Tell me your apps and I will tell you your mood: Correlation of apps usage with Bipolar Disorder State

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ABSTRACT

Bipolar Disorder is a disease that is manifested with cycling periods of polar episodes, namely mania and depression. Depressive episodes are manifested through disturbed mood, psychomotor retardation, behaviour change, decrease in energy levels and length of sleep. Manic episodes are manifested through elevated mood, psychomotor acceleration and increase in intensity of social interactions. In this paper we report results of a clinical trial with bipolar patients that amongst other aspects, investigated whether changes in general behaviour of patients due to onset of a bipolar episode, can be captured through the analysis of smartphone usage. We have analysed changes in smartphone usage, specifically app usage and how these changes correlate with the self-reported patient state. We also used psychiatric evaluation scores provided by the clinic to understand correlation of the patient smartphone behaviour before the psychiatric evaluation and after the psychiatric evaluation. The results show that patients have strong correlation of patterns of app usage with different aspects of their self-reported state including mood, sleep and irritability. While, on the other hand, the patients' application usage shows discernable changes in the period before and after psychiatric evaluation.

General Terms

Algorithms, Measurement, Experimentation, Human Factors

Keywords

Depression; Mania; Bipolar disorder; Smartphone Apps; patients; clinical trial; correlation;

1. INTRODUCTION

Mobile phones are becoming more and more an extension of our body and mind. Today there are hundreds of applications for mobile phones that support us in maintaining a lower cognitive load (reminders, contacts, calendar) and enhancing our body performance (sports, nutrition, sleep, etc.). Moreover, the amount of time that people spend with their mobile phone for other activities related to their everyday life such as entertainment (games, music, etc.), information (news, web, GPS navigation), working (email, messaging) and many more is rapidly increasing. Everyone can install and use applications that best fulfil their personal requirements; that better describe their particular needs, preferences and profile. In addition, people have different patterns of usage of mobile phones, which also depend on the personality and condition of the user.

Continuous usage of mobile phone applications in everyday life provides a trove of information that is particular to the user and their condition and suggests that there is a strong relationship between the apps that people use and their daily tasks and activities. This allows us to hypothesise that by tracking different mobile phone apps used within a day it would be possible to infer the type of activities the user typically carries out [15][16]. Moreover, analysis of use of applications in a longitudinal manner would be possible to predict the usage patterns of apps and therefore the activity patterns of users [17]. Such kind of analysis may be tuned to identify mobile phone app usage that may be related to specific monitoring purposes, such as person's health and wellbeing for example.

This work is within the lines discussed above and presents a study of the usage of mobile phone apps to infer people's health condition. In particular, this study is the first in current literature to investigate phone usage patterns and their correlation with the episode of the patients suffering from bipolar disorder, carried out in a clinical trial. The main focus on the study is app usage within the Smartphone and what this information can tell about the patients' state. The apps were classified in a number of categories such as social activities, browsing activities and entertainment activities and the time and frequency of their usage was monitored.

2. BIPOLAR DISORDER

Bipolar Disorder (BD) is a neurobiological disorder with cycling periods of mania and depression. Patients suffering from this

disorder may experience periods of mania and periods of depressive state in rapid succession. This is especially true for patients categorized as rapid cycling. Depressive episodes of BD are manifested through disturbed mood, psychomotor retardation, behaviour change, decrease in energy levels, and change in length of sleep. During a manic episode, a patient may show an abnormal period of elevated or irritable mood that is different from their normal behaviour. Social interactions may be intense and/or the patient may become hyper-verbal. In contrast, a depressive episode consists of loss of interest in daily activities or a low mood. For example, a patient may lose interest on his favourite activity/hobby. Moreover, the patient can show anxiety or become aggressive towards others. In this period there is a prevalence of feelings of guilt and thoughts of death or suicide resulting in an inability to concentrate. Finally, mixed episodes cause extreme swings of mood and energy. In this period a patient might be anxious, angry, and upset at the same time. Frequent mood changes produce severe irritability, anger reactions, and behaviour that is difficult to manage [2].

Several methods and test have been developed in order to diagnose bipolar disorder. The traditional method uses subjective clinical scales based on self-reporting that were developed in the early 1960s and other more recent variations of them. The efficacy of these scales has been proven in diagnosing bipolar disorder; however, these scales are a potential source of subjectivity in the diagnosis because patients' criteria can be influenced by their mood. Once bipolar disorder has been diagnosed, the main treatment is drug therapy, although the effectiveness depends on the timing of administration. Thus, therapy can be very effective if administered at the beginning of a patient's transition to a different episode. Otherwise, the effectiveness decreases as the time passes by. Clearly, timely

aspects, namely number of applications used by the user, number of times screen is on, and the time that the user spends on the smartphone. The hypothesis is based on the fact that each bipolar episode (depressive and manic) is directly manifested on behaviour changes, especially on social interactions; that is, manic patient tends to use relatively more the smartphone, interact more with friends through social applications. In contrast, in the depressive state the patient tends to decrease smartphone usage.

3. RELATED WORK
3.1 Pervasive technologies for well-being and medicine

With the proliferation of mobile devices in the last years, and the incorporation of different sensors, mobile computing has become an important instrument to monitor human behaviour in different domains applications. Mobile computing has been used to monitor both fitness activities and illnesses. To monitor fitness activities devices such as Polar, Nike+, Fitbit record heart rate, heart rate variability, distance travelled and so on, providing sufficient information to analyse and infer users' fitness level and progress over time.

Regarding the medical area, at the moment a number of works have used mobile computing to monitor different illnesses and provide a better understanding of them. For instance, work in [8] has identified design opportunities to support healthy sleep behaviours, since sleep analysis may be used to detect a number of sleep disorders, including sleep apneas. Also, work in [1] shown the potential of monitoring sleep apnea while measuring breathing and moving patterns using embedded microphone and accelerometer in mobile phones. Meanwhile, others works have used bluetooth and GPS data to analyze social interactions and

Table 1 Symptoms of Depressive and Manic episodes in bipolar patients

Depressive episode	Mania episode
1. Depressed mood and/or	1. Elevated and/or expansive mood and/or
2. Loss of interest and	2. Irritable mood and
Four other symptoms	Three (four is mood is only irritable) Other symptoms
3. Weight loss/gain	3. Inflated self-esteem or grandiosity
4. Insomnia or hypersomnia	4. Decreased need for sleep
5. Psychomotor agitation or retardation	5. More talkative than usual
6. Fatigue or loss of energy	6. Flight of ideas/racing thoughts
7. Feelings of worthlessness or inappropriate guilt	7. Distractibility
8. Diminished ability to think or concentrate	8. Psychomotor agitation /increased in goal directed activity
9. Recurrent thoughts of death, suicidal ideation/attempt	9. Excessive involvement in activities with high painful consequences

intervention is highly dependent on continuous and longitudinal monitoring of the state of patient, which is not feasible with the use of clinical questionnaires at a large scale.

As can be seen in Table 1, there are a number of symptoms and signs associated with depressive and manic episodes; some of them can be measured in a quantitative manner (i.e. using external sensors). Therefore, a feasible way to diagnose bipolar disorder and/or identify patient's transition between episodes is to use quantitative/objective data, instead of subjective information. As such, recognising the early warning signs makes it possible for the patient to receive treatment before a fully-fledged episode has onset.

Considering the objective information, our work focuses on hypothesis that a correlation between the patient state and the smartphone usage exists. Smartphone usage comprises three

user mobility in order to identify depression [10].

In the psychiatric field, a number of works [3][13][9] have focused on recognising and treating mood disorders. Through continuous sensing, smartphones enable monitoring of multiple dimensions of human behaviour, including physical, mental, and social interaction dimensions [7][6][11][12]. For the purpose of this work, there is a small number of works related to monitoring patients with mood disorder, but none that have monitored bipolar disorder through smartphone usage patterns. Work developed in [14] was designed to monitor depression using LiveNet system. The patients were carrying the mobile physiological sensing technology to track depression symptoms and objectively measure them. The authors emphasized the importance of validating electro-convulsive therapy (ECT), which resulted with positive effects on patient's depressive state. In [5] and [4], authors stated that monitoring via a set of sensors may free bipolar disorder

patients from various drawbacks. Furthermore, they investigate that the mood status related data could be reported via mobile phones as well as self-reporting in order to provide details about mental state of the patient and help set up therapeutic sessions between patients and caregivers. Moreover, other works have focused on automatic monitoring of patients suffering from bipolar disorder [13][6]; however, they have experienced issues regarding obtrusiveness of the monitoring technology. In a more recent work, authors have used physical activity data, and they have found a strong correlation between physical activity and bipolar patient state, allowing an early intervention [12][31].

3.2 Smartphone usage in medicine

Prevalence of chronic diseases is increasing all over the world and management of diseases represents one of the greatest health care challenges. As such, monitoring devices have the potential to support patients with chronic diseases through monitoring of their health aspects. Mobile computing and sensing technologies have shown the potential to improve healthcare quality, efficiency and reduce care costs.

Work carried out in [18][19][20][21] has focused on recognition and treatment of mood disorders in the field of psychiatry, utilizing technological solutions to tackle mental health issues. Compared with standard clinical practice for monitoring patients, measurements rely on observation data collected in laboratory setting or in person. For example, in [13] authors argue that increased knowledge about motor activity and repetitive movements of bipolar disorder patients during the manic episodes offers deeper insight towards new therapies. Therefore, accurate and continuous monitoring has become increasingly important in healthcare, where employing technology for patient monitoring can help assess the impact of mental illness on patients' daily activities and increase effectiveness in treating the mental disorder. Equipped with powerful embedded sensors, smartphones have become capable of monitoring multiple dimensions of human behaviour, including physical, mental, and social interaction dimensions [21][22][23][24][25].

A number of research activities have demonstrated the use of mobile phone applications allowing physicians to monitor patients with chronic heart failure [2] and detect early signs of arrhythmia that can indicate an imminent heart attack. The authors reported the feasibility of a new wireless telemonitoring system via a mobile phone. Furthermore, Alexander et al. [15] have shown the importance of using mobile phone monitoring patients with hypertension. The authors emphasize the importance of remote monitoring of vital parameters to diagnose health problems and provide early warning signals of potentially dangerous changes in patients' health status of patients with hypertension. Using mobile devices have shown significant improvement for blood pressure measurement.

Simpson et al. [26] applied self-monitoring among alcohol use patients in early recovery based on Interactive Voice Response (IVR) on mobile phones. The patients reported the positive effects of monitoring on urges to use alcohol and post-traumatic stress disorder symptoms.

Rapid improvements in mobile technologies are also facilitating involvement of psychiatry for monitoring patient's mental health. Mobile application "Optimism App" [27] designed to monitor depression, has been developed for patients to log self-reported mood, activities including exercises and quality of sleep. Providing feedback about their health status to the patients, it was highly recommended by psychiatrists to use in monitoring the patients' mental health.

However, despite the improvements of mobile technology, very few solutions have been implemented in clinical practice for ambulatory monitoring of patients with bipolar disease.

Assessing the activities of daily living is very often emphasized as an important aspect in order to understand progress of bipolar disorder. Blum et al. [21], [29] stated that monitoring via a set of sensors may free bipolar disorder patients from various drawbacks. Furthermore, they investigate that the mood status related data could be reported via mobile phones as well as self-reporting in order to provide details about mental state of the patient and help set up therapeutic sessions between patients and caregivers.

Several research initiatives have focused on automatic monitoring of patients suffering from bipolar disorder [18], [24]. However these initiatives have faced issues with obtrusiveness of monitoring technology. The work at PSYCHE project [30] used a smart textile platform and mobile phone to collect physiological data relevant to mental wellbeing. The authors have presented the importance of estimating the heart rate variability from respiratory rate. But such an approach may pose a discomfort in daily use caused by physiological sensors, such as ECG.

4. UNDERSTANDING SMARTPHONE USAGE OF PATIENTS

As stated above, the approach of this work is to have a better understanding of bipolar disorder through smartphone usage. Analysis of usage patterns has two main goals: firstly, to reveal which factors correlate with the smartphone usage and thus understand the correlation between patient state and smartphone usage over time. Secondly, to investigate whether there are differences between usage of smartphone before psychiatric evaluation and after psychiatric evaluation.

4.1 Data collection

In order to carry out the analysis, we have collected data from 18 patients with bipolar disorder. These patients were provided with a smartphone that contained MONARCA system and were monitored over a period of 5 months, from August 2012 to December 2012. Each patient was free to use the smartphone in any way they wanted, with no restrictions whatsoever placed upon the use. The MONARCA system collected data while running on the background, sampling accelerometer sensor, WiFi card, running applications, screen status, bluetooth, and microphone in a privacy-preserving manner. Moreover, the 18 bipolar patients provided every day self-assessment evaluation. These evaluations were used to address the first objective of this work. Thus, we compare subjective and objective data. The self-assessment includes the following items:

- Mood - Highly depressed (-3) to highly manic (3)
- Sleep - Amount of sleep, reported in half hour scale
- Medicine Taken - Yes/No
- Medicine Changed - Yes/No
- Activity - Highly inactive (-3) to highly active (3)
- Warning Signs - Number of active warning signs set by the patient (e.g. less than 8 hours of sleep)

- Mixed Mood - Yes/No
- Irritable - Yes/No
- Cognitive Problems - Yes/No
- Stress - No stress (0) to highly stressed (5)
- Alcohol - Number of alcoholic drinks

To analyse the correlation between patients' smartphone usage and their state, we have used information from the patients' self-reported state. On the other hand, in order to investigate whether there is a smartphone usage change before psychiatric evaluation and after psychiatric evaluation, we have used the actual psychiatric evaluation scores provided by the clinic. In psychiatric evaluations, clinicians used the following standard scales during the assessment of the patients:

- Hamilton Depression Scale (HAMD): HAMD scale has been applied to rate the severity of depression in patients through assessment of a range of symptoms. The higher the magnitude of symptoms, the higher is the scale of severity of depression (cut-off value: >=8)
- Young Mania Rating Scale (YRMS): YRMS is most frequently utilized rating scale to assess mania symptoms. The baseline scores can differ in general, depending on the patients' clinical features such as depression (YMRS=3) and for mania (YMRS=12).

Finally, in accordance to the data collected by the MONARCA system, the screen status is logged when there is a change from screen on to off or vice versa; the log also includes temporal information. The system also logs running applications in the interval of 5 minutes, including temporal information through a background process, in a transparent manner to the patient.

4.2 Data analysis methods

4.2.1 Correlation between patient state and smartphone behaviour

In order to identify which applications are used by the patient, we just considered those applications that are running within the time period when the screen status in on. As MONARCA system performs a scan every five minutes, for each day analyzed we compute the average number of applications used by the patient. Moreover, we compute the standard deviation to understand the variability of applications usage during the day.

Considering that patient mood is related to social interactions, ability to focus and other factors, we have classified the applications in five categories. Classification into categories was based on information from the Android market. Thus, we are able to correlate patient state with applications categories in order to have a better understanding of the disorder. In Table 2 we present a number of examples for each category.

Table 2 Smartphone apps classified by category

Social apps	Entertainment apps	Browser apps	Lifestyle apps	Tools apps
Facebook	Angry Birds	Chrome	Travel planning	Mobile payment
Twitter	NetFlix	Firefox	Life organizer	QR reader
WhatsApp	Youtube	Dolphin	Calories counter	Weather
Skype	Music	Tunny	Transportation app	Calculator
Google Chat	FM Radio	Android browser	Run keeper	Antivirus

Once we have classified the applications into categories, we proceed with the investigation of correlation of objective data with the assessment data; for this purpose we have used Spearman's rank correlation coefficient. From the objective data,

we have extracted a number of features that we have used to investigate correlation. These features are listed below:

- Number of applications;
- Standard deviation;
- Number of times the screen is on;
- Time when the screen is on;
- Percentage of social applications;
- Percentage of browser applications;
- Percentage of entertainment applications;
- Percentage of lifestyle applications;
- Percentage of tools applications.

In addition to this analysis, we have also carried out further analysis in order to investigate whether there is a change in patient behaviour, with respect to the applications used, before psychiatric evaluation and after psychiatric evaluation.

4.2.2 Change in smartphone behaviour in-between psychiatric evaluations

As mentioned earlier, we are also interested in discovering whether there is a change on the smartphone usage before and after each psychiatric assessment test. To carry out this kind of analysis we have compared the smartphone usage of one week before and one week after the day when the psychiatric evaluation took place. It is important to mention that for this analysis we excluded the days in which the patient went to the clinic for the psychiatric evaluation. This is because we were interested in natural patient behaviour and including days in which the patient was asked to go to the clinic for psychiatric evaluation would have biased our results.

4.3 Challenges and limitations

Although we have data from 18 patients over the course of around 5 months of monitoring period, there are gaps in the data, since there are instances when the patients turned off their smartphone or the patients did not provide the self-assessment test. Thus, for most users it was not possible to have access to a large amount of data. For the case of the second approach, just in a few occasions was possible to correlate data. Despite this, we obtained good results that show a good potential of using smartphone behaviour analysis to understand the state of bipolar disorder patients.

5. RESULTS AND DISCUSSION

5.1 Correlation between Smartphone usage and patient state

During the first analysis we were interested to investigate whether there is any correlation between smartphone usage and subjective data related to patient state. Literature suggests that patients in the depressive state show decreased levels of smartphone usage in comparison to their normal state, while the contrary holds true for patients in mania episode.

In Table 3 and 4, we present the correlations between objective and subjective data that are statistically significant (p<0.05). For each objective data, we have highlighted the major correlations. We do not show the remaining objective data because even though we obtained correlations that are statistically significant,

these correlations are low. Considering these results, we can provide the following observations:

Times screen status is on. When considering the number of times that patients used their smartphones, there are positive and

Table 3 Correlation between self-reported patient data and smartphone app usage (p < 0.05)

Entertainment Apps			Browser Apps			Amount of time screen is on		
Patient	Subjective data	r	Patient	Subjective data	r	Patient	Subjective data	r
48	Mood	0.37	57	Concentrate	0.21	57	Stress	-0.23
48	Concentrate	**-0.47**	100	Stress	**-0.30**	59	Mood	**-0.38**
57	Irritable	-0.26	100	Concentrate	**0.31**	86	Stress	-0.22
58	Concentrate	-0.27	102	Stress	**0.28**	101	Sleep	**-0.32**
58	Mixed mood	-0.26	102	Mood	**0.28**	102	Stress	0.25
59	Sleep	**0.41**	102	Sleep	-0.25	102	Sleep	**-0.27**
100	Mood	**-0.40**						
103	Mixed mood	-0.31						

Social applications. Previous works have demonstrated that depression is closely related to social isolation, absence of social interactions, and similar aspects. Therefore, it is interesting to find a strong correlation between social applications and patient state. Even though, there is a lack of physical social interactions, the patients have a negative correlation with stress level, irritability and mixed mood. That is, as the patient is in touch with his friends, or checking information about them, the stress level and irritability decrease.

Average number of applications. As we had postulated, there is a positive correlation when comparing the number of applications used with patient mood, and stress level. Thus, a patient in manic state tends to use more applications, on average. This is in contrast to the depressive state, where average number of application usage is less. As the behaviour is different for each patient we are not in position to define how many applications are

negative correlations. The higher correlation is negative when comparing with the stress level. Thus, as the patients experience less stress they use more their devices. Also, there is a negative correlation with mood level. As the mood scores may be closely related to stress scores, these negative correlations are also related.

Entertainment applications. With similar results to those obtained from social applications, when considering entertainment applications we obtained negative correlations compared with mixed mood, mood, irritability, and concentration. These results show that when the patient is not irritable, he/she does not experience mixed mood, or the patient does not experience concentration problems, they use more entertainment applications. Also, when the mood level is higher the entertainment applications usage increases.

Table 4 Correlation between self-reported patient data and smartphone app usage (p < 0.05)

Social Apps			Avg Apps			Times screen is on		
Patient	Subjective data	r	Patient	Subjective data	r	Patient	Subjective data	r
49	Sleep	-0.36	48	Stress	**0.37**	58	Stress	**-0.41**
64	Irritable	-0.28	48	Sleep	**-0.55**	58	Mixed mood	0.29
88	Stress	**-0.68**	49	Sleep	0.33	59	Concentrate	**0.33**
91	Stress	**0.44**	49	Mixed mood	**0.52**	82	Stress	-0.25
91	Mood	-0.23	58	Mood	0.31	84	Mood	-0.26
91	Sleep	-0.25	58	Sleep	-0.26	86	Sleep	-0.24
92	Stress	-0.28	58	Mood	0.31	91	Sleep	-0.25
93	Stress	-0.30	58	Sleep	-0.26	101	Stress	0.28
100	Stress	0.40	64	Mood	0.25	101	Mood	0.23
100	Mood	-0.32	64	Irritable	-0.28	101	Sleep	**0.42**
100	Mixed mood	-0.27	82	Mood	0.22			
102	Sleep	**0.41**	97	Sleep	-0.26			
102	Irritable	.24	102	Sleep	-0.34			
			102	Irritable	-0.23			

related for each patient episode (mania, normal, and depression). In addition, for three patients there is a negative correlation compared with sleep. This may occur due to sleep disturbance, caused by the bipolar episode.

Browser applications. For browser applications, most correlations are positive.

Amount of time patients interact with smartphone. An interesting result that we obtained is that there is a negative correlation

between the amount of time the screen status is on and the amount of time that patients sleep. This fact may be explained with the fact that patients that suffer from sleep disturbance may spend more time interacting with their mobile devices. Moreover, for two patients we obtained a negative correlation in comparison with the stress level.

Considering the above correlations, there are aspects of subjective reports by the patients that are correlated well with the measured objective data, namely smartphone app usage. Thus, clinicians may use objective data to aid in their diagnosis of stress levels, mood, sleep, and mixed mood, which in turn could assist in identifying a particular bipolar disorder episode, or in identifying when a transition among bipolar disorder episodes is taking place.

5.2 Correlation of Smartphone usage before and after psychiatric evaluation

For this analysis we have compared the average number of applications (denoted "Apps" in the table) and the variability of applications usage (denoted "Std"). In Table 5 we present statistically significant correlations of 3 patients. Unfortunately, due to sparse data it was not possible to compare applications usage for more patients; however, for those patients whose evaluations were analysed, the results are encouraging.

Table 5 Correlation of smartphone app usage before and after psychiatric evaluation (p < 0.05)

Patient	Evaluation	Correlation
103	Depression (Apps)	0.97
101	Depression (Apps)	0.90
97	Mania (Apps)	-0.94
	Mania (Std)	0.89

The first row corresponds to a psychiatric evaluation of patient 103. In this evaluation, the patient state was diagnosed having a depressive episode based on HAMD and YRMS scale. Thus, the correlation was positive for the average number of applications and the standard deviation. This correlation may be explained by the fact that after the patient was diagnosed as depressive, there was a change of behaviour. This behaviour change can be seen when considering increase of applications used. For patient 101 there is also a positive correlation when the diagnosis was depressive episode; however, there was not correlation on the variation of applications usage (Std). Finally, for the evaluation of patient 97, there is negative correlation when the diagnosis was manic state. Thus, after the psychiatric evaluation the applications' usage decreases (in average), although the variation on application usage within the day increases.

6. FINAL REMARKS

In this paper we have demonstrated the feasibility of using mobile computing to monitor patients with bipolar disorder. Our results show correlation between smartphone usage and subjective data that are closely related to bipolar disorder. Using objective data, clinicians have more information evaluate the state of the bipolar patients. The results also show that there is a change on smartphone usage before and after psychiatric evaluation.

During the data analysis we have noticed that the correlation between smartphone usage and patient state can be improved considering number of user interactions with applications. For instance, considering social applications users have a couple; however, on the mania episode the patient interacts with these applications on many occasions to be in touch with his/her friends, reviewing news, see photos, and so on. In contrast, on the depressive episode the interactions are less even though the number of running applications is the same.

Considering the correlations between objective and subjective data, our results show that not a single factors is present for all patients; each patient presents different levels of correlation for different aspects. Thus, when studying bipolar episodes, personalised models are better suited to detect early signs and facilitate timely intervention.

7. ACKNOWLEDGEMENTS

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