]	SMART	0.161	0.336	0.113	-0.498	0.820	0.479	0.632	18	16
Proudfoot et al[39]	MyCompass	0.435	0.115	0.013	0.209	0.661	3.771	<0.001	126	195
Reid et al[40]	MobileType	-0.012	0.190	0.036	-0.384	0.360	-0.064	0.949	68	46
Roepke et al[41]	SuperBetter	1.118	0.156	0.024	0.814	1.423	7.191	<0.001	97	93
Roepke et al[41]	SuperBetter Plus	0.518	0.148	0.022	0.227	0.809	3.488	<0.001	93	93
Tighe et al[42]	ibobbly	1.006	0.269	0.072	0.479	1.533	3.743	<0.001	31	30
Watts et al[43]	Get Happy	0.332	0.398	0.158	-0.447	1.112	0.836	0.403	10	15
Overall		***0.383***	***0.072***	***0.005***	***0.242***	***0.524***	***5.312***	***<0.001***	***1,716***	***1,698***



"In conclusion, the evidence to date indicates that mental health interventions delivered via smartphone devices can reduce depressive symptoms."

"… it was difficult to establish the single most effective components of smartphone interventions, or determine which populations these interventions are best suited for."

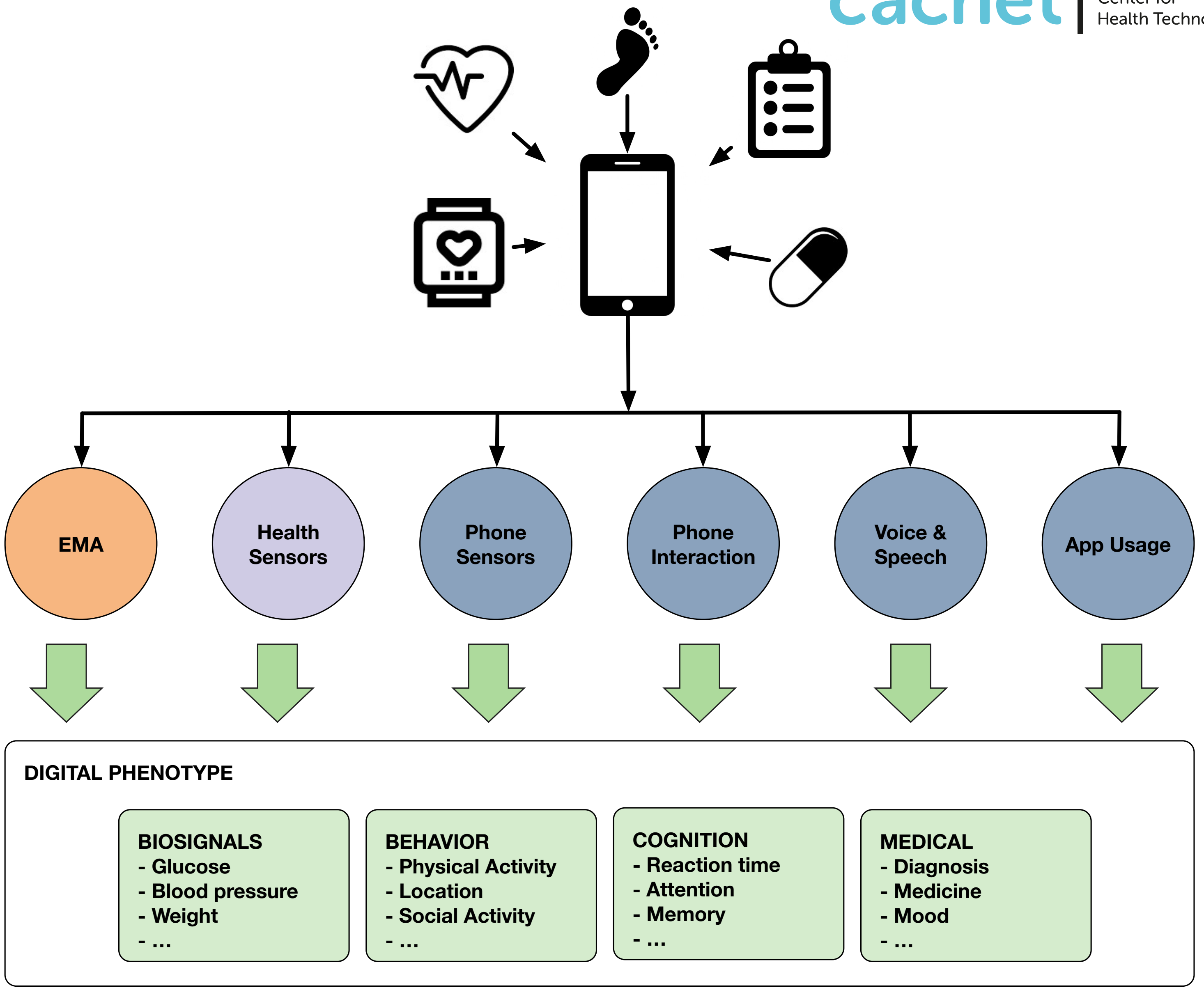
Figure 2 Meta-analysis of the effects of smartphone interventions on depressive symptoms. Box size represents study weighting. Diamond represents overall effect size and 95% CI.

LOOKING AHEAD…

… from apps to **platforms**
… from sensing to **intervention**
… from pilot studies to **clinical** uptake

Digital Phenotyping

"Continuous and unobtrusive measurement and inference of health, behavior, and other parameters from wearable and mobile technology"



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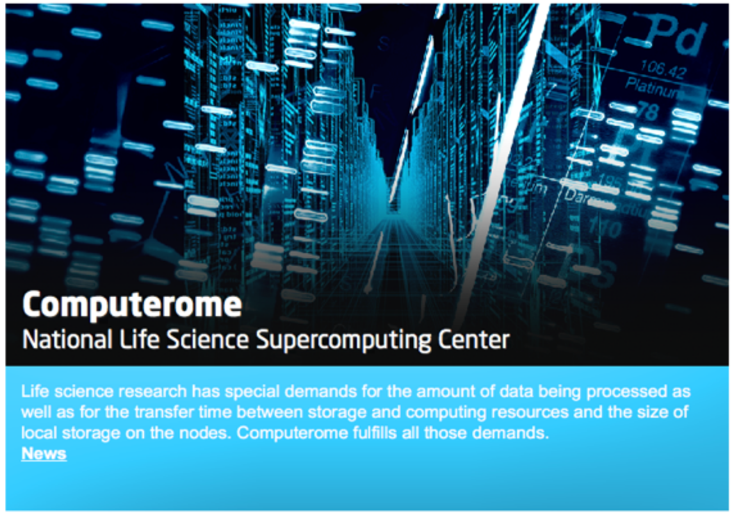
CARP – CACHET Research Platform

- **Standardization**
  - part of open international standards
  - Open mHealth
  - FHIR, IEEE 1752, ORK, ORS, ...
- **Sharing & Reuse**
  - application-specific support / development (API)
  - multi-study / multi-project platform
  - analysis of data across multiple studies
- **Privacy & Security**
  - enabling privacy & security as part of platform (GDPR)
  - secure local hosting @DTU Computerome

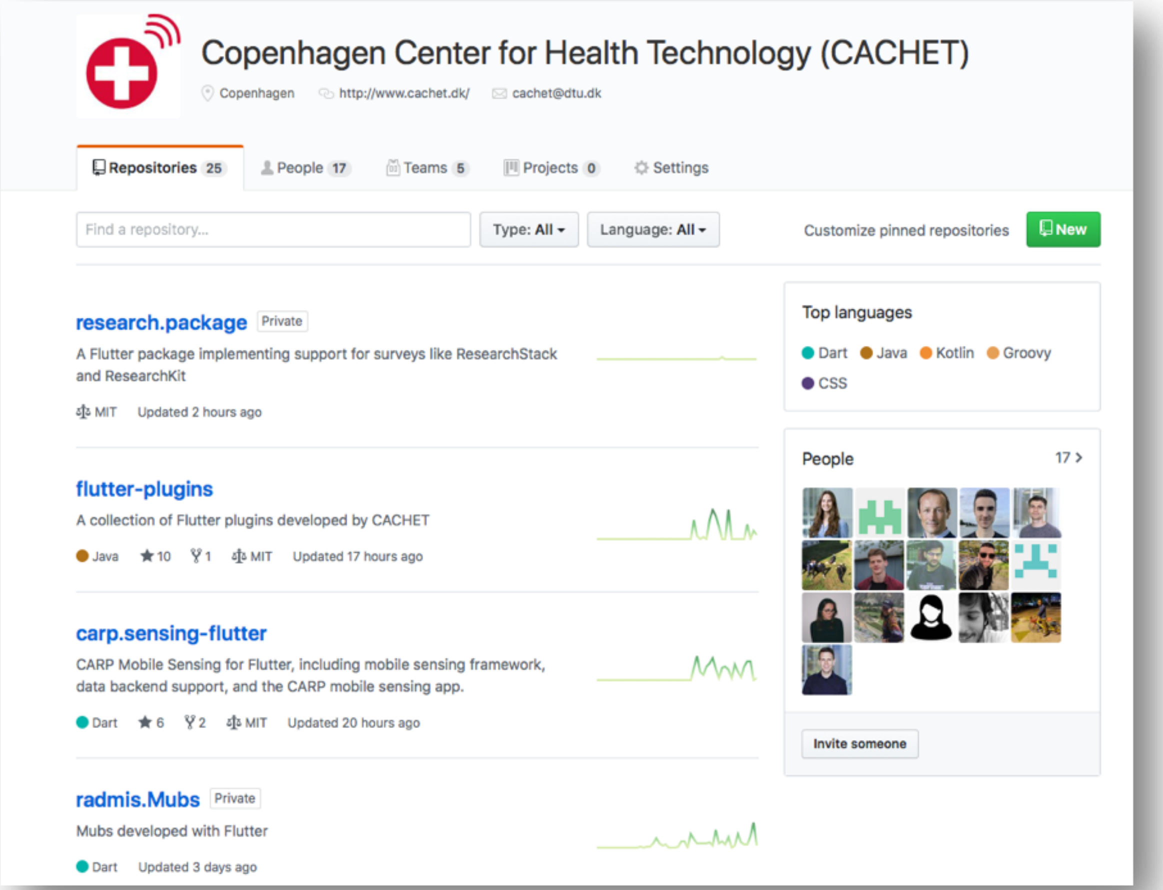


Type of mHealth Apps / Data

- Psychiatry
  - Cognitive assessment
  - Mood sampling (e.g. PHQ9)
  - Activity
  - ...
- Cardiovascular
  - BP, HR, HRV, ..
  - ECG, RR,
  - O2
  - physical activity
- Diabetes
  - blood glucose
- Generic
  - location
  - weight, height, ...
  - step count
  - met / cal
  - temperature
  - medication
  - surveys

CARP Mobile Sensing in Flutter

- CARP Mobile Sensing
  - framework
  - sensing packages (e.g. ECG, CGM)
  - app
- CARP Backend
  - firebase, CARP, ..
- Open mHealth schemas
  - in Flutter
- Research Package
  - Research Kit in Flutter
  - (like Research Stack for Android)



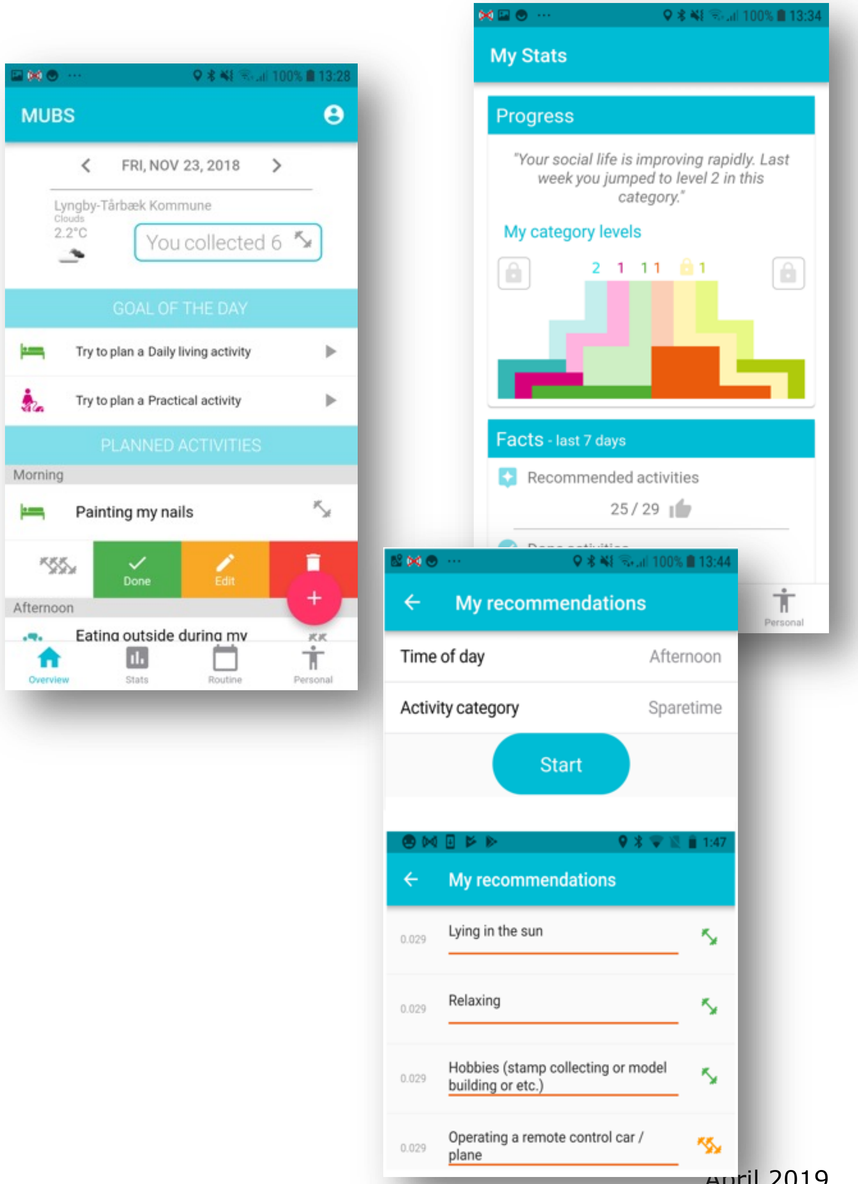
MUBS: A Näive Bayes Recommender System for Behavioral Activation

- Behavioral Activation (BA)
  - Activating patients to do more activities in six core categories

- Daily activity recommendation
  - just-in-time adaptive intervention

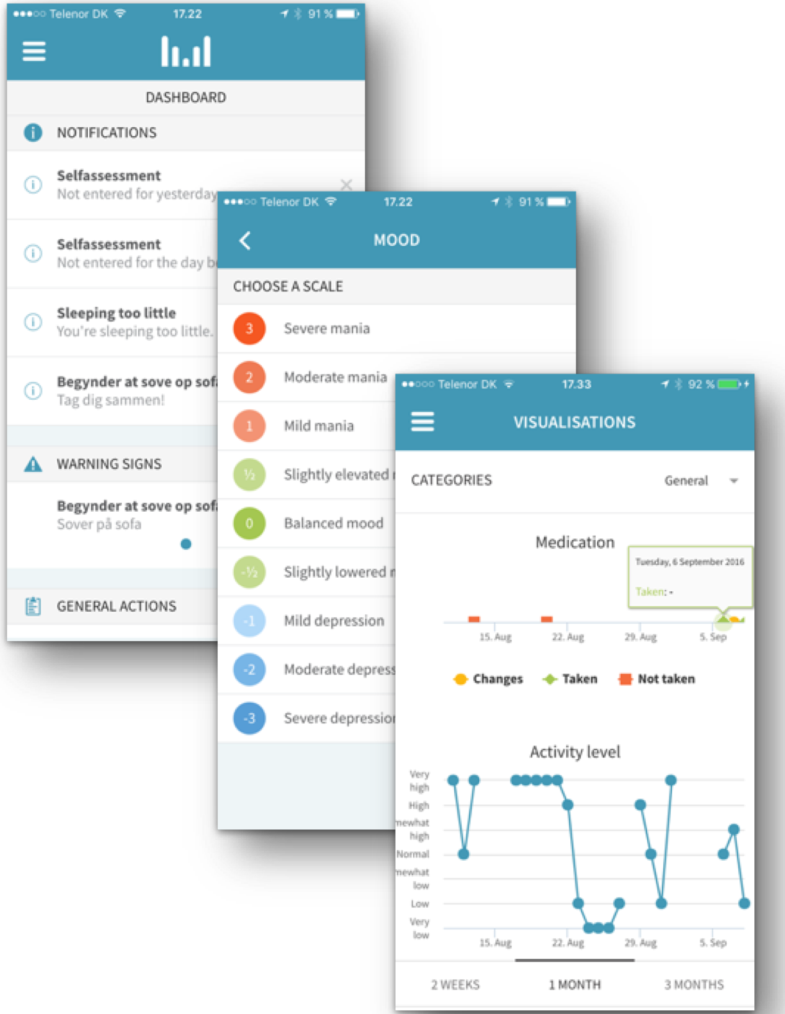
$$P(C_j|n_y) = \frac{P(C_j)\prod_{t=1}^{T}\sum_{i=1}^{|d_t|}P(w_{ti}|C_jT_t)}{P(n_y)}$$

- Features
  - activity, difficulty, category
  - time, day, weather, location, physical activity



RADMIS Project – RCT on Efficacy

- Randomized Clinical Trial (RCT)
  - #1 – reducing the rate and duration of readmission among patients
  - #2 – reducing severity of depression and mania
  - #3 – improve behavioral functions
  - blinded randomized trial (N= 200+200)
- Partners
  - Psychiatric Center Copenhagen
  - Technical University of Denmark
  - Monsenso
- Technology development
  - Data collection
  - Mood forecasting
  - **Cognitive Behavioral Therapy (CBT)**



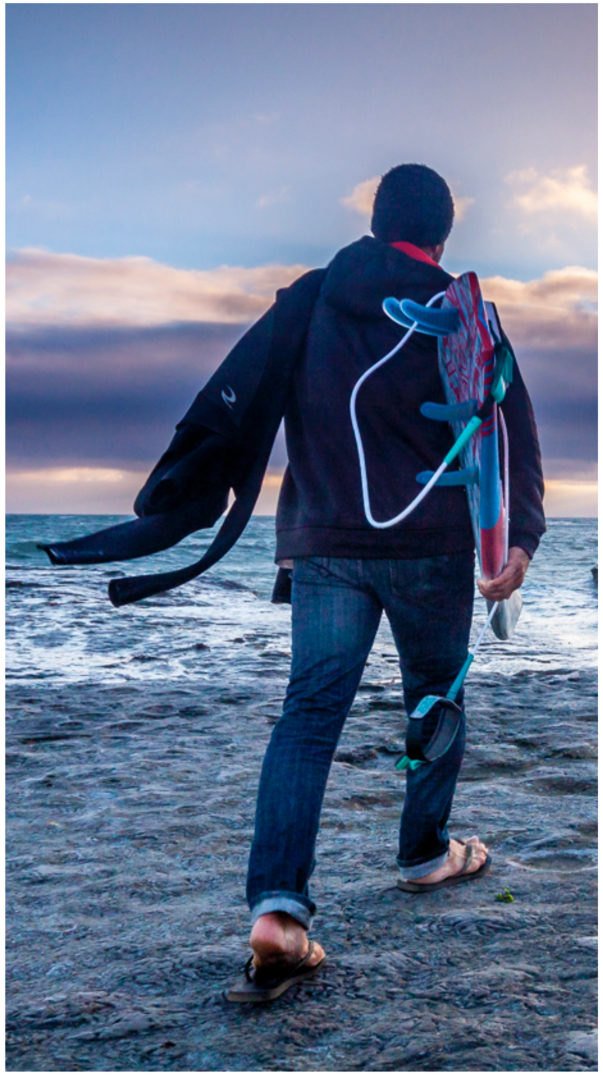
SUMMING UP

Summing up…

- **MONARCA** :: ubiquitous computing in mental health
  - self-assessment is usable and useful (patients & clinicians)
  - double-loop treatment setup
  - promising technical results
  - … but no clinical evidence

- Looking back at **10 years** of impressive research
  - 45 ubicomp technologies – mostly on sensing
  - 46 studies on correlations – but comparison were difficult
  - clinical evidence is mixed – but emerging across studies

- Looking ahead at the **next 10 years** of research
  - CARP platform :: mobile sensing app development in Flutter
  - MUBS :: designing technologies for intervention
  - RADMIS :: clinical efficacy in terms of reducing readmission



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MONSENSO

SEVENTH FRAMEWORK PROGRAMME

PIT LAB

Innovation Fund Denmark