VIEWPOINT

The application of 'mHealth' to mental health: Opportunities and challenges

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ABSTRACT

Recent advances in smartphones and wearable biosensors enable the gathering of 'real-time' psychological, behavioural and physiological data, in increasingly precise and unobtrusive ways. It is therefore now possible to collect moment-to-moment information about an individuals' moods, cognitions and activities, as well as automated data about their whereabouts, behaviour and physiological states. In this paper, we discuss the potential of these new mobile digital technologies for transforming mental health research and clinical practice. By drawing on a recent research project, we illustrate how traditional boundaries between research and clinical practice are becoming increasingly blurred and how in turn, this is leading to exciting new developments in the assessment and management of common mental disorders. The potential risks and key challenges associated with applying mobile technology to mental health are also discussed.

1. INTRODUCTION

Mobile digital technologies are increasingly able to gather multiple streams of real-time behavioural, physiological and psychosocial data, in precise and unobtrusive ways. Examples of these technologies include smartphones, wearable biosensors, and more recently 'smartwatches'. The range of personal data that can be gathered using such technology is truly vast, including personal accounts of affect, cognitions and behaviour, and objective/automated data about individuals' whereabouts, activities and physiological states.

Self-tracking mobile health applications ('mHealth apps') and wearable technology devices are now burgeoning in the consumer electronic market, and effectively creating a potential data goldmine for researchers interested in exploring disease mechanism. Some mobile technologies also potentially lend themselves to adoption as health technology interventions. In this paper, we discuss the potential of these new mobile digital technologies for transforming mental health research and clinical practice. By drawing on a recent research project, we illustrate how traditional boundaries between research and clinical practice are becoming increasingly blurred and how in turn, this is leading to exciting new developments in thinking about the assessment and management of common mental disorders.

Are smartphones the research tools of the future?

Research into psychopathology has traditionally relied on cross-sectional data, retrospective self-report and single-discipline approaches. However, the possibility of capturing a more fine-grained and dynamic picture of an individual's emotional state and their experience of interacting with their environments is now well within our reach.

Over the past twenty-five years, ambulatory assessment (AA) (1) and ecological momentary assessment (EMA) (2) methods – initially in the form of paper-and-pencil diaries, and then using increasingly sophisticated digital systems – have provided an important alternative to traditional research designs in clinical psychology and psychiatry, by capturing moment-to-moment information (most frequently about people's moods and activities) within the flow of daily life. Within this research paradigm, participants are followed for a period of time and complete questions at

multiple points throughout the day. This reduces the likelihood of poor recall and allows the measurement of changes throughout the day, and in response to different events, activities, environments and biopsychosocial states.

Within this methodological framework, smartphones are fast becoming "the central hub for ambulatory assessment" (1). Studies employing mobile digital technologies as research tools ('mResearch') offer some distinct advantages, not only over traditional research and assessment approaches, but also in comparison to other AA devices. For instance, EMA research has tended to use highly structured formats, with the aim of gathering robust longitudinal quantitative and "self-quantifying" data. Yet, smartphone technology is also ideally suited to yield rich user-driven data, including naturalistic speech, audio and visual data. Such data can provide crucial insights into the meaning, context, and functions of people's emotional states, activities and behaviour. Compared to more traditional research methods, mobile technology enables research participants to tell their stories in their own time and space, thus overcoming some the difficulties associated with collecting sensitive information by personal interview. Such technology also gives participants the freedom to decide and personalize how to record their thoughts; some may prefer to write about their experiences, others to talk about them, or to document them using photos or videos. Video-diaries and digital ethnographic methods offer another promising avenue for mental health research, as they also allow participants to generate a wealth of non-verbal data, and permit use of images and audio/video-clips to disseminate research findings, potentially widening their accessibility and impact.

Further potential of mResearch rests in the ability to gather a wealth of automated data, i.e., multi-dimensional, user-centred data that are not exclusively reliant on self-report. These data do not just potentially triangulate participant self-report but can also provide important insights into mechanisms implicated in the development and maintenance of psychiatric disorders. For example, regulation of negative affect is thought to be both an underlying and reinforcing mechanism for repeat self-harm (3). Yet, it is very challenging to accurately capture this relying wholly on self-report (4). A multi-dimensional data gathering system, which captures biomarkers of autonomic reactivity, as well as self-report accounts of emotional states - in real-time and in naturalistic settings - is likely to provide a fine-grained and ecologically-valid picture

of an individual's emotional state and associated behaviour.

Automated information about users' location and mobility, sleep quality and duration, and social context can further enrich these data, allowing for a better understanding of where, when and possibly *why* individuals experience a range of symptoms and behaviours at any particular point in time. This issue may be particularly germane in relation to individuals who experience difficulties with verbal communication, self-disclosure and autobiographical memory retrieval.

There is an established tradition of ambulatory physiological assessment and observational monitoring in behavioural medicine and clinical psychology, but traditional devices for observational and physiological AA have tended to target only one form of activity or information (e.g., acoustic information or physical activity or heart rate variability, etc.), and have been relatively expensive and often burdensome to wear, thus increasing their potential intrusiveness and the likelihood of reactivity effects (see Trull & Ebner-Priemer (2013) (1) for a comprehensive review). These factors, as well as power and storage limitations, have meant that most AA psychophysiological studies have lasted only 24 to 48 hours.

However, now, all these data can be readily collected by the sensors on a modern smartphone (5), and also on compatible sleep and activity-tracking devices such as *Jawbone* (6) and *Fitbit* (7), as well increasingly sophisticated smartwatches. Whilst mostly designed for the consumer market, these devices may also be usefully adopted in research aiming to understand complex psychological processes over long periods of time. Smartphones and smartphone-supported biosensors are multifunctional, relatively inexpensive, and have high general market penetration. An important advantage is that they are typically carried/worn by users throughout the day and if necessary also at night. This contributes to their potential as powerful and relatively unobtrusive research tools.

In addition, the application of these devices for research purposes potentially facilitates data collection from 'hard-to-reach' populations. To use the example of self-harm again, young people who self-injure may feel uncomfortable discussing their feelings and behavior in a one-to-one interview situation, or find it difficult to

verbalise what triggers or maintains their self-harming behavior. They may however be more willing to engage with a well-designed digital diary or blogging study (an example is the 'Day in the Life' Project, a blogging study aiming to capture everyday experiences of people living with mental health difficulties - see https://dayinthelifemh.org.uk/).

Smartphones and EMA add-on tools are increasingly being used to investigate mechanisms and phenomenology of psychopathology, including in psychotherapeutic contexts and treatment settings, as well as in psychopharmacological trials (8). A recent review of this literature suggests that the use of EMA techniques in mood disorder research (including via mobile technologies) is "feasible, generally acceptable, and highly promising" (9). Other work has focused on the use of EMA to investigate symptoms of borderline personality disorders (10), anxiety disorders (11), and mental illness more generally (12), and similarly concluded that despite some inherent challenges, this approach offers several advantages. Yet, previous experimental attempts to collect and analyse data using mobile digital technologies have been relatively limited in scope, mostly relying on quantitative self-report (mainly of mood and activities via patient reported outcome or experience measures) and/or employing a simple collection of sensing and monitoring technologies, in selected diagnostic groups (e.g., unipolar (13) or bipolar depression (14)). We therefore argue that the potential of these new technologies is yet to be fully explored and evaluated.

2. LESSONS FROM RESEARCH
INdividual SIGnals mHealth Technology - the INSIGHT Study

To assess the feasibility of researching a range of emotional symptoms and behavioural disturbance using smartphones and wearable biosensors, we developed and tested a prototype system ('INSIGHT' (15)) that allows real-time gathering of multiple streams of quantitative and qualitative data (including audio/video clips and still images), through a variety of sources and devices:

- A smartphone application ("app") recording location data and distance travelled, that also allowed participants to complete a regular multi-media diary ("*My Diary*") of a) daily moods and activities, b) intensity, duration and

contextual features of maladaptive thoughts and behaviour, c) other risk-taking and impulsive behaviours, d) flashbacks, and e) nightmares. The app was also linked to a secure Wordpress Blogging site (also available to participants on other devices, e.g. PCs, tablets), where participants could post pictures, videos and text about their broader life histories and experiences, as well as record daily moods and activities ("*My Story*").

* *Jawbone Up* wristband, recording physical activity, sleep quality and duration.
* Chest strap and custom-made wearable data logger for continuous measurement of heart rate (and heart rate variability).

[Insert figure 1 about here]

With a view to testing the utility and feasibility of this system on a common and serious behavioural problem, we focused our efforts on charting self-harming behaviour in a small group of men (n=5) recruited via a voluntary organization that supports individuals with personality disorders. Recruitment followed initial consultations with staff and service users about the nature of the study. Four participants were identified via staff referrals and a fifth participant came forward at a later stage, having heard about the research at the centre. All volunteers were over the age of 18. In light of the small sample, we are unable to comment on the generalisability of findings, yet some interesting points emerged. Firstly, compliance with our battery of measures was excellent. All participants took part in the study for at least three weeks (this was the study duration originally agreed with participants; one man volunteered to continue the study for an additional 28 days; another participants took part in the study for a total of 79 days). During this time, participants could make as many "My diary" and "My Story" entries as they wished. In total, participants made 230 "My Diary" entries, with all participants making at least one entry on most days, and 209 "My Story" entries (these were mostly text-based, but included 34 videos and eight photos). Participants' "My Diary" entries provided information about 92 episodes involving thoughts of self-harm and 21 separate incidents of self-harming behaviour (16).

It is notable that there was no financial incentive for participating in the study and it would appear that at least in this small group, making the entries was a sufficient incentive in its own right.

Another promising finding from our pilot study was that the experience of completing the battery was overwhelmingly positive for all participants. They all reported that the experience had been personally beneficial, meaningful and not inconvenient, despite some initial anxieties about damaging the technology or failing to operate it properly. Clearly, for some individuals, the process of gathering ecologically valid data may alone have vicarious therapeutic effects. Amongst the benefits mentioned by participants were the possibility of expressing one's feelings in a safe way, including when surrounded by other people ("*who assume you are just on Facebook or texting*"); helping them learn about themselves and "*see patterns*" in their thoughts and behaviours; and showing the video-diaries to their therapist, "*so they can see what I am actually like when I'm feeling depressed and down*". All the participants reported that they had gained insight into their experiences through research participation and there did not appear to be any significant adverse effects in relation to triggering self-harming thoughts or behaviour (16).

Our observation that the INSIGHT system may have had some beneficial effects raises an important question about the boundaries between observational research and clinical intervention. Gathering real-time data from vulnerable participants in their daily lives may have blurred these boundaries, arguably more so than in traditional mental health research. We were ethically bound to regularly monitor participants' well-being (mostly by monitoring their "My Diary" and "My Story" entries), and intervene where necessary. This meant working in close collaboration with a clinical service that advised on the suitability of potential participants for the study, and provided appropriate care and crisis support as required. This is potentially an example of where mHealth could act as a useful 'early warning system' for clinical teams. In addition, the prospect of self-monitoring and being monitored is likely to have also had an impact on participants' symptoms, or at least on how these were experienced and reported. In other words, digital monitoring will inevitably have a "Hawthorne effect" - the size and therapeutic (or anti-therapeutic) nature of such an effect has yet to be quantified.

3. MULTI-DIMENSIONAL REAL-TIME MONITORING OF EMOTION AND BEHAVIOUR - FROM mRESEARCH TO mHEALTH

As the study progressed, it became increasingly apparent that system that was originally conceived and developed as a data collection tool may also have clinical utility. Patient-led monitoring of symptoms is now standard practice in many areas of medicine and serves a wide variety of functions, from monitoring of symptom severity (e.g. blood glucose testing in diabetes, or anxiety and depression symptoms monitoring in CBT treatment services) through to monitoring of treatment side effects.

Previous research has shown that repeated self-monitoring can have therapeutic effects for mood and anxiety disorders (17, 18), possibly by improving insight into the longitudinal course of symptoms which in turn allows the identification of personalized 'relapse signatures'. Monitoring of context, antecedents and consequences is key in functional analyses of maladaptive behaviours and cognitive processes, and thus potentially instrumental in modifying behaviour (19). Moreover, if it occurs in real-time, it can shape timely personalised interventions, including behavioural prompts to highlight vulnerability and to encourage alternative behaviours (e.g. via behavioural activation for depressive symptoms and mindfulness-based exercises to enhance emotion regulation and distress tolerance) (20, 21). However, in the area of mental health, symptom and behavioural monitoring are generally performed retrospectively and reliant on self-report. As such, they are subject to recall bias, and limited in their ability to facilitate real time feedback and clinical intervention when a warning trigger is identified.

Using recent technologies along with novel data visualisation and analysis tools, it is not only possible to monitor psychiatric symptoms in real time and in naturalistic settings, but also to combine heterogenous datasets, for functional analyses and real-time dynamic risk assessment. In turn, these can help identify a sequence of events, emotions and behaviours preceding and following dysfunctional behaviour. For example, using data from our INSIGHT pilot study, we were able to visualise a broad range of data over time, including automated measures (e.g. activity, sleep quality, heart rate and variability), subjective measures (e.g. responses to questions about

affective state) as well as discrete events (e.g. reports of self harm) (figure 2), and participants' locations logged by the smartphone app, overlaid on a map (figure 3). The chart also allows filtering and zooming, to investigate more specific patterns and relationships (figure 4), and can be refined to link quantitative data (both automated and self-report) with audio/video clips and still images in which participants record and reflect on their symptoms and experiences. Such visual analyses can inform and enrich time series statistical models to reveal sequential dependencies between maladaptive behaviours and other key variables (e.g. mood, sleep, location, etc.) both within and between subjects. This may greatly increase understanding of the psychophysiological processes and mechanisms underpinning common mental disorders, and has the potential to unlock new therapeutic avenues. Further work is needed to establish the optimal components of INSIGHT, in terms of their individual and collective ability to map on to clinical relapse - bearing in mind the idiographic focus of EMA assessment (1).

[Insert figures 2-4 about here]

Subject to further testing and development, our digital data gathering system may function as a useful transdiagnostic tool for a) multi-dimensional and multi-media monitoring; b) real-time feedback (via data visualisations which users can share with their clinicians); and c) timely personalized intervention, when a relapse signature or early warning trigger is detected by the user, a clinician or even the system itself. The latter may include interventions delivered (at least partly) using smartphones, such as real-time supportive and psycho-education messaging or verbal feedback; medication and appointment reminders, bio-feedback, and a range of self-management tools.

mHealth: the future of mental healthcare?

We are not alone in supporting the case for integrating technological innovations in psychiatric treatment and research. Health-related smartphone applications and wearable biosensors are increasingly being seen as viable and cost-effective solutions to enhance clinical practice and improve treatment accessibility via mobile and 'connected' healthcare (22–26). This includes online and text messaging systems for monitoring and self-management of psychiatric symptoms, and a growing number of commercial mood tracking and diary 'apps'. Notable examples are "True Colours", "Buddy" and "Careloop", which allow users and clinicians to monitor symptoms and experiences using text, email and the internet; "Health Mapper", for smartphone-monitoring of a variety of health conditions; and self-help apps for stress, anxiety and associated urges and behaviours, such as "SAM", the "Stress and Anxiety Companion", "iCope", "DBT Coach" and "The Mindfulness App".

mHealth is a rapidly expanding field, and evidence of clinical effectiveness is currently limited (27). Assessment of efficacy and effectiveness is partially hampered by the challenge of evaluating rapidly evolving technology (28, 29). Nevertheless, an increasing number of studies suggest that there is sufficient theoretical underpinning and mounting evidence on the safety and acceptability of mHealth – supporting the greater use of technological innovations in mental healthcare (22), including for individuals with severe mental illness (30). High-level enthusiasm for this is reflected in recent government plans to introduce NHS accreditation and 'kitemarking' of health and wellbeing smartphone apps and digital services (31), and also in a recent report from the Chief Medical Officer (22), which stressed the need for "a strong emphasis on co-design and user needs as a key driver". If mHealth interventions are to be effectively incorporated into existing treatment processes, such 'users' should also include clinicians.

mHealth technologies, be they standalone apps or more complex systems incorporating wearable biosensors and self-tracking technologies, can collect exquisitely rich data about individual cases, in considerably greater volume than has been previously achieved. Over time, these data may make an important contribution towards our understanding of the psychophysiological processes underpinning mental disorders. The existence of such data also creates a very tangible form of 'precision

psychiatry' for individual patients. As argued by Insel (2014), "data mining can now begin to identify the links across levels, including the factors that will yield categories predicting prognosis or treatment response for individual patients". Eventually this approach may help "create a matrix of information for individual patients, leading ultimately to precision medicine for psychiatry" (32).

Risks and the need for regulation

There are naturally risks, as well as clinical and scientific opportunities associated with mHealth. In a rapidly expanding and largely unregulated field, existing mHealth systems and apps vary greatly in quality and scope. A recent systematic review identified only five apps that had been tested for clinical effectiveness (of which only two were available in 'app stores') amongst the over 3,000 mental health apps available for public download at the time of the research (27). In the UK, the NHS Health Apps Library contains (as of 10 May 2014) 27 apps categorised under mental health, having been reviewed by a clinical assurance team. This is almost 50% more than a year ago (22), but remains a very small proportion of the commercially available apps - for which there is currently no mechanism of quality control. An encouraging development in the field is the imminent publication of guidelines on the development of commercial health and well-being apps by the British Standards Institution. Nevertheless, it remains to be seen whether these voluntary standards will ultimately mean compliance with EU Medical Device Directives.

Further areas of concern are the risk of reinforcing inequalities and the so-called 'digital divide' (33); and of placing excessive emphasis on self-help in the immediate absence of evidence about effectiveness. In addition, there are important unanswered questions about whether and how data gathered via clinical or commercial mHealth tools can or should be used for research purposes, and, if so, how this process should be regulated.

There are certainly precedents of anonymised individual patient data - collected for clinical purposes - being used for research and service evaluation purposes (a recent example in England is the IAPT (Improving Access to Psychological Treatment) database (34)). However, there are also precedents of personal data being collected by consumer apps and 'smart' technologies which have then been used, without explicit

consent, for marketing, commercial and other purposes. Individual consent and confidentiality concerns need to be addressed, as well as the compliance of new systems to key governance arrangements, such as the Data Protection Act, European Data Protection Regulation, copyright and licencing laws. The use of e-data from mental health users has recently provoked discontent amongst users (35), and so these matters demand wider and urgent debate. Such debate will hopefully maximise the likelihood that services users are only exposed to novel mHealth technologies that are scientifically robust, safe, clinically effective and respectful of an individual's privacy.

Design and Clinical Challenges

Key challenges remain in developing the full potential of these technologies as adjuncts to clinical practice. These challenges principally relate to interaction, automation and 'blending' - i.e., the degree to which these technologies can and should be interactive, 'intelligent' and suitable for use as standalone interventions.

Multiple heterogenous datasets can be gathered and visualised, but without interpretation, these data lack meaning for patients, clinicians and researchers. Enabling effective interpretation, and hence productive intervention, is reliant upon developing methods and tools for data visualisation and interaction with the data that support clinical practice. Ideally, data visualisation should be contextually sensitive, individualised to the required degree and readily understandable to the end-user. This is a multidisciplinary challenge and one which is likely to be best met through a careful process of co-design.

There is also an important conversation to be had about the extent to which mHealth systems should rely solely on automation and 'machine learning'. The ability of such systems to help us define clear relapse signatures has a seductive appeal. Nevertheless, there is an inherent danger in becoming over-reliant on IT system intelligence. In addition, the use of complex technological systems may make patients and clinicians feel disconnected from one another. Decisions and approaches about what to automate, when to automate it and why are not known, nor is there currently sufficient evidence to guide us about how and when patients should receive feedback

about changes in their emotional state or potential risk of relapse. These are all empirical questions which need to be researched.

Further research is also needed to determine which patient groups benefit from mHealth as a stand-alone feature, and which groups would derive greater benefit from mHealth being delivered as an adjunct to face-to-face contact with a clinician. This is likely to be determined by severity of distress and the level of functional impairment. It is indeed possible that a sliding scale of 'blending' may develop over time, potentially mirroring the stepped care approach adopted by IAPT (36).

4. CONCLUSION

The field of digital healthcare is new and expanding rapidly. A number of key challenges lie ahead. Further pilot and feasibility studies are required in order to establish which emotional and behavioural features and which patient populations derive the greatest benefit from mHealth monitoring. Such piloting may also provide indicative effect estimates for the possible therapeutic value of mHealth monitoring. Appropriate quality control and governance arrangements are urgently needed in order to assure the public about key matters relating to safety and privacy. Subject to these matters being satisfactorily dealt with, the efficacy of these new technologies will require testing in appropriate designs – ideally in large randomised controlled trials (RCTs), but other designs may also be appropriate. As digital technologies allow for intensive measurement over time, and given the contemporary focus on individualised medicine, Single Case Experimental Designs (SCEDs) may be particularly useful for making causal inferences about mHealth interventions, as well as being more more time- and cost-effective than RCTs, and offering some important advantages in terms of internal and external validity (37-39).

Digital technologies create a new set of opportunities as well dilemmas, as the boundaries between research, monitoring and clinical intervention become increasingly blurred. Whilst this creates the possibility of true paradigm shifts, it also reinforces the need for researchers, clinicians and service users to work in close collaborative partnership to test the efficacy, safety and acceptability of the new technologies that we have at our disposal.

Search strategy and selection criteria

References for this Personal View were identified through searches of PubMed and PsycINFO for articles published from January, 1980, to March, 2015, by use of the terms "ecological momentary assessment", "experience sampling", "ambulatory assessment", "smartphone", "mHealth", "connected health", "psychopathology" and "mental health". Further targeted searches were undertaken with Google Scholar. Articles resulting from these searches and relevant references cited in those articles were reviewed. Only articles published in English were included.

Authors' contributions

Conceived the original study: LM AB BF KH. Technology and system development: AB BF LM KH. Data analyses and visualisations: LM BF. Contributed to interpretation of findings: All authors. Contributed to conceptualising, drafting and revising the manuscript: All authors.

Conflict of Interest

We declare that we have no conflicts of interest.

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