Development and evaluation of an emotion-sensitive assistance system for patients with bipolar disorder

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Pour mes parents, ma femme, ma petite fille et toute ma famille.

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Abbreviations

BD	Bipolar Disorder
mHealth	Mobile Health
AA	Ambulatory Assessment
IMIs	Internet and Mobile-based Interventions
SA	Self-Assessment(s)
EmAsIn	Emotion-sensitive Assistance systems for the reactive psychological Interaction with people
DSM-5	Diagnostic and Statistical Manual of Mental Disorders, 5th edition
BDI-II	Beck Depression Inventory-II
ASRM	Altman Self-Rating Mania Scale
HAMD	Hamilton Depression Rating Scale
YMRS	Young Mania Rating Scale
SCID-5	Structured Clinical Interview for DSM-5
EE	Expressed Emotions
CBT	Cognitive Behavioral Therapy
FFT	Family Focused Therapy
IPSRT	Interpersonal and Social Rhythm Therapy
EFT	Emotion-Focused Therapy
ECT	Electroconvulsive Therapy
TPA	Third-Party Assessment(s)
SD	Standard Deviation
n	Number of cases
SotD	Story of the Day
LIWC	Linguistic Inquiry and Word Count
FACS	Facial Action Coding System
M	Mean
s	Second(s)
r_s	Spearman rank order correlation
p	Probability
P1, P2, …	Participant 1, Participant 2, …
SCID-IV	Structured Clinical Interview for DSM-IV
LIFE	Longitudinal Interval Follow-up Evaluation

Zusammenfassung

In den letzten Jahren haben *Internet- und mobilbasierte Interventionen* für Bipolare Störungen mehr und mehr an Bedeutung gewonnen. Dabei ist insbesondere der *Mobile Health*-Ansatz ins Zentrum der Aufmerksamkeit geraten. Die entwickelten mobilbasierten Systeme nutzten bisher Selbstbeurteilungen von Patienten oder multiple Datenquellen, um den Stimmungsverlauf oder Stimmungsumschwünge abzubilden. Während Forschung und klinische Praxis sowohl die Bedeutung emotionaler Aspekte für den Störungsverlauf als auch die Relevanz von Fremdanamnesen für diagnostische Zwecke belegen, wurden beide Bereiche in mobilbasierten Systemen bislang nicht berücksichtigt. Das Forschungsziel für die vorliegende Dissertation war es daher, ein emotionssensitives Assistenzsystem für Bipolare Störungen zu entwickeln, das beides einbezieht: Das System sollte den verbalen und mimischen Emotionsausdruck von Patienten analysieren und zugleich ambulante Fremdbeurteilungen der Stimmung der Patienten durch nahestehende Personen ermöglichen. Die vorliegende Arbeit beschreibt den methodischen Ansatz und die Ergebnisse aus vier Abschnitten des Entwicklungsprozesses. Im ersten Schritt wurde mit einer Online-Umfrage und semi-strukturierten Interviews die Einstellung von Patienten zu technischen Assistenzsystemen und deren potentiellen Funktionen untersucht. Im zweiten Schritt wurden die theoretische und die technologische Basis des neuen Ansatzes erarbeitet und daraus das Systemkonzept abgeleitet. Im dritten Abschnitt wurde eine kleine Pilotstudie mit Patienten durchgeführt, in der ein erster Prototyp auf seine Akzeptanz und Machbarkeit hin untersucht wurde. Der letzte Schritt schließlich bestand aus drei Einzelfallstudien von Patienten, in denen der klinische Mehrwert des emotionssensitiven System-bestandteils (Fall 1 und 2) oder der Fremdbeurteilungen (Fall 3) untersucht wurde. Patienten zeigten positive Einstellungen in Bezug auf technische Assistenz oder innovative Funktionen wie Emotionserkennungsmodule (Schritt 1). Basierend auf diesen Erkenntnissen wurde das erste mobilbasierte Assistenzsystem für bipolare Störungen entwickelt, welches den Emotionsausdruck untersucht und Fremdbeurteilungen einbezieht (Schritt 2). Alle untersuchten Funktionen zeigten eine gute Akzeptanz. Selbstbeurteilungen zeigten zudem eine gute Machbarkeit, die Emotionserkennung war teilweise machbar, die Fremdbeurteilungen waren dies jedoch nicht. Mit Blick auf die technische Funktionalität erzeugte die verbale

Emotionserkennung zuverlässigere Ergebnisse als die mimische Emotionserkennung (Schritt 3). Manische Symptome korrelierten mit Veränderungen verhaltensbezogener Systemparameter. In einem Fall waren Stimmungsumschwünge mit Veränderungen des verbalen und mimischen Emotionsausdrucks assoziiert. Weiterhin gab es Hinweise auf einen diagnostischen und prognostischen Mehrwert der emotionssensitiven oder verhaltensbezogenen Parameter in Bezug auf Stimmungsveränderungen. Selbstbeurteilungen und Fremdbeurteilungen zeigten unabhängig der Machbarkeit eine hohe inhaltliche Übereinstimmung (Schritt 4). Bis auf die Online-Umfrage basieren alle Daten auf kleinen Stichproben oder Einzelfallstudien, was die Generalisierbarkeit der Ergebnisse einschränkt. Auch kann ein Selektionsbias durch eine hohe technische Affinität der Studienteilnehmer nicht ausgeschlossen werden. Zusätzlich erhöht der explorative Ansatz der Pilotstudie und der Fallstudien das Risiko der Alpha-Fehler-Kumulierung. Mehr Daten werden benötigt, um aussagekräftige Ergebnisse in Bezug auf die Machbarkeit und Validität der Systembestandteile zu erhalten. Dennoch deuten die Befunde auf eine gute Akzeptanz und moderate Machbarkeit des emotionssensitiven Ansatzes hin. Individuelle Unterschiede in der Wahrnehmung und Nutzung der Funktionen legen eine hohe Flexibilität technischer Systeme nahe, so dass einzelne Module ein- oder ausgeschaltet werden können. Die Ergebnisse deuten weiterhin auf einen klinischen Mehrwert der Emotionserkennung hin und belegen darüber hinaus die Individualität bipolarer Symptome und ihrer Auswirkungen. Zukünftige Forschung muss die Befunde bestätigen und den Fremdbeurteilungs-Ansatz evaluieren. Die Aufzeichnung des Emotionsausdrucks bipolarer Patienten könnte eine akzeptierte und machbare Ergänzung bisheriger Bestrebungen sein und zukünftig diagnostischen, prognostischen oder sogar therapeutischen Zwecken dienen.

Abstract

Over recent years, more and more attention has been paid to *Internet- and Mobile-based Interventions* for bipolar disorder. Especially the *Mobile Health* development has had a great impact on this field. Research projects have developed mobile-based systems that used self-assessment or multi-channel data to benefit mood monitoring or mood state recognition in bipolar disorder. Two potentially important factors, however, have not yet been considered within this context: Research and clinical practice indicate the importance of emotional aspects and third-party anamneses for the disease outcome or diagnostic purposes. Therefore, the objectives for this dissertation were the development and evaluation of an emotion-sensitive, technical assistance system for bipolar disorder that accounts for both: It was supposed to analyze the verbal and facial expressions of patients with respect to emotional cues. It was further supposed to allow for ambulatory third-party assessments of close contacts concerning the patients' mood states. The current work describes the methodological approach and results of four different stages throughout the developmental process. As for the first stage, the attitudes of patients towards technical systems and potential features were examined during an online survey and semi-structured interviews. Within the second stage, the theoretical and the technological bases were worked out in order to develop the system concept. The third stage was a small pilot study with patients examining a prototype of the system in regard to its acceptability and feasibility. Finally, three cases of patients were selected and analyzed separately to establish the clinical value of either the emotion-sensitive module (Case 1 and 2) or the third-party assessments (Case 3). Patients with bipolar disorder showed positive attitudes towards technical assistance and innovative features such as emotion recognition modules (Stage 1). Based on these findings, the first mobile-based system for bipolar disorder has been developed that analyzes emotional expressions of patients and allows for optional third-party assessments (Stage 2). All examined features were well-accepted. The incorporated self-assessments were feasible with a small sample of patients, the emotion recognition was partly feasible, but the third-party assessments were not feasible. In regard to the technical functionality, the analysis of verbal expressions was more dependable than the recognition of facially expressed emotions (Stage 3). Manic

symptoms correlated with behavioral changes within usage-related system parameters. With one patient, mood swings were associated with changes of verbally or facially expressed emotions. There were indications of a certain predictive value of expressed emotions or behavioral patterns with respect to occurring mood state changes. Furthermore, self-assessments and third-party assessments were highly correlated (Stage 4). Except for the online survey, the small samples or single case studies limit the generalizability of the results and a selection bias through a high technical affinity of participants cannot be excluded. Additionally, the exploratory approach of the pilot study and the case studies increases the risk of alpha inflation. More data is needed to generate substantial findings regarding the feasibility and validity of system features. However, the results indicate a good acceptability and a moderate feasibility of the emotion-sensitive module. Individual differences within the perception and usage of the features call for flexible systems, which allow to activate or deactivate modules. The results further support the individuality of bipolar symptoms and ramifications and they suggest a diagnostic and prognostic value of emotion recognition. More research is necessary to confirm these findings and to examine the third-party assessments. Yet, in the future, the long-term monitoring of emotional expressions in bipolar disorder may be an acceptable and feasible feature and might possibly be helpful to diagnostic, prognostic or even therapeutic purposes.

List of publications

a) Accepted manuscripts

[1] Daus H, Kislicyn N, Heuer S, Backenstrass M. Disease management apps and technical assistance systems for bipolar disorder: Investigating the patients' point of view. J Affect Disord. 2018; 229:351-357. https://doi.org/10.1016/j.jad.2017.12.059

[2] Daus H, Bloecher T, Egeler R, De Klerk R, Stork W, Backenstrass M. Development of an emotion-sensitive mobile Health approach for mood state recognition in bipolar disorder. JMIR Ment Heal. 2020; 7(7):1-10. https://doi.org/10.2196/14267

[3] Daus H, Backenstrass M. Feasibility and acceptability of a mobile-based emotion recognition approach for bipolar disorder. Int J Interact Multimed Artif Intell. 2021. https://doi.org/10.9781/ijimai.2021.08.015

[4] Daus H, Fink-Lamotte J, Backenstrass M. Mobile-based, emotion-sensitive video diaries and ambulatory third-party assessments as indicators of mood states in bipolar disorder. Minerva Psichiatr. 2021. Accepted manuscript.

1. General introduction

Bipolar disorder (BD) is one of the most common psychological disorders worldwide [5]. The disease characteristically presents itself with a combination of recurring depressive and (hypo) manic episodes [6,7]. These episodes, themselves, are defined by severe changes in the patients' mood, experienced emotions, cognition and several behavioral or (psycho) physiological aspects [8–12]. Due to the impact of such mood episodes and the often chronic course of the disease [5,6,13], affected patients and their relatives or related parties are burdened with psychological suffering and the impairment of relevant life areas [14,15]. For example, BD can affect social functioning, the occupational career or the socio-economic status of patients [16,17]. Although therapeutic approaches or medication can influence the course of BD positively [18–22], recurring episodes or even persisting symptoms are often [5,6,13]. As a consequence, additional strategies within the (ambulatory) patient care and the empowerment of self-management capabilities are of great importance [19,23,24]. Therefore, over recent years, the *Mobile Health* (mHealth) approach has gained more and more influence within the field of BD [25,26]. Internet and mobile-based technologies like smartphones, smartphone-intern sensors or external wearable devices (electronic devices mostly worn on the wrist to collect and analyze physiological data) have been used in order to assess and monitor illness activity, recognize mood state changes or deliver time-sensitive interventions [25–31].

Almost all mobile-based systems for BD use the methods of *Ambulatory Assessment* (AA) and, therefore, share the common advantages of good accessibility, cost efficiency, time-sensitivity of assessments or a high ecological validity through the natural environment [32,33]. However, the broad field of *Internet and mobile-based Interventions* (IMIs) or mere monitoring systems in BD depict an overwhelming but yet inconsistent or insufficient picture [34]. Although there are a few studies suggesting positive effects of mHealth approaches on depressive symptoms in BD [27,35,36], so far, this is not applicable for mania. Furthermore, on the one hand, some monitoring features like regular self-assessments (SA) or the analysis of automatically assessed sensor data have shown their potential to mood state recognition in BD [25,26,37–42]. Yet, other valuable sources of information

about occurring mood state changes or other important areas of bipolar symptom ramifications, have been neglected. While research implies that emotional aspects of BD are related to the course of symptoms and the social or global functioning of patients [8,43–50], the experienced and expressed emotions of patients have not yet been sufficiently considered. Beyond that, the potentially valuable external perspective of spouses or related parties on the symptoms of patients has not sufficiently been incorporated in the mHealth approach in BD [51,52].

Based on these potential shortcomings, this dissertation presents a newly developed, emotion-sensitive assistance system for BD, which addresses both afore-mentioned aspects: It considers and analyzes the emotional expressions of patients and allows for the involvement of related parties into the mood monitoring approach. The emotion-sensitive system has been developed within a multi-professional research approach resulting from the project *Emotion-sensitive Assistance systems for the reactive psychological Interaction with people* (EmAsIn). Within the next sections of the introduction, a brief overview of the theoretical and empirical background of this dissertation will be presented. Subsequently, the objectives and research questions as well as the expected output of the current work will be described in more detail (section 2). Following this, four different stages of the research project will be addressed by presenting the methodological approaches, results and implications of four theoretical or empirical studies (three research articles and one viewpoint article) throughout the developing process (section 3). Finally, the findings and the output of these stages will be discussed in a more holistic view by focusing on their clinical relevance and on their implications for further research (section 4). The four original articles, this dissertation is based on, will then be presented in the appendix of the current work.

1.1 Bipolar disorder

Depending on the study setting and the time period, the estimated prevalence of BD differs a lot between populations [53–55]. Recent meta-analyses report a lifetime prevalence of between one or two percent worldwide [5,53,56–58]. Although the etiology is not yet sufficiently clear, BD is assumed to be caused by multiple factors, including genetic or biological parameters as well as life stress, psychosocial influences or personality traits [59,60]. The disease itself is defined by a combination

of depressive and (hypo) manic episodes. In regard to the *Diagnostic and Statistical Manual of Mental Disorders, 5th edition* (DSM-5), depressive episodes present with at least five out of nine symptoms within a two-week period. These symptoms are depressed mood, loss of interest or pleasure, changes of weight or appetite, disturbed or increased sleep, motoric symptoms like restlessness or inhibition, fatigue or loss of energy, feelings of worthlessness or guilt, disturbed concentration or difficulties in decision-making and thoughts of death or suicidality [7]. At least one of these five symptoms has to be depressed mood or loss of interest or pleasure. The symptoms have to induce psychological distress or relevant impairment and may not be induced by any substances or medical conditions [7].

During manic episodes patients experience abnormally elevated, euphoric or irritated mood periods and an increase of their energy or activity level for at least one week. Three (four in case of irritated mood) or more additional symptoms must be present during the same time period. These symptoms are increased self-worth or ideas about grandeur, decreased need of sleep, increased talkativeness or urge to speak, increased speed of thoughts or flight of ideas, distractibility, motoric restlessness and engagement in many activities regardless of potentially negative consequences [7]. Again, the symptoms have to be severe enough to cause relevant impairment, hospitalization or have to be associated with psychotic symptoms. Moreover, the manic episode, too, may not be induced by substances or medical diseases. While hypomanic episodes share the same symptoms of mania, they are less severe and last for at least four consecutive days [7]. The DSM-5 further allows for several additional specifications of bipolar episodes or the course of the disease like, for example, “with mixed features” or “with rapid cycling”. Whereas rapid cycling describes a long-term course of the disorder with at least four separate mood episodes within a twelve-month period, “with mixed features” defines mood states or emotional states with predominant depressive or manic symptoms and contemporary characteristics corresponding to the other symptom group (depressive or manic) [7]. Consequently, mood episodes with mixed features (or mixed episodes) represent diverse and often very critical combinations of depressive and (hypo) manic symptoms [61,62].

Therefore, BD can present itself with very different symptomatology. Mood states can resemble symptoms of other disorders (e.g., schizoaffective disorder, unipolar

depression) and can be difficult to categorize or to assign to the correct diagnosis [5,59,63]. Thus, within diagnostics of BD, a multimodal approach is recommended [64]. Next to the patients' self-perception of depressive or (hypo) manic symptoms (e.g., *Beck Depression Inventory-II*, BDI-II [65]; *Altman Self-Rating Mania Scale*, ASRM [66]), several clinical rating scales or clinical interviews (e.g., *Hamilton Depression Rating Scale*, HAMD [67]; *Young Mania Rating Scale*, YMRS [68]; *Structured Clinical Interview for DSM-5*, SCID-5 [69]) are of interest. Beyond that, a thorough medical history including the long-term course of symptoms, family history and the exploration of differential diagnoses or comorbidities is essential. Apart from several recommended somatic or laboratory examinations (especially in the case of intended pharmacotherapy), the external view of close contacts or spouses within third-party anamneses is of great importance [64,70]. This perspective can be a key element within correct diagnostics since BD can induce biases in the self-perception of patients, especially during severe mood episodes [71,72]. Unfortunately, within primary care, this diagnostic effort cannot always be made and, consequently, BD often stays unrecognized or misdiagnosed for a long time period up to many years [6,59,63].

BD is further associated with broad emotion-related difficulties. First of all, patients with BD can show a generally increased emotionality [8,73] and, during mood episodes, there are typical patterns of changes within the experienced emotions [10]. In (hypo) manic mood, the emotional experiences show elevated levels of happiness, anger or fear. During depressive episodes, especially the emotional experiences of sadness and disgust are amplified [10]. Beyond that, BD is associated with difficulties in the processing of emotional information and in emotion regulation capabilities [8,44,74–76]. Studies further indicate difficulties of patients with BD in emotion recognition [48,49,76–80] as well as in the verbal or facial expressions of emotions [45,81,82], for example by using different emotional stimuli in order to examine the induced reaction. While these deficits might partially be modulated by the patients' mood states [77,78,83], they are certainly relevant to their everyday lives and influence important areas of their lives, such as the social relations [45,48,49]. In accordance with this, several studies have shown the strong and negative effects of emotional deficits on the social and global functioning of patients with BD [8,43–49]. Moreover, abnormalities within emotion dynamics have been

associated with future bipolar psychopathology [50]. Even severe outcome variables like suicidality are related to strong emotional responses of patients [43,84]. Finally, high expressed emotions (EE) within the families or relationships of patients are common and are related to the course of BD and relapse frequency [85–88]. As a consequence, emotional aspects significantly affect the long-term course of BD, and the consideration of emotional expressions might be relevant to accurate and comprehensive diagnostics [82].

There are several treatment options for BD including pharmacotherapy (e.g., mood stabilizers, antipsychotics [89,90]), psychotherapy (e.g., *Cognitive Behavioral Therapy*, CBT [91]; *Family Focused Therapy*, FFT [87,92]; *Interpersonal and Social Rhythm Therapy*, IPSRT [93]; or *Emotion-Focused Therapy*, EFT [94]) and other somatic (e.g., *Electroconvulsive Therapy*, ECT [95,96]), psychological, psychotherapeutic or psychosocial approaches (e.g., Psychoeducation [18,19]; self-management [24,97]; or occupational therapy [98]). Although therapeutic approaches can have positive effects on the severity and course of symptoms [18–21,90,96], frequent relapses, persisting or chronic symptoms and psychiatric comorbidities are not uncommon in bipolar patients [5,6,13,19]. Thus, the personal or economic consequences of this disease as well as the individual burden and suffering of the affected patients or their families can be enormous [14,15,99,100]. For this reason, additional strategies within patient care that have the potential to complement the pharmacological and psychotherapeutic treatment in BD are of great interest. Since IMIs, for instance, have shown the capability to support the constant self-monitoring of patients or the management of subsyndromal symptoms [27,31,35,101], the mHealth approach especially has got into focus (see next section).

1.2 Mobile Health in bipolar disorder

Within the context of the ongoing technological development and the openness of patients with BD towards the use of technical assistance for disease management purposes [24,102,103], lately, increasing attention has been paid towards IMIs for BD [26,27,31]. The initially mentioned advantages regarding the availability, accessibility or cost efficiency of mobile-based systems could benefit the ambulatory care of patients, especially of those without sufficient treatment [104]. The common self-monitoring of symptoms can be facilitated through digital assessments using

mobile devices or smartphone applications. Although the long-term adherence towards mHealth systems needs more research [105], several studies support their advantages with respect to their availability or adherence [38,106–110]. Moreover, the use of smartphones or wearable sensors has shown its benefit regarding the automatic monitoring of illness activity in BD [25,26,42,111]. For instance, sensor data (e.g., from activity trackers, accelerometers) were used in order to infer behavioral measures representing the activity levels of patients [25,26,37,112]. Other smartphone sensors, like the number of phone calls and messages, have been seen as sensitive measures of social behavior [40,113] and have shown several mood-dependent associations in patients with BD [40]. As a consequence, multiple studies investigating mobile-based approaches for BD support the potential of sensor data with respect to the recognition of mood-state changes [26,39,112,114].

Whereas the digital and partly automatic monitoring approaches might already take some pressure off the continuous self-monitoring of patients, the implementation of automatic interventions can have additional effects. For example, several studies have examined the combination of AA and time-sensitive, automatic system responses, like psychoeducational feedback, in order to improve the treatment compliance or self-management strategies of patients [115–119]. Positive effects could be found in regard to treatment or medication adherence, disease management or perceived self-efficacy or even biological rhythms [27,117,120–123]. Even mere text message reminders were able to improve the medication adherence of patients and further coincided with positive changes within their attitudes towards medication [122,123]. Beyond that, sensor data related to the current lighting conditions of the ambulatory setting and sound samples collected through smartphone microphones, enabled the recognition of social rhythms of patients with BD [41,124]. Accordingly, automatic interventions or notifications could be initiated following the recognition of disturbed rhythms and might, therefore, positively affect the course of BD.

Finally, although (so far) there seems to be no reliable effect of mobile-based interventions on manic symptoms, the results of several studies indicate a certain effectiveness regarding depressive symptoms in bipolar and other affective disorders [35,115,125,126]. For example, the mobile-based study approach of one research project combined questions about symptoms with semi-personalized

responses and found transdiagnostic (schizophrenia, depression and BD) effects of the intervention on depressive symptoms [35,36]. In summary, the mHealth approach seems to have the potential to benefit the disease management in BD through adjunctive, technical assistance in ambulatory care [104]. However, as promising as some of the described research approaches may be, many of the already available systems have deficits with respect to their theoretical or empirical foundation [29,121,127,128]. In addition, compared with their importance for the overall functioning or disease outcome [8,43–50], the emotional aspects of BD are underrepresented within the mHealth development. Yet, the incorporation of emotion-sensitive assessments might generate helpful information about the affective state of patients, symptom severity or relevant outcome-related variables such as their emotional reactivity [50,81,82,84]. Furthermore, compared with their highly relevant role within clinical practice or diagnostics [64,70,92,129], the perspectives of spouses, relatives or related parties of patients are underrepresented within the mHealth development, too. Thus, the integration of third-party assessments (TPA) might help diagnostic or prognostic purposes. Beyond that, such assessments might even give related parties the opportunity to feel included.

1.3 Need for research

Verbally and facially expressed emotions are certainly important indicators of internal, mental processes [130]. Therefore, sudden or severe changes of emotional expressions can point at psychological distress [131]. This might be especially relevant within the context of BD, which is associated with several emotion-related difficulties, an amplified emotionality and changes within the experienced emotions during mood episodes (see section 1.1). Up to the present, mobile-based approaches have monitored self-evaluated emotional impulsivity in patients [84]. Moreover, IMIs for BD have analyzed random sound samples through mobile devices [41,124,132], voice characteristics within phone calls [133,134] or socio-behavioral parameters like the keyboard activity of patients [135,136] to infer certain emotional states. Yet, to the knowledge of the author, audio files or social interactions have not been analyzed with respect to their emotional content. Experimental studies have examined emotional expressions of patients with BD in response to emotional stimuli within a standardized setting [45,81,82]. However, no

mobile-based system has, so far, focused on facial expressions of this patient group or analyzed these expressions in regard to the presence of emotional cues. Due to the relevance of emotion-related aspects of this disease for its symptomatology, course and outcome, these aspects should be considered more thoroughly within the design of future disease management systems [50]. In comparison with other measures, emotional expressions might be more directly linked to the emotional reactivity of patients [81] and might add valuable information to diagnostics [50,82]. Their long-term ambulatory monitoring might further increase our knowledge of the emotional experiences and expressions in BD and their relation to the patients' overall functioning.

Additionally, because of the characteristics of the disease and, hereby, especially those of the (hypo) manic states, the external perspective of related parties can generate essential information about the patients' condition (see section 1.1). There have been efforts to include spouses or close contacts of patients into mHealth approaches, for example in order to support these parties with information or to provide family interventions [51,52,137]. To the knowledge of the author, though, no ambulatory assistance system for BD has yet integrated TPA to gain more information about illness activity in patients. This potentially valuable source of information, too, should be considered during the design of future systems. The gained data may not only benefit diagnostic or prognostic purposes but might possibly also shift potentially difficult direct conversations about mood states towards more neutral digital assessments. Finally, there are disease management applications or systems for BD that are poorly investigated, methodologically flawed or do not meet the patients' needs [29,34,127,128]. This calls for certain standards of future developments: New assistance systems should be designed upon a solid theoretical and empirical basis and should account for the consumers' needs [34,128].

2. Objectives and expected output of this thesis

The objectives of the current dissertation concern the development and evaluation of an emotion-sensitive, technical assistance system for patients with BD that further allows the incorporation of third parties into the monitoring approach. In the future, a fully developed and dependable emotion-sensitive system might benefit diagnostic, prognostic, or even emotion-focused therapeutic purposes.

To this end, as a first step, the needs and attitudes of patients with BD towards technical assistance in their disease management had to be examined. According to the overall positive attitudes of consumers regarding mental health applications [138,139], a positive view of patients with BD on several (new and innovative) features of technical assistance systems was expected, too. With this in mind, two studies were conducted: an online survey (Study 1) and semi-structured interviews (Study 2) with patients with BD (see section 3.1 or the original article in the appendix [1]).

As a second step, the system concept in regard to an emotion-sensitive approach had to be developed by taking into account the theoretical and empirical background of related research areas. The theoretical, empirical and technological bases of the emotion-sensitive system had to be presented within a concise review. Moreover, to the knowledge of the author, the expected outcome of this step was to be the first mobile-based system that incorporates the analysis of emotional expressions of patients with BD and of additional TPA (see section 3.2 or the original article in the appendix [2]).

As a next step, the acceptability and feasibility of the emotion-sensitive approach were supposed to be examined during a small pilot study with patients with BD. All examined system features were expected to show a good feasibility and, in agreement with earlier research findings supporting a higher technical affinity with younger patients [103,140], all system features were expected to be more feasible with younger participants. Beyond that, as for emotion recognition, convergent results of the visual and auditive recognition software were expected. Due to the openness of patients with BD towards other technical disease management systems [115,141],

all features were expected to be well-accepted (see section 3.3 or the original article in the appendix [3]).

Finally, the clinical value of the newly developed system was supposed to be examined during three diverse case studies. The first two case studies were to be evaluated with respect to emotion recognition: In accordance with the typical patterns of experienced emotions during bipolar episodes [10], the recognized emotions in the verbal and facial expressions of both cases were expected to reflect and/or to predict clinical symptoms. Consequently, more positive emotional expressions were expected to coincide with more severe manic and less depressive symptoms. Moreover, the elevated expression of negative emotions was expected to coincide with more severe depressive and less manic symptoms. Additionally, because of the frequent behavioral changes in BD [12,40,63], patterns within the usage of the emotion-sensitive module were expected to be associated with bipolar symptoms. The third case study was supposed to examine the potential additional value of ambulatory TPA: The self-perception of patients (SA) and the external perception of related parties (TPA) were expected to be positively associated. Both assessment types were expected to be positively associated with clinically assessed bipolar symptoms. In regard to earlier research findings suggesting mood-dependent biases in the self-perception of patients with BD [71,72], the case study was further supposed to examine whether the external perspective showed a higher conformity with clinical assessments (see section 3.4 or the original article in the appendix [4]).

3. Methods, results and initial discussion of results

Within the following sections, the main aspects of the four included original articles, which are presented in the appendix, will be described. The articles will be summarized in the logical order throughout the developing and evaluation process of the emotion-sensitive assistance system. Thus, at first, the analysis of requirements will be considered (section 3.1). Following this, the development of the system concept will be presented by focusing on the emotion-sensitive system module (section 3.2). Afterwards, the empirical findings of the studies examining the feasibility and acceptability (section 3.3), or the clinical value of the approach (section 3.4) will be described. For each article (or logical step), the methodological approach and the results will be outlined, and the implications will be indicated in short discussion sections.

3.1 Analysis of requirements

The analysis of requirements was conducted prior to the development of the system concept and intended to examine the attitudes of patients with BD towards several aspects of technical disease management systems. Furthermore, the perspectives of patients in regard to some innovative features (especially the emotion-sensitive audio and video analysis) were assessed, since those had already been considered for the incorporation into the system concept. To this end, an online survey (Study 1) and a semi-structured interview study (Study 2) with participants suffering from BD were conducted [1].

3.1.1 Study 1

Within the eight-week period from December 2015 to January 2016, the online survey was placed on several websites relevant to BD or health issues. The websites originated from Germany, Austria and the United States.

3.1.1.1 Methods

Participants: Eighty-eight participants prior diagnosed with BD completed the online survey. On average, they were 31.8 years old (*SD* = 10.4) and 75 % of the participants (*n* = 66) were female.

Instruments: The survey was designed with a convenient online tool [142]. It consisted of 27 questions concerning demographic data, characteristics of applications or technical systems for BD, and available technological gadgets (e.g., wearable devices).

Analysis: The data was analyzed with the same online tool used for the realization of the survey [142].

3.1.1.2 Results

Participants were mostly motivated to submit regular SA of relevant symptom areas to applications (84.1 %). With respect to external assessments of their mood state by close contacts or professionals, more than half of the participants mainly agreed (59.1 %). As for the automatic assessment of possibly mood-related parameters, like their physical activity (65.9 %), sleep characteristics (61.4 %) or the usage of social applications (52.3 %), most participants agreed, too. Beyond that, many participants would have further appreciated the automatic recognition of facially expressed emotions (47.7 %) or of speech signals (45.5 %) for their mood recognition. Regarding the incorporation of wearable devices into disease management approaches, most participants were motivated to use such devices for the assessment of their physical activity (62.5 %), heart rate (69.3 %) or electrodermal activity (52.5 %). As far as the implementation of automatic interventions is concerned, there were several popular features like feedback about the mood state (87.5 %), data visualization (86.3 %), warnings of occurring mood episodes (84.1 %) or advice in current crises (80.7 %). See the original article in the appendix for further details [1].

3.1.2 Study 2

In order to gain more insight into the perspectives of patients with BD, the semi-structured interviews were conducted between January and August of 2016.

3.1.2.1 Methods

Participants: Fifteen participants suffering from BD were included into the interview study. On average, the participants were 44.2 years old (*SD* = 13.0). Nine of the participants were male (60 %).

Instruments: The interview guide included almost the same topics as the online survey, but it was developed using open-ended as well as closed-ended questions. Furthermore, with every question, additional comments could be made. Beyond the survey questions, the semi-structured interviews also included additional questions regarding feasibility or usability issues of technical systems or potential ideas for improvements. For example, participants were asked, “During stable mood, in what frequency could you imagine completing assessments about the most important symptoms?”. Altogether, approximately 50 questions were included, and the duration of the interviews was about 60 minutes.

Analysis: All answers of the interviews were recorded. The numerical data was analyzed using *Microsoft Excel V. 16.0.*

3.1.2.2 Results

Most participants were motivated to use an application for SA of bipolar symptoms (93.3 %) or other behavioral aspects (e.g., consume of alcohol, 80.0 %). However, external assessments were suggested by participants and, therefore, automatic assessments of physiological (93.3 %), neurocognitive (93.3 %) or sleep parameters (86.7 %) were perceived positively. Still a majority of the participants agreed with the monitoring of their social media usage (66.7 %), or movement patterns (60.0 %). However, flexible systems with optional features were suggested. Eighty percent of the participants were further interested in the analysis of short audio or video sequences regarding their contained emotional expressions. Partner applications that would incorporate external mood assessments by close contacts were very much favoured, too (93.3 %). Digital questionnaires (93.3 %) or automatic calls (86.7 %) were seen as feasible options for the realization of SA, and the majority of the participants (80 %) agreed with the use of wearable devices. Most of them (80 %), moreover, considered one daily interaction (that does not take up more than five minutes) reasonable. In regard to the potential interventions of disease management approaches, the most favoured features were an automatic feedback about the mood state (73.3 %), a medication reminder (66.7 %), advice in crises (86.7 %) or the visualization of all accessed data (93.3 %). For further details or examples of comments and explanations of participants, see the original article [1].

3.1.3 Discussion

Overall, the participants of both studies showed positive attitudes towards disease management apps or assistance systems. These results suggest a potentially high technological affinity of this patient group and, beyond that, they are consistent with the positive attitudes of other consumers towards evidence-based mental health apps [138,139]. Furthermore, the findings coincide with the often good feasibility and acceptability of new media assistance among patients with BD found in earlier studies [24,31,102,124]. Both samples mostly agreed with an automatic measurement of certain sensor parameters (e.g., with wearable devices) as well as with regular SA. As expected, even innovative features such as video analysis or partner apps were perceived favourably (especially during the interviews). However, the opinions and answers varied between participants and, in accordance with further research, some of them emphasized the importance of flexible systems with features that can be personalized, activated or deactivated [102,119]. The results further indicate that patients with BD would be motivated to interact with disease management apps or systems on a daily basis. As a consequence, symptom monitoring in BD should be facilitated and designed to be more time-sensitive by using smartphone technology [38,115,141]. Thus, the partially automatic monitoring of symptoms could complete the common SA approach [124,143] and, therefore, deliver important information about mood states even during phases of less-reliant self-monitoring [39,40,144]. So far, little or no empirical data supports the benefits of audio and video analyses or partner apps in the disease management of BD. Yet, the high motivation and openness of the participants regarding such new features indicate their acceptability or feasibility. From the clinical point of view, a well-conceptualized audio or video analysis should not invade the privacy of patients but could allow to monitor their emotional expressions. This might be clinically relevant, for example for the recognition of mood episodes. A partner app, on the other hand, might deliver information about a potentially valuable external perspective of close contacts of patients. This, too, might benefit the early recognition of mood state changes. Moreover, both features could improve the common understanding of illness activity in BD.

Limitations: Within both studies, selection biases due to the participants affinity for or interest in technical health assistance cannot be excluded. Beyond that, online

surveys do not allow flexible interactions with participants. Consequently, important information can be disregarded and a deep understanding of the opinions of participants can be inhibited. The interview sample, on the other hand, includes a small number of patients, which always raises the question of the generalizability of the results. Together, nevertheless, both approaches enable a more holistic view on the patients' perspectives, offering valuable results in regard to the development of an emotion-sensitive assistance system for BD.

3.2 Development of an emotion-sensitive assistance system

Within the development of an emotion-sensitive assistance system for BD, the afore-mentioned findings of the analysis of requirements (section 3.1) were considered. Therefore, the resulting system has been adapted to the need of patients with BD. Due to their key role in mood monitoring (see section 1.2), SA and the assessment of sensor data have been incorporated. Furthermore, the system allows for optional TPA and for short recordings of patients, which are analyzed with respect to emotional cues. In the following sections, the conceptual and technological approach of the emotion-sensitive system will be presented by focusing on the emotion recognition approach, the so-called *Story of the Day* (SotD) module [2].

3.2.1 System concept and components

The assistance system incorporates a smartphone app as well as a wearable device and gathers data from multiple channels in order to realize the detection of mood state changes in BD. The key component of the assistance system, the SotD module, aims to recognize socio-emotional cues in the communication behavior of patients and, in this way, enable conclusions about their emotional or mental states. To this end, the module analyzes the verbally and facially expressed emotions in short recordings that are self-initiated and authorized by the patients. Consequently, the SotD module relies on its regular use and collects active and passive emotion-related data (see section 3.2.2). Altogether, the assistance system allows for the assessment of sensible data by using the following resources:

a) SA regarding the mood, activity level and other symptoms of BD,

b) associated TPA of bipolar symptoms by related parties,

c) automatically assessed physiological parameters (e.g., heart rate or resting heart rate),

d) automatically assessed sleep parameters (e.g., sleep duration or quality),

e) automatically assessed sensor data indicating the behavioral activation (e.g., recognized activities, movement/acceleration or smartphone usage),

f) assessments of auditive and visual information (e.g., verbal or facial expressions) as emotional cues and indicators of mood states.

The SA (app-based) and the TPA (web application) are almost identical and contain six 7-point items (from -3 to 3) concerning bipolar symptoms. Whereas negative values are predominantly associated with depressive states, positive values reflect (hypo) manic symptoms. Additionally, potential early warning signs (e.g., mixed emotions or caffeine intake) can be included and, in this case, are evaluated with yes or no during each assessment. Behavioral aspects like movement patterns or social interaction are assessed with internal smartphone sensors. The monitoring of the patients' sleeping behavior or physiological parameters is realized through the connected wearable devices that users can wear on their wrists. Unlike other sensor data, the emotion-sensitive data is not assessed automatically but relies on the activation and use of the SotD module. The assistance system integrates the gathered data from all sources and visualizes the most relevant information in form of graphic representations. In case of recognized mood state changes, the fully developed system is supposed to send warning signals or, just like earlier approaches [115,117,118,120], to recommend certain strategies (e.g., to consult a doctor). Apart from further long-term analyses [2,145], rule-based evaluation models have been installed in order to increase the accuracy of the later state recognition (e.g., by individually adjusting the importance of certain parameters for each patient). For further details on the assistance system, see the original article [2].

3.2.2 Story of the Day

Earlier studies realized the analysis of ambient sound samples or voice features in BD without processing any emotion-sensitive information [41,124,132–134]. With the aid of the SotD module, however, patients intentionally record short audio and video sequences which are then automatically analyzed in regard to verbal and

visual emotional cues. With the SotD study version, smartphones with external microphones are kept in well-positioned holders for each assessment in order to secure a good recording quality. The SotD module then activates the internal smartphone camera as well as the attached external microphones. During the assessments, users are asked to narrate important events of their day and, at the end, to actively save their recordings. The auditive and visual data is analyzed separately. As for verbal information, recordings are analyzed with respect to the count of emotional words and further speech parameters (e.g., verbal fluency). Therefore, the used language within the recordings is automatically transcribed and the words corresponding to several emotional categories (e.g., positive emotions or negative emotions) are analyzed on the basis of the *Linguistic Inquiry and Word Count* (LIWC) program [146]. As for visual information, facial expressions during the SotD assessments are analyzed following the *Facial Action Coding System* (FACS [147]). To this end, each recording is divided in short intervals of single frames, which are then examined with respect to the facial expressions of basic emotions (e.g., happiness, sadness or anger). For a more detailed description of the SotD analysis, see the original article [2].

3.2.3 Discussion

The concept of the new emotion-sensitive system includes well-known components of the mHealth approach for BD: To start with, digitally realized and therefore more time-sensitive and practical SA of patients [38,106–109]. Secondly, automatically assessed sensor data in order to passively monitor illness activity [25,26,112,114]. Beyond that, as with earlier approaches [115,117–120,148], recommendations and self-management strategies in case of mood disbalances are part of the pursued system design. Apart from this, the emotion-sensitive system goes beyond existing mHealth approaches in BD and realizes the analysis of emotional expressions of patients and of ambulatory TPA by their close contacts. In order to accomplish an accurate emotion recognition, the well-established FACS [147] and LIWC [146] approaches were implemented into the assistance system since they present themselves with the necessary empirical basis for the current purpose. As a consequence, to the knowledge of the author, the current system is the first mobile-based approach that analyzes emotion-sensitive information (including the emotional

content of the spoken language within user-triggered recordings). Former studies still realized the analysis of ambient sound samples or voice features during phone calls – but without considering any emotional content or cues [41,124,132–134]. Hence, for the first time, the current approach accounts for the enormous effects of emotional deficits on the social and global functioning of patients [8,43–49]. In so doing, the emotion-sensitive approach may not only be of interest for mood state recognition purposes but might also benefit the understanding of emotional experiences and expressions or emotion dynamics in BD [50]. Beyond that, the strong association between the social and global functioning of patients and the emotional aspects of this disease might even make emotion-sensitive systems helpful to emotion-based treatment approaches in BD [94,149–151]. As for the implementation of TPA, some patients themselves emphasized the importance of this external perspective on their mood state during the initial interviews (see the original article corresponding to section 3.1 [1]). Furthermore, while the self-perception – of course – stays the most important perspective in mood monitoring, during severe bipolar episodes or in certain cases SA can be less dependable [71,72]. Additionally, BD is a great burden on relationships [14]. The involvement of related parties through web-based assessments might even reduce some tension as compared to strained direct interactions.

Limitations: Although the SotD module automatically analyzes emotion-sensitive data, it relies on its regular use and, therefore, on the patients' motivation and (possibly) on their mood state. This fact, however, guarantees the patients' privacy, since the module does not automatically record audio or video sequences without their active initiation. As far as the different emotional categories of the recognition approach are concerned, the SotD module does not examine disgust within the facial expressions of patients. Yet, this emotion is relevant to bipolar mood episodes [10] and should be considered during future developments of mobile-based recognition approaches. Finally, during the analysis of requirements, many patients appreciated the involvement of third parties within their mood monitoring approach. However, not all patients approved of this feature or had such trusting relationships (see section 3.1 or the corresponding original article [1]). That is why the assistance system was designed flexible, allows to activate or deactivate several features and, consequently, meets the patients' needs (see section 3.1 or the corresponding original article [1]).

3.3 Feasibility and acceptability

The first prototype of the presented emotion-sensitive assistance system for BD (section 3.2) has been examined during a small pilot study with patients [3]. The following sections focus on the feasibility and acceptability of the SA, the TPA and the SotD module. In order to prevent redundance or double content, the sections presenting the methodological study approach contain references to earlier chapters of this dissertation and hence have been kept concise.

3.3.1 Methods

Participants: Three male and two female patients with remitted BD were included in the pilot study and participated from April to December of 2018. The individual study duration of several weeks differed between patients (see section 3.3.2). The patients were between 24 and 51 years old (M = 39.40, SD = 9.94).

System features: The afore-mentioned smartphone application and the wearable device of the assistance system were the most important study instruments. The assistance system and its components (including the three concerned features of the SA, TPA and SotD module) have already been presented in section 3.2. For further details, see also the original articles in the appendix [2,3]. The study participants used the assistance system in their natural, ambulatory environment and were asked to use the examined features on a regular (e.g., daily) basis. As for participants who had included related parties, their contacts were asked to use the TPA regularly, too. Furthermore, there were more detailed instructions that were intended to guarantee correct SotD recordings [3].

Semi-structured interview: The perspectives and experiences of all participants were assessed at the end of their study participation during semi-structured interviews. The questions concerned all potential system features and were especially detailed in regard to the SotD module (see the original article [3]). Every question was answered on a 5-point scale ranging from 1 (“negative” or “not at all”) to 5 (“positive” or “exactly”) and allowed for free comments of the participants.

Indicators of feasibility and acceptability: Several behavioral or usage-related aspects were assessed in order to operationalize and measure feasibility: The participation duration of all participants, the usage frequency of all features and the

duration of SotD recordings. Beyond that, several aspects were seen as indicators of the technical feasibility of the SotD module: The count of recognized words, the accuracy of automatic transcriptions, the count of recognized faces and the amount of recognized emotional expressions in the audio and video data. Moreover, the congruence of the auditive and visual emotion recognition (i.e., their convergent validity) was analyzed and seen as a potential proof of concept and feasibility indicator. The acceptability measures were operationalized through the interview questions and the (numerical or free) answers of the participants (see the original article for further explanations [3]).

Design and analysis: The five study participants were mostly considered single cases with separate data analyses. Only with single research questions, a statistical group design was applied in order to realize correlation analyses or further methods. Over an intended time period of twelve weeks, the feasibility data was assessed within the natural environment of the participants. The correlations between their initial age and their usage frequency of the SA and the SotD were analyzed to examine a potential age effect. All recognized LIWC [146] word categories within automatic or manual SotD transcriptions were compared in order to assess the congruence of both sources. As for the expressions within recognized words or faces, the percentage of every emotional category was assessed according to the LIWC [38] and FACS [39] approaches. The correlations between corresponding or contradicting categories of both sources were analyzed to establish their congruence. The semi-structured interviews that were supposed to capture acceptability aspects were realized in German during individual sessions. The answers (quantitative and qualitative) were recorded and translated into English. All calculations were conducted with *IBM SPSS Statistics V. 26* or *Microsoft Excel V. 16.40*.

3.3.2 Results

Feasibility: The participants' assessment periods differed from 57 to 134 days (M = 87.40, SD = 32.14). The usage frequency of the examined features showed great differences between participants. Whereas the SA were used about daily by most participants, there were almost no TPA within the current study. As for the SotD, the number of single assessments ranged from 6 to 48. Further details and an illustration of the percentage of study days per participant with recognized usage of

the examined features can be found in the original article [3]. The average duration of the SotD recordings was between 90 and 150 s for all participants. The correlation analyses showed negative correlations between the participants' age and the percentage of study days with recognized SA [$r_S(3) = -.60$, $p = .285$] or SotD assessments [$r_S(3) = -.70$, $p = .188$]. The average count of recognized words by the LIWC [146] software within the automatically generated SotD transcriptions ranged from 106.29 to 240.77 words between participants. The automatic transcriptions and a sample of ten manual SotD transcriptions, on average, matched to approximately 90 % (see the original article [3]). In reference to the wordcount of the automatic transcriptions and for each participant individually, the LIWC software recognized average amounts between 3.00 % and 5.89 % of words corresponding to the category of positive emotions. As for words corresponding to the category of negative emotions, the average values ranged from 0.93 % to 2.01 % (see the original article for further details and more specific emotional categories [3]).

The video data of each SotD recording was automatically divided into single video frames. In regard to four participants, within more than 94 % of the frames the software successfully recognized faces. With one participant, however, only within 0.31 % of the frames face recognition was successful. Regarding the other four participants, on average, between 7.38 % and 17.44 % of the relevant frames (successful face recognition) contained the facial expression of happiness. The facial expression of sadness was hardly ever detected (average values of ≤ 0.02 % for all participants). No other emotional category was detected by the FACS analysis (see the original article [3]). There were several moderate or strong correlations between emotional LIWC or FACS categories for all participants with successful face recognition. For example, with one participant (P1), more facially expressed happiness was associated with less verbally expressed positive emotions. Regarding another participant (P2), more facial happiness coincided with more positive verbal expressions, and more facial sadness with a higher amount of sadness-related words in verbal expressions. Yet another participant (P3) showed a moderate correlation between facial expressions of happiness and the more frequent use of emotionally positive words. As for the last participant (P5), facial happiness coincided with the verbal expression of more positive and less negative emotional

words. For further details and the specific correlation coefficients, see the original article in the appendix [3].

Acceptability: Two out of five participants were able to evaluate the TPA (since their related parties used this feature) and perceived the assessments very positively (*M* = 4.50, *SD* = 0.71). All five participants showed positive attitudes towards the SA (*M* = 3.80, *SD* = 1.10) and SotD assessments (*M* = 3.40, *SD* = 1.14). The SotD instruction was evaluated as easily understandable (*M* = 4.60, *SD* = 0.55) and most participants agreed with a regular usage (*M* = 4.00, *SD* = 0.71). The intensity of their emotional activation during the SotD assessments was perceived as moderate (*M* = 2.80, *SD* = 1.30). Of the potential confounding factors, the participants perceived the missing dialog partner (*M* = 3.40, *SD* = 1.14) and the selfie mode (*M* = 3.40, *SD* = 1.14) during the assessments as influencing. Participants mostly denied an increased burden through the SotD usage (*M* = 2.00, *SD* = 1.41). Examples of additional free comments or explanations of the participants are illustrated within the original article [3].

3.3.3 Discussion

Feasibility: Whereas two study patients were not able to participate for the intended duration due to their late recruitment, none of the participants terminated prematurely. This fact could be seen as an indication of an overall feasible system. In accordance with the good feasibility of mobile-based SA during earlier studies [38,141], as expected, the SA were the most feasible during the current study, too. The TPA, however, were only used by two related parties of participants (with sparse entries). Consequently, this feature did not indicate its expected feasibility. Although the often-burdened social relationships in BD [14] might have played a role in this, the finding primarily could be explained by the web-based study approach of the TPA. As compared to mobile-based assessments, the approach may have been more effortful and should be modified in the future. Moreover, the mobile-based third-party approach should be investigated in larger family studies [152]. The SotD recordings were the most effortful study feature. Yet, they were still recorded regularly (i.e., about every or every second day) by two participants and occasionally (i.e., on ten to 16 percent of the study days) by the others. The current SotD study version might thus be feasible with some patients.

Still, the handling of the feature should be facilitated in order to increase its general feasibility. In accordance with earlier findings indicating a higher technical affinity of younger patients with BD [103,140], as expected, the SotD and the SA were more feasible with younger participants.

As far as the technical feasibility is concerned, the audio quality of the SotD recordings and the accuracy of the transcriptions were acceptable [153]. The face recognition worked well with most patients. The unsuccessful face recognition of one participant could be explained by the specific recording circumstances that were not according to the instructions [3]. Regarding the emotion recognition approach, most results support the consistency of the auditive and visual measures: Within both sources, the software recognized considerably more positive than negative emotions and corresponding FACS [147] and LIWC [146] categories were highly correlated in several cases. Additionally assessed clinical data showed a relatively stable mood of most of the study participants with mild or moderate (hypo) manic or depressive symptoms in between (see section 3.4 and the original articles in the appendix [3,4]). Following this, psychopathology may not have induced strong or persisting changes in the participants' emotional experiences or expressions (e.g., increased sadness during the SotD). Furthermore, technical issues may have influenced the results: Although the FACS and LIWC frameworks [146,147] are empirically established approaches, the FACS-based video analysis might have been less sensitive to the recognition of negative emotions (see the original article [3]). With one participant, the strong negative correlations between *FACS Happiness* and *LIWC Positive emotions* still seem to conflict with each other. However, earlier findings indicating disease-specific deficits in the (facial) expression of negative emotions [45,81] and additional characteristics of the concerned participant could be seen as clinical explanations (see the original article for further details [3]).

Acceptability: The positive view of the participants regarding all three examined features coincide with former research showing the overall positive attitudes of patients with BD towards technical assistance [102,121,141]. Especially the positive response on the SotD is impressive since there were still potential issues and confounding factors within its technical realization (i.e., experience of handling and usage). Yet, all participants were open to a regular usage (three to six times per week). The participants' suggestions for improvements matched the original SotD

concept [2,3] and should be considered with future systems. With respect to the overall perspectives of the study participants, the ambulatory monitoring of emotional expressions in BD should be acceptable.

Limitations: The generalizability of the current results is limited due to the small sample of patients and the different participation times. Moreover, the findings solely indicate the acceptability and feasibility of the approach (and its potential issues) and not its clinical value. Before implementing emotion recognition approaches into mobile-based systems for BD, detailed cost-benefit analyses would be necessary and the recognition approach would have to deliver valid and reliable results with respect to all relevant emotions [7,10].

3.4 Evaluation of the clinical value

The newly developed, mobile-based emotion recognition approach (i.e., SotD) and the ambulatory TPA have been examined in regard to their potential clinical value within three single case studies [4]. Case 1 and Case 2 concern the evaluation of the SotD. Case 3 evaluates the TPA. Within the following sections, the methodological approach, the most important results and their implications will be presented. Again, references to earlier chapters will be used in order to prevent redundance or double content.

3.4.1 Methods

Participants: The patients with BD corresponding to the single case studies used the emotion-sensitive system during the afore-mentioned pilot study in 2018. The two patients that used the SotD regularly (Case 1 and Case 2) consequently generated important data regarding its clinical value. The third patient (Case 3) did not use the SotD regularly and, therefore, generated insufficient emotion-sensitive data. Nevertheless, this patient involved a close contact person into the pilot study and thus delivered relevant third-party data. For further details on the participants, see the case-specific results (section 3.4.2) or the original article in the appendix [4].

Materials and measurements: The technological basis and the functionality of the system features have been presented in section 3.2 (see also the original articles in the appendix [2–4]). Apart from the AA, the participants had clinical appointments

every second week. During these sessions, bipolar symptoms and diagnostical information were assessed with clinical instruments (see next section).

Clinical instruments: The German version of the *Structured Clinical Interview for DSM-IV* (SCID-IV [154]) was used in order to assess diagnostical data at the beginning of the patients' study participation. The established diagnoses were specified according to the more recent DSM-5 [7]. The regular clinical assessments over the following participation periods were conducted using a modified version of the *Longitudinal Interval Follow-up Evaluation* (LIFE) interview [155]. The new interview version included the DSM-5 criteria for BD and evaluated all relevant symptoms retrospectively for all days of the prior assessment period. Finally, two clinical scores were calculated for each assessment day. The *Depressive score* added the number of depressive symptoms (from 0 to 9), and the *Manic score* the number of manic symptoms (from 0 to 8).

Indicators of bipolar symptom severity: Symptom severity was operationalized through the clinical scores of the LIFE interviews [155] and through the participants' self-evaluation of bipolar symptoms during the SA (see section 3.2 or the original articles [2,4]). More severe manic symptoms were expected to coincide with higher values of the SA score and the *Manic score*. More severe depressive symptoms were assumed in case of higher values of the *Depressive score* and lower values of the SA score.

Design and analysis: The data of all participants was analyzed separately within single case studies. The SotD assessments as well as the SA and TPA took place within the natural environment of the participants. All AA used smartphone- or web-technology. Beyond that, bipolar symptoms were evaluated bi-weekly and in retrospect using clinical interviews. The assessment periods corresponding to the three case studies were between 57 and 97 days long. Case 1 and Case 2 examined the contribution of the SotD to the recognition of bipolar symptoms. Therefore, the correlations of usage-related SotD parameters and the SA or the clinical scores of concurring days were analyzed. Beyond that, the correlations of recognized expressions corresponding to emotional LIWC [146] or FACS [147] categories (in percent and in relation to the count of recognized words or faces) and the SA or the clinical scores were analyzed. Moreover, Case 2 allowed for preliminary Granger

causality tests [156] in order to examine the prediction regarding symptom severity (see the original article for further details [4]). Case 3 examined the contribution of the TPA to the recognition of bipolar symptoms. To this end, the correlations of TPA and SA (and their respective items) of identical assessment days were analyzed. Moreover, the correlations of the resulting assessment scores and clinical scores of identical assessment days were analyzed. All statistical analyses were realized using *Microsoft Excel V. 16.40* and *IBM SPSS Statistics V. 26*. The Granger causality tests were conducted using the *R-package vars* [157,158].

3.4.2 Results

Case 1 and 2 (Story of the Day): Case 1 concerns a 38-year-old male patient with BD Type I. The participant used the assistance system for 97 days, conducted 97 SA and recorded 43 SotD sequences. As compared to the other cases, the patient showed a relatively instable mood over the assessment period (see the original article for an illustration of the symptom course [4]). The correlation analyses showed no significant Spearman correlations between the *Depressive score* and any of the SotD parameters. As for the *Manic score*, there were no significant correlations with the emotional FACS or LIWC categories but several significant correlations with usage-related parameters: The daily *Number of recordings* showed a moderate positive correlation, the *Count of words* and *Words per second* showed moderate negative correlations with manic symptoms. Consequently, in case of more manic symptoms more recordings were initiated but the speaking rate was lower and less words were expressed. Concerning the SA, the two SotD parameters *Number of recordings* and *FACS Happiness* showed significant and moderate positive correlations. This indicates that more manic or less depressive symptoms within the SA coincided with more recordings and more expressed facial happiness. For further details and exact values, see the original article [4].

Case 2 corresponds to a 24-year-old female patient with BD Type II who used the assistance system for 57 days. The participant conducted 54 SA and recorded 48 SotD assessments. The patient showed a relatively stable mood with intermediate small mood swings (see the original article [4]). The correlation analyses showed several significant correlations of the *Depressive score* and SotD parameters: The *Recording duration*, *Count of words* and *Words per second* were strongly and

negatively correlated. Thus, depressive symptoms coincided with shorter recordings, a lower speaking rate and less expressed words. Furthermore, *FACS Happiness* was moderately and negatively correlated, and *LIWC Negative emotions* showed a moderate positive correlation. Consequently, during increased depressive symptoms, there were less facially expressed happiness and more negative expressions within the spoken language. As far as the *Manic score* is concerned, several SotD parameters showed significant correlations, too: The *Recording duration*, *Count of words* and *Words per second* were moderately and positively correlated. Therefore, in case of manic symptoms, recordings were more extensive with a higher speaking rate and more verbal expressions. Beyond that, *FACS Sadness* showed a significant, moderate positive correlation. This indicates that mania coincided with more sad facial expressions. With respect to the SA, several significant correlations with SotD parameters could be found: The *Count of words* and *Words per second* showed moderate positive correlations with higher SA scores. Thus, more manic or less depressive symptoms within the self-perception coincided with more and more fluent verbal expressions. Moreover, *FACS Happiness* and *LIWC Positive emotions* were positively associated with the SA scores (with strong or moderate correlations), and *LIWC Negative emotions* showed a moderate negative correlation. Following this, more manic or less depressive symptoms within the self-perception coincided with more happy facial expressions and more positive as well as less negative emotional expressions within the speech. For further details, see the original article [4].

The Granger causality tests of Case 2 showed no significant predictions of the *Depressive score*. Yet, the *Manic score* was significantly predicted by several parameters: Of the usage-related aspects, especially the duration of the recordings and the number of expressed words increased prior to the manifestation of manic symptoms (with lag-1 models providing the best fits). As for the emotional expressions, facial happiness increased prior to the manifestation of manic symptoms (lag-2 model). Furthermore, the usage-related parameters significantly predicted the SA score: The length of the recordings as well as the expressed words and the verbal fluency increased before the SA score rose (lag-1 models). An illustration of the described findings can be found in the original article [4].

Case 3 (Third-party assessments): Case 3 concerns a 51-year-old male patient with BD Type I. The participant used the assistance system for a time period of 92

days. During his participation, 46 SA and 17 TPA of a close contact person were completed. On 13 participation days, both assessments were conducted. Both parties were interviewed in regard to the reasons for the small number of TPA. They stated that these assessments were mainly motivated by obvious mood swings throughout an otherwise stable phase of the patient. The correlation analyses showed a strong positive Pearson correlation of the scores of concurring TPA and SA. As far as single items are concerned, the items *Mood*, *Activity*, *Sexual desire*, *Self-worth* and *Energy* of both assessments showed strong or moderate positive correlations. Only one item that had been labelled differently within both assessments, the *Speed of thoughts* (SA) or *Urge to speak* (TPA), showed a strong negative correlation. No significant correlations were found between both assessment scores and simultaneously (i.e., on the same days) assessed clinical symptom scores. For the exact values of the correlation results, see the original article in the appendix [4].

3.4.3 Discussion

Case 1 and 2 (Story of the Day): Case 1 and 2 examined the clinical value of the SotD module. Since there were great differences between both cases (e.g., in regard to age, sex, symptom course or data structure), their comparison is complex. Nevertheless, there are consistent findings: Clinically assessed manic symptoms were more associated with behavioral changes captured by the SotD than with emotional parameters. This coincides with earlier research supporting the stronger behavioral ramifications of mania [11] and with the established role of behavioral sensor data in monitoring approaches [25,26,112,135]. Furthermore, the expression of facial happiness coincided with the self-perception of more manic or less depressive symptoms of both patients. This finding also assorts well with former research investigating the typical emotional patterns of mood episodes in BD [10]. Since other findings suggest a less impaired facial display of happiness in patients with BD (as compared with other emotions [45]), its expression might be more affected by the patients' mood state and thus might benefit mood state recognition.

Otherwise, both case studies indicate the high individuality of bipolar symptoms. The case-specific patterns of manic symptoms and usage-related aspects, for example, resemble well-known but still different ramifications of activation in BD [12]: Whereas

Case 1 showed a restless pattern of more recordings with less and less fluent verbal expressions in mania, with Case 2, manic symptoms coincided with more extensive narrations. Moreover, depression was associated with several changes of behavioral or emotional parameters in the second case study but did not reflect in any parameters with Case 1. All of the depressive effects found with Case 2 coincide with former research showing the loss of energy during depression or the associated emotional changes [10,12]. Thus, the results indicate that, with this patient, the system might be able to infer depressive states from changes within the SotD parameters. Case 2 further showed an association between facial sadness and manic symptoms. Due to the overall small amount of recognized sadness this result could be inconclusive. However, the correlation result might also be explained by the often complex or mixed emotional experiences of patients [8,10,73]. The self-perception results of both patients confirm the afore-mentioned activation patterns during mania. Apart from the described elevation of facial happiness within both cases, with Case 2, the self-perception further showed associations with verbal emotional expressions into the expected directions. Altogether, the findings of Case 2 seem more conclusive, which could be a consequence of the more regular SotD usage and the resulting, more continuous time series.

The data structure of the second case study thus allowed for preliminary Granger causality tests. The speech characteristics captured by the SotD as well as facial expressions of happiness could predict manic symptoms. These results agree with the correlation results, because all effects showed comparable directions. Furthermore, the behavioral SotD parameters could predict self-assessed symptoms, too. As a consequence, next to the reflection of contemporary symptoms, Case 2 indicates a certain prognostic value of the SotD for occurring bipolar symptoms.

Case 3 (Third-party assessments): The objective of the third case study was to examine the clinical value of the TPA. Given the sparse data, however, Case 3 could only generate some implications with respect to further research or improvements. Of course, the fact that only one case presented itself with multiple TPA induces questions about the feasibility and acceptability of the approach (see also section 3.3). Moreover, the afore-mentioned exploration of the participant and his related party indicates that close contacts may not be motivated to complete assessments during stable mood episodes of patients (see section 3.4.2). As for the

correlation analyses, as expected, the TPA were highly correlated with the patient's self-perception. Only the two items that had been defined differently in both approaches, *Speed of thoughts* (SA) or *Urge to speak* (TPA), showed a negative correlation. This finding might indicate that the increased speed of thoughts led to a less coherent thinking and, therefore, less verbal expressions of the patient (see also the restless pattern of Case 1). However, the finding confirms the importance of theoretically and empirically well-established mHealth systems [29,34,127,128]. It further implies that the corresponding items should be modified. In order to evaluate the clinical value of the third-party approach, more data would be necessary to analyze its congruence with the self-perception or the correlations of both perspectives with clinical symptoms. So far, there was only a tendency of stronger correlations between manic symptoms and the TPA (as opposed to the SA). Further research should examine whether this finding supports the occasional biases in the patients' self-perception in mania found in earlier studies [71,72].

Limitations: The exploratory approach with three single case studies comes with several limitations like small data sets, a restricted generalizability of findings or an elevated risk of alpha inflation. With respect to the new and innovative approach (and thus research area), however, detailed analyses of three exemplary cases and the avoidance of type II errors outweighed these limitations. In regard to Case 1 and Case 3, unfortunately, the results and their interpretation may have been further influenced by additionally missing values or small assessment numbers.

4. General discussion

The current dissertation concerns the development and evaluation of a technical assistance system for BD that incorporates the innovative features of a mobile-based emotion recognition approach and of ambulatory TPA. At the outset of this research work, positive attitudes of patients with BD towards technical assistance and the specific features of the current approach had been expected. Therefore, the newly developed system had been awaited to be well-accepted and feasible during a small pilot study. Emotional expressions and behavioral aspects captured through the system had further been expected to be associated with or to predict bipolar symptoms. Finally, TPA and SA had been awaited to be correlated, and both had been expected to show associations with clinically assessed symptoms.

The first developing step led to the dialogue with affected patients during semi-structured interviews and an online survey. The overall positive attitudes of the participants of both studies with respect to disease management apps or assistance systems coincide with the positive perception of mental health apps by other consumers [138,139]. The finding also agrees with the good acceptability of several technical applications among patients with BD [31,102,124,141]. Whereas the assessment of sensor data was mostly accepted by the participants of both studies, some of them emphasized the desire for a high flexibility of systems and the opportunity to deactivate such features. This finding, too, agrees with further research indicating the need of patients for a certain personalization of technical systems [102,119]. In spite of the overall positive attitudes, the participants of the online survey were more critical in their perception of several features, including the analysis of audio and video data. There were relevant differences within the composition of both samples that might have played a role in this result (e.g., considerably more female participants of the online survey). Beyond that, the more personal setting of the interviews might also have impeded negative feedback. The fact that both samples appreciated the inclusion of related parties in disease management approaches is especially interesting since relationships of patients with BD are often burdened by the disease [14,100,129]. The inclusion of close contacts, however, could benefit diagnostic or psychoeducational purposes and even affect

relationships positively. Thus, the openness of the study participants should serve as a motivation for the development of partner apps and third-party approaches in BD.

As a consequence, with the next step, a system concept was developed that incorporated TPA. The new feature is particularly innovative, since spouses or related parties of patients with BD have rarely been considered within mHealth approaches [51,52,137] and, to the knowledge of the author, have not yet been included for monitoring purposes. As mentioned before, the self-perception of patients is the most relevant factor in mood monitoring or diagnostics. Nevertheless, since this perception can occasionally be less reliable [71,72], acceptable and feasible TPA could help a more comprehensive view on mood states of patients. Next to the already established features of mobile-based systems, such as SA or the assessment of sensor data [25,26,37–42], the emotion-sensitive SotD module was the second innovative idea that was incorporated. Moreover, due to the importance of emotional aspects for relevant outcome variables like the social or global functioning of patients [8,43–49], this module is the key component of the newly developed system and of the current dissertation. The SotD allows for the recognition of verbally and facially expressed emotions and, in this way, goes beyond the existing approaches of speech analyses in mHealth [41,124,132–134]. As mentioned before, the emotion-sensitive module has to be used regularly to enable its automatic analysis of emotional expressions. As a consequence, its clinical value strictly depends on the usage behavior of patients. This aspect is clearly reflected in the results of the pilot study (see later discussion and section 3.3). Yet, the advantage of this characteristic lies in the missing interference with the patients' privacy or personal space. Due to research critically reviewing the given range of mobile-based systems and their methodological, technological or security-related issues [29,127,128], a well-established and thoroughly examined framework for the first emotion-sensitive system is seen as vital. The FACS [147] and LIWC [146] approaches, in spite of some limitations of the current results (see later discussion and section 3.3), proved themselves helpful to emotion recognition. Interestingly, another emotion-sensitive software that was initially examined (see the original article in the appendix [2]), the *EmoVoice* approach [159], did not result in beneficial data. With this software, the voice color is analyzed according to certain acoustic signals. These signals are used as emotional classification units in order to recognize

emotional or mental states (e.g., anger, happiness or sadness [159]). However, the emotion recognition according to this software did not work with the current approach. Here, future research has to show if another voice analysis software might still be helpful to emotion-sensitive systems for BD.

During the next step, the pilot study with five patients with BD was conducted. As for the emotion recognition approach, as expected, the findings were overall promising. The TPA, however, contrary to the expectations, did not show a good feasibility with the study sample. Nevertheless, even the results concerning the TPA contain valuable insights as to how the approach could be improved. The pilot study benefited from long participation times and a natural environment. Thus, the ambulatory setting increases the ecological validity of the results [32,33]. The findings show that mobile-based emotion recognition may be well-accepted and feasible, especially with younger patients who often show a greater technical affinity [103,140]. Thus, the results confirm the implications of the initial dialogue with affected patients and further agree with the mentioned acceptability of mHealth in BD [31,38,109,118]. The exploratory approach with five participants that were predominately seen and analyzed as single cases generated valuable insights into personal usage experiences. Although the SotD automatically analyzes recordings with respect to the contained emotional expressions, its regular usage still demands more effort than SA. In accordance with this, the participants of the pilot study had several suggestions for improvements, which might motivate them for a more regular usage (e.g., several times per week). Following developments of mobile-based emotion recognition approaches should thus be designed to be more practical (e.g., without microphones or holders), less irritating (no selfie mode) and should possibly allow for an automatic system feedback.

As for the evaluation of the clinical value during the final step of the process, the first two case studies explored the individual changes of patients in their emotional expressions and behavioral aspects captured by the SotD. As expected, with both cases, bipolar symptoms were associated with behavioral and emotional changes detected with the SotD module. Although not all effects showed the expected directions, this result is especially interesting since both cases were very different regarding their specific characteristics (e.g., age, sex, course of symptoms). Case 2 presented itself with a more continuous data set and less gaps in between two

consecutive SotD assessments. Therefore, the results of this case study may be more realistic and, in accordance with this, seem more conclusive: Most effects showed the expected directions and, consequently, suggest an empirical foundation of the emotion recognition concept. The impact of the results might be further increased by the combination of the clinical scores and the SA, because the results of all sources mostly correspond with each other. Both case studies further agree with former research indicating the high individuality of bipolar symptoms and their ramifications [12,160]. For instance, manic symptoms coincided with different patterns of behavioral changes (e.g., recording frequency, verbal fluency) with each patient. Furthermore, clinically assessed depressive symptoms were only correlated with behavioral changes in the second case study, and not with Case 1. Moreover, with respect to emotional expressions, only the self-assessed symptoms of Case 1 were associated with emotional changes (facial happiness correlated with higher SA scores). Case 2, however, showed multiple emotional changes during increased depressive or manic symptoms (e.g., depressive symptoms correlated with more verbally expressed negative emotions and less facially expressed happiness). All of these individual changes on several levels would probably have been too complex to observe without technical assistance. Yet, the gained insights deliver information about clinical symptoms and thus would be relevant to clinical practice. According to this, future mHealth developments should account for the high heterogeneity of individual changes on behavioral and emotional levels.

Together with the presented feasibility results, the third case study implies that the clinical value of TPA strongly depends on motivational aspects. Whereas research suggests the need and openness of spouses and close contacts of patients in regard to their involvement in mHealth developments [51,52], relevant features have to meet their expectations. Due to the not yet established role of TPA in mobile-based approaches, future systems should keep this feature optional. In reference to the sparse findings of Case 3, SA of patients and the perception of related parties might be highly correlated. While research suggests that this might especially be the case in stable or depressive mood and not necessarily in mania [71,72], the third case study could only generate statistical tendencies into this direction. If a more thorough examination of this approach determined that TPA were more reliable during manic episodes, this feature would be helpful to monitoring systems. All explored cases

together support the complexity and individuality of symptom manifestations in BD. Therefore, the clinical value of mHealth approaches could benefit from the often-applied incorporation of multiple data sources [40,112,124]. Since the individual benefit of those sources also differs between patients, the two innovative features of the current work might further strengthen the mHealth development in BD.

There are several methodological aspects that might limit the generalizability and impact of the presented findings. The small sample sizes (except for the online survey) or the case-based approach certainly call for larger studies investigating the feasibility, acceptability and validity of the emotion-sensitive system. Beyond that, missing values and small assessment numbers may have further influenced the results. Furthermore, even the case studies only allowed for the exploratory examination of the diagnostic or prognostic value of the SotD module. The intended automatic interventions or notifications of the system had not yet been implemented and could, therefore, not be evaluated. The detailed examination of the TPA was prevented by missing data, which raises questions about the feasibility of this feature and calls for several modifications. Additionally, the exploratory approach of the pilot study and the case studies increases the risk of alpha inflation. Due to the innovative research area, however, the avoidance of type II errors, and the detailed exploration of individual cases were considered more important. Nevertheless, before implementing any new features into disease management systems, thorough cost-benefit analyses would be necessary. As a consequence, more research is needed, TPA would have to add valuable information, and the emotion-sensitive module would have to recognize all relevant emotions [7,10] with a good validity and reliability.

With this in mind, the here presented findings and the emotion-sensitive approach might benefit mood state recognition as well as the understanding of emotional experiences and expressions in BD. Automatic feedback about their expressed emotions might also be helpful to patients in strained relationships or without regular social interactions. According to single comments of study participants, the SotD might further motivate patients to reflect upon their social experiences. After the consideration of ethical and legal implications, future systems could give patients the possibility to include their psychiatrists or psychotherapists [161]. In this way, sudden changes of the expressed emotions could be reflected during following appointments.

With respect to the high relevance of emotional aspects for the global functioning of patients or future psychopathology [8,43–50], emotion-sensitive systems might even be helpful to emotion-based treatment approaches in BD [94,149–151]. Beyond all that, a valid and reliable mobile-based emotion recognition approach could benefit the understanding of experienced and expressed emotions and their ramifications in other disorders as well. Finally, the SotD delivers a new approach for ambulatory speech analyses in clinical research.

5. Conclusion

The current work aims at the development and evaluation of an emotion-sensitive assistance system for BD that allows to analyze emotional expressions of patients and ambulatory TPA of related parties. The findings indicate predominantly positive attitudes of patients with BD towards technical assistance. Even new and innovative features, like the analysis of audio and video data, were perceived positively. Based on these insights – to the knowledge of the author – the first assistance system for BD has been developed that incorporates a mobile-based emotion recognition module and TPA through close contacts of patients. In accordance with the initial findings of the online survey and the interviews, the pilot study examining the first prototype of the system shows that the AA of audio and video data may be well-accepted and moderately feasible. Moreover, the emotion-sensitive module allows for the long-term analysis of emotional expressions without invading the perceived privacy of patients. The subsequent case studies further suggest that the emotional and behavioral aspects captured by the module may contain information regarding concurrent or occurring bipolar symptoms. The findings also show the individual complexity of behavioral or emotional changes that might, therefore, be difficult to recognize without technical assistance. Beyond that, the results imply that ambulatory TPA should be modified to be less effortful and more motivating. In that case, they might add helpful information about illness activity, for example during episodes with a less reliant self-perception of patients. So far, the third case study could only generate some indications in this regard. In the future, emotion-sensitive systems might benefit the understanding of emotional aspects in BD. Furthermore, they might possibly support diagnostic or prognostic purposes, or even emotion-based interventions in BD. Finally, a well-established mobile-based emotion recognition approach might be of interest for other research areas as well. However, there are methodological or technical issues that have to be addressed first, and larger studies are necessary to confirm the current findings and to increase their generalizability.

6. References

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Appendix

a) Accepted manuscripts

[1] Daus H, Kislicyn N, Heuer S, Backenstrass M. Disease management apps and technical assistance systems for bipolar disorder: Investigating the patients' point of view. J Affect Disord. 2018; 229:351-357. https://doi.org/10.1016/j.jad.2017.12.059

[2] Daus H, Bloecher T, Egeler R, De Klerk R, Stork W, Backenstrass M. Development of an emotion-sensitive mobile Health approach for mood state recognition in bipolar disorder. JMIR Ment Heal. 2020; 7(7):1-10. https://doi.org/10.2196/14267

[3] Daus H, Backenstrass M. Feasibility and acceptability of a mobile-based emotion recognition approach for bipolar disorder. Int J Interact Multimed Artif Intell. 2021. https://doi.org/10.9781/ijimai.2021.08.015

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Research paper

Disease management apps and technical assistance systems for bipolar disorder: Investigating the patients´ point of view

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ABSTRACT

Background: Smartphone-based disease management has become increasingly interesting for research in the field of bipolar disorders. This article investigates the attitudes of persons affected by this disorder towards the appropriation of mobile apps or assistance systems for the management of their disease.
Methods: We conducted two separate studies. Study 1 was an online survey with 88 participants. In study 2 we consulted 15 participants during a semi-structured interview. All the participants had formerly been diagnosed with bipolar disorder.
Results: More than half of the participants of study 1 and most participants of study 2 agreed with the use of an app or assistance system for self-ratings, third party ratings and an objective symptom monitoring. Potential interventions that were popular in both groups included a regular feedback, the visualization of monitored data and advice in crises.
Limitations: With study 1 we were not able to ensure correct diagnoses or to interact in a flexible way. In Study 2 those issues were resolved, but the small number of participants raises the question of a possible generalisability of the results. Furthermore, for both studies a selection bias could not be excluded.
Conclusions: Our results indicate positive attitudes of bipolar patients towards disease management apps and assistance systems. Even new and innovative features such as partner apps or the analysis of facial expressions in video data were appreciated and daily interactions were favoured. However, the variety of answers calls for flexible systems which allow activating or deactivating certain features.

1. Introduction

Bipolar disorders often take a chronic and severe course and therefore put a great burden on patients and their families as well as on society (Gitlin and Miklowitz, 2017; Murray et al., 2012). Especially challenging are the high relapse rates in bipolar disorder in spite of pharmacological treatment (Fountoulakis et al., 2012) and psychological approaches such as cognitive-behavioural therapy, psychoeducation or other psychosocial interventions (Miziou et al., 2015; Oud et al., 2016). In consequence, constant self-monitoring, the management of subsyndromal symptoms (Bonnín et al., 2012; De Dios et al., 2012) and additional strategies within personalized patient care (Catalá-López et al., 2013; Miziou et al., 2015) are often recommended.

With the ongoing technical development over the last few years smartphone technology has become more and more interesting for any kind of clinical research due to its potential benefits regarding the management of chronic diseases (Trull and Ebner-Priemer, 2013). For this reason, smartphone-based disease management might offer a chance to improve the treatment of bipolar disorder as well. Technical possibilities include the visualization of assessed self-rating data or the use of internal smartphone sensors and connected wearable devices to trace objective data in real life (e.g. phone activity or physiological parameters). Moreover, they allow for ecological momentary interventions in form of therapeutic feedback or psychoeducational information (Gravenhorst et al., 2015).

So far, there have been studies using mobile programmes, text messaging or specifically designed smartphone apps to support self-monitoring (Bopp et al., 2010; Schärer et al., 2015; Schwartz et al., 2016), the recognition of mood state changes and relapse prevention (Faurholt-Jepsen et al., 2015; Grünerbl et al., 2015; Javelot et al., 2014)

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in patients with bipolar disorder. Other studies provided patients with bipolar disorder with psychoeducational information and self-management strategies (Bilderbeck et al., 2016; Depp et al., 2015; Hidalgo-Mazzei et al., 2016; Miklowitz et al., 2012), psychosocial interventions (Matthews et al., 2016) as well as interventions to increase compliance and adherence (Wenze et al., 2014). Whereas the results are partly promising, as far as we know, many of the afore-mentioned approaches have not reached the end-users yet. Furthermore, the variety of apps easily accessible to patients with bipolar disorder have mostly not been evaluated by research and are of poor quality or security (Nicholas et al., 2015). Additionally, in reference to the great amount of actual research in this particular field too little attention has been paid to the patients´ point of view.

In general, consumers tend to have positive attitudes towards mental health apps (Proudfoot et al., 2010). As for disease management apps, there do exist different ethical and legal implications and the accessed information is a lot more sensitive. A few studies, nevertheless, have shown a good feasibility and acceptability of internet-based psychoeducation (Poole et al., 2012), of text-messaging-based self-monitoring (Bopp et al., 2010) and the use of personal digital assistants (Depp et al., 2015; Wenze et al., 2014) among patients with bipolar disorder. The same applies to some of the already mentioned smartphone apps for bipolar disorder (Bardram et al., 2013; Hidalgo-Mazzei et al., 2016; Matthews et al., 2016). One study explicitly investigated the experiences of bipolar patients with a study-specific smartphone app: The results suggest that this disease management app was well tolerated and could enhance the patients´ understanding of their disease or even induce behavioural change (Saunders et al., 2017). However, other examples show that not all features or sensor systems of disease management apps are equally accepted by patients affected by bipolar disorder (Javelot et al., 2014).

With this in mind, the aim of the present study was to assess the perspectives of patients with bipolar disorder regarding different aspects of disease management apps or assistance systems and several new and innovative features that have not yet been implemented in any systems discussed in current literature. We also intended to investigate the patients´ concerns or suggestions for improvements in this matter. For that purpose, we pursued two different approaches and developed an online survey (study 1) and a semi-structured interview guide (study 2). Both studies, of course, had their own advantages and limitations but addressed the same topics using very similar questions. In addition, both studies were non-invasive, did not cause any risk for the mental or physical health of the participants, and their full and informed consent was obtained.

2. Study 1

We developed an online survey and hyperlinked it to four different Internet forums for health care or bipolar disorder.[1] Two of the corresponding websites had their origin in the USA, one website originated in Germany and one in Austria.

2.1. Methods

2.1.1. Participants

From December 2015 to January 2016 a number of 154 visitors of these websites accessed our online survey. Of these respondents 133 (86.4%) stated that they had been diagnosed with bipolar disorder and were thus eligible for this study. Eighty-eight eligible respondents (66.2%) completed the survey. The remaining sample consisted of 22 (25.0%) men and 66 (75.0%) women who were between 18 and 62 years of age with a mean age of 31.8 years (SD = 10.4).

[1] The questions of the online survey and the internet addresses can be obtained from the corresponding author.

2.1.2. Instruments

The online survey was designed and tested using *Umfrageonline* (UmfrageOnline, 2016). The survey was voluntary, accessible to all visitors of the websites, and it consisted of 27 questions. Those questions concerned personal information (e.g. diagnosis or age), several aspects of disease management apps or assistance systems (e.g. accessed information or interventions) and available technology (e.g. use of internal smartphone sensors or wearable devices). For example, we asked, “Could you imagine placing stationary sensors at your apartment?” or “Could you imagine using the following features regularly?”. Participants could either choose one or multiple predefined answers (e.g. “yes”, “no” or “I don‘t know”) or they could rate certain features on predefined scales (e.g. “I disagree” up to “I agree”).

2.1.3. Analysis

All descriptive analyses were conducted using *Umfrageonline*.

2.2. Results

At the beginning of the survey participants could decide whether they wanted to proceed in English or in German. Twenty-three participants (26.1%) completed the German version of the survey. The other 65 participants completed the English version.

2.2.1. Accessed information

The majority of the participants agreed (55, 62.5%) or rather agreed (19, 21.6%) with “diary-functions” of disease management apps, which means doing and submitting self-assessments of their mood, activity or sleep. More than half of the participants agreed (28, 31.8%) or rather agreed (24, 27.3%) with the involvement of others (e.g. relatives, friends, physician) with the app and thus allowing for an external assessment of their mood state.

Even more participants agreed (59, 67.0%) or rather agreed (18, 20.5%) with an automatic measurement of certain parameters: The most commonly mentioned variables in this context were physical activity (58, 65.9%), bedtime hours and sleeplessness (54, 61.4%), social media usage (46, 52.3%), number and duration of phone calls and facial expression for mood recognition (each 42, 47.7%). Still a great number of participants would appreciate an automatic measurement of speech signals for mood recognition (40, 45.5%), duration and quality of sleep (38, 43.2%) and location information (34, 38.6%).

2.2.2. Technical implementation

About 60% of the participants (53, 60.2%) would wear a wearable device. More than half of the participants (48, 54.5%) could also imagine wearing such a device at night. The potential parameters that were most frequently favoured by the participants were heart rate (61, 69.3%), physical activity (55, 62.5%) or electrodermal activity (46, 52.3%). Only 34 (38.6%) of all participants could imagine placing stationary sensors in their own apartments (most likely light sensors or pressure mats in their beds).

2.2.3. Interventions

When participants were asked which specific interventions of disease management apps they would use most likely, the three preferred functions were the mood diary (78, 88.7%), feedback about the mood state (77, 87.5%) and the visualization of measured data (76, 86.3%). They most likely disapproved of third party (e.g. relatives, friends) notifications (46 “no”-answers, 52.3%) and automatically initiated consequences (e.g. account blocking) (51 “no”-answers, 60.0%). Fig. 1 illustrates a more detailed look on all reviewed interventions.

2.3. Discussion

Overall attitudes towards disease management apps and assistance systems were positive and our results suggest that the surveyed patient

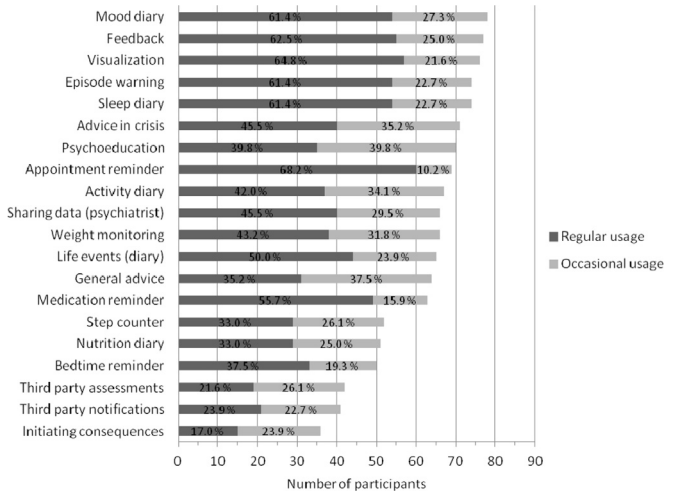

Fig. 1. Specific features of disease management apps for bipolar disorder and potential usage by the participants of the online survey (study 1).

group has a high technological affinity. Most of the participants agreed with an app-based automatic measurement of certain parameters as well as with self-assessments. Concerning the technical implementation, they preferred smartphone sensors or wearable devices to stationary sensors in their apartments. Whereas some potential app features were very popular (e.g. mood diary), automatically initiated consequences were critically perceived. Still, about half of the participants stated that they would use new features such as third party notifications or the analysis of their facial expression for mood recognition.

2.3.1. Limitations

We used two language versions of the online survey. Although we cannot assert that both versions measure exactly the same, the overall attitudes did not differ significantly between the two survey groups. Therefore, with data analysis no distinction was made in reference to the versions. In addition to that, the survey only addressed visitors of Internet forums for health care or bipolar disorder who might have a higher affinity for or interest in the new media and technical health assistance than other patients. Furthermore, with our online survey we relied on subjective information of the respondents and we were not able to ensure correct diagnoses or euthym mood states of the participants. Finally, an online survey does not allow a flexible interaction with the participants, which can inhibit understanding and cause researchers to disregard important information. Thus, we developed a semi-structured interview guide in order to ensure correct diagnoses and to gain a deeper understanding of the patients´ view.

3. Study 2

Semi-structured interviews with open-ended questions can help to reveal issues and problems that otherwise would not be realized and are thus valuable especially for qualitative research (Willems et al., 2005). We developed an interview guide that included the topics of the online survey to explore which specific features of disease management apps a different sample of patients with bipolar disorder would consider helpful. As we also wanted to explore the participants´ concerns and ideas in this matter, we added questions concerning the feasibility of such devices and suggestions for improvements.

3.1. Methods

3.1.1. Participants

From January to August 2016 we contacted support groups and approached outpatients of a psychiatric clinic that specializes in affective disorders to recruit participants who had formerly been diagnosed with bipolar disorder but did not fulfil the criteria for a mood disorder episode at the time. During the interviews we made sure that the lifetime-diagnosis of bipolar disorder was correct, and we specified the diagnosis according to the DSM-V (American Psychiatric Association, 2013) by using the relevant sections of the German Structured Clinical Interview for DSM-IV (Wittchen et al., 1997). The resulting sample consisted of 15 persons, including 9 men and 6 women. Eight participants could be diagnostically categorized into bipolar disorder type I, the other 7 into bipolar disorder type II. Five of the participants additionally fulfilled the rapid cycling criteria. The participants were between 21 and 73 years of age with a mean age of 44.2 years (SD = 13.0).

3.1.2. Instruments

The semi-structured interview included a combination of open-ended and closed-ended questions about several aspects of disease management apps or assistance systems (e.g. accessed information, feasibility or interventions), available technology (e.g. use of wearable devices) and suggestions for improvements. Many of the questions were very similar to those of the online survey.[2] For example, we asked, “Would you be willing to give an assessment of your actual mood via app?” or “What do you think about wearing a wearable device to assess psychophysiological parameters during the day?”. With every issue at hand, the interview allowed for additional comments or explanations. On the whole, the interview included about 50 questions and took approximately 60 min.

3.1.3. Analysis

The interviews were carried out in German. All answers of the participants to our questions and all additional comments or explanations were recorded. The most important comments will be exemplified in Table 1 to support the numerical data of our results section.

3.2. Results

3.2.1. Accessed information

The majority of the participants agreed with an app-based self-assessment of their mood, their self-confidence or guilt feelings, their activity level and behaviour (14, 93.3%) as well as of their sexual activity or their consumption of alcohol, caffeine etc. (12, 80.0%). One participant, for example, emphasized the relevance of his sexual desire for an early detection of an episode onset. Critical comments regarding the self-ratings addressed the reliability of subjective data and suggested external assessments (see Table 1 for comments).

Concerning such external assessments, most of the participants would support an objective analysis of psychophysiological data (14, 93.3%), neurocognitive functions (14, 93.3%) or sleeping behaviour (13, 86.7%). Although one person refused features that allow for an objective sleep monitoring, many positive reactions were caused (see Table 1). More doubts were mentioned concerning the analysis of GPS data or social media usage. Whereas 66.7% (10) of the participants would allow a disease management app to monitor their social media usage, most of them were very specific about the conditions and did not agree with an analysis of contents. Still, a majority of participants (9, 60.0%) would allow a disease management app to use GPS traces and analyze movement patterns, even though concerns in this matter were even bigger. One participant, for example, emphasized the risk of paranoia during manic episodes and suggested the option to deactivate this feature if necessary (see Table 1).

Furthermore, there were 12 participants (80%) who would actually allow an app or assistance system to analyze audio or video data

[2] The questions of the semi-structured interview can be obtained from the corresponding author.

Table 1
Comments of the participants of the semi-structured interview (N = 15) on selected issues.

Interview section and issue	Comment and participant number
Accessed information (self-assessments)	
Self-assessments in general	*"I'd rather not use it. I would fear data abuse due to other people."* P6
	"This certainly is very subjective, an external assessment would be better." P13
Sexual activity	*"Yes, one should do that. In hypomanic episodes I often overwhelmed my partner."* P8
Accessed information (objective analysis)	
Psychophysiological data	*"Yes, I´m already using an app with similar features."* P15
Sleeping behaviour	*"Yes! An objective analysis would be useful, interesting."* P10
	"Yes, I would be interested in that. I'll soon have a watch that monitors all of that. I mean sleep and activity." P14
Social media usage	*"Basically, yes. Usage behaviour: Yes. Contents: Rather no."* P1
	"Yes, as long as no contents are analyzed." P2
	"No, I would feel controlled. That invades my privacy." P12
Location information	*"Yes, but there's certainly the risk of paranoia in mania. It would be helpful if you could disable this feature."* P1
	"I wouldn't go for that. We live in a liberal-democratic state. By doing so, I would give up my rights." P13
Audio data	*"Yes, with the voice you can detect a lot. Because of that my friends always can tell when something is changing."* P14
Video data	*"That would depend on the situation. Perhaps one could also disable that feature?"* P10
	"I think that's an interesting approach." P12
Accessed information (third party assessments)	
Partner app	*"My partner is more important than myself when it comes to an evaluation of my mood state."* P5
Technical implementation	
Installation on own device	*"I´d prefer that, yes. But my phone memory is always crowded. The smaller the app the higher my readiness."* P15
Usage of a separate device	*"No, I'd have to explain it. Otherwise it would be less conspicuous."* P2
	"Rather not. That would be too inconvenient." P11
Digital questionnaires	*"The decision to fill out the questionnaires must be voluntary."* P3
	"Yes, if it doesn't have to be done immediately." P8
Automatic phone calls	*"It would be necessary to arrange set hours. An automatic call could be problematic if it happened randomly."* P1
Technical implementation (stationary sensors)	
Stationary sensors in general	*"That's going too far. Rather no."* P1
	"No, that's too intimate." P2
Light sensor or pressure mat	*"Most likely of the stationary installations. But that wouldn't be very informative."* P1
Feasibility	
Frequency of interactions and time exposure	*"Once a quarter."* P2
	"About five minutes for a daily assessment. If it were less frequent, ten minutes would be OK, too." P4
Interventions	
Frequency of feedbacks	*"Yes, one feedback per month. Or maybe every two weeks. In the case of warning signals also more frequently."* P1
	"Yes a short feedback every two days or every day." P7
	"Yes absolutely. Once a week would be good or every two weeks. Not every day though." P8
Medication reminder	*"No, but for many others it would be helpful."* P2
Assistance or advice	*"During mood episodes, advice and suggestions would be helpful. Otherwise psychoeducative information would be good."* P 1
	"As long as those suggestions stay individualized, yes. For example that you should visit the doctor, write down your duration of sleep or make breaks." P2
Visualization	*"Yes, all information well-organized would be helpful. It would be helpful if one could add additional comments, too."* P4
	"Yes, but nobody else should have access, not even my psychiatrist." P5
Interventions (automatic consequences)	
Account blocking	*"One should consider the possible consequences. Other people could notice it, for example the landlord or employer (…)."* P2
	"I wouldn't go for a complete blocking of my account, though. But maybe one could implement a limit for transactions over 5000 Euros." P13
Emergency calls	*"An emergency function would be useful, though. For instance, my wife is authorized to have me committed to a hospital."* P2
	"I would appreciate an emergency function." P13
Third party notifications	*"Yes, I would wish for a very fast intervention."* P3
	"As soon as indications point to self-endangerment, contact terminations and helplessness." P8
Overall view and suggestions	
Outpatient treatment	*"The transition from inpatient to outpatient treatment is difficult. It could help to improve patient care in this matter, increase certainty and bridge waiting periods."* P5
	"As a patient you get very few sessions. Assurance through an assistance system would be helpful." P9
General comments	*"Also information for and the involvement of loved ones is important."* P3
	"Yes, the assistance system would be a close companion." P7
	"It would be helpful if the information got forwarded to the physician. For example, he could have access to a certain webpage." P12
	"There should be the option to enter important events and thereby explain one´s peaks. You could say daily notes." P15
	"Of course, the daily monitoring and the recommended doctor´s visits would be helpful. (…) You would have a digital audience, so to speak." P15

regarding their emotional content (e.g. voice colour, facial expression). While a small number of participants were not sure about these features, only 1 (6.7%, audio analysis) or 2 (13.3%, video analysis) participants denied those questions. Other participants called this approach interesting or stressed the importance of their voice for an early detection of episode onset. Again, one participant suggested suppressible features that allow for situational adjustments (see Table 1).

Nearly all participants (14, 93.3%) supported the idea of a partner app, which would allow for a third party assessment through a significant other person. The most commonly mentioned party in this context was the "physician or therapist" (13, 86.7%), followed by "relatives or partner" (10, 66.7%) and "friends" (5, 33.3%). The relevance of an external view for the detection of a recurring mood episode is highlighted by the statement of one participant who trusts his partner more than himself when it comes to the evaluation of his mood state (see Table 1).

3.2.2. Technical implementation

The great majority (14, 93.3%) would prefer a disease management app to run on their own smartphone. Only 6 participants (40.0%) would

use a separate device for the management of their disease. The others explained their negative feedback with the inconvenience of the device and its possibly negative impression on other people. Most of the participants would approve of digital questionnaires (14, 93.3%) or automatic calls (13, 86.7%) for the realization of self-assessments but were very specific about the exact circumstances (see Table 1).

Whereas 12 participants (80.0%) would use a wearable device to analyze psychophysiological parameters, stationary installations of sensors in their own apartment were not very popular: Participants would most likely accept a light sensor (9, 60.0%) or a pressure mat in their bed (7, 46.7%) though they would not consider the achieved information very meaningful. Most participants strongly rejected the installation of cameras, microphones (each 13 “no”-answers, 86.7%) or motion detectors (10 “no”-answers, 66.7%) in their apartments, predominantly for reasons of privacy (see Table 1).

3.2.3. Feasibility

Regarding the potential frequency of interactions with a disease management app and the time exposure of a single interaction, there was a great range of perceptions from ten minutes per day to one short interaction every three months (see Table 1). Summing up, most participants (12, 80%) would consider one daily interaction reasonable, which takes about five minutes.

3.2.4. Interventions

About three quarters of the participants (11, 73.3%) would consider a regular feedback about their actual condition helpful. Comments mostly differed regarding the frequency of this feedback, again with a great range from daily feedback to one response per month. About two thirds (10, 66.7%) stated that they would profit from an integrated medication reminder. Interestingly, participants, who did not want to use this feature, often stressed its importance for others (see Table 1). Most participants also mentioned that they would appreciate further assistance or advice such as individualized steps of a crisis plan (13, 86.7%) or a reminder of doctor's appointments (8, 53.3%). Nearly all participants (14, 93.3%) would like to use a function that visualizes the course of all monitored parameters. Comments included suggestions for improvement such as additional comment fields and the issue of data access and security. Participants were more sceptical when asked if the app should independently initiate consequences (11 “yes”-answers, 73.3%). An automatic account blocking was perceived more critically than an emergency function (see Table 1).

When we asked the participants if an app or assistance system should notify other persons in the case of early warning signs, most of them agreed and did not make a distinction between depressive symptoms and manic symptoms. The most commonly mentioned party in this context again was the “physician or therapist” (12, 80.0% resp. 11, 73.3%), followed by “relatives or partner” (11, 73.3% resp. 10, 66.7%) and “friends” (6, 40.0%). Participants were more or less specific about the circumstances in which this notification should take place. For example, one participant named indications of self-endangerment, social withdrawal or helplessness as his personal criteria (see Table 1).

3.3. Discussion

Overall attitudes towards disease management apps and assistance systems were positive and participants assumed benefits regarding the issue of outpatient treatment. Most participants agreed with self-assessments or an app-based measurement of certain parameters. Whereas some features (e.g. analysis of movement patterns, social media usage) were only accepted under specific conditions, other features like individualized advice in crisis or feedback were highly appreciated. Even new features such as video analysis, automatic consequences (e.g. account blocking) or partner apps were perceived favourably. With a partner app, participants most likely asked for the involvement of their physicians or therapists, closely followed by their relatives or partners. Some participants especially emphasized the importance of an external view on their own mood state. Regarding the technical implementation, nearly all participants preferred an app to run on their own smartphone and use internal sensors or wearable devices and not stationary sensors in their apartments. They justified their opinion with privacy issues or the impression additional equipment would make on others. Most participants were prepared to interact with a disease management app on a daily basis with a single interaction lasting about five minutes.

3.3.1. Limitations

A selection bias due to the participants´ affinity for or interest in technical health assistance and an effect of the interview setting cannot be excluded. Nevertheless, there were some participants who, in spite of the overall positive results, adopted a critical attitude. Furthermore, we interviewed a small number of patients and there is always the question of the generalisability of single statements in qualitative research. This is why we only exemplify the most important comments in Table 1 and, moreover, pursued our two different approaches – the semi-structured interview and the online survey.

4. General discussion

With the ongoing development of smartphone technology in mind, we aimed to assess the views of patients with bipolar disorder about disease management apps or assistance systems and about new and innovative features in this area. We also wanted to find out the patients´ worries and doubts and to acknowledge their suggestions for improvements. For that purpose, we pursued two different approaches and conducted an online survey (study 1) and a semi-structured interview (study 2).

The overall positive attitudes towards disease management apps or assistance systems in both studies are consistent with the positive attitudes of other consumers towards evidence-based mental health apps (Proudfoot et al., 2010) and the good feasibility and acceptability of several types of new media assistance among patients with bipolar disorder (Hidalgo-Mazzei et al., 2016, 2015; Matthews et al., 2016; Saunders et al., 2017). Most of the participants of our two studies would allow apps or assistance systems to use internal smartphone sensors but did not approve of stationary sensors in their own apartments due to privacy issues. Wearable devices on the other hand were mostly accepted by both groups and offer many possibilities in symptom monitoring (Gravenhorst et al., 2015). However, whereas about half of the participants of both studies stated that they were currently using a mobile health app (mostly not specific to bipolar disorder), only a few participants had already dealt with wearable technology or the measurement of psychophysiological data. Thus, presumably the majority of our participants could not completely estimate the amount of effort that is necessary when using such devices.

Despite the overall positive results, the answers varied a lot and single participants emphasized the importance of flexible systems that allow patients to activate or deactivate certain features. This result coincides with the findings of the afore-mentioned feasibility and acceptability study of Saunders et al. (2017). Accordingly, not all potential features were equally popular with both our samples. The participants of study 1 were more critical concerning the acquisition of social media usage or GPS information and were less likely to agree with an analysis of audio data. They were also less likely to approve of new features such as video analysis, third party notifications or other automatically initiated consequences (e.g. account blocking).

These differences could be partly explained by the composition of our samples, which did not entirely match. The anonymous character of the online survey might also have facilitated negative feedback. Nevertheless, there was still a majority of participants in both studies that would appreciate the involvement of a third party in disease management apps. With the often tense relationships of patients

affected by bipolar disorder (Gitlin and Miklowitz, 2017), this result is somewhat surprising. Even so, a partner app could help to improve communication between patients and their relatives or deliver psychoeducative information to family members and increase their understanding of the disease.

Furthermore, with smartphone technology, symptom monitoring can be facilitated and can provide real-time data (Depp et al., 2015; Hidalgo-Mazzei et al., 2016; Schwartz et al., 2016). It can also shift pure self-assessment to a partially automatic monitoring of illness activity (Faurholt-Jepsen et al., 2015; Matthews et al., 2016) and discriminate between mood states in patients (Faurholt-Jepsen et al., 2016). The generated data could be helpful to patients themselves and provide important information for their psychiatrists, therapists and researchers in the field of bipolar disorders.

Some studies even suggest the benefits of disease management apps for an early detection of episode onset and timely interventions (Grünerbl et al., 2015; Osmani, 2015). Especially with young patients smartphone technology could also help to make self-management strategies more attractive and available (Nicholas et al., 2017). Of course, until now there is not enough empirical data that support the contribution of smartphone-based symptom monitoring and smartphone-based interventions to the treatment of bipolar disorder (Faurholt-Jepsen et al., 2015; Hidalgo-Mazzei et al., 2015). As further research is necessary, the high motivation and openness of the participants in our two studies should serve as an incentive for future developments of disease management apps or assistance systems.

Not only should those developments consider all ethical and legal implications, but they should also carefully regard the patients´ point of view on established and new features such as partner apps or the analysis of facial expressions in video data. Our results show that patients are ready to interact with disease management apps or assistance systems on a daily basis. However, the great variety of answers and specific statements of participants call for flexible systems that allow patients to activate or deactivate certain features. Only if the patients´ point of view stays at the centre of our efforts, devices can be designed which not only satisfy clinical standards but actually support patients with bipolar disorder in their everyday struggle with their disease.

5. Conclusions

Our two studies indicate that patients with bipolar disorder have predominantly positive attitudes towards mobile disease management apps or technical assistance systems. Moreover, many patients would consider certain app features helpful in monitoring, detecting or managing illness activity. For that purpose, they would agree with regular app-based self-ratings and an objective analysis of different parameters or symptoms through internal smartphone sensors or wearable devices. Even new and innovative features such as app-based video analysis and third party assessments or notifications are appreciated and brief interactions on a daily basis are favoured. However, patients would appreciate flexible systems that allow them to activate or deactivate certain features. Thus, as long as the patients´ point of view and all the ethical and legal implications are considered, mobile apps or assistance systems might offer a great chance for monitoring and managing bipolar disorder.

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Author statement

Both studies were non-invasive, did not cause any risk for the mental or physical health of the participants, and their full and informed consent was obtained.

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Viewpoint

Development of an Emotion-Sensitive mHealth Approach for Mood-State Recognition in Bipolar Disorder

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Abstract

Internet- and mobile-based approaches have become increasingly significant to psychological research in the field of bipolar disorders. While research suggests that emotional aspects of bipolar disorders are substantially related to the social and global functioning or the suicidality of patients, these aspects have so far not sufficiently been considered within the context of mobile-based disease management approaches. As a multiprofessional research team, we have developed a new and emotion-sensitive assistance system, which we have adapted to the needs of patients with bipolar disorder. Next to the analysis of self-assessments, third-party assessments, and sensor data, the new assistance system analyzes audio and video data of these patients regarding their emotional content or the presence of emotional cues. In this viewpoint, we describe the theoretical and technological basis of our emotion-sensitive approach and do not present empirical data or a proof of concept. To our knowledge, the new assistance system incorporates the first mobile-based approach to analyze emotional expressions of patients with bipolar disorder. As a next step, the validity and feasibility of our emotion-sensitive approach must be evaluated. In the future, it might benefit diagnostic, prognostic, or even therapeutic purposes and complement existing systems with the help of new and intuitive interaction models.

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KEYWORDS

bipolar disorder; mood recognition; emotion recognition; monitoring; mobile apps; assistance system; mHealth

Introduction

With a prevalence of more than 1%, bipolar disorder is one of the most common mental disorders worldwide [1]. The disease is associated with the suffering of the affected people and their relatives and poses great challenges to them in their everyday lives [2,3]. The depressive and (hypo) manic episodes can have extensive social and economic consequences for patients with bipolar disorder and their families [3]. In particular, the high relapse rates within bipolar disorder are unsettling for all parties concerned: Even with pharmacological treatment [4] and different psychological approaches [5,6], these relapses cannot completely be prevented in many cases.

Because of the frequently severe and chronic course and the individual and social consequences, additional strategies and support options within patient care are necessary [6,7]. With the proceeding technological development and the digitalization of the health care system, increasing attention has recently been paid to internet- and mobile-based interventions in the field of bipolar disorders [8-10]. Internet-based interventions, such as psychoeducational tutorials, can help to reach a great number of patients. Mobile-based approaches often assess real-time information about illness activity or deliver time-sensitive messages to patients in an ambulatory setting. To achieve this, most systems use smartphone technology, external sensor systems, or wearable devices (portable computer systems that assess and analyze psychophysiological data). In our research project, we developed a new mobile-based assistance system for bipolar disorder. In this viewpoint, we describe the theoretical and technological basis of our approach.

Over the past years, the use of smartphone apps or mobile programs has been investigated with samples of patients with bipolar disorder with an often good feasibility [11-16]. Because of the mobility of digital systems, for example, ambulatory self-assessments can easily be integrated in the patients' daily routines. This benefits a better availability and can increase the adherence compared with nondigital approaches [11,12,17-19]. Furthermore, the self-assessment approach can be expanded by additional assessments of sensor data: wearable devices or internal smartphone sensors can be used to trace a patient's mood state [20-22]. Thus, sensor data can aid in automatic recognition of mood-state changes and can support relapse prevention [23-27]. In order to improve disease management as well as treatment compliance and medication adherence in patients with bipolar disorder, self-assessments of patients can be combined with automatic feedback within certain situations [13,14,16,28]. Even simple SMS text message reminders two times per week can improve medication adherence of these patients and help them to create a more positive attitude toward their medication [29]. Interestingly enough, smartphone apps can also support the biological and social rhythms of patients with bipolar disorder. This might lead to a smaller degree of rhythmic disbalances in the long-term course of their disease [30-32]. Beyond that, several studies indicate that mobile-based approaches can reduce the symptom severity in bipolar or other mood disorders [13,14,33-36].

However, the existing approaches neglect the emotional aspects of bipolar disorders. For example, during mood episodes there are typical patterns of experienced emotions: whereas manic states are often characterized by increased happiness or anger and fear, depressive states often show patterns of elevated sadness and disgust [37]. Bipolar disorders are further associated with a generally amplified emotionality [38,39] and difficulties in emotion processing and regulation [40-44], in emotion recognition [45-47], and in the expression of emotions [48,49]. These deficits might partially be related to the current mood state of patients [41,46,47]. Yet, they strongly affect their social and global functioning and are related to severe outcome variables such as suicidality [39,40,42-45,48]. Consequently, emotional aspects have a great impact on the patients' everyday lives and the long-term course of bipolar disorder.

So far, mobile-based approaches have analyzed the keyboard activity of patients with bipolar disorder [22] or even ambient sound samples [31,32,50] or voice features during phone calls [23,51]. However, to our knowledge, none of the referenced approaches have analyzed the emotional content of audio data or social interactions. Moreover, psychological research has so far focused on emotional responses of fully or partially remitted patients with bipolar disorder by analyzing their facial expressions during standardized tasks [48,49]. Yet, there does not exist any mobile-based approach that analyzes facial expressions of these patients regarding their emotional cues. In reference to the importance of emotional aspects in bipolar disorder, they should play a more important role in the design of mobile Health (mHealth) approaches too. Compared with other behavioral measures, the emotional expressions of patients with bipolar disorder could reflect their emotional reactivity more sensitively [49]. Beyond that, the ambulatory setting would allow to monitor individual changes over time and mood states in real life [52,53]. Thus, emotion-sensitive mHealth systems for bipolar disorder might even increase our understanding of the experienced and expressed emotions of patients or of their impact on the patients' social and global functioning.

The EmAsIn Project

Within the *EmAsIn* project (Emotion-sensitive Assistance systems for the reactive psychological Interaction with people) we developed the first emotion-sensitive, technical assistance system for patients with bipolar disorder. Because self-assessments of symptoms are the well-established basis of mood monitoring in bipolar disorder [11,12,17-19], our system also includes regular self-assessments of patients. It further analyzes automatically assessed sensor data, because physiological or behavioral data have been shown to be useful in mood-recognition approaches [23-27], and sleep data have been in the focus of bipolar research for a certain period now [54]. In addition, we incorporated third-party assessments of relatives or related parties, because some patients themselves emphasize the importance of an external point of view regarding their current condition [55]. As a consequence, some of the pressure might be taken off the constant self-monitoring of patients with bipolar disorder. The additionally assessed data could also help in individual cases or during certain periods (eg, during severe mood episodes) with less reliable or accurate self-assessments [56,57]. The importance of emotional aspects of bipolar disorders [37-49] motivated us to develop the key component of our system, the emotion-sensitive *Story of the Day* module. It analyzes audio and video data to explore the emotional experiences and expressions of patients. While many apps in this field are poorly investigated [58], we emphasized the importance of an empirically validated basis of our emotion-sensitive approach [59-61]. To consider the patients' point of view, we initially started a dialogue with patients with bipolar disorder, which indicated their overall positive attitudes toward our innovative ideas [55].

System Concept and Features

Our assistance system includes an Android smartphone app and a connected wearable device, which can be both code protected and password protected. It uses multichannel data acquisition to realize an early recognition of mood-state changes in bipolar disorder. It further intends to complement the rather technical exchange of information between systems and patients with new and intuitive interaction models. Therefore, it aims to recognize socioemotional cues in human communication behavior and hereby infer conclusions about emotional and mental states. To this end, the emotion-sensitive Story of the Day module analyzes the verbal and facial expressions of patients in short and actively user-triggered recordings with respect to their emotional content or the presence of emotional cues. Consequently, this module collects active and passive emotion-related data of patients with bipolar disorder and relies on its regular use (see "Story of the Day" section). If all the features of the assistance system are activated, it can gather information about mood states and the course of bipolar disorders with the aid of the following resources:

- daily self-assessments of patients regarding their mood, activity level, and other relevant symptoms;
- regular third-party assessments by relatives or other related parties regarding the most important symptoms;
- automatic assessments of (psycho-) physiological parameters such as heart rate or resting heart rate;
- automatic assessments of sleep duration and quality;
- automatic assessments of several behavioral parameters such as recognized activities, movement/acceleration, steps per day, range of motion, or smartphone usage behavior (eg, used apps, number of calls per day);
- assessments of auditive information (eg, voice, emotional content, speech duration, or breaks) as emotional cues and indicators of mood states;
- assessments of visual information (facial expressions) as emotional cues and indicators of mood states.

All data resources are presented in Table 1, which also indicates their mandatory or optional usage within the assistance system. Users can switch between different features and tasks by opening the menu of the app. If this feature is activated, the app reminds them of their tasks by using push notifications at a predefined time of the day. Daily self-assessments consist of six 7-point items (from –3 to 3) about symptoms that are relevant to depressive as well as to (hypo-) manic mood states. Negative values are predominantly associated with depressive symptoms, whereas positive values should reflect (hypo) manic states. In addition, as in earlier approaches [19], each user can choose from a given list of potential early warning signs (like *mixed emotions* or *increased caffeine intake*) or can create new items. These items are then incorporated into the daily self-assessments, where they are evaluated with *yes* or *no*. The third-party assessments are very similar to the self-assessments, but they are realized by using a separate and individually secured web application.

The assistance system uses smartphone sensors to assess several of the behavioral aspects, for instance, with regard to movement or social interaction (without analyzing content information). Information about sleeping behavior and (psycho-) physiological data is continuously collected with the help of the connected wearable device, which users wear on their wrists (see Multimedia Appendix 1 for more detailed information). Whereas most of the sensor data are automatically assessed, users are asked to use the Story of the Day module on a regular basis (eg, once per day). Once information is gathered through the different sources, the assistance system integrates all data with the aid of an external server and visualizes the accessed information in the form of graphic representations over time. In addition, users can implement a digital version of their own, personal crisis plan with individual strategies for different mood states and locally stored contact information. They can also enter information about their actual medication to use the medication reminder of the system. To facilitate the handling, users can use their own and secured web application to insert and manage information.

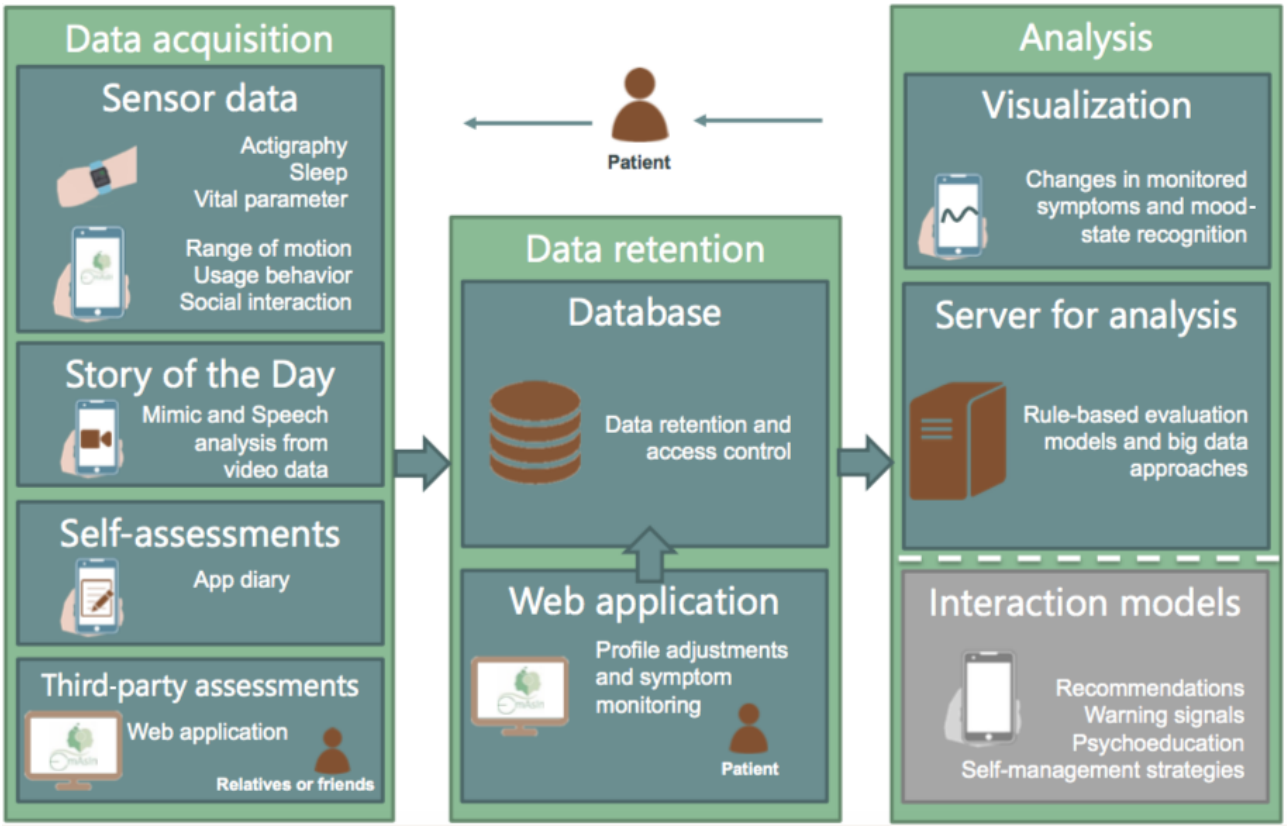
The system is supposed to recognize mood-state changes in patients with bipolar and to react by sending warning signals or, like other approaches [13,14,28,30], by proposing recommendations (eg, to consult a doctor) and self-management strategies. All system components are fully developed; only the interventions that depend on the automatic mood-state recognition have not been implemented at the actual stage of development. Apart from long-term analyses using big data approaches, neural networks, and machine learning approaches [62], we are pursuing rule-based evaluation models to allow for an increasing accuracy of the state recognition. To this end, patients can adjust the importance of certain parameters for their own mood-recognition approach. For example, they can assign values between 1 and 3 to each relevant factor (self-assessments, third-party assessments, behavioral, physiological and sleep data, or emotional expressions) to implicate their individual importance (with 1 being *less important*, 2 *moderately important*, and 3 *very important*). The system then includes the individual assignments when integrating and analyzing the assessed data. Beyond that, patients may also assign these values to the warning signs, which are then analyzed as separate factors. Figure 1 illustrates the concept of the assistance system.

Table 1. Data resources of the assistance system.

Information source and its components	Parameters	Category
Sensor data		
Smartphone		
Location	Range of motion[a], visited locations[a]	Activity and behavior
Accelerometer	Movements/acceleration[a]	Activity and behavior
Smartphone usage	Usage duration[a], number of calls[a], click rate[a]	Activity and behavior
Social interaction	Usage of social apps[a], number of messages (SMS text messages, emails, instant messengers)[a]	Social behavior
Wearable		
Vital	Heart rate[a], resting heart rate[a]	Physiological data
Movement patterns	Steps/distance per day[a], recognized activities[a]	Activity and behavior
Sleep	Sleeping/wake up time[b]	Sleep duration
	Bedtime/getting out of bed[b]	Sleep efficiency
	Wake phases[b], activity at night[b]	Sleep quality
Self-assessments		
Smartphone		
Diary	Self-assessments[b]	Self-image
Third-party assessments		
Web application		
Diary	Third-party assessments[a]	Perception by others
Story of the Day		
Smartphone		
Microphone	Speech duration[b], breaks[b], words per minute[b]	Activity/urge to speak
	Emotional words[b], color of the voice[b], loudness[b]	Emotional expression
Camera	Facial expressions[b]	Emotional expression

[a]Optional.
[b]Mandatory.

Figure 1. Concept of the assistance system.



Story of the Day

As opposed to earlier approaches, which analyzed ambient sound samples or voice features without processing emotional information [23,31,32,50,51], our emotion-sensitive module analyzes intentionally recorded sequences regarding the contained auditive and visual emotional cues. When a recording is initiated on the start screen of the Story of the Day module, the app uses the smartphone camera to capture video data. In order to secure a sufficient recording quality, the users mount their smartphones in well-positioned holders before activating this feature. Furthermore, external microphones are attached to the smartphones to improve the audio quality of the recordings. At the beginning of each recording sequence, the users are asked to describe an important event of their day. After telling their story the recording must actively be ended and the users are asked if they want to save the recording. If the microphone and camera do not record any information (ie, no recognized voice or face), the recording is automatically discontinued.

The app analyzes the assessed auditive and visual information separately. The verbal information is analyzed regarding the use of emotional words, the color of the voice, its energy level (ie, loudness), the verbal fluency, and the speech rate as well as the extent to which the story is narrated. The count of emotional words in automatic transcriptions of the used language of each recording is based on the *Linguistic Inquiry and Word Count* (LIWC) program [59] and includes the emotional categories of positive emotions, negative emotions, sadness, anxiety, or anger. The voice analysis follows the *EmoVoice* approach [60], a framework that uses acoustic signals as emotional classification units and recognizes emotional or mental states on the basis of these signals. For each audio file, the system analyzes segments of 250 ms and assigns values between 0 and 1 to the categories anger, boredom, disgust, fear, happiness, and sadness. The automatic recognition of emotions in facial expressions during the Story of the Day recordings is based on the *Facial Action Coding System* (FACS) [61]. In short intervals of 1 frame/second, facial expressions are examined evaluating the 4 emotions, namely, happiness, sadness, anger, and anxiety. For each emotion, the percentage frequency of its coding is calculated.

Discussion

Internet- and mobile-based approaches have become increasingly important to psychological research in the field of bipolar disorders. In particular, the aspiring mHealth approach benefits a consistent self-monitoring of patients with bipolar disorder [11,12,17-19] and allows for mood-recognition approaches based on automatically assessed sensor data [20,21,23-27]. Our new assistance system incorporates some of the well-known components of mHealth systems for bipolar disorder and combines them with the innovative features of third-party assessments and the analysis of emotional expressions.

While the self-perception of patients with bipolar disorder is certainly the most important factor in mood monitoring, self-assessments can be less reliable in specific cases or during severe episodes [56,57]. Beyond that, some patients trust the assessments of relatives or related parties more than their own perception, when it comes to their mood states [55]. Thus, our third-party assessments could help to gain a more comprehensive

view regarding the patients' mood states. In reference to the great burden, which bipolar disorders are putting on the relationships of patients [63], the third-party assessments might even reduce some of the tension: They can shift the external feedback from possibly strained direct interactions to regular web-based assessments.

Our Story of the Day module, as far as we know, is the first mobile-based approach to analyze the emotional expressions of patients with bipolar disorder. As opposed to the analysis of ambient sound samples or voice features during phone calls [23,31,32,50,51], the actively user-triggered Story of the Day recordings allow us to analyze visual and auditive information as well as the emotional content of the spoken language. The well-established FACS [61], LIWC [59], and EmoVoice approach [60] should provide the technical implementation of our emotion-recognition approach with some helpful framework. This development is especially promising when the effects of emotional deficits on the social and global functioning of patients are considered [39,40,42-45,48]. Consequently, our emotion-sensitive approach is not only interesting in the context of mood-state recognition but might also increase our understanding of experienced and expressed emotions of patients with bipolar disorder. The received feedback in regard to their emotional expressions might be especially informative to patients without regular or with strained social interactions. Moreover, the emotional and narrative character of our Story of the Day module might aid a less technical or distant usage experience and might motivate patients to reflect upon their daily (social) experiences and interactions.

Of course, our new assistance system comes with its limitations. Most importantly, the predictive value of our approach concerning its mood-state recognition and its efficacy and effectiveness with respect to relapse prevention has to be addressed in empirical studies with patients with bipolar disorder. In addition, not all patients approve of the involvement of relatives or related parties in their mood-monitoring approach [55]. Our Story of the Day module must also be used on a regular basis to enable its automatic analysis of emotional expressions. Thus, like self-monitoring systems, our emotion-sensitive approach may depend on the patients' mood state and motivation. However, as a consequence, the Story of the Day module does not automatically assess audio or video data and thus does not interfere with the patients' privacy or personal space. Beyond that, our assistance system allows patients to activate or deactivate certain features (eg, the third-party assessments) and meets the patients' expectations of flexible systems [55,64]. Furthermore, based on our preliminary findings, we estimate that the Story of the Day recordings should not take up more than 2 minutes per day. In the future, our Story of the Day approach might be even less effortful as it could possibly be realized in a more natural setting without smartphone holders or external microphones.

Whereas the EmoVoice approach [60] and, in part, the LIWC approach [59] incorporate the analysis of verbally expressed disgust into our emotion-sensitive module, the Story of the Day module does not recognize this emotion in the facial expressions of patients. Because disgust is one of the more frequently experienced emotions in bipolar disorder [37], subsequent mobile-based FACS approaches [61] should possibly be programmed to include this emotion as well. Finally, our Story of the Day module does not react to suicidal statements and suicidality is not assessed during the self-assessments. The monitoring of suicidal tendencies or even time-sensitive interventions in case of severe suicidal crises with technological help comes with extensive ethical or legal considerations and can have unexpected effects [65]. Accordingly, before implementing such features into mobile-based approaches for bipolar disorder, their feasibility and effects should be examined thoroughly.

With this in mind, there are still some issues to be dealt with in the further development of our assistance system and more research is needed to examine the clinical value of our system. However, our assistance system and its new and innovative features might improve the understanding of the patients' mood state and could provide important information about the patients' expressed emotions as well as their (social) interaction behavior. Considering the strong association between emotional aspects and the social and global functioning of patients with bipolar disorder, in the future, emotion-sensitive systems might be even useful during emotion-based treatment approaches in bipolar disorder [66-68].

Conclusion

The mHealth approach offers many opportunities to support patients with bipolar disorder in their everyday struggle with their disease. However, the existing mobile-based approaches do not consider the importance of emotional aspects in bipolar disorder and their implications regarding the social and global functioning of patients. With our assistance system, we aim to address this issue and have therefore implemented the emotion-sensitive Story of the Day module. With the help of this module, our system analyzes the emotional experiences and expressions of patients besides regular self-assessments and third-party assessments as well as the analysis of further sensor data. In the future, emotion-sensitive approaches might not only benefit a better understanding of the patients' emotional states, but they might also be used to complement the technical exchange of information between systems and patients with more intuitive interaction models. Moreover, they might even support emotion-based interventions in bipolar disorder.

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Conflicts of Interest

None declared.

Multimedia Appendix 1

Assessment and analysis of sleep data.
[DOCX File , 13 KB-Multimedia Appendix 1]

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Abbreviations

FACS: Facial Action Coding System
LIWC: Linguistic Inquiry and Word Count

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Feasibility and Acceptability of a Mobile-Based Emotion Recognition Approach for Bipolar Disorder

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Abstract

Over the past years, the mobile Health approach has motivated research projects to develop mood monitoring systems for bipolar disorder. Whereas mobile-based approaches have examined self-assessment or sensor data, so far, potentially important emotional aspects of this disease have been neglected. Thus, we developed an emotion-sensitive system that analyzes the verbal and facial expressions of bipolar patients in regard to their emotional cues. In this article, preliminary findings of a pilot study with five bipolar patients with respect to the acceptability and feasibility of the new approach are presented and discussed. There were individual differences in the usage frequency of the participants, and improvements regarding its handling were suggested. From the technical point of view, the video analysis was less dependable than the audio analysis and recognized almost exclusively the facial expressions of happiness. However, the system was feasible and well-accepted. The results indicate that further developments could facilitate the long-term analysis of expressed emotions in bipolar or other disorders without invading the privacy of patients.

Keywords

Assistance Systems,
Bipolar Disorder,
Emotion Recognition,
Intelligent Systems,
Mobile Health.

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I. Introduction

EMOTIONAL expressions are an important indication of how we are feeling. Thus, sudden or severe changes in those expressions can be signs for psychopathological syndromes or diseases. One of the most common mental disorders worldwide is bipolar disorder [1], which is defined by its depressive or (hypo-) manic episodes [2]. These episodes are characterized by typical changes in the emotional experiences of patients: For example, patterns of elevated happiness and anger during mania or sadness and disgust during depression [3]. Beyond that, patients with bipolar disorder often show emotion-related difficulties like deficits in emotion regulation [4]–[8] and recognition [9]–[12] or in the afore-mentioned expression of emotions [13], [14]. Therefore, in bipolar disorder, the processing of emotional information and the verbal or facial expressions following emotional stimuli might be influenced by mood-dependent biases or regulation strategies like emotional avoidance [15]–[17]. Since all of these areas are important to the everyday lives of patients, the deficits affect their overall functioning [18]–[20].

Depending on the severity and the course of this disease, its personal and economic consequences can be enormous [21], [22]. Thus, within patient care, strategies that complement the medical and psychological treatment are of great interest [23], [24]. Over the past years, the increasing technical possibilities have strengthened the *mobile Health* (mHealth) approach in general and, just as much, in bipolar disorder [25], [26]. Especially the advantages regarding the availability, accessibility and cost efficiency of technical systems show their potential to benefit the ambulatory care system. Many mobile-based approaches for bipolar disorder include self-assessment or sensor data in mood monitoring or recognition approaches [27]–[33]. Yet, none of the existing systems have focused on the emotional aspects of this disease [34]. The expressed emotions of patients, however, could be an important indication of their emotional reactivity [14] and possibly of their affective state or recurring episodes [34].

Within the research project *Emotion-sensitive Assistance systems for the reactive psychological Interaction with people* (EmAsIn), an emotion-sensitive mHealth approach for bipolar disorder has been developed. The system, which has already been described in detail [34], combines the common self-assessment (SA) or sensor approaches with other, innovative features. It incorporates an emotion-sensitive module that retrieves audio and video data from short and actively user-triggered recordings of patients. The auditive and visual information is analyzed in respect to emotional cues or content [34]. Beyond that, the system includes optional, external assessments or third-party assessments (TPA), which are realized by involving close contacts into the ambulatory approach.

In this article, we examine the feasibility and acceptability of several system features. Therefore, data from a pilot study with patients with

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bipolar disorder is presented and discussed. As indications regarding the feasibility of the emotion-sensitive module, the SA or the TPA approach, some usage-related aspects (like the completion of the participation periods or the frequency of feature usage) were assessed. Concerning the emotion-sensitive module, the accuracy of the word and face recognition, the detected emotional expressions and the convergence between the emotion recognition within both sources (auditive and visual) were seen as further indications of its feasibility. In order to examine the acceptability of the features, interviews with the participants were conducted. All features were expected to be feasible and, in accordance with research suggesting a higher technical affinity of younger patients [36], [37], a higher feasibility with younger participants was expected (A). In more detail, a good usability (A.1) and convergent results of the recognition approach (A.2) were expected. Since participants of an earlier interview study of the authors had been open towards the innovative features [35], all features were expected to be well-accepted (B).

II. Methods

A. Participants

From April to December 2018 five ambulatory patients with remitted bipolar disorder participated in the pilot study for an individual duration of several weeks (see results section). The study sample included three men and two women. Four participants, according to DSM-V, could be diagnostically categorized into bipolar I disorder, the fifth person into bipolar II disorder. The participants (between 24 and 51 years old) had an average age of 39.40 years (SD = 9.94).

B. System Features

The most important study instruments were smartphones with a pre-installed system application and a wearable device that participants wore on their wrists. The overall system acquires data from multiple sources in order to recognize mood state changes of patients. Next to the features described below, the system analyzes physiological or sleep data (e.g., heart rate or sleep duration) and behavioral patterns (e.g., recognized activities or smartphone usage). Since the overall concept of the system has been presented on another occasion [34], the following sections were reduced to essential technical aspects of the emotion recognition approach and the other two examined features.

The application analyzes intentionally initiated recordings of its users by activating the smartphone camera and microphone, as soon as this function is selected. Users then are instructed to tell their *Story of the Day* (SotD), a narrative of an important event of their day. In the study setting, smartphone holders and external microphones were included to ensure a good quality of the recordings. Only if the user approves, the system saves the recording locally and analyzes the given information. In that case, automatic transcriptions of the verbal information are analyzed in regard to the word count of different emotional categories by following the *Linguistic Inquiry and Word Count* (LIWC) approach [38]. For example, the specific categories of sadness, anxiety or anger include words like “to regret”, “nervous” or “outraged”. The more comprehensive categories of positive or negative emotions contain words of all the specific, emotional word categories with positive or negative connotations. The visual information, on the other hand, is automatically separated into multiple video frames per second. All captured facial expressions then are analyzed regarding the presence of one of four basic emotions (happiness, sadness, anger and anxiety) by following the *Facial Action Coding System* (FACS) [39].

The app-based SA approach has also been developed within the research project and has not been clinically evaluated yet. It includes six 7-point items regarding the most important symptoms of bipolar disorder. All items can be assessed by choosing values from -3 to 3 with negative values or positive values representing depressive or (hypo) manic symptoms. The related and newly developed TPA of partners or related parties are realized using separate web applications (and are, therefore, not necessarily assessed via smartphone). They also include six items that are almost identical with the SA items, and are answered using the same scale [34].

The participants of the pilot study were asked to keep their daily routines as they were and to integrate the assistance system as far as possible. Whereas some system components were designed to be optional [34], the three presented features (or, two features in case of missing third parties), should have been used regularly (e.g., on a daily basis). The SotD was supposed to take about two minutes per day and to contain narrations of recent events that had affected the emotional experiences of the narrator. Furthermore, the stories were supposed to be recorded in a well exposed room without the presence of other persons and with a frontally placed camera (smartphone). During the pilot study, the assistance system was not yet fully developed and did not automatically react to the assessed data or recordings.

C. Semi-structured Interview

Potential technical issues and the individual usage experiences were examined at the end of the study participation during semi-structured interviews. The interview guide included questions about all system features. The section about the emotion recognition approach was especially detailed and concerned aspects like the perceived emotional intensity or potential confounding factors while telling the SotD. For example, the participants were asked, “Do you think that your perceived emotions or your emotional expressions were influenced by the missing dialog partner?” All questions could be answered on 5-point scales from 1 “negative” or “not at all” to 5 “positive” or “exactly”. Beyond that, every issue allowed for explanations or comments. The nine interview questions that are relevant to this article (seven of them SotD-related) took about ten minutes.

D. Indicators of Feasibility and Acceptability

The measurement of the feasibility was operationalized through several usage-related aspects: The duration of the study participation of all patients (in reference to the targeted duration, see section E) was seen as an indicator regarding the feasibility of the overall system. Furthermore, for all features, the usage frequency (in reference to the study duration) was assessed and seen as a feasibility measure. As for the SotD module, the duration of the recordings was seen as an additional measure of their usability. Moreover, the technical functionality of this module was assessed in order to infer its (technical) feasibility. Thus, the count of recognized words was assessed, and the congruence of automatic transcriptions with a sample of manual transcriptions was analyzed (see section E). The count of the recognized faces was assessed and compared to the count of video frames in order to evaluate the recognition. The amount of the recognized emotional expressions of several emotional categories (in reference to the count of words and frames with faces) was assessed and seen as a further (technical) feasibility measure of the module. Finally, by analyzing the congruence of the emotion recognition results of both sources, the measure of their convergent validity was included as a feasibility indicator, because it could be seen as a potential proof of concept. The acceptability of the features was operationalized and assessed through questions of the interviews. Therefore, the selection of the participants regarding the possible answer choices or additional comments delivered the acceptability measures.

E. Design and Analysis

As for most of the research questions, the five participants were considered single cases and their data was analyzed separately.

However, in spite of the small number of participants, in regard to some specific questions (e.g., the age effect or the acceptability), correlation analyses or other methods were applied within a statistical group design. The long-term assessment of the feasibility data (see section D) was realized within the ambulatory environment of the patients (ambulatory assessment). An individual assessment period of twelve weeks (about 84 days) per participant was aimed for. With respect to the potential age effect on the usage behavior, the correlations between the age of the participants at the beginning of the study and the frequency of their SA or the SotD assessments were calculated. The congruence between the automatic SotD transcriptions and a sample of ten manual transcriptions (as a feasibility measure of the emotion-sensitive approach) was assessed by comparing all recognized LIWC [38] word categories (e.g. pronouns, numbers or specific themes like "money") within both sources. The percentage of the recognized emotional expressions within all recognized words and faces of each SotD assessment was analyzed following the LIWC [38] and FACS [39] approaches. The congruence of both recognition sources (convergent validity) was analyzed by calculating the correlations between corresponding or contradicting LIWC and FACS categories. The interviews, which were developed to assess acceptability aspects, were conducted in German with a single measurement time point at the end of the study participation. The answers as well as the comments were recorded, translated into English and delivered quantitative and occasional qualitative data. All descriptive or correlative analyses were conducted using *Microsoft Excel V. 16.40* and *IBM SPSS Statistics V. 26.*

III. Results

A. Feasibility

The individual study duration of the five participants was at least 57 and up to 134 days. On average, the patients of the pilot study participated for 87.40 days (*SD* = 32.14). As illustrated in Table I, the individual study duration of some participants considerably exceeded or fell below the targeted assessment period.

TABLE I. Study Duration, Assessment Numbers and SOTD[a] Duration for Each Participant

Code	Study duration in days	SA[b]	TPA[c]	SotD		
		N	N	N	Duration in s (M, SD)	
P1	134	110	1	14	94.36	38.73
P2	97	100	0	43	92.81	36.42
P3	92	46	17	15	104.47	31.91
P4	57	64	0	6	96.17	47.91
P5	57	54	0	48	148.02	43.91

[a]SOTD = Story of the Day; [b]SA = self-assessments; [c]TPA = third-party assessments.

1. Usage-related Aspects

The individual assessment numbers for the SA, TPA, and SotD for each participant are also shown in Table I. On several occasions, the same features were used several times during the same days. That is why, for example, one participant completed 64 SA within 57 days (see Table I). According to the study instruction of daily usage, Fig. 1 illustrates solely the percentage of participation days for each patient, on which they (or their related parties) used the three concerned features at least once. In reference to the SA, the usage frequency for all participants ranged from 40.22 % to 96.49 % of the participation days. The TPA were only used by related parties of two of the participants, resulting in a minimum of 0 % usage and a maximum of 17.39 % of the participation days. For the SotD assessments, the usage frequency ranged from 8.21 % to 82.46 %. Together, the five participants of the pilot study recorded 126 SotDs. As one can see in Table I, the individual mean values for the audio file duration ranged from 92.81 s to 148.02 s.

There were strong, negative correlations between the age of the participants and the percentage of days, on which they used the SA [$r(3) = -.60$, $p = .285$] and the SotD [$r(3) = -.70$, $p = .188$].

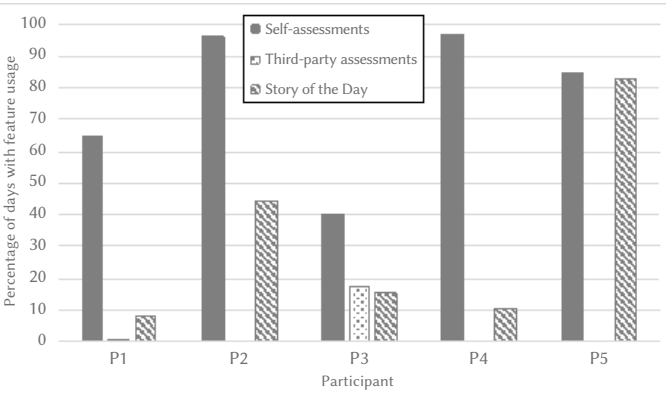

Fig. 1. Usage frequency for specific system features and each participant in reference to the individual study duration (in days).

2. Functionality of the Emotion Recognition Approach

Within the automatic transcriptions of the SotD audio files of each participant, on average, the LIWC program [38] recognized between 106.29 and 240.77 words (see Table II). A random sample of ten audio files was also transcribed manually and then analyzed with the LIWC software. All recognized LIWC word categories (not only emotional categories) within the manual and the corresponding automatic transcriptions matched from 72.00 % to 93.00 % (*M* = 87.30, *SD* = 6.70). The LIWC analysis of the audio data of all participants found, on average, between 3.93 and 11.15 single words corresponding to the category of positive emotions. This means that, for example, all audio files of one participant contained on average 5.47 single words belonging to that specific category. The corresponding mean values for each participant are illustrated in Table II. For the category of negative emotions, the individual mean values ranged from 1.33 to 4.52 words per file (see Table II). Regarding the more specific emotional category of sadness, the LIWC analysis resulted in mean values between 0.43 and 1.04 words per file (Table II). For the other two afore-mentioned, specific emotional LIWC categories (anxiety and anger), all corresponding mean values resulting from the analysis were ≤ 0.67.

TABLE II. LIWC[a] Analysis of the SOTD[b] Recordings for Each Participant

Code	Number of words		Positive Emotions		Negative Emotions		Sadness	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
P1	106.29	81.40	3.93	3.17	2.21	1.67	0.43	0.51
P2	140.02	59.40	5.93	2.87	1.91	1.82	0.53	0.74
P3	173.33	58.17	5.47	3.20	3.00	2.56	0.93	1.16
P4	149.67	89.91	6.00	3.85	1.33	1.21	0.83	0.98
P5	240.77	92.79	11.15	4.87	4.52	2.42	1.04	1.01

[a]LIWC = Linguistic Inquiry and Word Count; [b]SotD = Story of the Day; P1 (*N* = 14), P2 (*N* = 43), P3 (*N* = 15), P4 (*N* = 6), P5 (*N* = 48).

In percent (compared to the total wordcount of the audio files and for each participant separately), there were average amounts from 3.00 % to 5.89 % of words belonging to the category of positive emotions in the recordings (see Fig. 2). In regard to the category of negative emotions, the individual mean values ranged from 0.93 % to 2.01 % of words per file. The more specific category of sadness accounted for 0.34 % to 0.58 % of the wordcounts (see Fig. 2).

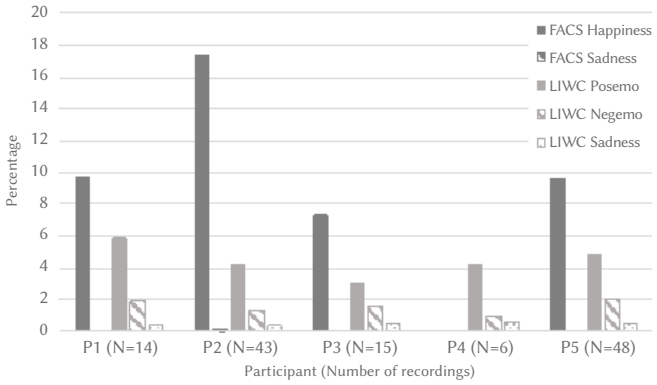

Fig. 2. Percentage of recognized emotions of Facial Action Coding System (FACS) categories and Linguistic Inquiry and Word Count (LIWC) categories in the Story of the Day recordings in reference to the individual number of frames with recognized faces (FACS) or the individual word count (LIWC).

The corresponding SotD video files were separated by the assistance system into, on average and for each participant separately, 2787.42 to 4443.42 video frames. For two assessments, the smartphone application apparently did not work accurately, and no video data was recorded. Both assessments belonged to P1 and had to be excluded from the calculations concerning the FACS [39] analysis. With four participants, within more than 94 % of the video frames there were recognized faces. As for P4, only 0.31 % of the video frames contained recognized faces. Thus, the individual mean values of frames with recognized faces that could be analyzed by the FACS-based software ranged from 7.00 to 4438.25 (see Table III). When the 6 video files of P4 without face recognition are not taken into account, for the remaining four participants, the FACS analysis found individual mean values of 209.93 to 538.51 frames with recognized happiness in the facial expressions (see Table III). However, the automatic FACS analysis detected almost no sadness in the facial expressions, resulting in individual mean values of all participants of ≤ 0.60 frames with recognized sadness (see also Table III). Beyond that, the FACS analysis detected none of the other two examined emotional FACS categories (anxiety or anger). Regarding the participants with successful face recognition, the individual mean percentage of frames with happiness out of all relevant frames (with faces) ranged from 7.38 % to 17.44 % (see Fig. 2). The mean percentage of sadness for all participants was ≤ 0.02 % (see Fig. 2).

TABLE III. FACS[a] Analysis of the SOTD[a] Recordings for Each Participant

Code	Frames with faces		Happiness		Sadness	
	M	*SD*	*M*	*SD*	*M*	*SD*
P1	2919.17	1051.87	243.42	205.14	0.00	0.00
P2	2749.60	1122.88	538.51	638.62	0.60	3.81
P3	2961.33	963.49	209.93	219.27	0.00	0.00
P4	7.00	12.25	0.17	0.41	0.00	0.00
P5	4438.25	1315.08	435.88	384.13	0.02	0.14

[a] FACS = Facial Action Coding System; [b] SOTD = Story of the Day; P1 (*N* = 12), P2 (*N* = 43), P3 (*N* = 15), P4 (*N* = 6), P5 (*N* = 48).

In order to examine, if the measures for the verbal and facial emotional expressions had delivered convergent results, the correlations between the most important LIWC and FACS categories were analyzed for each participant separately. For all participants with working face recognition, there were moderate or strong correlations between specific verbal and facial emotion recognition categories (see Table IV for all correlations). In regard to P1, the most prominent results were strong negative and significant correlations between the FACS category happiness and the LIWC category positive emotions (see Table IV). Thus, in this case, a higher amount of recognized expressions of happiness within the video frames coincided with less emotionally positive words within the LIWC analysis.

Concerning P2, the most prominent results were strong positive and significant correlations between FACS happiness and LIWC positive emotions or between FACS sadness and the LIWC sadness categories (see Table IV). Consequently, more video frames with expressed happiness coincided with a higher amount of positive words. And more recognized sadness within the FACS analysis was associated with more sadness-related words in the LIWC analysis. As for P3, there were no significant results, and there was only one moderate correlation indicating that more facially expressed happiness was associated with the use of more emotionally positive words (see Table IV). Regarding P5, there were several moderate and significant correlations: The FACS happiness categories were positively associated with LIWC positive emotions and negatively associated with LIWC negative emotions (%). Therefore, more recognized happiness within the facial expressions coincided with more emotionally positive and less emotionally negative words within the spoken language of this participant.

B. Acceptability

During the semi-structured interviews at the end of their individual study participation, the five participants showed positive attitudes towards the app-based SA (*M* = 3.80, *SD* = 1.10). One participant, nevertheless, emphasized the relevance of external assessments due to a potentially less-reliable self-perception (see Table V). Yet, only two participants were able to use the TPA with the help of related parties. These two participants perceived the assessments very positively (*M* = 4.50, *SD* = 0.71). Other participants still commented on this feature and expressed their interest in external assessments that could compensate for biased retrospective assessments regarding their mood (see Table V). With respect to the SotD module, the overall view of the five participants was relatively positive (*M* = 3.40, *SD* = 1.14) and comments mentioned positive "side-effects" of this feature (see Table V). The instruction of this module was easy to understand (*M* = 4.60, *SD* = 0.55), and most participants could imagine using this feature on a regular basis (*M* = 4.00, *SD* = 0.71). However, comments differed regarding the potential frequency of this usage or included recommendations for possible modifications (see Table V).

When asked, if their perceived emotions during the SotD recordings and during the described current events were of a similar intensity, the participants showed a moderate agreement (*M* = 2.80, *SD* = 1.30). They further agreed that the missing dialog partner, to some degree, had influenced their perceived and expressed emotions during the SotD (*M* = 3.40, *SD* = 1.14). Comments specified that some participants had experienced the strange feeling of being observed while talking into the camera. Yet, they further mentioned that this effect was not persistent (see Table V for comments). The "selfie mode" during the recordings was perceived as somewhat influencing, too, but less strong than the missing interaction (*M* = 3.00, *SD* = 1.23). However, some participants were somewhat irritated by seeing their own emotional expressions (see Table V). When asked, if they felt burdened by the SotD recordings, the participants did not agree (*M* = 2.00, *SD* = 1.41).

TABLE IV. Pearson Correlations Between FACS[a] and LIWC[b] Categories

Codec	FACS[a]	LIWC[b]					
		Positive Emotions	Positive Emotions (%)	Negative Emotions	Negative Emotions (%)	Sadness	Sadness (%)
P1	Happiness	**-.73****	-.36	-.29	.06	-.03	.30
	Happiness (%)	**-.72****	-.12	-.36	.02	-.09	.20
P2	Happiness	**.49****	.14	.25	.02	.07	-.06
	Happiness (%)	.28	.13	.15	.04	.04	-.03
	Sadness	.00	-.03	.18	.14	**.53****	**.35***
	Sadness (%)	.00	-.03	.19	.14	**.53****	**.36***
P3	Happiness	.31	.18	.21	.05	.19	.10
	Happiness (%)	.14	.15	.00	-.09	-.07	-.12
P5	Happiness	**.44****	.05	.05	**-.31***	-.04	-.19
	Happiness (%)	**.37****	.18	-.08	**-.31***	-.08	-.16
	Sadness	.09	.17	-.21	-.20	-.15	-.15
	Sadness (%)	.09	.17	-.21	-.20	-.15	-.15

[a]FACS = Facial Action Coding System; [b]LIWC = Linguistic Inquiry and Word Count; [c]P4 excluded due to failed face recognition, for P1 and P3 the FACS analysis did not detect any sadness; P1 (N = 12), P2 (N = 43), P3 (N = 15), P5 (N = 48); ** Correlation is significant at the 0.01 level (2-tailed); * Correlation is significant at the 0.05 level (2-tailed).

TABLE V. Comments of the Participants on Selected Issues

Interview section and issue		Comment and participant number
Self-assessments		*"It´s a good feature, but I didn´t use it regularly. My self-perception isn´t that good, thus, third-party assessments are very important."* P1
Third-party assessments		*"I would recommend using that feature and keeping it simple. Maybe one could also notify the partner to facilitate simultaneous comparisons.* P1
		"If you would ask me how I felt last week, I wouldn´t remember. Thus, third-party assessments would be helpful [in regard to future systems]." P5
Story of the Day	**Overall view**	*"It helps your self-perception and forces yourself to observe yourself."* P3
	Regular usage	*"If it was easier to use."* P1
		"Two or three times a week, yes. Seven times would be difficult. It´s mentally challenging and you don´t have a story to tell each day." P3
		"In theory, yes. I don´t like filming myself, but if there was a feedback and it would help my situation, yes." P4
		"If there was a feedback, yes. But not on a daily basis." P5
	Missing dialog partner	*"It irritates, yes. I feel strange when I´m being filmed, it would be different with a real counterpart."* P4
		"At the beginning it´s strange to talk to the camera, because you feel observed. Later it´s like keeping a diary." P5
	Selfie mode	*"I tried to focus on the camera, because it irritated me to see my own feelings on screen."* P5

IV. Discussion

The mHealth approach offers many opportunities for the ambulatory care system and the disease management of patients with bipolar disorder. Within the EmAsIn project, to our knowledge, the first emotion-sensitive assistance system for bipolar disorder was developed and examined. The following sections of the current article first address the presented results regarding the (technical) feasibility and acceptability of the newly developed system. Subsequently, the implications of these findings with respect to clinical practice and further research as well as methodological issues will be discussed.

A. Feasibility

In order to evaluate the feasibility of the approach, several usage-related aspects (study participation, usage frequency, recording duration) and, concerning the SotD, rather functionality-related aspects (accuracy of word or face recognition, recognized emotions, congruence of verbal and facial emotion recognition) were assessed.

1. Usage-related Aspects

There were individual differences regarding the study participation and the usage frequency of the examined features. Three patients participated longer than proposed. Especially one participant was motivated to exceed the estimated study duration by seven weeks. Two of the participants were not able to participate for the originally intended duration of twelve weeks, because they were recruited only eight weeks before the project-intern assessment period ended. Consequently, no patient terminated the participation prematurely, which might indicate an overall feasible, ambulatory system. In reference to the specific features, the SA was the most feasible. Four out of five participants used it almost on a daily basis or even more frequently with multiple assessments on single days. Due to their well-established role in other monitoring approaches for bipolar disorder with comparable response rates [40], [41], this result was expected. The TPA were only used by related parties of two participants. Solely in one case there were multiple entries. Therefore, within the current study setting, this feature was not feasible. This result could

be explained within the context of the often-strained relationships of patients with bipolar disorders [21] or of the relationship status of the participants. Yet, another important issue might have been the web-based study approach that did not allow for push messages or reminders and might have been more effortful in its handling. In the future, this feature should be realized with associated smartphone applications. Thus modified TPA might be valuable and feasible with patients in reliable relationships and should be examined in larger studies, possibly conceptualized as family studies [42].

The SotD assessments were more effortful than the SA due to the installation of external study microphones and holders and because of the necessity to narrate a freely chosen story. Two of the participants still used the SotD on a regular basis (i.e., almost daily or almost every second day). The other three participants used the SotD much less frequently (i.e., on about ten to 16 percent of their participation days). Although these results show that the SotD (in its current version) might be feasible with some patients, modifications regarding its handling or the usage experience may be necessary to increase its general feasibility. The presented results further indicate that not only the SA but even more the SotD approach may be more feasible with younger patients. This confirms findings of earlier studies examining how the age of patients with bipolar disorder affects their new media usage [36], [37].

2. Functionality of the Emotion Recognition Approach

Following the insights of an earlier pre-study with healthy participants, the SotD study approach was extended by the external microphones and holders. This hardware change did improve the previously worse recording quality of the auditive information and, thereby, did increase the accuracy of the automatic transcriptions or the count of correctly recognized words to an acceptable level [43]. In concern to the video analysis, there were six assessments without working face recognition. The corresponding recordings were examined more closely and could be explained with unfavorable recording angles and a relatively low lighting. As a consequence, instructions should be even more specific. Furthermore, future systems should inform their users on missing face recognition or they should be trained to be less vulnerable for disturbances. By analyzing the expressions within both sources (auditive and visual), the recognition software found far more positive than negative emotions. Although several factors may have contributed to these results (see following sections), the recognized emotions might still reflect the expressed emotions of the participants: In order to explore further research questions, additional clinical data of the five study-patients was assessed. Most of them showed relatively stable mood throughout their study participation, including moderate (hypo) manic or mild depressive symptoms but no severe depressive episodes. Therefore, strong or persisting changes in their emotional experiences, that could have elevated the amount of expressed sadness during the SotD assessments, may not have been induced by psychopathological symptoms. Beyond that, most of the correlations regarding the emotional LIWC [38] or FACS [39] categories seem to support the consistency of the auditive and visual measures. At first glance, however, the strong negative correlations between the FACS parameters for happiness and the LIWC category of positive emotions with one participant seem conflicting.

Clinically speaking, these results could still be explained: The participant showed mild depressive symptoms and a limited emotional reagibility throughout the whole study but yet parathymic smiles during the bi-weekly clinical assessments. These deficits coincide with findings of earlier studies indicating difficulties of patients with bipolar disorders in the (facial) expression of negative emotions [13], [14]. Therefore, the emotion recognition results presented here might represent a further indication of disease-specific deficits in the emotional expressions of bipolar patients. The verbally expressed information could have consciously been adapted to the assessment situation, while the missing correspondence within the facial expressions might have represented a more basic process of emotional avoidance. This interpretation might, in part, also explain the higher percentage of positive emotions within the FACS data of all patients (as compared to the LIWC results). Nevertheless, technical or conceptual issues may have further contributed to these results: Whereas the LIWC [38] and FACS [39] approaches delivered an empirically established framework for emotion recognition, the FACS-based video analysis might have been less sensitive to the recognition of negative emotions due to insufficient training data during the aforementioned pre-study.

Moreover, the results might suggest that short recordings of approximately two minutes or less could contain sparse emotional expressions altogether. In that case, ambient sound samples or random voice features, which have shown some potential regarding the prediction of mood state changes in bipolar disorder [27], [44]–[47], could increase the obtained information. However, as far as we know, none of the existing mobile-based approaches for bipolar disorder have analyzed the emotional content of verbal or facial expressions. It would already be difficult to realize the emotion recognition approach with random sound samples. The assessment of random video data with the emotion-sensitive approach would almost be impossible without harming the (perceived) privacy of patients. With this in mind, the SotD approach goes beyond the existing mHealth systems for bipolar disorder [34]. It allows for the analysis of even more sensitive and personal ambulatory data without harming privacy issues.

B. Acceptability

In order to evaluate the acceptability of the approach, semi-structured interviews were conducted with each participant. In accordance with earlier studies that indicate the positive attitudes of bipolar patients towards technical assistance [35], [41], [48], the participants of the pilot study perceived all three examined system features positively. As for the TPA, although only two patients included other persons into the data acquisition, the participants emphasized the importance of this feature. This coincides with comparable opinions of patients with bipolar disorder during an earlier, project-related interview study [35]. Considering the discussed and not yet perfectly solved issues of the SotD module, the positive response of the participants on this feature is quite impressive. Although only two out of five study participants used the SotD regularly (about three to six times per week), all of them were open to a more regular usage. The mentioned conditions, like an easier usage experience (e.g., without microphone or holder) or automatic reactions towards the told stories, matched the original concept of the assistance system [34]. In accordance with the process of development, these aspects had not been implemented within the study setting. They should, however, be technically convertible in the future. Thus, from the acceptability point of view, the ambulatory long-term assessment of emotional expressions in bipolar disorder should be possible.

C. General Discussion

Overall, the results of the pilot study regarding the emotion recognition approach are promising (while the TPA were not feasible). The ambulatory study setting with participation times of several weeks increased the knowledge gain regarding the acceptability and feasibility of the approach by accounting for a long-term, realistic and natural environment [49], [50]. The results indicate that emotion-sensitive systems may be feasible and well-accepted, especially with younger patients. These findings coincide with the good feasibility or acceptability of mHealth systems using self-monitoring, sensor or wearable data with bipolar patients [25], [29], [30], [40] and with the

positive attitudes of this patient group towards innovative, technical strategies for disease management [35].

The explorative approach of the pilot study with five patients, who were mostly considered as single cases, allowed for detailed insights into an ambulatory application scenario and into personal usage experiences. Although the SotD module "solely" requires its regular usage to assess active and passive emotion-related data, it comes along with more effort than common SA. Consequently, younger patients, who show a higher technical affinity [36], [37], used the study version of the SotD more frequently than older participants. And all participants were very specific about the conditions of a regular (e.g., several times per week) long-term usage. In accordance with this, future developments should be more practical (e.g., without microphones or holders), less irritating (no selfie mode) and should realize a perceived system-interaction or feedback during the SotD assessments. Furthermore, in case of the informed consent of patients and after thorough consideration of all ethical and legal implications, future systems could include the attending physicians or therapists. Thus, individual and sudden changes in the emotional expressions of patients could be thoroughly reflected during subsequent sessions.

Of course, the current approach and the small sample size with individual differences within the participation times of the patients limit the generalizability of the findings. Beyond that, detailed cost-benefit analyses would be necessary before implementing emotion-sensitive modules into disease management approaches for bipolar disorder. Therefore, more research is needed and, aside from its acceptability and feasibility, the mobile-based emotion recognition approach would have to provide valid and reliable results regarding all relevant emotions of mood episodes in bipolar disorder [3], [51]. As a consequence, it could facilitate the monitoring and understanding of emotional aspects in this disease and enable following research to examine its potential clinical value or contribution towards mood state recognition. The strong relation between emotional deficits of bipolar patients and their global and social functioning [4], [6]–[9], [13], [52] might make the gained information helpful to therapeutic approaches [13] and relapse prevention. Last but not least, a well-functioning, mobile-based emotion recognition approach could help our understanding of emotional experiences or expressions and their ramifications in other disorders as well.

V. Conclusion

As far as we know, the examined assistance system incorporates the first, mobile-based emotion recognition approach for bipolar disorder. Whereas the openness of patient groups towards technical or mobile-based assistance in their disease management has been investigated on several occasions, the pilot study shows that even the ambulatory assessment of audio and video data may be well-accepted and feasible. Beyond that, the approach allows for the long-term analysis of verbally and facially expressed emotions without harming the perceived privacy of patients or data privacy. Thus, the emotion-sensitive mHealth approach could affect other research areas or fields of application as well. However, to that end, some methodological and technical issues have to be addressed by future developments, and further empirical studies with larger samples of patients are necessary to increase the generalizability of the results.

Author Statement

The EmAsIn project was approved by the ethical committee of the Faculty of Behavioural and Cultural Studies, Ruprecht-Karls-University Heidelberg.

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Conflicts of Interest

The authors herewith declare no potential conflict of interest in respect to research, authorship and/or publication of this article.

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Mobile-based, emotion-sensitive video diaries and ambulatory third-party assessments as indicators of mood states in bipolar disorder

Emotion recognition and third-party assessments in bipolar disorder

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BACKGROUND: This article investigates the clinical value of a newly developed, mobile-based emotion recognition approach and ambulatory third-party assessments with respect to the recognition of symptom severity in bipolar disorder.

METHODS: We present three case studies with patients with bipolar disorder, examining either the emotion recognition approach (Case 1 and 2) or the third-party assessments (Case 3). Correlative analyses or Granger causality tests were conducted in order to evaluate the statistical association between the assessed parameters and clinically evaluated or self-assessed bipolar symptoms.

RESULTS: As for Case 1 and 2, manic symptoms are associated with changes of usage-related behavioral aspects of the system. Especially with Case 2, there are multiple mood-dependent changes in the verbally or facially expressed emotions. Granger causality further indicates the predictive value of facially expressed happiness and behavioral patterns regarding occurring manic symptoms of this patient. As for Case 3, third-party assessments are highly correlated with self-assessed symptoms.

LIMITATIONS: The exploratory and case-based approach comes with the limitations of small data sets, an increased risk of alpha inflation, or the limited generalizability of the results. Furthermore, missing values limit the implications of Case 1 and 3.

CONCLUSIONS: The findings indicate that bipolar symptoms are related to complex changes on the behavioral and emotional levels captured by the recognition approach. The results further support the high individuality of symptom ramifications that should be considered by future systems. More research is needed to confirm these findings and to examine the value of third-party assessments.

Key words: bipolar disorder; emotion recognition; video analysis; audio analysis; mobile health

Introduction

Bipolar disorders and their recurring depressive or (hypo) manic episodes induce high levels of suffering in the affected patients and their families or related parties [1,2]. Even though therapeutic approaches like medication or psychoeducation can have positive effects, persisting symptoms are often and relapses cannot always be prevented [3]. As a consequence, bipolar disorders influence the social relations of patients, their occupational capacities and their socio-economic status [4,5]. Thus, additional strategies within the (ambulatory) care of patients are important [6].

Over recent years, the "mobile Health" (mHealth) approach has shown a great impact within this field [7,8]. Studies investigating mobile-based approaches for bipolar disorders often used smartphone applications to realize daily self-assessments of symptoms with an overall good feasibility and acceptability [9,10]. The implementation of wearable technology or smartphone-intern sensors into mobile-based systems allowed to extent the approach by additional sensor data during several studies: For example, activity trackers, accelerometer data or passively assessed keyboard activity of smartphones were examined in order to find associations with and to monitor bipolar symptoms [11–13]. Beyond that, smartphone sensor data related to social interaction or communication behavior, like the amount of incoming or outgoing as well as answered or unanswered calls and messages, have shown mood-dependent associations with illness activity in bipolar disorder [14]. Passively assessed smartphone sensor data, including information about lighting conditions or microphone sound samples, further enabled the indication of social rhythms in patients with bipolar disorder [15]. Consequently, time-sensitive notifications or psychoeducational messages in case of recognized rhythmic disturbances might benefit the course or recurrence of bipolar symptoms.

So far, a wide range of research projects examining Internet- and mobile-based interventions (IMIs) in bipolar disorder has used such automatic messages to deliver helpful self-management strategies or psychoeducational support [8]. In this way, mobile-based approaches can benefit the treatment adherence, self-management or even biological rhythms of patients, for instance during critical times [8,16]. The growing field of mobile-based disease management systems for bipolar disorder comes upon a patient group that has shown its openness towards technical assistance on several occasions [17,18]. Even smartphone-based assessments posing questions about all relevant symptoms twice a day were feasible and showed great response rates with patients with bipolar disorder [9]. Moreover, the results of several studies investigating mobile-based interventions in depression indicate their positive effects on depressive symptoms [19]. Comparable results can also be found in bipolar disorder, meaning that mobile-based approaches mainly show their impact on depressive symptoms: For example, during one study, the combination of mood-related questions and semi-personalized interventions in response to the assessments reduced depressive symptoms in patients with bipolar or other disorders [20]. Following this, the mHealth approach has the potential to complement the self-monitoring of patients with bipolar disorder in a sensible way. However, many available applications have not fulfilled the high standards of theoretically and empirically evolved systems which take the consumer needs into consideration [7,18,21]. Furthermore, important aspects of bipolar disorders have not yet been considered within mHealth approaches for this disease. For example, mood episodes change the patients' emotional experiences towards typical patterns of increased happiness and anger on the one hand or sadness and disgust on the other hand [22]. Additionally, bipolar disorders are associated with generally increasing emotionality [23,24] and deficits in the processing or regulation of emotions [25,26]. There have also been studies implying difficulties in the recognition

[27,28] and expression of emotions [29,30]. This is especially relevant regarding the social context [27,29].

Therefore, the emotional aspects of bipolar disorders are important factors in reference to the global functioning of patients [24–26]. The incorporation of emotion-sensitive assessments within mobile-based systems could deliver important information with respect to symptom severity or relevant outcome variables [31]. Another essential information source regarding the mood state of patients are the perceptions of their relatives, partners or otherwise related persons. Their perspective, too, is underrepresented within existing mHealth approaches. Research and clinical practice imply that some patients may have some difficulty in realistically perceiving themselves, especially during acute episodes [32,33]. Moreover, patients have emphasized the importance of an external point of view on their mood state because of their own potential biases [17,34].

Within the research project "Emotion-sensitive Assistance systems for the reactive psychological Interaction with people" (EmAsIn), as far as we know, the first emotion-sensitive mHealth approach for bipolar disorder with incorporated external assessments of related parties has been developed [31]. Apart from the common self-monitoring or the analysis of sensor data, the system analyzes the verbal and facial expressions of emotions within short video diaries of patients. To this end, the system includes the recognition of expressed emotions without harming the privacy of its users. Furthermore, the ambulatory approach allows patients to consider third-party assessments regarding their symptoms by close contacts.

In the current article, we examine the clinical value of the emotion recognition approach and of the third-party assessments in with respect to the recognition of symptom severity in bipolar disorder. Because of this new and innovative field, we present three diverse case studies that allow for an exploratory approach and the detailed examination of mood-

related changes in the assessed data. Due to their individual characteristics, the first two case studies are well-suited to explore the emotion recognition approach: According to the patterns of experienced emotions during mood episodes [22], the recognized emotions in the verbal and facial expressions of both cases were expected to reflect and/or to predict clinical symptoms. Thus, a higher amount of expressed positive emotions was expected to be associated with more severe manic and less depressive symptoms. Accordingly, a higher amount of expressed negative emotions was expected to be associated with more severe depressive and less manic symptoms. Moreover, the usage behavior in regard to the module was expected to be associated with symptom severity. The third case study explores the potential additional value of third-party assessments: Concurrent self-assessments and third-party assessments were expected to be positively associated. Both perspectives were expected to coincide with clinically assessed symptoms. With respect to research suggesting biases in the self-perception of patients [32,33], we examine whether third-party assessments were better corresponding to clinical assessments.

Materials and methods

The overall concept of the assistance system has already been presented in detail [31]. Therefore, in the following sections, only the most important characteristics and methodological aspects will be described.

PARTICIPANTS: The three patients with bipolar disorder corresponding to the three case studies used the system for several weeks in 2018. Two patients (see Case 1 and 2 for demographic data) delivered data regarding the potential clinical value of the emotion recognition approach, since they used the module on a regular basis (see case-specific sections). One other patient (Case 3) delivered insufficient emotion recognition data (only

occasional usage) but involved a related party that completed several assessments. Therefore, this case study was included in order to examine the third-party approach (see Case 3).

MATERIALS AND MEASUREMENTS: The patients received a smartphone with the pre-installed system application and several other materials (e.g., external microphone). The emotion-sensitive assessments and the self-assessments were realized with the application at a freely chosen time during the day. The third-party assessments were realized with separate web applications for related parties [31]. Beyond the ambulatory assessments, the patients had bi-weekly clinical appointments. These appointments were used to assess symptoms or diagnostical data by using well-established clinical instruments or modified versions of existing instruments (see Clinical instruments).

Emotion-sensitive module: With the help of this module, short and actively triggered recordings were analyzed in regard to the presence of verbal and facial emotional expressions [31]. In order to record the video and audio data, the module used smartphone cameras and external microphones. During each assessment, patients were asked to tell a narrative of one or several important events of their day, the so-called "Story of the Day" (SotD). In order to ensure a good recording quality the users had to follow specific instructions [34]. The spoken language was automatically transcribed and the transcriptions were analyzed using the "Linguistic Inquiry and Word Count" (LIWC) software [35]. Consequently, the count of words belonging to several emotional categories was calculated. For the current objectives, especially the two specific categories of "Positive feelings" and "Sadness" (containing words like "love" or "to regret") and the two comprehensive emotional categories of "Positive emotions" and "Negative emotions"

(containing words of all specific categories with positive or negative connotations) were of interest [as a further explanation regarding the distinction between specific or more comprehensive word categories: both categories of Positive feelings and Positive emotions contain the words “happiness” and “love”, but only the category of Positive emotions contains words like “pleasant” or “admired”]. As for visual information, the recordings were automatically separated into multiple frames per second. For each frame, the software aimed at a correct face recognition. If this was successful, facial expressions were analyzed with respect to the detection of several basic emotions by following the “Facial Action Coding System” (FACS) [36]. In regard to the technical incorporation of their recognition, “Happiness” and “Sadness” have been the most dependable categories throughout the different stages of development [34]. These two FACS categories were included into the current analysis.

Self-assessments: The app-based self-assessment (SA) approach incorporated the six items “Mood”, “Energy”, “Activity”, “Sexual desire”, “Speed of thoughts” and “Self-worth”. All of these items could be evaluated on numerical rating scales with seven points from -3 to 3. Thus, possible scores ranged from -18 to 18 with high or low values representing manic or depressive symptoms [31].

Third-party assessments: The items of the web-based third-party assessment (TPA) approach were almost identical with those of the SA, and the answer scale as well as the resulting scores were identical [31]. There were, however, differences in regard to one item: Instead of “Speed of thoughts” (SA) the users were asked to evaluate the “Urge to speak” (TPA) of the concerned patient.

Clinical instruments: Initially, the patients were clinically assessed using the German version of the Structured Clinical Interview for DSM-IV [37]. Diagnoses were specified according to DSM-5 [38]. During the following bi-weekly appointments, symptoms were assessed using a modified version of the "Longitudinal Interval Follow-up Evaluation" (LIFE) interview [39]. The interview was adapted to the given scope by including the DSM-5 criteria for bipolar disorder. Consequently, bipolar symptoms were evaluated in retrospect for each day of the prior two-week period. For each day, the interview resulted in two scores: The "Depressive score" was calculated by adding all depressive symptoms (from 0 to 9), the "Manic score" by adding the manic symptoms (from 0 to 8).

Indicators of bipolar symptom severity: The measurement of symptom severity was operationalized through the clinical assessments using the LIFE interview on the one hand, and through the self-perception of patients using the app-based SA on the other hand. Higher values in regard to the Manic score and the SA were interpreted as the presence of more severe manic symptoms. Higher values in regard to the Depressive score and lower values with respect to the SA were seen as an indication of more severe depressive symptoms.

DESIGN AND ANALYSIS: All patients were considered single case studies. The long-term assessment of audio and video data, usage-related SotD parameters ("Number of recordings" [per assessment day], "Recording duration" [average duration in sec], "Count of words" [for each assessment day], "Words per second" [for each assessment day]) and the SA or TPA data were realized through smartphone- and web-technology in the natural environment of the patients. Furthermore, symptoms were retrospectively assessed and

evaluated bi-weekly using clinical follow-up interviews. The case-specific assessment periods ranged from 57 to 97 days (see later presentation).

Case 1 and Case 2: Within these two case studies, the clinical value of the SotD in regard to the recognition of current or occurring bipolar symptoms was examined. Therefore, for both cases and each assessment day, the correlations between the usage-related parameters and the clinical scores or the SA were calculated. Moreover, the correlations between the amount of recognized emotions (in percent and in reference to the count of recognized words or faces) corresponding to the LIWC or FACS categories [35,36] and the clinical scores or the SA were calculated. Beyond that, as for Case 2, the given data structure with less missing emotion recognition data allowed for preliminary Granger causality tests in order to measure prediction with respect to symptom severity. Therefore, a time series panel analysis (TSPA) was performed on vector auto-regression (VAR), which quantifies the linear dependency of a set of variables at time (t) on the same n previous points in time (t-n, ... t-1) [40]. On the basis of this analysis, the number of lags included in the best fitted model was selected and the Granger causality analysis was performed for this model only.

Case 3: Within this case study, the clinical value of the TPA in regard to the recognition of current bipolar symptoms was examined. Therefore, the correlations between the TPA and SA scores of concurring days were calculated as well as between the corresponding single items. Furthermore, the correlations between the TPA or SA scores and the corresponding clinical scores of these days were calculated.

Statistical programs: All descriptive and correlative analyses were conducted using "Microsoft Excel V. 16.40" and "IBM SPSS Statistics V. 26". The Granger causality tests were performed using the "R-package vars" [41,42].

Case 1 and 2: Story of the Day

Case 1 refers to a 38 year old male patient with bipolar I disorder according to DSM-5 [38], who used the assistance system for 97 days from May to August in 2018. Within this time-period, he completed 97 SA and 43 SotD assessments. Case 2 refers to a 24 year old female patient with bipolar II disorder according to DSM-5 [38], who used the system for 57 days from October to December in 2018. She completed 54 SA and 48 SotD assessments. Apart from a six-day window at the end of her assessment period, there were only occasional SotD assessments missing in-between.

RESULTS:

Case 1: The long-term course of clinically assessed symptoms of Case 1 is illustrated in Fig. 1. This case showed an instable mood of the patient and the SotD was used almost every second day. There were no significant Spearman correlations between the Depressive score and the usage-related parameters of the emotion-sensitive module or emotional FACS or LIWC categories (see Table 1). Concerning the Manic score, there were significant correlations with usage-related SotD parameters (see Table 1). There was a moderate positive correlation with the daily Number of recordings. This indicates that more assessments were recorded in case of more manic symptoms. The Count of words showed a moderate negative correlation with the Manic score, as did Words per second. As a consequence, a lower speaking rate and less expressed words were associated with more severe manic symptoms. Regarding the emotional FACS or LIWC categories, there

were no significant correlations (see Table 1). With respect to the SA, there were two significant and moderate positive correlations with the Number of recordings and FACS Happiness (see Table 1). Thus, higher SA scores (more severe manic or less depressive symptoms) were associated with more recordings and more happiness.

Case 2: This case showed a relatively stable mood with rather small or less frequent mood swings. However, the patient used the SotD almost daily and thus it should have captured these swings. The long-term course of clinically assessed symptoms of Case 2 is presented in Fig. 2. There were significant Spearman correlations between the Depressive score and usage-related characteristics or emotional FACS and LIWC categories (see Table 1). As for Recording duration, Count of words and Words per second, there were strong negative correlations indicating that recordings were shorter, contained less words and the speaking rate was lower in case of depression. Within the emotional categories, FACS Happiness showed a moderate negative and LIWC Negative emotions a moderate positive correlation with the Depressive score. Thus, during depressive mood, the facial expressions contained less happiness, and there were more negative verbal expressions.

As for the Manic score, there were also significant but moderate positive correlations with Recording duration, Count of words and Words per second (see Table 1). Consequently, recordings were longer, contained more words and the speaking rate was higher in case of mania. Furthermore, there was a significant and moderate positive correlation with FACS Sadness. Thus, manic symptoms were associated with more facially expressed sadness. Regarding the SA, there were several significant correlations with usage-related characteristics or emotional categories (see Table 1). Higher scores were moderately and positively correlated with Count of words and Words per second. Following this, the perception of more severe manic or fewer depressive symptoms was associated with more

expressed words and a higher speaking rate. FACS Happiness or LIWC Positive emotions showed strong or moderate positive correlations and LIWC Negative emotions a moderate negative correlation with the SA. Consequently, a higher SA was associated with more facial happiness, more positive and less negative verbal expressions.

There were no significant predictions for the Depressive score (see Table 2). However, with lag-1 or lag-2 models providing the best fits, the Manic score was significantly predicted by Recording duration, Count of words and Words per second (see Table 2). Figure 3 illustrates that especially the length of the recording and the number of expressed words rose before manic symptoms increased. Thus, the length and the extent or fluency of narrations contained prognostic information regarding manic symptoms after one or two days. Beyond that, mania was significantly predicted by FACS Happiness (2-lag model). Figure 3 shows that the facially expressed happiness increased before more manic symptoms manifested. This indicates that this emotional expression added information in regard to mania two days later. The SA score was also significantly predicted by Recording duration, Count of words and Words per second (lag-1 models, see Table 2). Figure 3 depicts that the SA score, too, rose after the extent or fluency of the narrations had increased. Consequently, these characteristics showed the greatest prognostic value with respect to the self-perception of symptoms on the subsequent day.

DISCUSSION: Case 1 and 2 were analyzed in order to evaluate the clinical value of the emotion-sensitive module. Both cases are very different in regard to the age, sex, type of bipolar disorder and symptom course of the patients, which might increase the impact of some consistent findings. However, these characteristics combined with the differences between the data structures of both cases also make the comparison of their results difficult. Yet, there are two concurrent findings within both cases: The severity of

clinically assessed manic symptoms manifested rather on the behavioral than on the emotional level. This result assorts well with former research suggesting the stronger behavioral manifestation of manic states [43] and with the afore-mentioned studies showing the potential of behavioral sensor data in mood monitoring [11–14]. Secondly, facially expressed happiness was associated with more severe manic symptoms or less depressive symptoms within the SA of patients. This result, too, agrees with earlier research examining the typical emotional changes during bipolar episodes [22]. Additionally, this aspect agrees with earlier findings indicating that the facial expression of happiness might be less impaired than other emotional expressions in bipolar disorder [29]. As a consequence, the facial expression of happiness might be more directly influenced by the patients' mood and might thus be especially informative regarding mood state recognition.

Apart from that, there are many differences between both cases that support the high individuality of bipolar symptoms: As for Case 1, the pattern of manic symptoms and the usage behavior most likely indicates restlessness (more recordings were started, but fewer words were used with a possibly less coherent language/speaking rate). Case 2, on the other side, shows that mania was associated with more extensive narrations. At the behavioral level, this could possibly be explained with increased performance and erratic behavior. Therefore, both patterns support the importance of behavioral parameters in mood monitoring approaches [11–14] and both resemble known ramifications of activation in bipolar disorder but with different aspects [44]. Furthermore, with Case 1, depressive symptoms were not reflected in the SotD data, whereas Case 2 showed multiple associations between depression and behavioral as well as emotional categories. All of these effects are into the expected directions and can be explained by research findings demonstrating the lack of energy in depression, the decrease of happiness or the

increase of sadness [22,44]. The current findings might indicate that – for this patient – the SotD is able to detect emotional and behavioral changes in depression.

Contrary to expectations, Case 2 showed more sad facial expressions in case of more severe manic symptoms. Although the module only recognized occasional sad expressions, this circumstance could point to the often complex or mixed emotional experiences during bipolar episodes [22–24]. This aspect, too, may argue for the monitoring of emotional expressions, because the contained information would possibly get lost with mere self-assessments or behavioral monitoring. With respect to the self-perception of both patients, the results support the activation patterns found in mania. Beyond the facial expression of happiness, Case 2 further showed associations between self-rated symptoms and linguistically expressed emotions according to expectations. Consequently, the overall results of the second case study seem more conclusive. This might be due to the fact that the corresponding patient used the SotD more regularly and the time series shows less gaps.

The more continuous data set of Case 2, moreover, allowed for preliminary Granger causality tests: The results show that the extent and fluency of the narrations as well as facially expressed happiness were predictive variables for mania. Whereas different speech parameters have already been in the focus of research projects analyzing sensor data to infer mood states in bipolar disorder [15,45,46], the prognostic value of verbal and facial expressions, so far, have not been sufficiently established. Since the direction of all effects of the Granger causality tests is comparable to the correlation results (see Fig. 3), the tests were able to increase the impact of these findings. The behavioral aspects, apart from their already established benefit for mood monitoring [11–14], had also predictive value for the self-assessed symptoms of Case 2. Therefore, this case study indicates that

the SotD may not only capture contemporary mood symptoms but might further generate prognostic information.

Case 3: Third-party assessments

Case 3 refers to a 51 year old male patient with bipolar I disorder according to DSM-5 [38], who used the system for 92 days from May to August in 2018. He completed 46 SA and his related party completed 17 TPA. At 13 measurement time points (i.e., days), both parties completed their assessments. During a detailed exploration of both parties, the small number of TPA was explained with an overall relatively stable mood of the patient. Therefore, the initiation of TPA through the related party was motivated by obvious mood swings of the patient.

RESULTS: There was a strong positive Pearson correlation between the 13 SA and TPA scores [$r(11) = .82$, $p < .001$]. As for the items Mood [$r(11) = .67$, $p = .013$], Activity [$r(11) = .82$, $p < .001$], Sexual desire [$r(11) = .65$, $p = .015$], Self-worth [$r(11) = .83$, $p < .001$] and Energy [$r(11) = .48$, $p = .095$] there were strong or moderate positive correlations. The only item that has been defined differently in both approaches, Speed of thoughts (SA) or Urge to speak (TPA), was strongly and negatively correlated [$r(11) = -.57$, $p = .043$]. There were no significant Spearman correlations between the SA or TPA scores and the clinically assessed symptoms of the same measurement time points (and no significant differences between both perspectives in this regard, either).

DISCUSSION: Although the inclusion of related parties is an important part of diagnostics and clinical practice [47], to our knowledge, third-party mood monitoring has only recently reached the mHealth approach in bipolar disorder [31]. Thus, Case 3 should

have been examined in order to evaluate the clinical value of the TPA. Based on the given results, however, this aim was probably too ambitious. The findings can, nevertheless, give implications regarding future need of research or methodological issues and necessary improvements. First of all, the fact that only one case study included multiple TPA rises questions. Due to the small number of cases, interpretations regarding the relationship status or quality of patients would be far-fetched. Yet, the finding could be seen as an indication of trust in the self-assessments of patients or the automatic monitoring of the system. Furthermore, the afore-mentioned exploration indicates that during a stable mood period, related parties might not be motivated to join monitoring approaches.

Concerning the correlation results, Case 3 shows that, as expected, the external view and self-perception were highly correlated. Whereas most single items were also positively associated, the strong negative correlation between Speed of thoughts (SA) and Urge to speak (TPA) had not been expected. Clinically speaking, this finding could still be explained: In accordance with Case 1, where mania was associated with the restless pattern of more recordings but less expressions, an increased speed of thoughts of Case 3 might have reduced the patient´s coherent thinking and thus his verbal expressions. Yet, this result calls for modifications of the approach and supports the claim of a good theoretical and empirical basis of mHealth systems [7,21]. As for the initial question of the clinical value, more data regarding the congruence of both perspectives (SA and TPA) and their association with clinical symptoms would be of interest. The third-party perspective would only increase the gained (diagnostic) information, if it was a better fit for symptoms during episodes with a less-reliant self-perception of patients. Based on the small number of measurement time points, Case 3 could only generate some clues: There was a tendency of higher correlations between manic symptoms and the TPA (especially regarding the

single item Sexual desire). This could cautiously be interpreted within the context of studies indicating occasional biases in the self-perception of patients in mania [32,33].

General discussion

The current article examines the clinical value of the EmAsIn approach for bipolar disorder, which is an emotion-sensitive, mobile-based assistance system that analyzes emotional expressions and allows for assessments of close contacts [31]. Initially, recognized emotions and behavioral aspects captured by the emotion-sensitive module had been expected to be associated with clinical symptoms. Third-party assessments had been expected to be positively associated with self-rated and clinically assessed symptoms. In the following sections, the implications of the three case studies will be discussed with a more holistic point of view.

The first two studies explore the case-specific changes in the expressed emotions and behavioral patterns. In spite of their diverse characteristics, within both case studies, symptoms have manifested on behavioral and emotional levels captured by the SotD. Especially with Case 2, most effects support the expectations and thus indicate a certain empirical basis of the conceptual approach. The combination of two clinical scores and of the patients' self-perception further increases the impact of the results, because most findings coincide with all perspectives. Beyond that, both studies support the individuality of symptoms and ramifications [44,48]. For example, Case 1 showed more recordings with less and slower verbal expressions in the case of mania. With Case 2 on the other hand, frequency did not change with manic symptoms, but narrations were more extensive or emphatic. And, as for Case 1, clinically assessed depression did not reflect within the behavioral parameters. With Case 2, on the other hand, depressive symptoms were related to shorter recordings with less extensive or fluent narrations.

Additionally, only the self-perception of symptoms of Case 1 manifested on the emotional level (more facial happiness in case of higher SA scores). Case 2, however, is more complex and showed multiple mood-dependent changes within the emotional expressions: For example, apart from associations with the self-rated symptoms, negative verbal expressions and especially missing facial expressions of happiness were associated with clinically assessed depression. Yet, only facial sadness was correlated with clinically assessed mania. For the therapeutic eye, these changes could be too complex to observe, and even the self-perception of patients might not detect them all. The insights gained by monitoring these changes could still be relevant as they also contain information regarding clinical symptoms. Therefore, future systems should consider the high heterogeneity of symptom ramifications on the behavioral and emotional levels.

The results of Case 3, together with the missing TPA of the first two studies, indicate that their clinical value, first of all, depends on motivational factors. Research not only suggests that there is need for easily accessible support strategies of related parties in bipolar disorder, it also implies their openness towards mHealth approaches [49,50]. However, as long as this feature does not appeal to relatives of patients, the ambulatory setting and the technological approach do not benefit the accessibility, availability and time-sensitivity of this potentially valuable perspective. As a consequence, mobile-based third-party approaches should be designed to meet the patients' needs [17] and those of their close contacts [49,50]. The potential benefit might still differ strongly between patients, though. Future systems should keep this perspective as an optional adjunctive. Based on sparse results, there might be a high conformity between the self-perception of patients and the external view. This might especially be the case during stable mood periods or depression. In case of mania, research suggests more biases in self-perception [32,33]. Case 3 has at least generated statistical tendencies indicating that TPA might be

more dependable during manic symptoms. If further research did support this hypothesis, ambulatory TPA could be helpful to mood monitoring.

Overall, the three case studies show how complex and individual the manifestations of bipolar symptoms can be and how valuable the often-applied multi-channel monitoring [13–15] may be to clinical practice (especially since the individual benefit of features differs between patients, too). Whereas existing mHealth systems for bipolar disorder have not yet – possibly for privacy reasons – analyzed the emotional expressions of patients, the SotD realizes their monitoring without harming privacy issues [31]. Case 2, in particular, indicates the clinical value of this approach. Of course, there have been several limiting factors within the methodological approach and with respect to the presented data. The missing values or small assessment numbers of Case 1 and 3 may have influenced the results and, therefore, their interpretation. Furthermore, the case-based approach limits the generalizability of the results, and the exploratory approach has increased the risk of alpha inflation. However, in view of the innovative field, we have weighed the detailed exploration of single cases and the avoidance of type II errors higher. The gained insights should be examined during larger studies. Nevertheless, the findings indicate that additional possibilities for capturing emotional expressions, behavioral aspects, or maybe even the perspectives of close contacts, might benefit diagnostic purposes and understanding within clinical practice in bipolar disorder.

Conclusions

The ambulatory assessment of behavioral aspects and verbally and facially expressed emotions through a mobile-based, technical assistance system may contain information with respect to existing or occurring mood symptoms in bipolar disorder. The results support the individuality of changes on behavioral and emotional levels. Since these

changes can be very complex and impossible to detect during occasional appointments, the automatic recognition might benefit monitoring approaches. The article further shows that additional ambulatory mood assessments by related parties of patients, first of all, should be designed to be motivating without effort. Only then, as indicated by the third case study, this approach might possibly add valuable information to mHealth systems, for example by compensating for mood dependent self-assessment biases during manic episodes.

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TABLES

Table I. Spearman correlations between the parameters of the emotion-sensitive module and bipolar symptoms within clinical assessments or self-assessments of Case 1 and 2.

Case	Parameter[1,2]	Depressive score[3]	Manic score[3]	Self-assessments[4]
Case 1	Number of recordings	-.06	.47**	.30**
	Recording duration	.06	-.09	.20
	Count of words	.14	-.31*	.08
	Words per second	.19	-.37*	-.20
	FACS Happiness (%)	.02	.26	.32*
	FACS Sadness (%)	.29	.01	-.10
	LIWC Pos. Emotions (%)	-.09	.00	-.12
	LIWC Neg. Emotions (%)	.10	.01	-.04
	LIWC Pos. Feelings (%)	-.23	.01	.13
	LIWC Sadness (%)	.22	-.10	-.15
Case 2	Number of recordings	.02	.07	-.03
	Recording duration	-.57**	.44**	.27
	Count of words	-.59**	.45**	.34*
	Words per second	-.53**	.31*	.40**
	FACS Happiness (%)	-.45**	.05	.50**
	FACS Sadness (%)	-.11	.31*	.25
	LIWC Pos. Emotions (%)	.03	-.10	.29*
	LIWC Neg. Emotions (%)	.32*	-.14	-.39**
	LIWC Pos. Feelings (%)	-.16	-.02	.28
	LIWC Sadness (%)	.17	-.06	-.26

Table note: [1]FACS = Facial Action Coding System; [2]LIWC = Linguistic Inquiry and Word Count; [3]Number of depressive or manic symptoms according to LIFE interviews; [4]App-based ambulatory assessments with scores from -18 (depressive symptoms) to 18 (manic symptoms); *Correlation is significant at the 0.05 level (2-tailed); **Correlation is significant at the 0.01 level (2-tailed).

Table II. Results of the Granger causality tests of Case 2 with respect to the parameters of the emotion-sensitive module and the bipolar symptoms within clinical assessments or self-assessments (best fitted models).

	Depressive score[3]					Manic score[3]					Self-assessments[4]			
Independent variable[1,2]	lag	F	df	p		lag	F	df	p		lag	F	df	p
FACS Happiness (%)	2	1.97	(2,72)	0.148		2	5.14**	(2,72)	0.008		2	2.38	(2,80)	0.100
FACS Sadness (%)	1	0.00	(1,78)	0.988		1	2.34	(1,78)	0.130		1	0.59	(1,86)	0.443
Recording duration	1	0.39	(1,78)	0.535		1	11.30**	(1,78)	0.001		1	8.78**	(1,86)	0.004
Count of words	1	0.17	(1,78)	0.678		1	12.29**	(1,78)	0.001		1	9.64**	(1,86)	0.003
Words per second	1	0.09	(1,78)	0.764		2	3.15*	(2,72)	0.049		1	5.08*	(1,86)	0.027
LIWC Pos. Emotions (%)	2	0.54	(2,72)	0.583		5	0.54	(5,54)	0.746		1	0.02	(1,86)	0.876
LIWC Neg. Emotions (%)	1	0.38	(1,78)	0.540		2	0.69	(2,72)	0.507		1	0.99	(1,86)	0.322
LIWC Pos. Feelings (%)	2	0.29	(2,72)	0.749		2	0.84	(2,72)	0.435		1	0.03	(1,86)	0.874
LIWC Sadness (%)	1	0.42	(1,78)	0.519		2	1.00	(2,72)	0.371		1	0.98	(1,86)	0.326

Table note: [1]FACS = Facial Action Coding System; [2]LIWC = Linguistic Inquiry and Word Count; [3]Number of depressive or manic symptoms according to LIFE interviews; [4]App-based ambulatory assessments with scores from -18 (depressive symptoms) to 18 (manic symptoms); ** Correlation is significant at the 0.01 level; * Correlation is significant at the 0.05 level.

TITLES OF FIGURES

Figure 1. Long-term course of bipolar symptoms of Case 1 according to clinical ratings (LIFE interviews). Depressive symptoms are illustrated as negative values for a better visualization.

Figure 2. Long-term course of bipolar symptoms of Case 2 according to clinical ratings (LIFE interviews). Depressive symptoms are illustrated as negative values for a better visualization.

Figure 3. Illustration of the main Granger causality results of Case 2 regarding the parameters of the emotion-sensitive module and bipolar symptoms within clinical assessments (LIFE interviews) or self-assessments.

Figures

Figure 1.

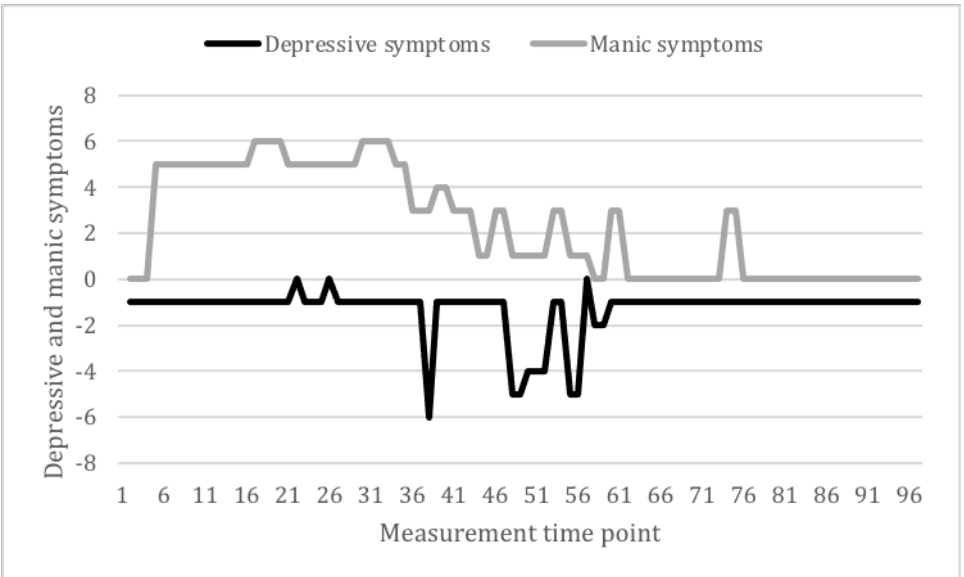

Figure 2.

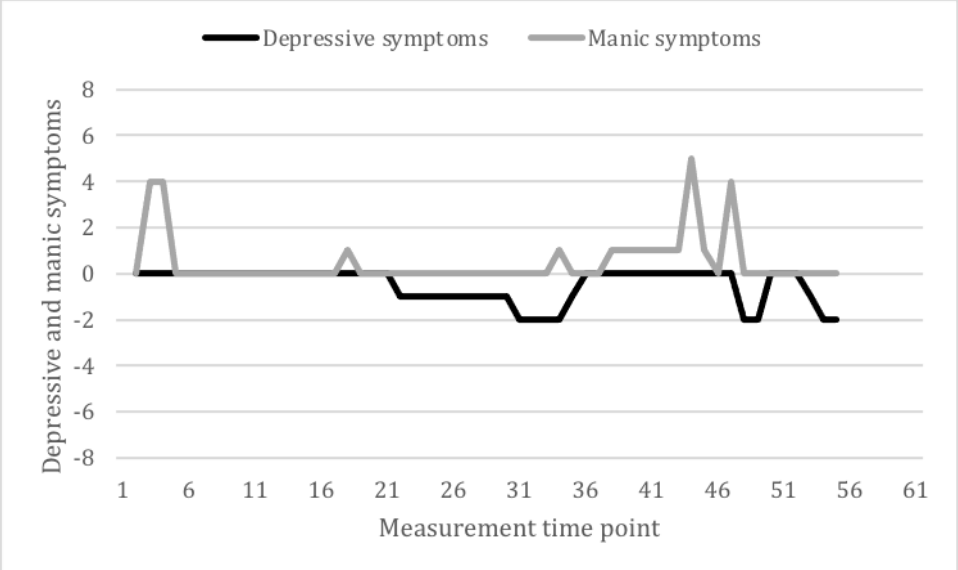

Figure 3.

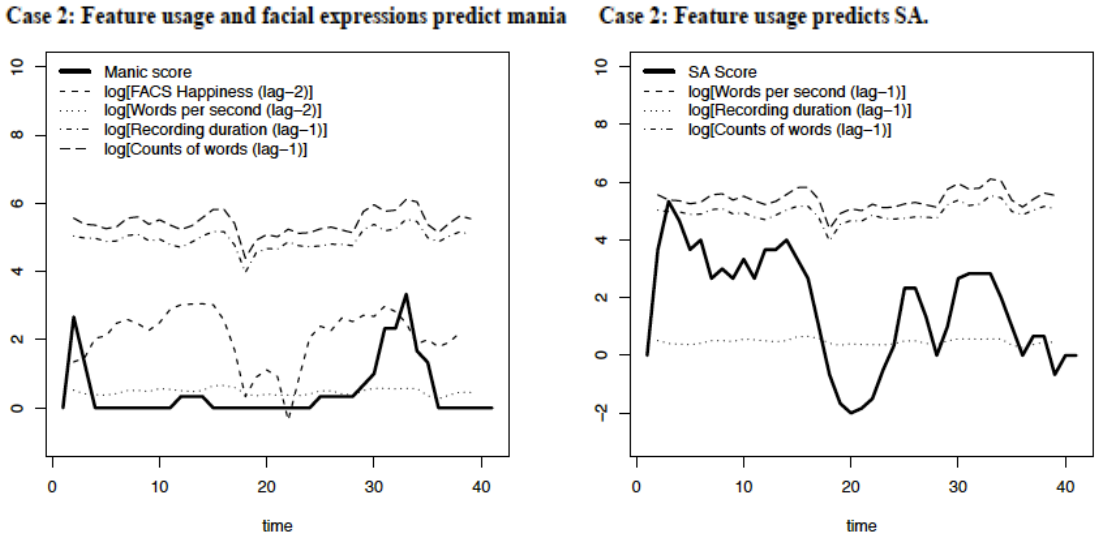

Figure note: On the left side, usage-related aspects of the emotion-sensitive module and facially expressed emotions are presented in relation to manic symptoms. On the right side, the time trends of the usage-related aspects are presented in relation to the self-assessment scores. The values are smoothed relatively to the lags used in the models and all emotion-sensitive values are logarithmized for visual reasons. FACS = Facial Action Coding System; SA = self-assessment.