ExperienceSampler: An Open-Source Scaffold for Building Smartphone Apps for Experience
Sampling

Sabrina Thai & Elizabeth Page-Gould

University of Toronto

Authors' note: Sabrina Thai and Elizabeth Page-Gould, Department of Psychology, University of Toronto, Toronto, Ontario, Canada.

This research was supported by a Social Sciences and Humanities Research Council of Canada (SSHRC) Canadian Graduate (Doctoral) Scholarship to Sabrina Thai and a SSHRC Research Grant to Elizabeth Page-Gould. Portions of the present research were presented at the 16th Annual Meeting of the Society of Personality and Social Psychology, Long Beach, CA, USA, the Lifespan Social-Personality Preconference at the 17th Annual Meeting of the Society for Personality and Social Psychology, San Diego, CA, USA, and the 18th Annual Meeting of the Society for Personality and Social Psychology, San Antonio, Texas, USA.

We thank Matthew Ng, Michelle Hu, Aliya Aneja, and Shayne Sanscartier for their assistance with data collection. We also thank Ian Dennis Miller, Modupe Akinola, Rebecca Grunberg, Daniël Lakens, Chao Zhang, Amanda Sharples, Katherine Tamminen, and Penelope Lockwood for their helpful comments and suggestions during the development of ExperienceSampler.

Correspondence concerning this article should be addressed to Sabrina Thai who is now at the Department of Psychology, McGill University, 1205 Dr. Penfield Avenue, Montreal, Quebec, Canada, H3A 1B1, or Elizabeth Page-Gould, Department of Psychology, University of Toronto, 100 St. George Street, Toronto, Ontario, Canada M5S 3G3. Email: sabrina.thai@mail.mcgill.ca or liz@psych.utoronto.ca

In press, Psychological Methods

Abstract

Experience sampling methods allow researchers to examine phenomena in daily life and provide various advantages that complement traditional laboratory methods. However, existing experience sampling methods may be costly, require constant Internet connectivity, may not be designed specifically for experience sampling studies, or require a custom solution from a computer programming consultant. In this paper, we present ExperienceSampler, an open-source scaffold for creating experience-sampling smartphone apps designed for Android and iOS devices. We designed ExperienceSampler to address the common barriers to using experience sampling methods. First, there is no cost to the user. Second, ExperienceSampler apps make use of local notifications to let participants know when to complete surveys and store the data locally until Internet connection is available. Third, our app scaffold was designed with experience sampling methodological issues in mind. We also demonstrate how researchers can easily customize ExperienceSampler even if they have no programming skills. Furthermore, we evaluate the utility of ExperienceSampler apps with results from one social psychological study conducted using ExperienceSampler ($N = 168$). Mean response rates averaged 84%, and the median response latency was 9 minutes. Taken together, ExperienceSampler creates cost-effective smartphone apps that can be easily customized by researchers to examine experiences in daily life.

ExperienceSampler: An Open-Source Scaffold for Building Smartphone Apps for Experience Sampling

Experience sampling¹ is a survey research method that repeatedly assesses people's experiences as they occur in daily life (Conner, Tennen, Fleeson, & Barrett, 2009; Reis, Gable, & Maniaci, 2014; Shiffman, Stone, & Hufford, 2008). Typically, a participant is notified to take a short survey at random times during the day, thus allowing researchers to “sample” from participants' daily “experiences.” This method offers various advantages that can complement traditional laboratory methods and help researchers to better understand human experiences. First, experience sampling increases the ecological validity of research findings because data is collected in natural, spontaneous contexts on multiple occasions, which increases the representativeness and generalizability of data (Reis et al., 2014). Second, experience sampling data is collected in the moment, which means that recall bias has less impact on measurement (Robinson & Clore, 2002; Tversky & Kahneman, 1973). Third, experience sampling allows researchers to distinguish between within-person and between-person processes by repeatedly measuring the same person, which also increases statistical power (Conner et al., 2009). Finally, experience sampling allows researchers to study low intensity behaviors or events that may be difficult to capture using more traditional methods (Bolger & Laurenceau, 2013). Given these advantages, it is no surprise that experience sampling has become increasingly popular across behavioral science disciplines. Indeed, a quick search on Google Scholar reveals over 3.7 million results that mention experience sampling.²

¹ Experience sampling is also known as ecological momentary assessment, ambulatory assessment, everyday experience methods, and intensive longitudinal designs.

² These search results are as of March 3, 2017.

Over the years, technology has advanced in ways that make it easier to conduct experience sampling studies. The first generation of experience sampling researchers would give participants a packet of printed surveys and a pager, signaling participants to complete new surveys with the pager. The first major revolution in experience sampling methodology occurred with the invention of the personal data assistant (PDA), which were small personal computers that could be used both to signal participants and provide the survey interface. PDAs also offered greater control over the data collection process, such as the ability to limit access to the PDA between responses and time stamp responses (Burgin, Silvia, Eddington, & Kwapil, 2013). However, both the pager and PDA approaches required researchers to purchase hardware upfront, give it to participants, and recover it after data collection. Over the past decade, pagers and PDAs have been largely replaced by smartphones and tablets.

A popular modern approach uses the short message service (SMS) on smartphones (e.g., SurveySignal; Hofmann & Patel, 2015). The SMS method uses text messages as a signaling device by texting the participant a hyperlink to an online survey, which is accessed through their phone's web browser. This approach drastically lowers researchers' hardware costs because participants can use their own devices. Using existing phones also makes experience sampling fit in more naturally with participants' daily routine. Furthermore, researchers only need to know how to create an online questionnaire using their favorite survey program (e.g., Qualtrics, Survey Monkey; Hofmann & Patel, 2015). The downside to this approach, however, is that participants must have cellular connectivity to receive signals and respond to new surveys. If participants are in an area with no cellphone service (e.g., the subway, basement of a building), they will receive their signals much later than intended or may even miss the survey altogether. In addition, researchers must pay to send text messages (e.g., \$0.10 each), which can add up quickly when

collecting data from many participants over an extended period of time. Some cellphone carriers charge for receiving text messages, which means participation may cost some participants money in addition to time. Altogether, SMS approaches have reduced the upfront costs to experience sampling and the barriers to conducting an experience sampling study, but they still have operating costs and limitations.

Another approach using smartphones is to collect data with an application (“app”) installed locally on participants’ smartphones. Similar to the PDA approach, the device itself is used for both signaling and data collection. Furthermore, depending upon how the app is programmed, it may not require constant cellular connectivity. This approach also allows researchers to take advantage of all the smartphone’s features, unlike the SMS approach. For example, participants can use their smartphone cameras to take pictures of their surroundings or interaction partners. Researchers can also program apps to record GPS data to fully understand the participants’ physical surroundings during survey completion and take advantage of accelerometer sensors to detect whether participants are moving or staying still. Currently, researchers who want to use a local app for experience sampling must buy a license for one of the current apps available or program an app from scratch in-house.

The current apps available for experience sampling are limited in various ways (see Conner, 2015, for full review of available options). First, many of these apps are only available for one platform (e.g., only works for Android devices), limiting the population from which the participant sample is drawn, resulting in selection bias. Second, some of the apps designed specifically for experience sampling require researchers to interact with a third-party company to customize the app for their study, which can be quite costly (e.g., more than \$1000). Third, some of these apps have quotas for the number of participants that can be run or the total number of

signals researchers can send, placing an unnecessary limit on the research design and statistical power. Furthermore, many of the apps available are not designed specifically for experience sampling and may lack the necessary features. In addition, the existing apps may demand additional fees before allowing researchers to take full advantage of the smartphone features. Truly, the most economical and flexible way to collect experience data is with a custom-programmed app, but designing an app from scratch requires advanced programming skills.

We have designed an open-source scaffold for creating smartphone apps, ExperienceSampler, to address and reduce many of the barriers researchers face when conducting experience sampling studies. ExperienceSampler allows you to create a smartphone app that is customized for your experience sampling study. In the first section of this paper, we describe ExperienceSampler, its features, and its uses. In the second section, we list the software and services needed to set up and implement the app. In the third section, we provide instructions for setting up and implementing the app and data-collection infrastructure. In the fourth section, we review initial evidence regarding the effectiveness of ExperienceSampler apps, such as participant compliance, response latencies, and attrition rate. Finally, we conclude by addressing some of the limitations and future directions of ExperienceSampler.

Description of ExperienceSampler

ExperienceSampler is an open-source scaffold for creating smartphone apps that are compatible with both Android and iOS (e.g., iPhone) devices. An ExperienceSampler app appears as an icon on the home screens of participants' smartphones. When it is time to take a survey, a notification pops up and chimes to signal to participants that they should take a survey (see Figure 1). Participants tap the notification to launch the app, or they can tap on the app's icon directly to launch it. Once the ExperienceSampler app is launched, participants complete the

survey through the touch screen interface of their phones (see Figure 2). At the end of the survey, the app will send the data to the server if the device is connected to the Internet either through cell connectivity or a Wi-Fi network. Researchers can also implement a feature that will prompt participants to resend the data after re-connecting to the Internet if the device is not connected when participants have completed their survey. If participants are unable to send the data immediately after completing the questionnaire, the most recently stored data will be uploaded to the researchers' server or a spreadsheet in the researchers' Google Drive account the next time the app is open when participants are connected to the Internet.

The ExperienceSampler scaffold has various features that make it ideal for experience sampling studies. ExperienceSampler includes features essential for constructing surveys. It can accommodate the most commonly used experience sampling question types – Likert-scale, multiple choice, open-ended, and checklist (Reis et al., 2014) – as well as question logic, question branching, and piped text.

This app scaffold also provides researchers with greater control over the data collection process. Researchers can disable the questionnaire for specified periods of time between questionnaires to prevent participants from hoarding (i.e., providing multiple reports from memory at a single moment; Broderick, Schwartz, Shiffman, Hufford, & Stone, 2003). Each response is also time-stamped to the millisecond³, so researchers can determine whether responses were actually collected in the same moments, or whether the participant was interrupted in the middle of completing the questionnaire and resumed that questionnaire at a later point in time. Alternatively, researchers can also have the questionnaire reset after a

³ If researchers plan on conducting global studies, it will be important to also record the time zone of the participant. We thank an anonymous reviewer for this helpful suggestion.

specified period of time so that responses from different moments are not grouped together in one set of responses. Responses that belong to the same moment are also tagged with a unique identification number that represents the time when the participant started the questionnaire in Epoch time⁴. This feature allows a compliance script that we developed to determine whether participants have completed a sufficient number of questionnaires for the day and allows our Google and R scripts to sort that data for analysis.

ExperienceSampler apps also include two features that minimize the costs that participants must incur in order to participate in experience sampling studies using smartphones. First, to minimize the usage of participants' data plans, questionnaires are completed on the phone, and the data is stored on the phone until devices are connected to the Internet. Thus, participants who have no data plans or do not wish to use their data plans can simply wait until they have Wi-Fi to send data to the server. This feature also allows researchers to install ExperienceSampler apps on tablets and iPod touches rather than smartphones as long participants carry these devices around with them regularly. The size of the data being sent is also very small so participants who use their data plans will not incur any major costs. This feature also allows for real-time data updates.

Second, ExperienceSampler eliminates concerns regarding whether participants might incur additional costs for receiving SMS messages. ExperienceSampler apps use the local notification system available on Android and iOS devices to carry out the signaling function essential for experience sampling studies. The local notification system is "local" because it does not require a cell signal or an Internet connection. Notifications are scheduled after participants have installed and set up the app on their phones. The scheduled notifications are recorded and

⁴ Epoch time is the number of seconds that have elapsed since January 1, 1970, which is also referred to as Coordinated Universal Time (UTC). It is also known as Unix time.

sent to the server so that researchers can check response latencies and compliance. The local notification system also allows the app to have a snooze function, which enables participants to delay answering the questionnaire for a specified period of time before they are sent another reminder to complete the survey.

ExperienceSampler can also be easily customized for various types of experience sampling designs by simply altering when notifications are scheduled. For interval-contingent designs (i.e., participants complete questionnaires at predetermined times), notifications can be set to repeat every day of the experience sampling phase at specified times. For signal-contingent designs (i.e., participants complete questionnaires whenever they are signaled), researchers can set signals to occur at set intervals (e.g., every 2 hours) or randomly within a specified range (e.g., every 1.5 to 3 hours after each signal) in a set period of time (i.e., daily data collection period). The app can also be used for event-contingent recording (i.e., participants complete a questionnaire every time an event that matches a predetermined definition occurs); however, there is no preset notification system that can be implemented for event-contingent designs. Furthermore, having the questionnaire readily available on participants' phones may make it more likely that participants will complete the questionnaire soon after the event has occurred given that 90% of people tend to carry their smartphones with them everywhere (Rainie & Zickuhr, 2015).

Given these features, ExperienceSampler incorporates the advantages of the other experience sampling approaches while minimizing or eliminating their disadvantages. Like the PDA approach, it provides researchers with a great deal of control over the data collection process that is not available through the use of online questionnaire services. Like the SMS approach, it eliminates the high hardware costs by using devices that participants already own.

Moreover, it is less cumbersome for participants because they only need to carry one device that is already part of their daily life. Furthermore, it allows researchers to make use of tablets and other iOS devices (e.g., iPod touch) in their research because the app only requires an Internet connection to send data to the server. Thus, researchers do not need to worry about whether participants will miss notifications due to limited cellular connectivity. Unlike the SMS approach, additional costs to the participant are minimized, if not eliminated, by the use of local notifications for signaling (as opposed to text messages) and questionnaires that are completed on the device (as opposed to online). Furthermore, ExperienceSampler is compatible with both Android and iOS devices, which made up 99.6 % of the market share of all smartphones worldwide at the end of the fourth quarter of 2016 (Gartner, 2017) and more than 96% of American smartphone users in early 2016 (comScore, 2016), thus minimizing the effect of selection bias inherent to apps that are limited to only one platform. ExperienceSampler also greatly reduces, and may even eliminate, the high cost of conducting experience sampling studies because it was designed using technologies that are either open-source or available for free. At most, researchers will have to pay \$299 USD/year to distribute the iOS version of the app in-house, which we will discuss in more detail later. This is a flat rate that places no limits on the number of devices on which the app can be installed or the number of signals that can be sent. Technical costs are also limited compared to other apps currently available. The app is easy to customize; researchers who feel comfortable adapting existing syntax for new statistical analyses can adapt ExperienceSampler for their needs without prior knowledge of JavaScript. Customizing the app will also introduce these researchers to JavaScript, which is a useful programming language because it can be used to design various other tools for research. Finally, researchers familiar with web technologies such as JavaScript can customize the app to include

other features such as the camera or accelerometer to answer other research questions because the app is open-source. By making ExperienceSampler open source, we seek to facilitate the use of experience sampling methods by creating a low-cost yet infinitely extensible solution.

Creating an Experience Sampling App with ExperienceSampler

There are four overarching steps that will take you to the point of actively collecting experience sampling data: (1) Install necessary software and services; (2) Build the uncustomized scaffold for your ExperienceSampler app; (3) Customize your ExperienceSampler app; (4) Distribute your ExperienceSampler app to participants' mobile devices. We have created a detailed, easy-to-follow website that takes you through the details of each of these steps: <http://experiencesampler.com/>. The advantage of keeping the tutorial mostly on the website is that we can maintain the instructions to stay current with updates to the mobile platforms and software required to use ExperienceSampler. Moreover, we know that the instructions on the website work, given that a number of research groups have already used it to create and deploy their own experience sampling apps⁵. Thus, in this paper, we will only describe the process of creating your own app with ExperienceSampler at a high level, directly referencing the relevant points on the website.

As described in the *Necessary Materials and Services* section of the ExperienceSampler website (<http://experiencesampler.com/materials>), there are a number of software programs that you will need to install on your computer to develop your own ExperienceSampler app. In addition, to be able to install your ExperienceSampler app on participants' iOS devices (i.e., iPhones, iPads, iPods), you will also need to enroll in either the Apple Developer or Apple

⁵ See our testimonials page on the ExperienceSampler website for feedback from these research teams: <http://experiencesampler.com/testimonials>

Enterprise Developer⁶ program. Enrollment in one of these programs is the only cost involved in creating an app with ExperienceSampler, and it only applies if you want to distribute your app to Apple devices. If you are interested in distributing iOS applications, we highly recommend that you enroll in the Apple Enterprise Developer Program instead of the regular Apple Developer Program. Normally, people who use iOS devices install apps through the Apple App Store, which has a lengthy and opaque approval process, and does not allow you to limit who can install your app.⁷ The Enterprise Developer Program allows you to develop and distribute iOS apps “in house.” This is advantageous because it circumvents App Store approval, decreasing the lag time between development and distribution, and allows you to control who is downloading the app. There are a number of other advantages to choosing the Apple Enterprise Developer Program over the Apple Developer Program, but it also requires more time and effort to enroll in the Enterprise Developer Program. We compare the two options and describe how to enroll in each in detail in the *Necessary Materials and Services* section of the ExperienceSampler website.

Once you have set up your development environment by installing the necessary software, you are ready to begin building your app. ExperienceSampler uses an open-source platform called *Cordova* that allows you to write apps for multiple mobile platforms using the most

⁶ The iOS Developer University Program (<https://developer.apple.com/programs/ios/university/>) may also be relevant to your needs. However, there are a few limitations to this developer program. The Developer University Program is aimed at training students to develop iOS apps. Although it allows apps to be distributed through email or private websites, there may be limitations to whom the apps can be distributed. As an additional consideration, this program limits the number of devices that can be registered to 200, and registering devices requires participants to come into the lab. If your study can work within these parameters, then the Developer University Program is free.

⁷ You can also choose to distribute your app through the Apple App Store. This is an especially attractive option if your app is for a large-scale and/or longitudinal study. However, it is difficult to get accepted by the App Store if your app is purely meant to collect research data. Please review the App Store Review Guidelines for more information on the type of apps they accept and reject (<https://developer.apple.com/app-store/review/guidelines/>).

commonly used set of web languages: (1) HTML, which creates web pages; (2) CSS, which is used to style websites; (3) JavaScript, which is the scripting language that allows websites to perform various actions and functions. As described in the *Create App* section of the ExperienceSampler website (<http://experiencesampler.com/createapp>), the first thing you will do is create your app using Cordova. We recommend that you create two duplicate apps, one that you will use for all your participants who use Android devices and the other that you will use for all your participants with iOS devices. Next, you will add platforms to each of these apps, which means that you tell Cordova which platform (i.e., iOS, Android) you would like to target with each app. As described under the *Adding Plugins* subsection of the *Create App* section of the website, there are a number of plugins that are needed for both the iOS and Android versions of the app. So, the final step in building the scaffold for your ExperienceSampler app is to install the necessary plugins. In addition to the plugins that are global for both the Android and iOS versions, ExperienceSampler takes advantage of local notifications on participants' devices to signal to participants that a new experience sampling survey is ready to be completed. These plugins are third-party plugins written for Cordova, so they are unique to each platform. Thus, you will need to install the Android local notifications plugin for your Android app and the iOS local notifications plugin for your iOS app. It is because we are using these third-party plugins for local notifications that ExperienceSampler is currently only able to run on Android and iOS devices; other platforms supported by Cordova (e.g., Windows or BlackBerry smartphones) do not have comparable local notifications plugins at the time of the writing of this paper.

Now you have created a shell for your apps, and you are ready to customize our code to create an experience sampling app that collects the data you want. The customization step is the longest step involved with ExperienceSampler, but you will be able to do it if you patiently

follow the instructions available in the *Customize* section of the ExperienceSampler website (<http://experiencesampler.com/customize>) in order. Overall, there are five stages involved in customizing ExperienceSampler for the specifics of your research project (see Figure 3 for a portion of the template file that you will customize): (1) Customizing the questions and messages; (2) Setting up a system for saving data; (3) Adding any advanced question features like branching and “piped text” that uses earlier responses as prompts for later questions and response options; (4) Setting up the snooze function and deciding on any timeout periods; (5) Scheduling notifications that will alert participants to a new survey. There are many question types available for ExperienceSampler, including rating scales, multiple choice, checklists, sliders, open-ended, and time and date pickers. You can also include descriptive text and instructions. In between the first and second stages is when you will do the bulk of your testing to ensure that the survey works and asks the questions that you want. The biggest decision of the second stage is whether you want to use Google to store your data or setup your own http server. Once you have chosen an approach and set it up, then you will tell ExperienceSampler where to save the data. This stage will also need to be extensively tested because you must ensure that you are saving data and can retrieve that saved data. In the third stage, you will add any advanced question features like question logic or piped text. The fourth stage involves deciding how you want to control your participants’ responses. Do you want to allow them to “snooze” the notification if they cannot complete the survey immediately, and if so, then how soon after they snooze the notification should they be notified again? Similarly, do you want to incorporate a timeout, such that participants must complete the survey within a certain period of time from when they were notified before you want to consider it a missed signal? After making those decisions, the last stage of customizing involves deciding on the number of notifications (i.e.,

surveys) participants will complete each day and in between what hours of the day you want them to be notified. The notification window can be idiographically customized for each participant. Once you have completed your customization, you are ready to prepare your app for distribution to your participants' mobile devices, which is described in the *Wireless Distribution* section of the website (<http://experiencesampler.com/distribution>).

Finally, you are ready to use ExperienceSampler to collect experience sampling data. When participants begin the study, you will guide them on how to download and install your ExperienceSampler app on their phones. At that point, they will enter any setup information you have programmed into your app (e.g., participant id, hours of the day you want them to be notified), and they should be ready to begin the study. We have also created three additional scripts, which can be found on our website, to assist you during the data collection and data organization phases of your study. While the study is running, you can implement two scripts that we have created using Google Script that will check compliance and send compliance-related emails to participants (<http://experiencesampler.com/compliance>). These tools are only available if you choose to use the Google option for storing your data. Similarly, we have written scripts using Google Script and R that will organize the participants' data into the appropriate structure for data analysis (i.e., long form; <http://experiencesampler.com/data-organization>). These scripts organize all the data into one complete data file. Researchers can then read this csv file into the statistical analysis program with which they are most comfortable for data analysis. We refer researchers to Bolger and Laurenceau's (2013) *Intensive Longitudinal Methods* and Mehl and Conner's (2012) *Handbook of Research Methods for Studying Daily Life* for more extensive discussions of data analytic techniques for this type of data.

Example ExperienceSampler Study

We evaluate the effectiveness of ExperienceSampler with data collected in a study that we conducted to examine cross-relationship comparisons (i.e., comparing one's own relationship to other relationships) and social interactions in daily life. In this example, we evaluated the same key parameters evaluated by Hofmann and Patel (2015) for SurveySignal: average response rate, median response delay, and attrition over the course of the mobile phase.

Method

Participants. We recruited 168 smartphone users who passed the initial screening for our inclusion criteria (i.e., have at least a high school education, own an Android phone or iPhone, are currently dating or married, could participate in the study with their partners, could attend two lab sessions with their partners). Of these participants, 149 participants had phones and operating systems that were compatible with the app. Fifteen participants completed the experience sampling portion of the study online through Qualtrics, and the remaining four participants did not complete any of the experience sampling portion of the study. Only 156 participants (78 males and 78 females; $M_{\text{age}} = 27.22$, $SD = 7.73$, range = 17 to 61 years old) completed all three portions of the study (see *Procedure* section). In our final dataset, we had 40 heterosexual dating and 38 heterosexual married couples from the community. Participants received up to \$50 for completing the study, depending on the extent to which they completed the experience sampling components of the study. Participants received \$30 for attending the intake and exit sessions (i.e., \$15 per session), \$2 for each day they completed 5 or more experience sampling surveys and the nightly diary component (for a maximum of \$14), a \$3 bonus if they completed all their experience sampling components, and a second \$3 bonus if both they and their partner completed all their experience sampling components.

Procedure. Participants were recruited from the community through flyers posted around campus and the community, and online ads posted on online classified sites such as Craigslist. Participants who met the study inclusion criteria were invited to an in-lab information and intake session. During the intake session, research assistants taught the participants about cross-relationship comparisons and reviewed the experience sampling questions. Participants then completed an intake questionnaire. The experience sampling portion of the study started the next day and lasted seven days. After the experience sampling period, participants returned to the lab to complete an exit questionnaire and debriefing session. Participants were also asked if we could contact them in 6 months to complete a follow-up questionnaire.

Experience sampling component. We chose to use a signal-contingent design in which participants were randomly signaled throughout the day to determine the prevalence of cross-relationship comparisons (see Reis et al., 2014 for advantages and disadvantages of this approach). Participants received six signals each day, and signals were spaced 1.5 to 2 hours apart. We customized the signals to each participant's schedule: Participants received their first signal about 1 hour after waking up and their last one before dinner. We allowed waking and dinner times to vary for weekdays and weekends.

In the experience sampling questionnaires, participants were first asked to indicate whether they made a cross-relationship comparison. If they did, we presented them with the cross-relationship comparisons questionnaire. If they did not, we presented them with the daily social interaction questionnaire.

All participants also received an additional signal at the end of the day reminding them to complete their online daily diary on Qualtrics. Some participants interpreted the nightly reminder as another notification to complete an experience sampling questionnaire. Thus, we received

responses to seven experience sampling questionnaires from some participants on some days.

We did not count these additional experience sampling questionnaires in our evaluation measure calculations; the maximum number of questionnaires that can be completed each day was set as six for each participant.

Results

To determine the utility of the app, we calculated the same evaluation measures, and their bootstrapped 95% confidence intervals with 10,000 resamples, that were used for SurveySignal (Hofmann & Patel, 2015) for the participants who completed all three parts of the study.⁸ We present the evaluation measures of both SurveySignal and ExperienceSampler in Table 1. We first calculated the mean response rate, which was the average across participants' individual response rates (i.e., the percentage of signals to which they replied)⁹. The mean response rate in our study was 84.44%, 95% CI [81.24, 86.76]. On average, participants received 5.90 signals each day, 95% CI [5.84, 5.94], and completed 4.98 questionnaires each day, 95% CI [4.79, 5.13].

We then calculated the median response latency, which is defined as the time that elapses between receiving the signal and responding to the first question of the survey. Because the response latencies are heavily right skewed (*range* = 0.00 to 1439.82 minutes; see Figure 4), we report the median instead of the mean. Fifty percent of responses occurred within the first 9.22 minutes, 95% CI [8.42, 10.04] after the notification was fired. Twenty-five percent of responses occurred within the first minute of receiving the signal, 52 seconds, 95% CI [45, 59], and 75% of

⁸ The data and R script used to produce these results can be found on the Open Science Framework project page for this manuscript: <https://osf.io/238sd/>

⁹ We divided the number of signals responded to by the theoretical number of signals each participant received (6 per day). Some participants, however, did notify us to let us know they received fewer than the theoretical number on some days. For those days, we used the number of notifications participants told us they received. To see the calculated response rate values for each participant, see the dataset titled "Response Rate with Calculated Values.csv" using the above Open Science Framework link.

responses occurred within the first 31.40 minutes, 95% CI [29.81, 32.95]. The vast majority of responses (89%) occurred within the first hour of receiving the signal, 59.69 minutes, 95% CI [58.00, 62.53].

The retention rate was computed as the number of participants who completed most of the experience sampling phase and returned to the lab for an exit session. Two participants withdrew consent to participate after the information portion of the intake session and did not complete the intake questionnaire. Another two participants completed the intake session, but did not complete any of the experience sampling questionnaires. We did not include these four participants in our calculation of the retention rate. Only eight out of remaining 151 participants using the app dropped out of the study during the experience sampling portion of the study, indicating a retention rate of 94.67%, 95% CI [89.33, 97.33].

Discussion

Experience sampling studies provide researchers with detailed descriptions of the psychological processes that individuals experience in their daily lives. The increasing prevalence of smartphones has made conducting experience sampling studies easier than ever. Researchers can now take advantage of the convenient and cost-effective solution of using participants' own devices, thus eliminating the high hardware costs associated with using the PDA approach that once dominated experience sampling methodology. ExperienceSampler presents another option for researchers seeking to conduct experience sampling studies that further reduces research costs and integrates well with participants' daily routines.

Pros and Cons of ExperienceSampler

Pros. ExperienceSampler apps overcome two of the major barriers of experience sampling studies: cost and high technical effort (Hofmann & Patel, 2015). This method is much

more cost-effective than current options (i.e., \$299 USD for iOS devices and no cost for Android devices) and imposes no quotas on the number of participants that can be run and the number of signals that can be sent. The data-storing infrastructure needed to support studies run using ExperienceSampler is also cost-effective and utilizes as many programs and services that researchers can access free of charge to further minimize the cost of conducting an experience sampling study. Furthermore, ExperienceSampler apps do not require constant Internet connectivity or cell signal, thus allowing participants to complete questionnaires anywhere and minimizing the costs participants may incur for participating in the study. As for high technical effort, though this app does require some programming, it is comparable to the level of programming needed to adapt existing syntax for a new set of statistical analyses. The instructions on the website have already been used by people with no programming experience, as long as you are patient in going through each step in order. That is, in most use cases, researchers simply need to substitute their own values and variables into the script in order to adapt it for their research project. In addition, because ExperienceSampler is open-source, researchers who want to add advanced features are able to do so¹⁰.

Moreover, ExperienceSampler incorporates the strengths of the PDA approach – greater control over the data collection process – with the convenience of the SMS approach. ExperienceSampler apps include many of the features necessary for researchers to exert greater control over the data collection process such as time-stamped responses, real-time data uploads, timeout screens to prevent hoarding, and a snooze function. ExperienceSampler can also be customized to various experience sampling designs. Furthermore, ExperienceSampler apps

¹⁰ Moreover, ExperienceSampler is hosted on GitHub (<https://github.com/sabrinathai/ExperienceSampler>). So, if you “fork” the project on GitHub, then you can customize ExperienceSampler in a way that can be used and cited by other researchers in the future.

minimize the effect of selection bias that is inherent to local apps that are only compatible with one operating system. Finally, our response and attrition rates suggest that this method is generally reliable and comparable to other methods (e.g., SurveySignal; Hofmann & Patel, 2015).

Cons. ExperienceSampler still has a few limitations. First, because ExperienceSampler apps can only be used on Android and iOS devices, researchers who are concerned about selection bias or who have a very specific population that is limited in size may choose to use other options, such as SurveySignal (Hofmann & Patel, 2015), to ensure that all participants who meet the inclusion criteria can participate in the study. Researchers may also choose to use a text messaging approach that is not limited to smartphones similar to the method used by Berkman, Dickenson, Falk, & Lieberman (2011). Secondly, because the ExperienceSampler scaffold is not natively coded for Android and iPhone, we must depend on other programmers coding natively using Java and Objective-C to create new features and update current features, which can delay the distribution of an app. Furthermore, ExperienceSampler usually requires updates whenever major platform updates occur, such as when a new iOS version is released. Though this does not occur often (i.e., once a year), it can also delay distribution or stall data collection if a new OS is released after data collection has started. This would apply to any iOS-based app, however. Finally, ExperienceSampler does require some programming skill; however, as stated earlier, the programming ability required is similar to adapting existing syntax for a new set of statistical analyses.

Ideas for Advanced Customization

Because ExperienceSampler is open-source, researchers who are familiar with JavaScript, or who have a collaborator who is familiar with JavaScript, can easily adapt the app to include more advanced smartphone features that they may want to use in their research. For example,

researchers interested in the influence of physical surroundings on behaviors have many ways they could augment their ExperienceSampler app. Researchers could include the camera function in ExperienceSampler to allow participants to take pictures of their surroundings when answering survey questions and then upload them to the researcher's server. Researchers could also choose to program the app to collect GPS data so that they can look up the exact location of participants when they complete the survey. GPS data can also allow for location-based notifications. Location-based triggers will signal participants when they are in a predefined area using push notifications, which do require a cell signal. This feature may make event-contingent studies easier to conduct because researchers can program ExperienceSampler to fire whenever participants are in locations in which their phenomenon of interest is likely to occur. For example, researchers interested in health behaviors may wish to signal participants whenever they are in the vicinity of their local gym. Other researchers who are interested in movement may take advantage of the device's accelerometer and record how many steps the participants are taking before and after completing the survey.

In addition, experienced programmers can incorporate mobile sensing features (for review of these features see Harari et al., 2016) into their ExperienceSampler apps as these become more readily available (see AWARE, 2017 for some native Android mobile sensing plugins), which will also facilitate more accurate responses to event-contingent designs. For example, researchers interested in social interactions can use sensors to detect when the participant is having a conversation with another person in order to notify participants to complete event-contingent surveys regarding their interactions.

Advanced programmers may also choose to store their data using SQL (e.g., SQLite) if their data has a fixed structure. This allows researchers to monitor data writing in real time and

spot data-sending problems more quickly. The open source nature of ExperienceSampler and the ability to use features native to the device make it possible for researchers to take advantage of smartphones' capabilities to collect the data needed to answer their questions of interest; a possibility that is currently unavailable with SurveySignal and may be costly to implement with existing proprietary app options.

Training Benefits

Learning to customize ExperienceSampler involves learning the basics of JavaScript. We also encourage researchers who are unfamiliar with JavaScript to take advantage of this opportunity to learn it for more general use in their own research. JavaScript is a popular programming language that can be used to create various web-based tools to conduct research. In addition to programming the app, we used JavaScript to send emails reminding participants to complete their daily surveys and to visit the lab for their in-lab appointments. These uses of JavaScript greatly reduce the number of research assistants needed to conduct an experience sampling study and further reduce the costs associated with conducting such a labor-intensive study.

Alternative Uses for ExperienceSampler

Although ExperienceSampler was designed for experience sampling studies, it can also be used as survey software if you would like to deploy a survey on a tablet or phone for any reason. Researchers can use the app for daily diary studies to increase the convenience of completing nightly surveys by scheduling notifications to fire at a particular time of day over the data collection period. Alternatively, researchers can also use the app to collect data in the field. For example, if researchers are collecting data from participants at a particular event, such as a speed-dating event (Finkel, Eastwick, & Matthews, 2007), they do not need to worry about

Internet connectivity. They can simply customize their ExperienceSampler app so that there is no timeout period, no scheduled notifications, and the unique key can act as the participant ID. You could also use ExperienceSampler to create a behavioral coding app for tablets or smartphones that researchers could then take to public places and record behavioral observations. Furthermore, researchers can collect data using either an Android or iOS tablet as a part of their normal lab protocols, which may make data collection much easier for both the researcher and participants by eliminating the need to set up booths with computers and the need for data entry if pen-and-paper questionnaires are used.

Conclusion

In recent years, many scientific findings have come under scrutiny as being false positives, in part because studies lack the statistical power necessary to detect effects of interest (Ioannidis, 2005; Schimmack, 2012). Experience sampling studies help address this concern by allowing researchers to study processes as they unfold within each person – increasing statistical power – and across a wide variety of contexts in daily life – increasing ecological validity. Furthermore, experience sampling studies can help develop a better descriptive understanding of how various phenomena operate so that researchers can develop better theories informed by data (Funder, 2009). By introducing ExperienceSampler and making it open-source, we hope to remove or reduce many of the barriers that prevent researchers from conducting such studies and facilitate a better understanding of the human experience.

References

- AWARE. (2017). AWARE – Android Mobile Context Instrumentation Framework. Retrieved March 6, 2017, from <http://www.awareframework.com/>
- Berkman, E. T., Dickenson, J., Falk, E. B., & Lieberman, M. D. (2011). Using SMS Text Messaging to Assess Moderators of Smoking Reduction: Validating a New Tool for Ecological Measurement of Health Behaviors. *Health Psychology, 30*(2), 186–194. <https://doi.org/10.1037/a0022201>
- Bolger, N., & Laurenceau, J.-P. (2013). *Intensive Longitudinal Methods: An Introduction to Diary and Experience Sampling Research*. New York, NY: Guilford Press.
- Broderick, J. E., Schwartz, J. E., Shiffman, S., Hufford, M. R., & Stone, A. A. (2003). Signaling does not adequately improve diary compliance. *Annals of Behavioral Medicine, 26*(2), 139–148.
- Burgin, C. J., Silvia, P. J., Eddington, K. M., & Kwapil, T. R. (2013). Palm or Cell? Comparing Personal Digital Assistants and Cell Phones for Experience Sampling Research. *Social Science Computer Review, 31*(2), 244–251. <https://doi.org/10.1177/0894439312441577>
- comScore. (2016, April 6). comScore Reports February 2016 U.S. Smartphone Subscriber Market Share. Retrieved March 25, 2017, from <http://www.comscore.com/Insights/Rankings/comScore-Reports-February-2016-US-Smartphone-Subscriber-Market-Share>
- Conner, T. S. (2015, May). Experience sampling and ecological momentary assessment with mobile phones. Retrieved from <http://www.otago.ac.nz/psychology/otago047475.pdf>

- Conner, T. S., Tennen, H., Fleeson, W., & Barrett, L. F. (2009). Experience Sampling Methods: A Modern Idiographic Approach to Personality Research. *Social and Personality Psychology Compass*, 3(3), 292–313. <https://doi.org/10.1111/j.1751-9004.2009.00170.x>
- Finkel, E. J., Eastwick, P. W., & Matthews, J. (2007). Speed dating as an invaluable tool for studying romantic attraction: A methodological primer. *Personal Relationships*, 14, 149–166. <https://doi.org/10.1111/j.1475-6811.2006.00146.x>
- Funder, D. C. (2009). Naive and Obvious Questions. *Perspectives on Psychological Science*, 4(4), 340–344. <https://doi.org/10.1111/j.1745-6924.2009.01135.x>
- Gartner. (2017, February 15). Gartner Says Worldwide Sales of Smartphones Grew 7 Percent in the Fourth Quarter of 2016. Retrieved March 25, 2017, from <http://www.gartner.com/newsroom/id/3609817>
- Harari, G. M., Lane, N. D., Wang, R., Crosier, B. S., Campbell, A. T., & Gosling, S. D. (2016). Using Smartphones to Collect Behavioral Data in Psychological Science: Opportunities, Practical Considerations, and Challenges. *Perspectives on Psychological Science*, 11(6), 838–854. <https://doi.org/10.1177/1745691616650285>
- Hofmann, W., & Patel, P. V. (2015). SurveySignal: A Convenient Solution for Experience Sampling Research Using Participants' Own Smartphones. *Social Science Computer Review*, 33(2), 235–253. <https://doi.org/10.1177/0894439314525117>
- Ioannidis, J. P. A. (2005). Why Most Published Research Findings Are False. *PLoS Medicine*, 2(8), e124. <https://doi.org/10.1371/journal.pmed.0020124>
- Mehl, M. R., & Conner, T. S. (Eds.). (2012). *Handbook of research methods for studying daily life*. New York, NY: Guilford Press.

Rainie, L., & Zickuhr, K. (2015). *Americans' View on Mobile Etiquette*. Pew Research Center.

Retrieved from <http://www.pewinternet.org/2015/08/26/chapter-1-always-on-connectivity/>

Reis, H. T., Gable, S. L., & Maniaci, M. R. (2014). Methods for Studying Everyday Experience in Its Natural Context. In H. T. Reis & C. M. Judd (Eds.), *Handbook of Research Methods in Social and Personality Psychology* (Second, pp. 373–403). New York, NY: Cambridge University Press.

Robinson, M. D., & Clore, G. L. (2002). Belief and feeling: Evidence for an accessibility model of emotional self-report. *Psychological Bulletin*, 128(6), 934–960.

<https://doi.org/10.1037/0033-2909.128.6.934>

Schimmack, U. (2012). The ironic effect of significant results on the credibility of multiple-study articles. *Psychological Methods*, 17(4), 551–566. <https://doi.org/10.1037/a0029487>

Shiffman, S., Stone, A. A., & Hufford, M. R. (2008). Ecological Momentary Assessment. *Annual Review of Clinical Psychology*, 4, 1–32.

<https://doi.org/10.1146/annurev.clinpsy.3.022806.091415>

Tversky, A., & Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. *Cognitive Psychology*, 5(2), 207–232. [https://doi.org/10.1016/0010-0285\(73\)90033-9](https://doi.org/10.1016/0010-0285(73)90033-9)

Table 1

Evaluation Measures

Platform	<i>N</i>	Sampling Period in Days	Mean Response Rate	25 th Percentile Response Latency (seconds)	Median Response Latency (minutes)	75 th Percentile Response Latency (minutes)	Survey Completion Rate	Retention Rate
SurveySignal Average	1852	5.4	76.7	< 60	8.09	=< 23	96.4	89.4
ExperienceSampler	143	7	84.44 [81.24, 86.76]	52 [45, 59]	9.22 [8.42, 10.04]	31.40 [29.81, 32.95]	86.62 [85.73, 87.52]	94.67 [89.33, 97.33]

Note. Values that appear inside the square bracket represent the 95% bootstrapped confidence interval with 10,000 resamples. The

SurveySignal values represent the average of 8 studies. Mean response rate = the average across participants' individual response rates (i.e., the percentage of signals they replied). 25th Percentile, Median, and 75th Percentile response latencies = the time that elapses between receiving the signal and responding to the first question of the survey. Hofmann and Patel (2015) did not report the exact value of the 25th and 75th percentile. Survey completion rate = percentage of completed surveys in the database. Retention rate for ExperienceSampler = the number of participants who completed most of the experience sampling phase and returned to the lab for an exit session. Retention rate for SurveySignal = percentage of participants in the mobile phase who provide at least one response on the last day of the experience sampling schedule. Because our exit session included an exit questionnaire, we used this retention rate metric to determine the number of participants who completed all three components of our study. In contrast, the SurveySignal studies examined did not have an exit session; thus, participants completed the entire study on the last day of experience sampling schedule.

Figure 1. ExperienceSampler local notifications on locked and unlocked screens. The notification on the left is for a scheduled signal, and the notification on the right is for a snooze signal.

Figure 2. Participant view of answering a rating scale item.

The image shows a mobile application interface for a rating scale. At the top, a status bar displays signal strength, carrier name 'ROGERS', time '4:30 PM', and battery level '98%'. Below the status bar, the instruction 'Please indicate how you feel right now.' is displayed. The main content area contains seven blue buttons with white text, arranged vertically. The buttons are labeled with a number and a description: '3 Very positive', '2 Somewhat positive', '1 A little positive', '0 Neutral', '-1 A little negative', '-2 Somewhat negative', and '-3 Very negative'. The bottom of the screen is a solid dark blue bar.

ROGERS 4:30 PM 98%

Please indicate how you feel right now.

3 Very positive

2 Somewhat positive

1 A little positive

0 Neutral

-1 A little negative

-2 Somewhat negative

-3 Very negative

Figure 3. Researcher view of ExperienceSampler index.js file that will be customized. The code on the top is before customization, and the code on the bottom is after customization.

```
{
  "type": "question type",
  "variableName": "variableName",
  "questionPrompt": "Exact question wording",
  "minResponse": /*minimum numerical value of the
                  scale or multiple choice option*/,
  "maxResponse": /*maximum numerical value of the
                  scale or multiple choice option*/,
  "labels": [
    {"label": "label for minimum numerical value of
scale or first option for multiple choice question"},
    {"label": "label for maximum numerical value of
scale or second option for multiple choice question"},
  ],
}
```

```
{
  "type": "mult2",
  "variableName": "mood",
  "questionPrompt": "Please indicate how you feel right now.",
  "minResponse": -3,
  "maxResponse": 3,
  "labels": [
    {"label": "3 Very positive"},
    {"label": "2 Somewhat positive"},
    {"label": "1 A little positive"},
    {"label": "0 Neutral"},
    {"label": "-1 A little negative"},
    {"label": "-2 Somewhat negative"},
    {"label": "-3 Very negative"},
  ],
}
```

Figure 4. Histogram displaying the distribution of response latencies for the first hour from our study.