Double-Loop Health Technology: Enabling Socio-technical Design of Personal Health Technology in Clinical Practice

Personal health technology is rapidly emerging as a response to the challenges associated with significant increase in chronic noncommunicable diseases. The overall design paradigm behind most of these applications is to manually and automatically sample data from sensors and smartphones and use this to provide patients with an awareness of their illness and give recommendation for treatment, care, and healthy living. Few of these systems are, however, designed to be part of a complex socio-technical care and treatment processes in existing healthcare systems and clinical pathways. In this chapter, we present a case of designing personal health technology for mental health, which is integrated into hospital-based treatment. This system helps patients to manage their disease by tracking and correlation behavior and disease progression and provide feedback to them, while also deployed as part of a clinical outpatient treatment. Hence, clinicians are “in the loop” and can monitor and provide feedback to patients. The chapter outlines the case and discusses lessons learned from it with respect to the socio-technical design of personal health technologies to be embedded as part of clinical treatment.

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Supporting smartphone-based behavioral activation: A simulation study
Behavioral activation has shown to be a simple yet effective therapy for depressive patients. The method relies on extensive collection of patient reported activity data on an hourly basis. We are currently in the process of designing a smartphone-based behavioral activation system for depressive disorders. However, it is an open question to what degree patients would use this approach given the high demand for user input. In order to investigate this question, we collected paper-based behavioral activation forms from 5 patients, covering in total 18 weeks, 115 days, and 1,614 hours of self-reported activity data. In this paper we present an analysis of this data and discuss the implications for the design of a smartphone-based system for behavioral activation.

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Activity-Based Collaboration for Interactive Spaces

Activity-based computing (ABC) is a conceptual and technological framework for designing interactive systems that offers a better mapping between the activities people conduct and the digital entities they use. In ABC, rather than interacting directly with lower-level technical entities like files, folder, documents, etc., users are able to interact with ‘activities’ which encapsulate files and other low-level resources. In ABC an ‘activity’ can be shared between collaborating users and can be accessed on different devices. As such, ABC is a framework that suits the requirements of designing interactive spaces. This chapter provides an overview of ABC with a special focus on its support for collaboration (‘Activity Sharing’) and multiple devices (‘Activity Roaming’). These ABC concepts are illustrated as implemented in two different interactive spaces technologies; ReticularSpaces [1] and the eLabBench [2, 3]. The chapter discusses the benefits of activity-based collaboration support for these interactive spaces, while also discussing limitations and challenges to be addressed in further research.

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Big Data hvor N=1

Forskningen vedrørende anvendelsen af ‘big data’ indenfor sundhed er kun lige begyndt, og kan på sigt blive en stor hjælp i forhold til at tilrettelægge en mere personlig og helhedsorienteret sundhedsindsats for multisyyge. Personlig sundhedssteknologi, som kort præsenteres i dette kapitel, rummer et stor potentiale for at gennemføre ‘big data’ analyser for den enkelte person, det vil sige hvor N=1. Der er store teknologiske udfordringer i at få lavet teknologier og metoder til at indsamle og håndtere personlige data, som kan deles, på tværs på en standardiseret, forsvarlig, robust, sikker og ikke mindst anonym facon.
Can smartphone-based electronic markers discriminate between patients with bipolar disorder, healthy first-degree relatives and healthy control individuals

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Collaborative Affordances of Medical Records

This article proposes the concept of Collaborative Affordances to describe physical and digital properties (i.e., affordances) of an artifact, which affords coordination and collaboration in work. Collaborative Affordances build directly on Gibson (1977)'s affordance concept and extends the work by Sellen and Harper (2003) on the affordances of physical paper. Sellen and Harper describe how the physical properties of paper affords easy reading, navigation, mark-up, and writing, but focuses, we argue, mainly on individual use of paper and digital technology. As an extension to this, Collaborative Affordances focusses on the properties of physical and digital artifacts that affords collaborative activities. We apply the concept of Collaborative Affordances to the study of paper-based and electronic patient records in hospitals and detail how they afford collaboration through four types of Collaborative Affordances; being portable across patient wards and the entire hospital, by providing collocated access, by providing a shared overview of medical data, and by giving clinicians ways to maintain mutual awareness. We then discuss how the concept of Collaborative Affordances can be used in the design of new technology by providing a design study of a ‘Hybrid Patient Record’ (HyPR), which is designed to seamlessly blend and integrate paper-based with electronic patient records.

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Reducing the rate and duration of Re-ADMISsions among patients with unipolar disorder and bipolar disorder using smartphone-based monitoring and treatment - the RADMIS trials: Study protocol for two randomized controlled trials

Background: Unipolar and bipolar disorder combined account for nearly half of all morbidity and mortality due to mental illness and substance use disorders, and burden society with the highest health care costs of all psychiatric and neurological disorders. Among these, costs due to psychiatric hospitalization are a major burden. Smartphones comprise an innovative and unique platform for the monitoring and treatment of depression and mania. No prior trial has investigated whether the use of a smartphone-based system can prevent re-admission among patients discharged from hospital. The present RADMIS trials aim to investigate whether using a smartphone-based monitoring and treatment system, including an integrated clinical feedback loop, reduces the rate and duration of re-admissions more than standard treatment in unipolar disorder and bipolar disorder. Methods: The RADMIS trials use a randomized controlled, single-blind, parallel-group design. Patients with unipolar disorder and patients with bipolar disorder are invited to participate in each trial when discharged from psychiatric hospitals in The Capital Region of Denmark following an affective episode and randomized to either (1) a smartphone-based monitoring system including (a) an integrated feedback loop between patients and clinicians and (b) context-aware cognitive behavioral therapy (CBT) modules (intervention group) or (2) standard treatment (control group) for a 6-month trial period. The trial started in May 2017. The outcomes are (1) number and duration of re-
admissions (primary), (2) severity of depressive and manic (only for patients with bipolar disorder) symptoms; psychosocial functioning; number of affective episodes (secondary), and (3) perceived stress, quality of life, self-rated depressive symptoms, self-rated manic symptoms (only for patients with bipolar disorder), recovery, empowerment, adherence to medication, wellbeing, ruminations, worrying, and satisfaction (tertiary). A total of 400 patients (200 patients with unipolar disorder and 200 patients with bipolar disorder) will be included in the RADMIS trials. Discussion: If the smartphone-based monitoring system proves effective in reducing the rate and duration of readmissions, there will be basis for using a system of this kind in the treatment of unipolar and bipolar disorder in general and on a larger scale.
Bipolar disorder is an often disabling mental illness with a lifetime prevalence of 1%-2%, a high risk of recurrence of manic and depressive episodes, a lifelong elevated risk of suicide and a substantial heritability. The course of illness is frequently characterised by progressive shortening of interepisode intervals with each recurrence and increasing cognitive dysfunction in a subset of individuals with this condition. Clinically, diagnostic boundaries between bipolar disorder and other psychiatric disorders such as unipolar depression are unclear although pharmacological and psychological treatment strategies differ substantially. Patients with bipolar disorder are often misdiagnosed and the mean delay between onset and diagnosis is 5-10 years. Although the risk of relapse of depression and mania is high it is for most patients impossible to predict and consequently prevent upcoming episodes in an individual tailored way. The identification of objective biomarkers can both inform bipolar disorder diagnosis and provide biological targets for the development of new and personalised treatments. Accurate diagnosis of bipolar disorder in its early stages could help prevent the long-term detrimental effects of the illness. The present Bipolar Illness Onset study aims to identify (1) a composite blood-based biomarker, (2) a composite electronic smartphone-based biomarker and (3) a neurocognitive and neuroimaging-based signature for bipolar disorder. The study will include 300 patients with newly diagnosed/first-episode bipolar disorder, 200 of their healthy siblings or offspring and 100 healthy individuals without a family history of affective disorder. All participants will be followed longitudinally with repeated blood samples and other biological tissues, self-monitored and automatically generated smartphone data, neuropsychological tests and a subset of the cohort with neuroimaging during a 5 to 10-year study period. The study has been approved by the Local Ethical Committee (H-7-2014-007) and the data agency, Capital Region of Copenhagen (RHP-2015-023), and the findings will be widely disseminated at international conferences and meetings including conferences for the International Society for Bipolar Disorders and the World Federation of Societies for Biological Psychiatry and in scientific peer-reviewed papers. NCT02888262.
Behavioral activities collected through smartphones and the association with illness activity in bipolar disorder

Smartphones are useful in symptom-monitoring in bipolar disorder (BD). Objective smartphone data reflecting illness activity could facilitate early treatment and act as outcome in efficacy trials. A total of 29 patients with BD presenting with moderate to severe levels of depressive and manic symptoms used a smartphone-based self-monitoring system during 12 weeks. Objective smartphone data on behavioral activities were collected. Symptoms were clinically assessed every second week using the Hamilton Depression Rating Scale and the Young Mania Rating Scale. Objective smartphone data correlated with symptom severity. The more severe the depressive symptoms (1) the longer the smartphone’s screen was “on”/day, (2) more received incoming calls/day, (3) fewer outgoing calls/day were made, (4) less answered incoming calls/day, (5) the patients moved less between cell towers IDs/day. Conversely, the more severe the manic symptoms (1) more outgoing text messages/day sent, (2) the phone calls/day were longer, (3) the fewer number of characters in incoming text messages/day, (4) the lower duration of outgoing calls/day, (5) the patients moved more between cell towers IDs/day. Further, objective smartphone data were able to discriminate between affective states. Objective smartphone data reflect illness severity, discriminates between affective states in BD and may facilitate the cooperation between patient and clinician.

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Dedicated workspaces: Faster resumption times and reduced cognitive load in sequential multitasking

Studies show that virtual desktops have become a widespread approach to window management within desktop environments. However, despite their success, there is no experimental evidence of their effect on multitasking. In this paper, we present an experimental study incorporating 16 participants in which a traditional Windows 7 environment is compared to one augmented by virtual desktops. Within the experimental condition, each virtual desktop acts as a dedicated workspace devoted to an independent goal-oriented task, as opposed to the control condition where only one single workspace is available to perform the same tasks. Results show that adopting virtual desktops as dedicated workspaces allows for faster task resumption (10 s faster on average) and reduced cognitive load during sequential multitasking. Within our experiment the majority of users already benefited from using dedicated workspaces after three switches to a previously suspended task, as the time lost on setting up workspaces was compensated for by faster subsequent task resumption. These results provide a strong argument for supporting goal-oriented dedicated workspaces within desktop environments.
Designing Context-Aware Cognitive Behavioral Therapy for Unipolar and Bipolar Disorders
This position paper presents our preliminary design of context-aware cognitive behavioral therapy for unipolar and bipolar disorders. We report on the background for this study and the methods applied in the ongoing design process. The paper ends by presenting and discussing different design options. We hope this will be useful input for further discussion at the workshop.

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Electronic self-monitoring of mood using IT platforms in adult patients with bipolar disorder: A systematic review of the validity and evidence
Background: Various paper-based mood charting instruments are used in the monitoring of symptoms in bipolar disorder. During recent years an increasing number of electronic self-monitoring tools have been developed. The objectives of this systematic review were 1) to evaluate the validity of electronic self-monitoring tools as a method of evaluating mood compared to clinical rating scales for depression and mania and 2) to investigate the effect of electronic self-monitoring tools on clinically relevant outcomes in bipolar disorder.

Methods: A systematic review of the scientific literature, reported according to the Preferred Reporting items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines was conducted. MEDLINE, Embase, PsycINFO and The Cochrane Library were searched and supplemented by hand search of reference lists. Databases were searched for 1) studies on electronic self-monitoring tools in patients with bipolar disorder reporting on validity of electronically self-reported mood ratings compared to clinical rating scales for depression and mania and 2) randomized controlled trials (RCT) evaluating electronic mood self-monitoring tools in patients with bipolar disorder.

Results: A total of 13 published articles were included. Seven articles were RCTs and six were longitudinal studies. Electronic self-monitoring of mood was considered valid compared to clinical rating scales for depression in six out of six studies, and in two out of seven studies compared to clinical rating scales for mania. The included RCTs primarily investigated the effect of heterogeneous electronically delivered interventions; none of the RCTs investigated the sole effect of electronic mood self-monitoring tools. Methodological issues with risk of bias at different levels limited the evidence in the majority of studies.
Conclusions: Electronic self-monitoring of mood in depression appears to be a valid measure of mood in contrast to self-monitoring of mood in mania. There are yet few studies on the effect of electronic self-monitoring of mood in bipolar disorder. The evidence of electronic self-monitoring is limited by methodological issues and by a lack of RCTs. Although the idea of electronic self-monitoring of mood seems appealing, studies using rigorous methodology investigating the beneficial as well as possible harmful effects of electronic self-monitoring are needed.
The Personal Health Technology Design Space

Interest is increasing in personal health technologies that utilize mobile platforms for improved health and well-being. However, although a wide variety of these systems exist, each is designed quite differently and materializes many different and more or less explicit design assumptions. To enable designers to make informed and well-articulated design decision, the authors propose a design space for personal health technologies. This space consists of 10 dimensions related to the design of data sampling strategies, visualization and feedback approaches, treatment models, and regulatory constraints.

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Voice analysis as an objective state marker in bipolar disorder

Changes in speech have been suggested as sensitive and valid measures of depression and mania in bipolar disorder. The present study aimed at investigating (1) voice features collected during phone calls as objective markers of affective states in bipolar disorder and (2) if combining voice features with automatically generated objective smartphone data on behavioral activities (for example, number of text messages and phone calls per day) and electronic self-monitored data (mood) on illness activity would increase the accuracy as a marker of affective states. Using smartphones, voice features, automatically generated objective smartphone data on behavioral activities and electronic self-monitored data were collected from 28 outpatients with bipolar disorder in naturalistic settings on a daily basis during a period of 12 weeks. Depressive and manic symptoms were assessed using the Hamilton Depression Rating Scale 17-item and the Young Mania Rating Scale, respectively, by a researcher blinded to smartphone data. Data were analyzed using random forest algorithms. Affective states were classified using voice features extracted during everyday life phone calls. Voice features were found to be more accurate, sensitive and specific in the classification of manic or mixed states with an area under the curve (AUC)=0.89 compared with an AUC=0.78 for the classification of depressive states. Combining voice features with automatically generated objective smartphone data on behavioral activities and electronic self-monitored data increased the accuracy, sensitivity and specificity of classification of affective states slightly. Voice features collected in naturalistic settings using smartphones may be used as objective state markers in patients with bipolar disorder.
Voice analysis as an objective state marker in bipolar disorder

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Smartphone data as an electronic biomarker of illness activity in bipolar disorder

Objectives
Objective methods are lacking for continuous monitoring of illness activity in bipolar disorder. Smartphones offer unique opportunities for continuous monitoring and automatic collection of real-time data. The objectives of the paper were to test the hypotheses that (i) daily electronic self-monitored data and (ii) automatically generated objective data collected using smartphones correlate with clinical ratings of depressive and manic symptoms in patients with bipolar disorder.

Methods
Software for smartphones (the MONARCA I system) that collects automatically generated objective data and self-monitored data on illness activity in patients with bipolar disorder was developed by the authors. A total of 61 patients aged 18–60 years and with a diagnosis of bipolar disorder according to ICD-10 used the MONARCA I system for six months. Depressive and manic symptoms were assessed monthly using the Hamilton Depression Rating Scale 17-item (HDRS-17) and the Young Mania Rating Scale (YMRS), respectively. Data are representative of over 400 clinical ratings. Analyses were computed using linear mixed-effect regression models allowing for both between individual variation and within individual variation over time.

Results
Analyses showed significant positive correlations between the duration of incoming and outgoing calls/day and scores on the HDRS-17, and significant positive correlations between the number and duration of incoming calls/day and scores on the YMRS; the number of and duration of outgoing calls/day and scores on the YMRS; and the number of outgoing text messages/day and scores on the YMRS. Analyses showed significant negative correlations between self-monitored data (i.e., mood and activity) and scores on the HDRS-17, and significant positive correlations between self-monitored data (i.e., mood and activity) and scores on the YMRS. Finally, the automatically generated objective data were able to discriminate between affective states.

Conclusions
Automatically generated objective data and self-monitored data collected using smartphones correlate with clinically rated depressive and manic symptoms and differ between affective states in patients with bipolar disorder. Smartphone apps represent an easy and objective way to monitor illness activity with real-time data in bipolar disorder and may serve as an electronic biomarker of illness activity.
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**Design Toolbox for Personal Health Technology**
Department of Applied Mathematics and Computer Science
Period: 01/02/2018 → 31/01/2021
Number of participants: 3
Phd Student:
Maharjan, Raju (Ekstern)
Supervisor:
Bækgaard, Per (Intern)
Main Supervisor:
Bardram, Jakob Eyvind (Intern)

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Project: PhD

**Design Toolbox for Personal Health Technology**
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Period: 01/02/2018 → 31/01/2021
Number of participants: 3
Phd Student:
Maharjan, Raju (Intern)
Supervisor:
Bækgaard, Per (Intern)
Main Supervisor:
Bardram, Jakob Eyvind (Intern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Offentlig finansiering
Project: PhD

**Patient Training for Gaze Controlled Telepresence**
Department of Management Engineering
Period: 01/02/2018 → 31/01/2021
Number of participants: 3
Phd Student: 
Zhang, Guangtao (Intern)  
Supervisor: 
Bardram, Jakob Eyvind (Intern)  
Main Supervisor: 
Hansen, John Paulin (Intern)

Financing sources
Source: Internal funding (public) 
Name of research programme: Forskningsrådsstipendium  
Project: PhD

Open-access data platform for behavioural monitoring and visual analytics for mental health

Technical University of Denmark  
Period: 15/10/2017 → 06/01/2018  
Number of participants: 3  
Phd Student: 
Moradi Vastegani, Milad (Intern)  
Supervisor: 
Matic, Aleksander (Ekstern)  
Main Supervisor: 
Bardram, Jakob Eyvind (Intern)

Financing sources
Source: Internal funding (public) 
Name of research programme: Marie Curie (EU-stipendium)  
Project: PhD

Computer- and Smartphone-based Assessment of Cognitive Functioning in Affective Disorders in Young People

Technical University of Denmark  
Period: 01/06/2017 → 31/05/2020  
Number of participants: 3  
Phd Student: 
Hafiz, Pegah (Intern)  
Supervisor: 
Kessing, Lars Vedel (Ekstern)  
Main Supervisor: 
Bardram, Jakob Eyvind (Intern)

Financing sources
Source: Internal funding (public) 
Name of research programme: Marie Curie (EU-stipendium)  
Project: PhD

In-situ and Personalized Cognitive Behavioural Therapy for Mental Health

Technical University of Denmark  
Period: 01/09/2016 → 31/08/2019  
Number of participants: 4  
Phd Student: 
Rohani, Darius Adam (Intern)  
Supervisor: 
Puthusserypady, Sadasivan (Intern)  
Main Supervisor: 
Bardram, Jakob Eyvind (Intern)

Financing sources
Source: Internal funding (public) 
Name of research programme: Samfinansieret - Andet
Reducing the rate and duration of re-admission among patients with unipolar and bipolar disorder using smartphone-based monitoring and treatment

According to WHO, depression is becoming a leading cause of disability. The RADMIS project seeks to design smartphone-based monitoring and treatment technology for depressive patients. The goal is to establish the efficacy of this technology by measuring re-admission and clinical outcome.

Copenhagen Center for Health Technology
Department of Applied Mathematics and Computer Science
Embedded Systems Engineering
Cognitive Systems
Psychiatric Center Copenhagen, Rigshospitalet
Period: 01/03/2016 → 01/09/2019
Number of participants: 2
Acronym: RADMIS
Number of related Ph.D. students: 2
Project participant:
Bardram, Jakob Eyvind (Intern)
Winther, Ole (Intern)

Financing sources
Source: Public research programme (public)
Name of research programme: Innovation Fund Denmark
Web address: http://innovationsfonden.dk/en
Amount: 11,000,000.00 Danish Kroner
Year of approval: 2016

Machine learning for smartphone-based monitoring and treatment of unipolar and bipolar disorders

Technical University of Denmark
Period: 01/03/2016 → 28/02/2019
Number of participants: 3
Phd Student:
Busk, Jonas (Intern)
Supervisor:
Bardram, Jakob Eyvind (Intern)
Main Supervisor:
Winther, Ole (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Forskningsrådsfinansiering
Project: PhD

Data mining and visualization of human behavior data sets

Technical University of Denmark
Period: 01/08/2013 → 15/03/2017
Number of participants: 6
Phd Student:
Cuttone, Andrea (Intern)
Supervisor:
Jørgensen, Sune Lehmann (Intern)
Main Supervisor:
Larsen, Jakob Eg (Intern)
Examiner:
Bardram, Jakob Eyvind (Intern)
Kjærgaard, Mikkel Baun (Ekstern)
Musolesi, Mirco (Ekstern)

**Financing sources**
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)

**Relations**
Publications:
Data Mining and Visualization of Large Human Behavior Data Sets
Project: PhD