An ecological momentary sampling tool for movement patterns and psychiatric symptom variability: A pilot study

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D.B. King, A. Sixsmith, H.Y. Shahir, M. Sadeghi, M. Razmara, N. O'Rourke. An ecological momentary sampling tool for movement patterns and psychiatric symptom variability: A pilot study. Gerontechnology 2016;14(2):105-109; doi:10.4017/gt.2016.14.2.006.00 **Purpose** In this report, we describe the development of an Ecological Momentary Sampling (EMS) application (app) for smart devices (EMS-Tool) to collect movement and mental health information from older adults with bipolar disorder. Participants are randomly prompted within self-specified windows of general availability and asked about important events of that day, medication adherence, sleep quality, and symptom levels at that moment. Up to three prompts are received twice daily at Time 1, 20 min, and 25 min after Time 1 if no questionnaire is submitted. Voluntary EMS questionnaires can also be submitted outside of these 30-minute windows. We also measure global positioning system (GPS) data every six minutes. **Methods** We outline three non-linear (iterative) main activities of the development process: (i) requirements elicitation and analysis, (ii) high-level and detailed design, and (iii) implementation and testing. In a pilot study, participants were prompted to complete am and pm versions of our brief EMS questionnaire over two weeks. They were also asked to complete identical printed-page versions and indicate their location. **Results** All questionnaire responses submitted via our app were recorded with near perfect reliability when responses were immediately transmitted and when temporarily stored by the device until back in 4G LTE or WiFi range. **Discussion** Beyond its initial development for our BADAS (Bipolar Affective Disorder and older Adults) Study, there is an array of research and clinical applications for this EMS-Tool. This includes data collection over extended periods to populate online self-care and care-management tools intended to foster symptom awareness and health enhancing behaviors.

Keywords: bipolar disorder, ecological momentary sampling, mobile technology

With the expanding integration of mobile and smart-device technology in daily life, there is a growing need to apply this technology within a research context in order to optimize the collection of behavioral data. This is especially true for the growing senior population, for whom such technologies may facilitate and improve participation in social and behavioral research. Recent polls have indicated that approximately 39% of American adults 55-64 years of age and 18% of those 65 and older are smartphone owners[1]. Among those 65+ years of age, ownership has grown by 5% since 2012, suggesting a rapid adoption of mobile technology by older adults. The trend in smartphone usage is such that the majority of online adults (at least 80%) also have a smartphone[2].

One important outcome of these trends lies in the opportunity to enhance research methods in studies with older adults. In this paper we describe the development of an Ecological Momentary Sampling (EMS) tool (abbreviated 'EMS-Tool') for the collection of self-report and movement information using mobile smartphone technology. We report findings from a pilot field study in which this technology was used to collect behavioral and psychological data over two weeks.

Ecological momentary sampling is a preferred methodology to study behavior, mood-in-the-moment, and change over time[3]. Intensive 'snapshot' assessments enable rapid and reliable measurement in the moment thus minimizing retrospective reporting biases[3]. The growth of mobile smart devices in recent years provides opportunities to develop these kinds of ecological research tools to advance behavioral research and clinical practice.

Our EMS-Tool randomly prompts participants within self-specified windows of general availability (pre-determined by participants) and asked about important events of that day, medication adherence, sleep quality and symptom levels at that moment. Up to three prompts are received twice daily at Time 1, 20 min after Time 1, then 5 min later (25 min after Time 1) if a questionnaire is not submitted. Voluntary EMS questionnaires can also be submitted outside of these 30-minute windows. We also measure global positioning system (GPS) data every six minutes. EMS-Tools capture real-time experiences of people rather than depending on retrospective accounts characteristic of traditional behavioral research. Although applicable in a variety of research contexts, the EMS-Tool was developed for the BADAS (Bipolar Affective Disorder and older Adults) Study, an ongoing collaboration between clinicians and technology-and-aging experts.

Bipolar disorder (BD) is a chronic mental health condition characterized by periods of clinical depression, mild elation (hypomania) or extreme elation or irritability. The sequence, timing, severity and duration of manic and depressive episodes vary across patients and over time[5]. Wellness with BD also varies widely as even optimal medication management fails to forestall all mood episodes. Despite advances in treatment and management, for many, BD remains highly debilitating with significant adverse effects on health and quality of life[6]. The World Health Organization (WHO) estimates that BD is the 6th leading cause of disability worldwide. Yet social science research specific to older adults with BD is largely nonexistent[4].

To date, research has yet to determine how and to what degree gerontological factors affect the presentation of BD in later life (e.g., comorbid physical health conditions, retirement, bereavement). Ecological sampling offers opportunities to enhance study methods. For instance, expansion and contraction of movement patterns (the subject's geographical range) may harbinger the onset of manic or depressive mood episodes.

Methods

Our BADAS study iOS application (app) was developed on client-server architecture. The purpose of the app is to collect information on behaviors, psychological states, and movement activities of older adults with bipolar disorder. A sample scenario for this system is as follows: upon automated notification based on predefined time preferences (including sound notification, standard badge app icon as indicated by a red circle containing the number 1 at the top right corner of the app, and/or lock screen alert on an iOS device), and if the application is subsequently opened on the device, a questionnaire is delivered to the participant. Questionnaire responses and location information are transferred to a server and stored for further analysis. Otherwise, the system will log the missed questionnaire. Notification schedules may vary; however, the app was designed to accommodate multiple response points (e.g., 2) per day over multiple days (e.g., two or more weeks).

In-depth collaboration of the software development team and the gerontology research group was a key factor in the user-led development of the mobile application. An iterative, incremental agile approach to address inevitable changes in requirements during the development process, as one would expect, proved to be a sensible choice. Three non-linear (iterative) main activities of the development process are (i) requirements elicitation and analysis, (ii) high-level and detailed design, and (iii) implementation and test. These are reviewed in further detail within the context of the current EMS-Tool development.

Requirements

A requirements specification of a software system is a complete description of the behavior and functionalities of a system to be developed. It typically includes a set of functional requirements, which define interactions between users and the system as well as between different system components. In addition, it contains a set of non-functional requirements, or quality attributes, which impose constraints on the design and implementation. The requirements of the mobile application were elicited and analyzed in part through discussions with domain experts from research and clinical practice. We categorize the requirements into four major categories: questionnaires, data-storage, communication, and configuration. The general idea behind each category of requirements is expressed in the following:

(i) Questionnaires**.** The application should be able to flexibly generate different types of questionnaires dynamically at run time. Each questionnaire may contain different types of questions such as multiple choice or descriptive field response.

(ii) Data-storage**.** Collected data, including GPS locations and responses from users, should be securely stored in the device and on the server.

(iii) Communication. All collected information should be transferred to the server as soon as possible. In addition, it is required to have the ability to monitor certain user activities and responsiveness through an interactive dashboard.
(iv) Configuration. Researchers as well as participants both have preferred time windows for answering questionnaires, and the system ought to accommodate these preferences to the extent possible.

Detailed design
We have designed the main components of the system to satisfy all of the requirements. To validate the proposed component design prior to the actual implementation, we have simulated the main functionalities of each component in CoreASM[7], an open source tool suite for rapid prototyping, analysis, and experimental validation. The tool suite provides a platform-independent execution engine and a GUI for interactive visualization and control of simulation runs.

Implementation and testing
The implementation of our EMS-Tool includes: (i) an iOS app, which accommodate different device screens including iPhone 4, 4S, 5, 5C, 5S, 6, 6 Plus, 6S, and 6S Plus, as well as iPad and iPad mini; (ii) a backend server, and (iii) a web interface for supervisors. The app comprises a password-protected section for supervisors where they can configure a questionnaire based on user availability, questionnaire availability, study duration, and user preferences (such as ringtones). It also has a participant section that lists available questionnaires and allows the participants to complete a questionnaire by entering a numerical code, which is set by the supervisor at the time of configuration. User passwords are stored securely on the iOS secure keychain services. The app is designed such that every time it is open, it checks whether a newer version is available and instructs the user to upgrade to fully utilize the latest features and patch against software bugs.

For the server, all options including cloud servers such as Google app engine and Amazon AWS are considered and studied. To be compliant with Canadian patient health record policies and the requirements of the study for the ethics approval process, a local server at Simon Fraser University is dedicated for this study. The backend uses J2EE standards to implement the functionalities required for communicating with the app as well as the web interface for supervisors. Supervisors' passwords are encrypted (using salting and hashing) and securely stored in a MySQL database, which is placed behind a firewall to limit the remote access to specific machines. In

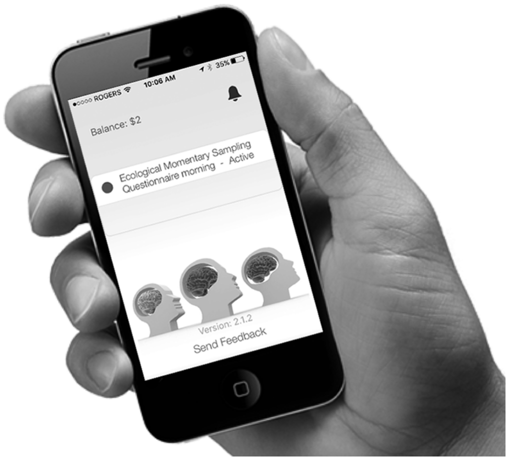

Figure 1. iPhone version of our experiential sampling application for iOS

addition, the database is backed up regularly to minimize the risk of lost data. Questionnaire responses and user location info are transferred using the https protocol (i.e., transport layer security) and are deleted from the app local storage once transferred to the server.

The app is designed to work completely offline; stored data are transferred to the server once the device is connected to the Internet (LTE or WiFi). In addition, whenever the server is not responsive because of a transmission error or high traffic, the app schedules data transfer for a later time.

In parallel with implementing the functionalities of the system, we followed an intensive testing plan. The development team has performed unit tests (i.e., testing individual units of the source code) and regression tests (i.e., comprehensive testing of all functional areas and quality attributes, like performance, of the system after any change) in order to identify any possible defects. After each major software release (milestone), the research team has performed system (end-to-end) tests to validate that the integrated system meets all the requirements. All in all, development and research teams have tested the entire functionalities of the system in four separate iterations. The app is currently undergoing various testing phases in target populations and is working as designed. We report findings from one such pilot study in which the application was tested in-field for a period of two weeks.

Pilot study
We undertook a two-week pilot study to assess the functionality of our EMS-Tool in the field with the assistance of seven non-clinical adults while in Canada (Vancouver and Ottawa), the USA (Seattle and Baltimore), and Australia (Melbourne).

They downloaded the app onto an iPhone or iPad and were prompted twice daily to report their mood at that moment (brief Positive and Negative Affect Scale8), describe a memory from their past, and report the functions or purposes of this memory. These EMS 'snapshots' were time- and GPS-stamped; GPS coordinates were collected by GPS tracker embedded in the smartphone.

Data were transmitted automatically when the device was in LTE or WiFi range, and stored to be transmitted at a later time when the device was in range. In addition to submitting responses electronically, participants also recorded their responses manually in small booklets in order to ensure accurate recording and data transmission by the app. Reliability between the app and questionnaires booklets was assessed using bivariate correlation, while differences were assessed using paired t-tests.

Results

All participants were prompted twice daily each day as intended. Both am and pm prompts were received within pre-specified windows of availability as defined by participants. Periods of availability adjusted automatically when crossing time zones. No participants reported being prompted outside of these windows. Recent testing indicates that battery drain for the BADAS app is less than 2-3% of total usage (depending on which other iPhone/iPad applications are used).

Reliability

Responses submitted via iPad and iPhone were encrypted, transmitted, received, and recorded on our university server. Responses were virtually identical between the app and booklet questionnaires. This included positive mood ratings ($r=0.95$), negative mood ($r=0.98$), responses regarding memory functions provided along sliding scales ($0.84<r<0.98$), and text descriptions of participants' memories. Moreover, recorded GPS coordinates matched the locations reported by participants 99% of the time.

Rates of questionnaire completion upon being prompted were higher for iPhone (58%) than iPad (48%). We anticipated this, as the iPad is less portable. However, numbers of reported memories were similar for both devices, $t(151)=0.38$, $p=0.70$. When participants began a questionnaire, scale responses were almost always complete (i.e., minimal missing data). This may be due to the pop-up that notified participants before submitting the questionnaire if any items remained unanswered. In accord with ethics requirements, participants were able to skip items if they choose; we tried to ensure that these items were not skipped inadvertently. Almost 82% of respondents were able to report a recent autobiographical memory when prompted.

Voluntary versus prompted

Positive and negative mood was similar for voluntary versus prompted responses. This was true for both booklet responses [$t(72)=0.26$, $p=0.80$; $t(72)=1.53$, $p=0.13$, respectively] and app responses, $t(82)=0.84$, $p=0.40$; $t(82)=0.97$, $p=0.36$, respectively. Also, participants' reported mood was similar for voluntary and prompted questionnaires. In other words, mood does not appear to confound voluntary versus randomly prompted questionnaire responses. Instead, it appears that these study methods enable us to capture a range of psychological states of differing valence and magnitude across the day.

Discussion

In this brief report, we describe progress to date in the collaborative development and pilot testing of our EMS-Tool for older adults with bipolar disorder. Pilot study findings indicate that our iOS app is a reliable tool for collecting and transmitting self-report and location data, supporting the functionality of the app for an adult population. It is the intent of our BADAS study to capture range of movement in relation to mood and symptom variability. We are now recruiting 200 adults with BD, half 50+ years of age, living in Canada, the USA, UK, Ireland, South Africa, Australia and New Zealand. We have also developed a yoked partner/spouse app to examine the role of symptoms and interpersonal factors in the quality of life for both those with BD and their partner carers.

Although developed within the context of BD, the range of applications for this EMS-Tool with other populations and in other contexts is great. Integration of GPS technology remains particularly germane to senior populations, for whom social contact and physical activity are important determinants of quality of life.

Aside from research, various applications are possible, including the creation of operational software to foster self-care and care-managements tools for older adults with mental health conditions. Beyond its initial application in the BADAS project, we envision significant opportunities for the advancement of clinical, methodological, and technological domains in gerontology with the development of this smartphone application.

Acknowledgement
Support for the BADAS project was provided by the Canadian Institutes of Health Research (CIHR; MOP 134209 - 259022) and the Age-Well Technology and Aging Network

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