Detecting and Capitalizing on Physiological Dimensions of Psychiatric Illness

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Abstract: Serious mental illnesses, including bipolar disorders (BD), account for a large share of the worldwide healthcare burden—estimated at $62.7B in the U.S. alone. Bipolar disorders represent a family of common, lifelong illnesses associated with poor functional and clinical outcomes, high suicide rates, and huge societal costs. Interpersonal and Social Rhythm Therapy (IPSRT), a validated treatment for BD, helps patients lead lives characterized by greater stability of daily rhythms, using a 5 item paper-and-pencil self-monitoring instrument called the Social Rhythm Metric (SRM). IPSRT has been shown to improve patient outcomes, yet many patients struggle to monitor their daily routine or even access the treatment. In this paper we describe how biological characteristics of bipolar disorder can be taken into consideration when developing systems to detect and stabilize mood episodes. We describe the co-design of *MoodRhythm*, a smartphone and web app, with patients and therapists. It is designed to support patients in tracking their health passively and actively over a long period of time. *MoodRhythm* uses the phone's onboard sensors to automatically track sleep and social activity patterns. We report results of a small clinical pilot with experienced IPSRT clinicians and patients with bipolar disorder and finish by describing the role physiological computing could have not just in monitoring psychiatric illnesses according to existing broad categories of diagnosis but in helping radically tailor diagnoses to each individual patient and develop interventions that take advantage of idiosyncratic characteristics of each person's illness in order to increase patient engagement in and adherence to treatment.

1 INTRODUCTION

Bipolar disorder (BD) is recognized as one of the most debilitating illnesses - responsible for more disability-adjusted life years than all forms of cancer – and affects approximately 2.6% of the population worldwide (Merikangas et al., 2011). While the median age of onset for bipolar disorders is 25, the number of children and teens diagnosed in the past decade has significantly increased (Moreno et al., 2007). Individuals with bipolar disorder are frequently severely disabled and their rate of completed suicide is least 15 times that of the general population (Harris and Barraclough, 1997).

Most patients with bipolar disorder (BD) struggle to receive quality treatment and, particularly, to access the psychosocial treatments that have been shown to be critical to sustained wellness and improved functioning. Thus, it is not surprising that this common, lifelong, and life-threatening illness (Murray and Lopez, 1996), is associated with poor functional and clinical outcomes (Judd et al., 2003), high suicide rates (Baldessarini and Tondo, 2003), and huge societal costs (Woods, 2000).

In the past decade, the biological components and neurological dimensions of serious mental illnesses like bipolar disorder have begun to be identified (Craddock and Sklar, 2013). For many years, scientists searched for the 'bipolar' gene. Recent breakthroughs indicate that the picture is much more complicated than this. Genetic variants are increasingly tied to neurobiological deficits and idiosyncratic characteristics that have been witnessed in BD for some time. Several genes have been identified that are associated with BD – some are shared with Schizophrenia (Craddock and Sklar, 2013). People diagnosed with the illness can possess some of these genes and not others. How each person's genetic beginnings interact with their environment is crucial. In short, each person's bipolar disorder is unique to them; the particular

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manifestation of the illness depends on which genes a person has. For example, empirical evidence suggests that the MAOA gene is associated with impulsive behaviour associated with manic episodes in some forms of bipolar disorder (Preisig et al., 2000).

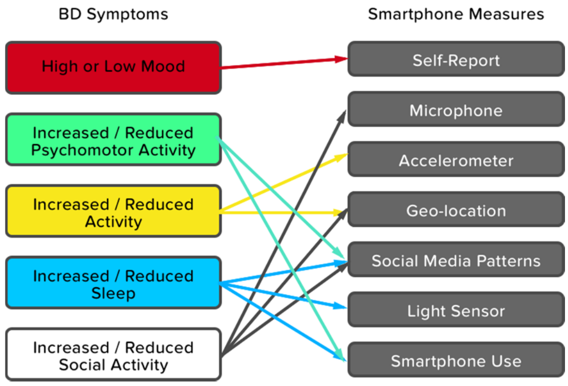


Figure 1: Bipolar Symptoms and Smartphone Sensing.

We propose taking the neurobiological components of bipolar disorder into consideration to measure wellbeing and to engage patients in treatment. The evolution and rapid dissemination of smartphones has created unprecedented opportunities for personalized data collection in an extremely granular, unobtrusive, and even affordable way. A recent community-based survey with over 1,500 people with serious mental illnesses found that 72% of patients with bipolar disorder owned and used mobile phones regularly for calling, texting, and the internet (Ben-Zeev et al., 2013).

Smartphone sensing capabilities are uniquely suited to the detection of key parameters of bipolar disorder: (1) sleep-wake/activity, (2) mental activity and the nature and (3) the frequency of social interaction (See **Figure 1** below). Indeed, examining the criteria for episodes of hypo/mania and depression, one finds that key indicators of episode onset (changes in activity, sleep, rate and intensity of speech, frequency and intensity of social contact) can all be passively collected from a smartphone. Smartphone sensing might also support patients who find self-tracking challenging and thereby increase the quantity.

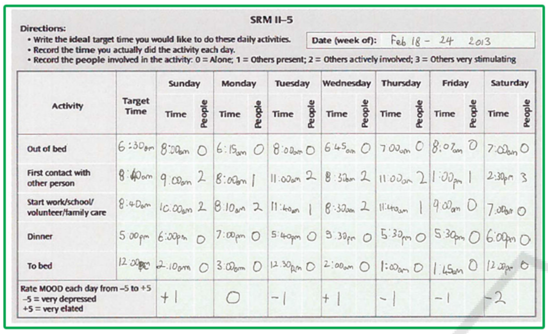
Neuropsychiatric disorders account for 28% of the global burden of health (Mathers and Loncar, 2006). There is considerable potential for physiological computing to identify novel methods to monitor, diagnose and intervene in the treatment of serious mental illness. In this paper, we describe the grounding of our system development in evidence-based therapy and basic research on the physiological components of bipolar disorder. We illustrate the potential of this approach by reporting the positive results of a small clinical pilot with 3 patients and 3 clinicians who used *MoodRhythm*, a smartphone app to monitor and stabilize biological rhythms.

2 TREATMENT OF BIPOLAR DISORDER

By far the most common treatment for bipolar disorder is pharmacotherapy (i.e. treatment by drugs). This is despite the fact that there is limited evidence to support the efficacy of many drugs used as part of treatment (Geddes and Miklowitz, 2013) and that non-adherence to drug treatments can reach as high as 60% (Strakowski et al., 1998). Evidence-based treatment guidelines have suggested that optimum management of bipolar disorder needs the combination of pharmacotherapy and psychotherapy (Goodwin and Consensus Group of the British Association for, 2009) and while most psychotherapies for bipolar disorder have been repurposed from elsewhere, there is an increasing recognition of a need for treatments that consider the underlying neurobiological and psychosocial mechanisms of bipolar disorder (Geddes and Miklowitz, 2013).

One of the most prominent features of bipolar disorder is its rhythmicity, including mood episodes that cycle on an approximately regular basis and symptoms that reflect disturbances in the body's natural rhythms (Levenson and Frank, 2011). A number of theories and models have emerged over the past several decades that relate sleep and circadian rhythm disturbances to affective illnesses such as bipolar disorder (Harvey, 2008). This interest in biological rhythms has led to a complementary interest in the social rhythms that serve to regulate these biological rhythms and in examination of the role of lifestyle regularity in affective illnesses. A growing number of investigations link social rhythms, mood changes, and mood episodes in patients with affective illnesses (e.g., (Haynes et al., 2006). Substantial evidence now indicates that interventions targeting social rhythms, sleep-wake rhythms, and light-dark exposure may markedly improve affective illness outcomes (e.g., Frank et al., 2005).

Interpersonal and Social Rhythm Therapy (IPSRT) is a highly specific behavioral intervention designed to regulate daily routines which, in turn, is hypothesized to entrain underlying circadian rhythms. The therapy was created specifically to treat bipolar disorder, unlike most other available treatments, and has been validated in a series of single and multi-site studies (Frank et al., 2005, Swartz et al., 2009). IPSRT targets activity patterns as well as sleep timing and duration, factors that are considered to mediate treatment outcomes. The Social Rhythm Metric-5 (SRM) is a validated five-item self-report assessment measure of the regularity of daily routines (see **Figure 2**). The SRM helps to record and quantify the regularity of social routines.


SRM II–5

Directions:
- Write the ideal target time you would like to do these daily activities.
- Record the time you actually did the activity each day.
- Record the people involved in the activity: 0 = Alone; 1 = Others present; 2 = Others actively involved; 3 = Others very stimulating

Date (week of): Feb 18 – 24 2013

Activity	Target Time	Sunday		Monday		Tuesday		Wednesday		Thursday		Friday		Saturday	
		Time	People	Time	People	Time	People	Time	People	Time	People	Time	People	Time	People
Out of bed	6:30am	8:00am	0	6:15am	0	8:00am	0	6:45am	0	7:00am	0	8:07am	0	7:00am	0
First contact with other person	8:40am	9:00am	2	8:00am	1	11:00am	2	8:32am	2	11:00am	2	1:00pm	1	2:30pm	3
Start work/school/ volunteer/family care	8:40am	10:00am	2	8:10am	2	11:40am	1	8:30am	2	11:40am	1	9:00am	0	7:00pm	0
Dinner	5:00pm	6:00pm	0	7:00pm	0	5:40pm	0	9:30pm	0	5:30pm	0	5:30pm	0	6:00pm	0
To bed	12:00am	2:10am	0	3:00am	0	12:30am	0	2:00am	0	1:00am	0	1:45am	0	12:00pm	0
Rate MOOD each day from −5 to +5 −5 = very depressed +5 = very elated		+1		0		−1		+1		−1		−1		−2	

Figure 2: Paper-based Social Rhythm Metric.

Although the SRM has been proven effective for tracking social routines, its paper-and-pencil format has multiple disadvantages both as a clinical tool and a research instrument. Even well intentioned patients often forget to complete it or do so inaccurately, particularly if concentration is challenged by mania or depression. The paper format is also not conducive to summarizing collected data such as creating a graph of trends over time that could be used in treatment to enhance patients' self-awareness of their social rhythms.

3 DESIGN PROCESS

In order to realize the potential of physiological monitoring into practice requires that we develop the algorithms and methodologies to transform raw data into actionable knowledge. Yet, there are crucial questions to consider when applying these technologies including what is important to individuals to track and how to ensure that they can make sense of the collected data.

While there is a long history of using some forms of sensing (e.g., activity and light exposure) in efforts to understand and treat bipolar disorders, patient adherence and acceptance of this technology can limit the effectiveness of this approach (Prociow et al., 2012). Individuals with bipolar disorder are particularly sensitive to issues of stigma and often refuse to use any device that might identify them as 'different.' Acceptance of novel treatments can be an issue: even those who agree to wear devices such as an actigraph, frequently do not do so consistently (Camargos et al., 2013). Most important, the promise of passive sensing has not yet had an impact on clinical practice: the data collected via sensors have been limited almost exclusively to research as opposed to clinical settings.

Our goal in developing *MoodRhythm* was to use patient smartphones to provide a combination of active and passive methods to track daily rhythms, to relay this information to clinicians, and to provide feedback to patients to enable them to improve their moods by establishing more regular daily rhythms.

In order to ensure the new system, *MoodRhythm*, was well-accepted and met the needs of individuals with bipolar disorder we sought to engage both clinicians and individuals with bipolar disorder integrally in the development of the application through Participatory Design (Schuler and Namioka, 1993). This is a user-centered development "approach towards computer systems design in which the people destined to use the system play a crucial role in designing it" (Schuler and Namioka, 1993). The end-user is involved at all phases of the design process, having an equal hand in directing development directions. Involving end-users early on and working closely with them can help avoid unpromising design paths, develop a more comprehensive understanding of the target domain and ultimately increase the likelihood that the resultant technology meets the needs of the end users.

Clinicians and patients worked in a Participatory Design process with the research team to create revise and finalize the initial implementation of the *MoodRhythm* system. This entailed each member of the design team using prototypes on their personal devices over a minimum of 10 weeks each to identify improvements and articulate new scenarios of use.

The goal of IPSRT is to help patients establish and maintain a stable social rhythm. *MoodRhythm* allows patients to track the 5 basic activities used in the prototypical paper version of the SRM: (1) waking time, (2) first contact with another individual, (3) starting their day, (4) dinner, and (5) bedtime, but also to add custom activities that may be more informative based on a particular patient's needs or habits (see **Figure 3**). The app allows tracking of mood and energy as well on a −5 (very low) to +5 (very high) scale.

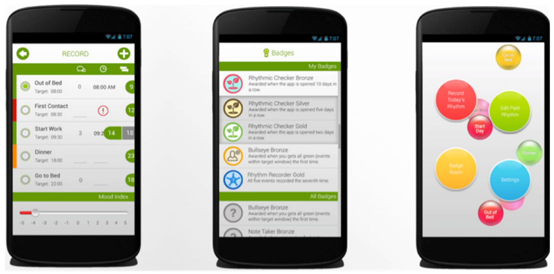


Figure 3: Screens for the *MoodRhythm* prototype.

Patients can set daily targets and track how closely they meet these target times. Notes can be used to record additional information such as the amount of medication taken or factors that may have affected a patient's routine or mood.

The diary is designed to provide an at-a-glance summary of the patient's successes in meeting their rhythm goals for both the current and preceding days. If the patient completes an activity within their customizable time window (the default is 45 minutes), then the bar to the left turns green. When the window is about to elapse and an event is not yet recorded, the bar appears yellow (a "warning" that a potential rhythm disruption is occurring). If a patient misses the target, then the bar turns red.

Individuals with bipolar disorder have been shown to possess "a hypersensitivity to reward-relevant stimuli" (Nusslock et al., 2012). To explore ways to increase patient adherence to self-report and to a stable routine, we incorporated badges elements into our system. *MoodRhythm* uses a behavioral reward system to encourage rhythmicity - a series of badges are given to users as they meet their therapeutic goals. Badges are given based on user adherence to self-report and their daily rhythmicity.

Table 1: Participant Feedback where 1 = Strongly Disagree, 7 = Strongly Agree.

	Mean	SD
The way MoodRhythm works overall is consistent	6.4	0.54
MoodRhythm has the functions and capabilities I would expect it to have	6.2	0.83
It is easy to learn to use MoodRhythm	6.4	0.89
This product felt trustworthy	6.4	0.89
This app is attractive	5.2	2.04
I like using the interface of this app	6.2	1.30
Interacting with this product require a lot of mental effort	1.6	0.54
The characters on the screen were easy to read	6.4	0.89
I felt comfortable using the system	6.2	1
Overall, I am satisfied with how easy it is to use this app	6	1

MoodRhythm also explores the possibility of using a range of smartphone sensors to passively detect social rhythms, levels of social interaction, and other aspects of daily life that are critical to wellness among individuals with bipolar disorder. It takes advantage of a variety of sensor data sources on the smartphone platform with the ultimate aim to infer many of the activities included in the prototypical, paper-based SRM instrument. Our platform continuously collects data from the phone's light sensor, accelerometers, and microphone, as well as information about phone usage events such as screen unlocks and battery charging state.

Our work in this area also draws on several years' worth of peer-reviewed algorithm design and empirical research in these areas, with sleep and social inference accuracies approaching 85%–90% with minimal intervention on the user's part. We use an empirically validated weighting of inputs from audio, accelerometer, light level, screen unlock, and charging state data sources in order to arrive at an estimation of the time that the user spent sleeping in a given 24-hour period (Rabbi et al., 2011). Another algorithm computes the frequency and duration of face-to-face conversations that a phone's owner has over the course of the day based on an analysis of audio data continuously collected using the smartphone's built-in microphone. For a more detailed description of the *MoodRhythm* system please see (Voida et al., 2013).

4 STUDY

To assess the impact of *MoodRhythm*, we conducted a small qualitative pilot study of the initial prototype lasting two months and involving three patients and three clinicians engaged in IPSRT. Each participant completed a usability measure at the end of the study.

Potential participants were identified through the Depression and Manic-Depression Prevention Program at Western Psychiatric Institute and Clinic, Pittsburgh. Inclusion criteria required patients to be already participating in a treatment program at the clinic, to be able to provide informed consent and to have a confirmed diagnosis of BD. Participants were excluded if they were unwilling or unable to comply with study procedures or had active suicidal ideation requiring inpatient or intensive outpatient management. No compensation was provided to participants. The Institutional Review Board at the University of Pittsburgh approved this research.

All three patients had used paper charts previously to track their social rhythms and moods – citing strengths of this medium as: *"portable and low upkeep"* and *"easy to use"*. Weaknesses mentioned included that this method makes it: *"hard to look at data points over long term"* (2 patients), and is inconvenient to use and results in invalid data: *"since I'm not very organized I sometimes lose them or forget to take them out and make the notations I should in a timely way. Counting on memory at the end of the week rarely reflects what the reality was"*.

Each participant completed a usability measure based on agreement with several statements where a 1 ("Strongly Disagree") to 7 ("Strongly Agree"). As **Table 2** above indicates, patient participants found the app easy to learn and use, attractive and trustworthy. This provides evidence that *MoodRhythm* appears to overcome several limitations of the paper-SRM and directly tackles the challenges patients and clinicians face by providing a convenient self-monitoring app, supporting clinical interventions by graphing patterns and correlations over time. A clinician commented accordingly: *"I think that this app could be a significant contribution to the treatment of mental health conditions and specifically bipolar disorder due to the illness' proven sensitivity to life's rhythms."*

A principal factor related to the convenience of using the smartphone to record activities:

> *"First and foremost, it was convenient, which meant that I remembered to note when activities actually occurred and how I felt (instead of trying to remember two days later)." Patient 1*
>
> *"It was right there for me with the rest of the utilities I use every day on the phone. I never had to look for it or a pen." Patient 2*
>
> *"It fits my needs nicely. It's always with me" Patient 3*

Another key aspect of *MoodRhythm* was reducing the time to receive feedback for patients, who typically only go through the paper forms when they see their psychiatrist: *"Getting the visual feedback when my day worked within the targeted times gave me more confidence that I could meet my doctor's expectations."(2 patients)* This was echoed by a clinician who commented: *"The prompt feedback that patient's receive via the device (i.e. items turn green when a task is completed "on time") will much more effective versus receiving the feedback only when they are with their therapist."*

Making it easy to collect the data and providing feedback opens up the possibility for patients and therapists to take a longitudinal view of patient's social rhythms and mood: *"... it occurs to me how very little of this very important information is available to a therapist when interviewing or treating an individual. We rely almost entirely on patient memory to make treatment decisions and when a person experiences depression, hypomania and/or anxiety the memory is often blurry at best."*

Patients and clinicians had varied reactions to sensing related to issues of privacy and awareness.

Patients indicated they were open to sensing in areas where they felt their perception of the behaviour was unreliable *("My perception of social interaction might be different than its perception. It would be interesting to hear how this works")* or where the behaviour was challenging to track *("sleep is difficult to record and evaluate sleep. Having something that makes this easier would help me make sure I'm getting enough sleep and at the right times."*).

However, patients tended to be interested in one aspect of sensing, but not another. In response to a question about using smartphone sensing to detect levels of social interaction, one patient commented: *"That's just creepy."* One clinician echoed this concern indicating that sensing might not be universally accepted: *"I think for a subset of patient's this may be very helpful but overall patient's may have concerns about privacy.*

There may be ways to tackle these concerns by being more transparent about how app sensing works. Smartphone sensing, unlike devices like the Fitbit, can naturally occlude is being tracked. One patient reported never installing an app when it requested access to her smartphone's sensors such as GPS or the microphone. She suggested that it might be helpful explaining why granting access will help the patient later on, show samples of what this data will look like and explain how it is stored (i.e. raw data or features of the data).

5 DISCUSSION

This study provides early yet encouraging evidence that technologies that combine sensors and self-report have promise in the treatment of serious mental illness and may be well accepted by individuals with bipolar disorder and their clinicians.

For the participants in this study, *MoodRhythm* overcame the limitations of the paper-SRM and directly tackled the challenges patients and clinicians face by providing a convenient self-report app, enabling long-term and symptomatic use via the use of smartphone sensors and supporting clinical interventions by graphing patterns and correlations over time.

We believe that these and similar technologies might be applied in a multi-phase manner. The combination of self-report and passive sensing has wide application for lifelong diseases like bipolar disorder where it can be extremely challenging to maintain regular self-tracking, but where self-report information, particularly at the outset of treatment, can be a highly valuable activity leading to critical insights for the patient about the relationship between social rhythm regularity and mood.

MoodRhythm aims to make recording daily routine information easier for individuals with bipolar disorder and provide more clinically relevant information to the clinician. This work applied several design approaches that could be applied in the design of systems to support individuals with psychiatric illness. They are to: 1) consider ways to make therapeutically beneficial behaviours appealing based on the pathology of the psychiatric illness (e.g., reward susceptibility); (2) think of the system as an agile tool that will need to be different things to different patients at different times (e.g., allow different elements to be enabled/disabled) and (3) communicate clearly how sensor inferences are collected and what the benefits to them are.

Prior work applying technology to the treatment of bipolar disorder have not accounted for the significant biological aspects of the illness. While this study's results are clearly preliminary – a rigorous evaluation of the resulting system is needed – it does provide an example of how sensing and patient-facing technologies can be designed and deployed which take into consideration the biological underpinnings of mental disorders. We are currently completing a longer-term study evaluating the system's effectiveness against existing interventions using the paper-based IPSRT instrument (SRM-5).

In addition to mood disorders, circadian dysregulation has been implicated in cancer, diabetes, obesity, bulimia nervosa, and Alzheimer's disease. Rhythm entraining interventions offer the potential to help stabilize these disorders. Health promotion/illness prevention strategies targeting healthy lifestyles and cardiovascular disease prevention may also take similar approaches. Therefore, an app that takes into consideration aspects of the neurocognitive characteristics of a user group to promote sleep-wake regulation and rhythm regularity has a wide range of potential applications beyond our initial targets, although the design of each app might have to be tailored to the specific end-users.

6 CONCLUSION

Psychiatric illnesses represent a considerable burden of diseases in the world. Increasingly the genetic components that result in cognitive and behavioural characteristics of these illnesses are being identified. In the case of bipolar disorder, while current research indicates that each person's bipolar disorder is unique, current clinical criteria place patients into accurate but not highly specific categories. By taking into account the pathology of the illness, there is long-term potential to create more nuanced diagnoses and treatment models on an individual-by-individual basis. Smartphone sensors and applications offer the possibility to both monitor and engage patients, in order to create more nuanced diagnoses and to take account of idiosyncratic neural characteristics to increase engagement in treatment.

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