Heed: Exploring the Design of Situated Self-Reporting Devices

GAURAV PARUTHI, University of Michigan
SHRITI RAJ, University of Michigan
SEUNGJOO BAEK, University of Michigan
CHUYAO WANG, University of Michigan
CHUAN-CHE HUANG, University of Michigan
YUNG-JU CHANG, National Chiao Tung University
MARK W. NEWMAN, University of Michigan

In-situ self-reporting is a widely used data collection technique for understanding people's behavior in context. Characteristics of smartphones such as their high proliferation, close proximity to their users, and heavy use have made them a popular choice for applications that require frequent self-reporting. Newer device categories such as wearables and voice assistants offer their own advantages, providing an opportunity to explore a wider range of self-reporting approaches. In this paper, we focus on exploring the design space of Situated Self-Reporting (SSR) devices. We present the Heed system, consisting of simple, low-cost, and low-power SSR devices that are distributed in the environment of the user and can be appropriated for reporting measures such as stress, sleepiness, and activities. In two real-world studies with 10 and 7 users, we compared and analyzed the use of smartphone and Heed devices to uncover differences in their use due to the influence of factors such as situational and social context, notification types, and physical design. Our findings show that Heed devices complemented smartphones in the coverage of activities, locations and interaction preferences. While the advantage of Heed was its single-purpose and dedicated location, smartphones provided mobility and flexibility of use.

CCS Concepts: • **Human-centered-computing → Ubiquitous and mobile computing → Empirical studies in mobile and ubiquitous computing; • Human-Computer-Interaction → HCI design and evaluation methods;**

Additional Key Words and Phrases: Context-aware systems, Self-reporting devices, qualitative study, real-world study, Experience Sampling, ESM, EMA

ACM Reference Format:

Gaurav Paruthi, Shriti Raj, Seungjoo Baek, Chuyao Wang, Chuan-che Huang, Yung-ju Chang, Mark W. Newman. 2018. Heed: Exploring the Design of Situated Self-Reporting Devices. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 2, 3, Article 132 (September 2018), 21 pages. https://doi.org/10.1145/3264942

1 INTRODUCTION

Social science researchers and ubiquitous computing system designers share the need to understand how particular groups of people behave in their natural environments. The experience sampling method (ESM)[9,15], also known as Ecological Momentary Assessment (EMA) [30], is a well-established technique for eliciting self-report data

Authors' addresses: Gaurav Paruthi (gparuthi@umich.edu), Shriti Raj, Seungjoo Baek, Chuyao Wang, Chuan-che Huang, Yung-ju Chang, Mark W. Newman, School of Information, 105 S. State St. Ann Arbor, MI 48109, USA. Yung-ju Chang, 1001 University Rd, Hsinchu City, Taiwan, 300

2474-9567/2018/9-ART132 $15.00
https://doi.org/10.1145/3264942

from people in a variety of contexts while introducing minimal disruptions that would impact the phenomena under study. Developing ESM tools that can be deployed in an ever-widening variety of contexts while reducing the intrusiveness of requesting and receiving self-reports has been the subject of much study, particularly within the Ubiquitous Computing research community [16,17,21,27].

In order to receive timely reports, the ESM method relies on tools to carry on two important functions- a) remind the user to self-report, and b) provide the user with an interface to report the relevant measures. The earliest ESM studies used dedicated, single-purpose reporting devices such as pagers to remind study participants to initiate paper reports [11]. As smartphones became ubiquitous, researchers began to leverage them for ESM, thereby relieving subjects of the need to carry a separate device to participate in a study. Smartphones have been found to be within the same room as their users almost 90% of the time, and within arm's reach almost 50% of the time [12]. Although smartphones offer significant advantages for ESM studies, they have nevertheless been found to impose a burden on the user [17]. Researchers have thus tried to further improve ESM tools by reducing the interaction burden on the user [37]. Newer device categories such as smartwatches and other wearables can reduce the time required to access the device, thus supporting *micro-interactions* that lower the interaction burden and increasing reporting frequency [27]. Yet, smartwatch interfaces come with their own set of disadvantages relative to smartphones, such as a high abandonment rate [39], additional effort required to learn their management [24], and relatively limited screen real-estate.

The interest in exploring newer device categories is guided by the goal of reducing the burden of high-frequency self-reporting and thus increasing the temporal density of reports. One of the main strategies used is to reduce the time a user spends accessing the device (access time) while aiming for a high compliance rate. Multi-device experiences that take advantage of the complementary nature of different device types [13] aim for similar goals by allowing the user to choose the most convenient device to achieve a task. A similar opportunity exists for self-reporting applications, where a wide range of multi-device approaches can make it easier for researchers and designers to choose a multi-device strategy that best fits their intended self-reporting application.

The Internet of things (IoT) paradigm represents many trends, one of them being the ability to design and build physical computational devices at low cost. This opens up an opportunity to build new forms of self-reporting devices that may come with their own sets of tradeoffs. In this paper, we investigate an emerging class of self-reporting devices that are situated in the environments of their users, providing a more convenient way to self-report in certain contexts. Existing Situated Self-Reporting (SSR) devices have been shown to be unobtrusive and convenient tools that allow users to log repeating actions [36].

In the rest of the paper, we first review existing literature and highlight the opportunity in the design space for SSR devices. We then present the design and implementation of Heed, an instantiation of an SSR device that is distributed, low-power, low-cost, supports multiple simple constructs, and has a wooden enclosure with embedded sensors that support touch interactions. To explore the tradeoffs offered by SSR devices, we conducted two studies of one-week duration, one with 10 and the other with 7 users in their natural environments.

The findings from these studies can inform the future design of situated self-reporting devices. We uncover insights about the use of SSR devices. Qualitatively we show that Heed devices were complementary to smartphones in nuanced ways. While the advantage of Heed was its single-purpose design and dedicated location, smartphones provided mobility and flexibility of use. Finally, we discuss what we learned about the design of SSR devices from the design and evaluation of Heed. The lessons we learned have implications for the design of SSR devices that may be deployed in future real-world studies. Moreover, we present some unintended consequences of SSR devices that researchers should be aware of.

2 BACKGROUND

Self-reporting approaches are commonly subject to bias due to the limited opportunities available to a person to respond. For instance, if smartphones are used, users can respond only when they are able to engage with them. A user who is away from the smartphone may not wish to or be able to engage. The trigger strategy can also lead to biases in reporting. Lathia et al. (2013) demonstrate that particular aspects of the design of an experience sampling study (e.g. random sampling of times, contextual sampling) are linked to bias in the resulting data [21].

Furthermore, it can be argued that infrequently occurring events of interest may occur at times when a subject doesn't have access to the reporting device, is not prompted to enter a report, doesn't remember to initiate a report, or perceives the reporting device (e.g., a smartphone) to be intrusive or stress-inducing and decides not to interact with it.

In addition to the bias, self-reporting involves manual work that may impose a burden on the user. For example, self-reporting fatigue leads users to abandon reporting altogether in some situations [8]. The difficulty in accessing particular reporting devices, such as smartphones, further contributes to the burden of using them to answer questions, especially when the devices are not within arm's reach [12]. This perceived barrier to self-reporting may result in lower compliance with ESM studies.

Ubicomp and HCI researchers have explored multiple approaches for reducing the burden of self-reporting. One such approach used is to figure out the optimal frequency for prompts such that the annoyance level is minimized. Although required report frequency depends upon the research setting (required level of recall and time to finish questionnaire) [2], some researchers suggest that "a sampling frequency of five to eight times per day may yield an optimal balance of recall and annoyance" [18]. Intrusiveness is also known to be alleviated by the use of decision theory methods to generate prompts at opportune moments and reduce the overall number of prompts [23]. Other approaches to reduce the burden include utilizing novel user interfaces [32,37], understanding the role that choice of strategy plays in answering research questions [21], and understanding the effects of device characteristics [16]. One approach that is relatively unexplored is the use of single-purpose devices to minimize the access time and thus, reduce burden of self-reporting.

Single-purpose reporting devices in some ways represents a return to an earlier stage of ESM tool development. As noted, the earliest ESM studies used dedicated reporting devices (pagers) for the single purpose of generating self-reporting reminders (i.e., subjects did not use the devices for any other communication) [11]. Smartphones, in contrast, are used for an ever-expanding set of activities [40]. This generality of purpose contributes to the complexity and increased access time associated with using smartphones for in situ self-reporting. Dedicated self-reporting devices, placed strategically in the environment of the user, might be a way to avoid some of the disadvantages imposed by smartphone-based ESM tools.

The design of single-purpose situated self-reporting devices remains largely unexplored, with the notable exception of SAL [19]. SAL is a small, situated, ambient logger designed for personal goal tracking. SAL is inspired by Weiser's original vision for ambient, calm, and peripheral computing [33]. SAL was found to be unobtrusive and convenient for logging progress towards behavior goals [36]. The lower cost of IoT devices provides an opportunity to design situated self-reporting devices that are customized for an intended user and application. Inspired by similar comparative studies of self-reporting devices that quantified the trade-offs of using earlier approaches such as PDAs [4], pen-and-paper [3], and more recently smartwatches [17] and head-mounted displays [16], we sought to explore the design space of low-cost self-reporting devices that are situated in the environment of the user.

3 DESIGN PROCESS AND IMPLEMENTATION

3.1 Situated Self-Reporting Devices

A *situated device* is one that is designed to be used in a particular environment, supporting the activities performed by users in that environment. Such devices need to provide their users with ease of access and use in the relevant context. They also need to fit in with the physical environment in which they are placed, as well as the physical arrangements and concurrent activities of the environment's occupants. By this definition, situated devices are common in contemporary environments, and include thermostats, light switches, and clocks. Less common situated devices have been explored in the research literature as well (e.g.,[26,28,29]). We expect that the ease of use offered by situated devices can also be leveraged to lower the burden of self-reporting in certain contexts. In the following paragraphs, we first define situated self-reporting (SSR) devices and briefly discuss their design dimensions. We then present an instantiation of SSR device, that we designed, built, and evaluated in order to explore the design space of SSR devices.

An SSR Device is a situated device intended to be placed in a location to optimize user's self-reporting efficacy. With SAL as a starting point, we wish to expand the notion of SSR devices by systematically exploring some of their key design dimensions. In Table 1, we propose a provisional design space for SSR devices to initiate an exploration of tradeoffs between self-reporting device use. SSR devices may vary along each of these dimensions as needed to fit into particular situations and self-reporting needs. As an example, the mode of interaction (e.g. touch, gesture) supported by a device depends on context in which the user self-reports and the measure that is intended to be reported using the device. For instance, imagine an ESM study that intends to study the stress level of the user while driving. In the context of a driving a car, a self-reporting device must not distract the user and provide for a quick interaction that fits with other interactions that the driver is used to when driving. One might

Table 1. Selected design dimensions of SSR devices and the instantiation of Heed on those dimensions.

Design Dimension	Description	Heed's characteristics
Mode of Interaction	How does the user interact with the device? Possibilities include voice prompts, touch or gestures.	Touch
Notification type	How is the user reminded to self-report? Possibilities include haptic, sound and lights	Single light notification
Construct complexity supported	What kinds of self-reporting constructs are supported by the device? Device may support a one or more than one simple construct items (e.g. stress level) or may support multi-dimensional constructs (Mood-Affect) or compost constructs.	Multiple simple constructs
Context Awareness	How much does the device adapt to its sensed context? For instance, its notification is triggered by user's proximity or other contexts.	Notifications are shown when the user was nearby
Number of users	How many users does the device serve? Possibilities include a single user device or a multi-user device.	Single user
Distributed	How many devices does the user use? A system may consist of one or more than one self-reporting devices	Heed is a single user - many devices
Material	What materials were used for the device? Materials affect the durability as well as the feelings that may evoke in participants. Possibilities include wood, ceramic, and plastics.	Wood along with a glossy paper overlay for the interface.
Cost of device	How much does it cost to make the hardware?	Very low cost (~$5)
Energy requirements	How is the device powered? Possibilities include an always connected power source, user is asked to charge, and self-contained power source.	Runs without charging for ~7 days
Connectivity	How does the device send or receive data? Possibilities include direct Wi-Fi connection, user's phone, etc.	Uses Bluetooth to connect to phone
Other reporting features	What are the ways in which the user can report on the device? Possibilities include participatory, in-situ and post-hoc. Does the device provide the ability to edit/ undo reports previously made?	Only in-situ
Purpose	What is the purpose of the device? Is it a single-purpose device? Or is it multi-purpose? If a conversational home-assistant is used for self-reporting, it will be a multi-purpose SSR. SAL had two main purposes of logging and reflecting on one's progress towards a goal.	Single-purpose

imagine the use of a simple device consisting of buttons that mimic the natural interactions with the systems in the car could achieve the goal of minimizing the access time while being less burdensome for the driver.

Informed by the design space of SSR devices elaborated in Table 1, we developed Heed - a simple, illustrative example of an SSR device. Heed devices are intended to enable general users to report simple constructs, such as activities performed, stress, sleepiness, and social context. They are low-cost SSR devices, distributed in locations chosen by the user to optimize the user's self-reporting behavior. Table 1 describes Heed's characteristics, that is the design choices made for Heed along the design dimensions of the design space. We evaluated the use of Heed devices in two real-world studies to investigate the influence of its key characteristics, such as the location and context of its use, on users' self-reporting behavior.

3.2 Implementation

The Heed system consists of the Heed devices, the Heed phone app, and a server. The user interacts with the devices and the phone app to enter self-reports. The phone app regularly pushes the data to the cloud-based server. The self-reports stored on the Heed devices are also regularly synced with the phone app and then to the cloud. The following subsections describe the implementation of the devices and the phone app in more detail.

3.2.1 Heed Devices

To build the Heed devices, we used a circular soft-potentiometer that consumed relatively less power than capacitive touch, thus extending battery life at the expense of expressivity. In addition to this linear touch sensor, the Heed device consists of a microcontroller, a Bluetooth Low Energy (BLE) module, and an LED. We used an off-the-shelf low-power BLE + microcontroller module [41]. Fig 1 shows each of these components laid out on a table. The devices were optimized for low power, going to sleep at night and after a report was made. To minimize the space requirements, we designed our own Printed Circuit Board, integrating all the components in a small form factor. The code was written and uploaded to each device using the Arduino IDE.

We chose a round shape for the device for aesthetic reasons. The small form factor limits Heed to providing seven touch points, which is adequate for reporting using simple constructs such as a five-point Likert scales. We chose wood as the material for the enclosure for two main reasons. Firstly, wood is reported to inspire a perceived sense of durability [25]. Secondly, we received positive feedback about the aesthetics of the wood enclosure during our iterative design process. The wood enclosure was overlaid with a button map printed on glossy sticker paper,

Fig 1. (Left) Individual components of each Heed device include a circular touch-sensitive soft-potentiometer, LED, a micro-controller with an integrated BLE module, and a custom designed Printed Circuit Board. (right) The Heed devices used in Study 1.

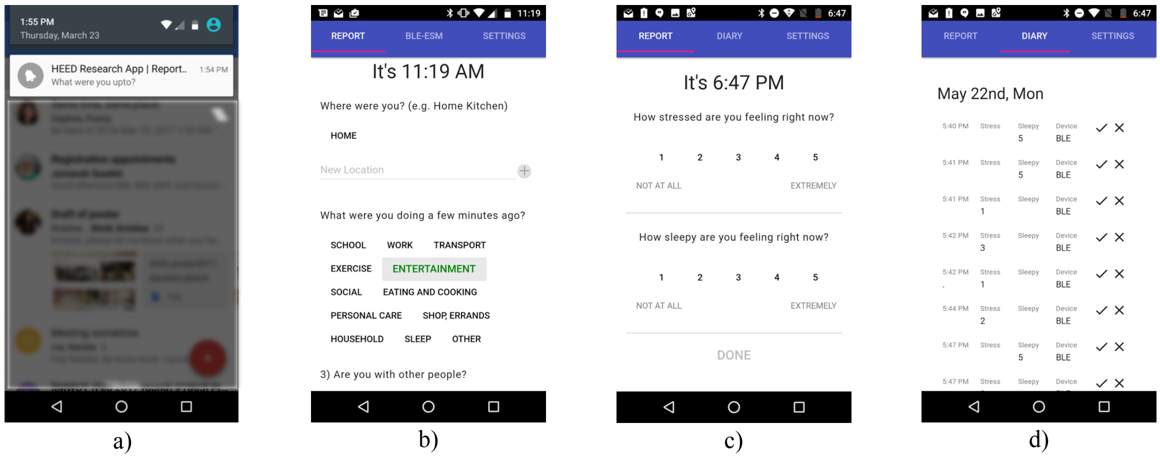

Fig 2. (a) Notification from the Heed app. (b and c) The reporting interface of the app for Study 1 and Study 2 respectively. (d) end-of-day diary interface on the mobile app

allowing it to be easily customized for the intended self-reporting task. A laser cutter was utilized to prepare the wood and paper parts of the enclosure.

The final design of the Heed device allows the researcher to customize the enclosure to the specific application of self-reporting by printing a customized overlay. That said, within the context of a particular study, a disadvantage of Heed's design is the lack of flexibility offered by the interface (by comparison, a smartphone screen can dynamically change to offer different self-report options). We note that such constraints are mostly due to the cost and energy requirements of Heed and could be circumvented by other SSR devices that offer dynamic displays (e.g., LCDs).

Heed devices are meant to be located in the most visited spaces of the user. To provide users with flexibility in where the devices are placed, we designed Heed to be compact and to run continuously, without needing the user to charge it for the duration of the study. In our initial exploration of materials and the physical design of Heed we sought a sweet spot where the devices were neither too ambient (where they could be ignored) nor too distracting (where they would become an annoyance). We also designed Heed devices to sync with the user's smartphone via Bluetooth for two reasons: a) it allows the device to trigger notifications only when the user is nearby and b) it allows the device to sync in real time.

An envisioned application for Heed is its use for self-reporting over measures that require a single touch interaction, such as those that ask the user to report on a 5-point Likert scale. For instance, if the intended application is eliciting stress levels from users, the touch-point labels on the Heed device may correspond to the value of the stress levels (1-5) that need to be given as response options to the user.

3.2.2 Heed Phone App

The Heed app is designed to perform four main tasks: a) allow self-reports to be made on the smartphone, b) collect the user's location, c) collect end-of-day diary entries from the user, and d) manage Heed devices. Notifications to self-report remain visible for one minute and then disappear (Fig 2). The app tracks the user's location every five minutes in addition to whenever an action is performed. The app connects with and syncs data with nearby devices. It can trigger or schedule a notification on the Heed device. The app also allows the user to configure the time window within which notifications can be made, and researcher to configure other study-relevant parameters.

The general flow of the reporting interface of the app is designed to look similar to other self-reporting app interfaces (e.g., [5,16]). When the app is opened, the interface presents the questions that the participants are expected to answer for the active study. For example, in Fig 2 (c), participant is asked to report their stress and sleepiness on two 5-point Likert scales.

The app also has the ability to provide the user with an end-of-day diary interface (Fig 2c). The diary interface can be used by the user to verify the data they provided throughout the day, as well as share any overall comments or feedback with the research team. The tool is always available to the participants and allowed them to remove any invalid responses. The data from the Heed devices is displayed on the diary as soon as the devices finished syncing with the database via the mobile app. In our evaluation studies, the end-of-day diary data helped us to verify if the Heed devices and the smartphone application were working smoothly.

The mobile app software is written in HTML/JavaScript using Cordova libraries [42]. The software requires Internet connectivity to transmit participants' reports and other system logs. The app relies on background services to monitor and synchronize with the Heed devices, thus restricting its use to smartphones with Android OS, which allows such background services to run continuously.

4 EVALUATION

To evaluate Heed devices, we conducted two one-week-long studies with 10 and 7 participants (Table 2). The rationale for using two studies was to explore the use of devices for reporting different constructs that required different types of responses. Stress and sleepiness may be reported on a Likert scale, while activity reporting requires multiple options. All participants were selected for the one-week study based on their smartphone's compatibility with our apparatus (any version of Android 4 or later was allowed).

The incentive for participating in either study was $65 for seven days of reporting. Participants were notified every 45-60 minutes on the phone and/or on all nearby Heed devices depending on the study condition. Participants could also choose to initiate a report on either the app or a device at their own discretion. The self-reporting interface on the phone and the device was disabled for 30 minutes after each report. At the end of each study day (9pm), participants were notified via email to verify their reports using the end-of-day diary interface on the smartphone app.

At the end of the study, all participants were asked to return to the lab for a follow-up interview. During this in-depth semi-structured interview, participants were asked about their overall experiences, their device preferences, and how their preferences might have changed throughout the study. We also asked participants to answer a post-study questionnaire that asked them to evaluate certain characteristics of the two device types (phone and Heed), including the comfort of use, the effect on social interactions, the effect on their stress levels, and the likelihood of future use.

Table 2. Details of the two studies

	Study 1	*Study 2*
Self-reporting measures	Activities and Social	Stress and Sleepiness levels
Interaction type	Activities: Select from options Social: Tap if with people	Likert scale (1-5)
Study design	2 days only Phone 2 days only Heed 3 days both Phone and Heed	7 days both Phone and Heed
Number of Heed devices per participant	5	3

4.1 Study 1: Activity and Social Context Reporting

For the first study, we recruited 10 participants for a one-week evaluation. The study was conducted between April and May 2017. We asked participants to report on two commonly tracked measures ESM studies (e.g. [20]). : a) the activities they were doing, and b) if they were with other people. Moreover, reported activities provide deeper insights into the context in which a device or smartphone was used.

During the initial interview, we asked participants to reflect on where they spend most of their time. Each participant was provided with five Heed devices, four to be located in their frequently visited locations and one to be carried with them when possible. We then guided them to choose the locations where they would place the devices (kitchen, bedroom, etc.) and the activity labels on the devices, relevant to those locations (e.g. bedroom-> sleep, personal care, entertainment, etc.). We then customized the five devices for each participant by printing the overlay for each device on sticker paper. Each overlay, consisted of seven buttons, 5 buttons were labelled as the activities that user decided for the location of that device, one as "other", and one as "with people". In our backend, each device was mapped to a single location and the buttons on the device to the list of activities as printed on the overlay. Participants were asked to report either during an activity or at the end of an activity. If they had begun a new activity and it had been less than 15 minutes, they were asked to report the previous activity. Participants could also report their "Sleep" right after they woke up.

On Heed, the users reported their activity by pressing the button with the label of their activity (Fig 3). The activity labels were adapted from prior literature [1]. On the phone, participants were instructed to report their location with room-level granularity (e.g. home-bedroom). Fig 4 compares the reporting interface on Heed and Phone. The capabilities offered by the phone interface differed from the Heed device in a few ways. First, it was able to display all possible activity options while Heed devices displayed 6 activities selected by the participant during the initial interview. Second, there was an additional prompt on the app asking for the room-level location of the user. The location prompt was not necessary on the Heed devices as they were situated in one given location.

We decided to keep the total duration of the study to be 7 days as it allowed the devices to function normally without needing another charge. We divided the study duration into three phases. For the first phase (~2 days), participants reported only via their smartphones. In the second phase (~2 days), participants reported only via the Heed devices. In the third phase (~3 days), participants had the option to choose between the smartphone and the devices when reporting. This distribution of days was selected for qualitative purposes to help participants distinguish between the use of smartphone and Heed.

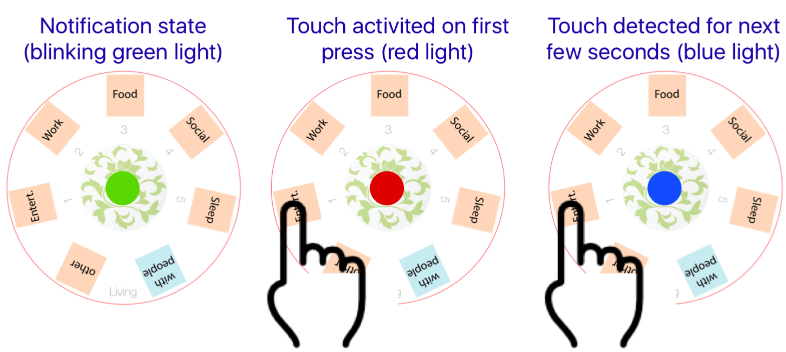

Fig 3. In Study 1, users reported their activities by pressing the button with the label of their activity. They reported their social context by pressing the button with the label "with people" if they were with other people.

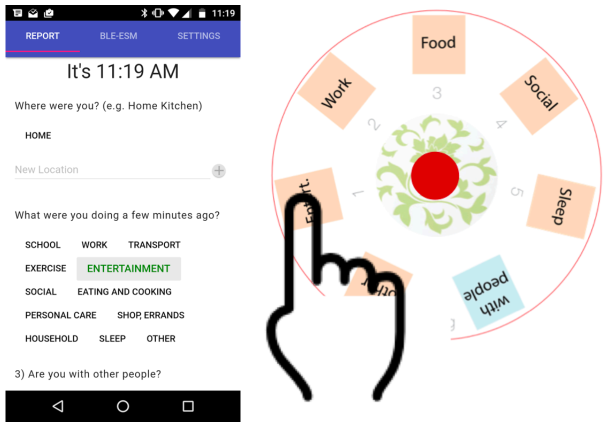

Fig 4. Comparison of the self-reporting interfaces used in Study 1, on smartphone (left) and the Heed device (right). Participants reported their recent activity and whether they are with people.

4.2 Study 2: Stress and Sleepiness Reporting

In the second study, we recruited 8 participants for a one-week evaluation. The study was conducted between May and June 2017. Each participant was provided with three Heed devices to be placed in three of their most-visited spaces. We asked participants to report on two measures: stress and sleepiness. Stress and sleepiness are commonly tracked in ESM studies [20,35]. We used a five-point Likert scale for the two constructs as suggested in prior works [16,35]. The interfaces for stress and sleepiness reporting on Heed devices and smartphones are shown in Fig 5. The interaction with Heed device involved tapping the measure (stress/sleepy) and a value from 1 to 5 (Fig 6). Similar to the first study, we asked participants to reflect on their most visited spaces and guided them to choose locations where they might place the three devices. All participants decided to place one device

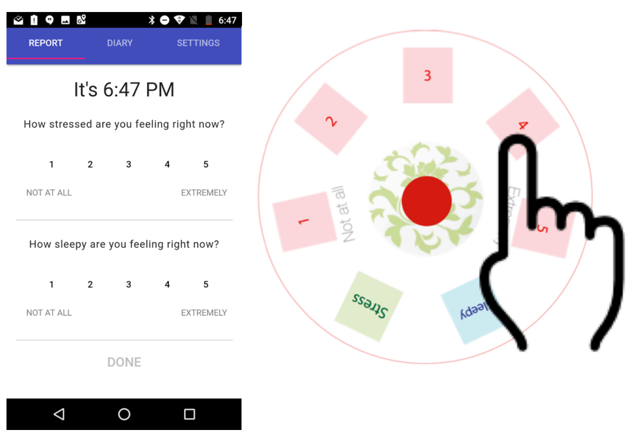

Fig 5. Comparison of the self-reporting interfaces used in Study 2, on smartphone (left) and the Heed device (right). Participants reported their stress and sleepiness levels.

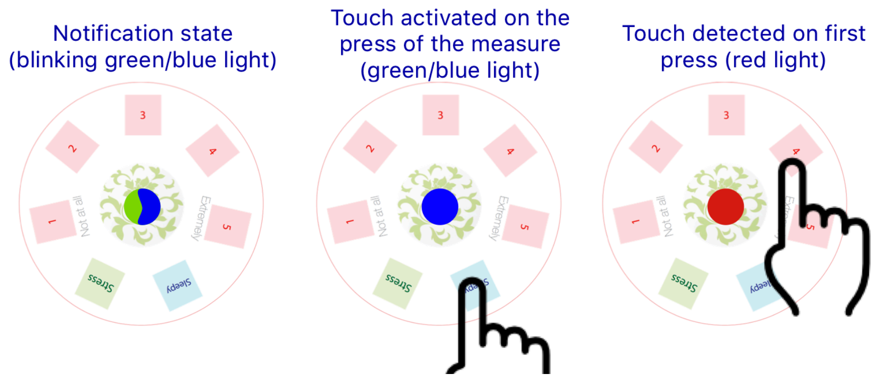

Fig 6. In Study 2, users reported their stress and sleepiness reporting by first pressing the measure and then a number indicating their level

near their office desk. All except one participant placed two devices in their home (the exception placed one device in his car and one at home).

5 DATA ANALYSIS

In-depth semi-structured interviews were conducted by the first author with all 17 participants. Each interview lasted approximately 45 to 60 minutes. The qualitative data analysis harnessed open coding and thematic analysis techniques during the first stage of reading the transcripts [10,22]. Such a strategy allowed us to construct participants' daily experience with the Heed devices and the smartphone application on their own ground. Three members of the research team read transcripts while listening to audio-recordings in an effort to reflect the on-site presence and participants' context in the analysis process. We highlighted meaningful statements and noted spontaneously emerging thoughts in the margins of the transcripts (bracketing [31]). The purpose of this practice was to help us reflectively set aside our prejudices or preconceptions regarding Heed and the smartphone application usage and to attain a certain level of "neutrality" during the analysis process [14].

During this process, we extracted 156 meaningful statements and created notes for each of them. Each memo contained participants' feedback, memorable experiences, and thoughts for further improvement, with regard to the Heed device and the smartphone application. In another round of analysis, coded data were grouped under themes using affinity diagrams [34].

5.1 Participant Overview

Participants ranged in age 18-35 in Study 1 (7 male, 3 female) and 26-55 in Study 2 (4 male, 3 female). Study 1 participants were all graduate students and Study 2 participants varied in their occupation with 2 graduate student interns and 5 working in the administrative department of a university. One participant (not included in the 7) dropped out of Study 2 as she had privacy concerns about leaving her Bluetooth and GPS switched on at all times. Two participants reported having participated in ESM studies before. Five participants reported having done some kind of self-reporting in the past for personal reasons. Almost all participants reported that they kept their smartphones in silent or do-not-disturb mode in their natural use. One participant reported changing the notification mode for the study so that she could report more. Most participants in Study 1 mentioned that they would like to decrease the time they spent on the phone and would not like to use it while working.

Table 3. Overall Report frequency and Compliance rates in the two studies

	Report Frequency (reports/day)		Compliance Rate (reports/notifications)	
	M	SD	M	SD
Study 1	11.53	5.35	19.36%	0.13
Study 2	9.79	6.68	28.93%	0.15
Study 1 (Heed)	7.63	5.24	11.05%	0.06
Study 1 (Phone)	3.9	2.22	8.30%	0.07
Study 2 (Heed)	4.17	2.8	15.52%	0.13
Study 2 (Phone)	5.62	4.31	13.40%	0.1

6 RESULTS

In this section, we first provide an overview of the number of reports obtained in the two studies, and the report frequency and compliance rate. This is followed by the themes that emerged in our qualitative analysis. Specifically, we found that Heed was preferred by users for self-initiated reports. Additionally, Heed's attributes and proximity to the user affected response from Heed. We also describe how location affected self-reporting from both phone and Heed. Lastly, we report cases of unexpected use of Heed. Each theme is supported by participant quotes. The participant identifiers are in the order of their participation, so P1-10 were in Study 1 and P11 to P17 were in Study 2.

6.1 Overview of Participants' Reports

Participants reported 346 (229 Heed and 117 Phone) times in Study 1 and 411 (175 Heed and 236 Phone) times in Study 2. There were 78 prompted and 268 self-initiated reports for Study 1, and 265 prompted and 146 self-initiated reports for Study 2.

We calculated the *report frequency* for each participant as the average number of reports made per day of the study condition and the *compliance rate* as the ratio of reports made to the notifications received (Table 3). The total duration of the analyzed data (conditions where both Heed and phone were used simultaneously) was 3 days for Study 1 and 6 days for Study 2. For Study 1, the average reporting frequency was 11.53 (SD=5.35) and the compliance rate was 19.36%. (SD=0.13). For Study 2, the study lasted 6 days over which the average reporting frequency was 9.79 (SD=6.68) and the compliance rate was 28.93%. (SD=0.15).

In the post-study questionnaire, we compared participants' scores for Heed and smartphone for the following characteristics: the comfort of use, the effect on social interactions, the effect on their stress levels, and the likelihood of future use. We received much feedback on the physical form factor and choice of materials of Heed. The overall feedback was positive, with a few exceptions. The choice of LED light for notification elicited feedback from participants, with many of them suggesting the use of sound in the future. We do not go into detail regarding such findings as we wanted to focus on findings that are the most relevant to a broader set of SSR devices.

6.2 Preference of Heed for Self-Initiated Reports

One of our motivations was to know if physically situated Heed devices would elicit more responses because their physical presence would act as a trigger for users to report. In Fig 7, we compare the report frequency of the respective devices when they self-initiated their reports. Although, the differences between the two studies (duration, number of Heed devices, self-reporting measures) make it difficult to make any generalizable claim that one device was more preferred than the other, we highlight some important findings. In Study 1, we suspect two

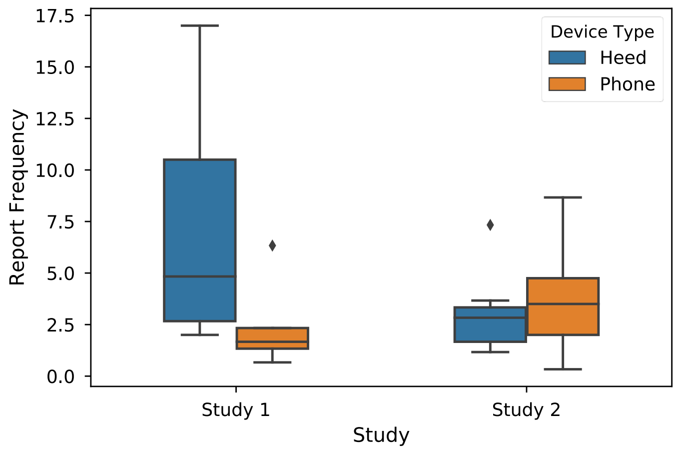

Fig 7. Comparison of report-frequency between devices when the user reported at their own discretion in the two studies. In Study 1, the report frequency from Heed devices was higher than the report frequency from smartphone.

main reasons for a higher report frequency via the Heed devices when users self-initiated reports, that is without being prompted. We describe them next.

Heed devices serve as physical reminders

Qualitatively, we found that the Heed device served as a physical reminder. Several participants mentioned that they self-initiated from Heed devices because the physical presence of Heed reminded them to report. For instance, P15 noticed the devices while going from one room to another and that prompted him to report, "*I might have been doing laundry. On Friday I worked from home, so I might have been on my way to let the dog out or something like that. But I would notice it right away and go, "Oh, okay. I should touch it."*" P7 explicitly mentioned, "*I see them around the house, which is, I guess, a more physical reminder [as compared to phone]*." Many such instances strengthen our claim that SSR devices can act as triggers for users to self-initiate reporting.

Attitudes towards phone use affected Heed use

The report frequency of Heed devices was greater than that of smartphones in Study 1, but similar to that of smartphones in Study 2. There could be two reasons for this. First, this may be explained by the difference in participants' attitude towards each device. We observed their attitudes by looking at their responses in the pre-study and post-study questionnaires when asked about their preference on the future use of each device. In the post-study questionnaire, participants in Study 1 (M=2.9, SD=1.1) scored smartphones lower than participants in Study 2 (M=4, SD=0.82). Moreover, in the pre-study questionnaire, many Study 1 participants qualitatively reported that the use of smartphones was something that they would like to reduce in their daily life. For instance, P6 said, "*Yes. I try to stay away from it[phone] during office hours: 8 am - 5 pm, Monday - Friday.*" This attitude towards smartphone use was absent from participant responses in the Study 2 pre-study questionnaire, where participants reported using their phones quite frequently without wanting to reduce usage. For instance, P13 said, *"I look at my phone at least every 15 minutes, except for during some blocks of time at work when I am in meetings.*" We suspect that because Study 1 participants were trying to reduce phone use, their tendency to report from Heed was higher. Second, the difference could potentially be attributed to the fact that the number of Heed devices given to each participant in Study 2 was less than the number of devices given in Study 1.

6.2 Influence of the Attributes of Heed on Self-Reporting

Our participants noted two attributes of Heed that affected self-reporting. These attributes include micro-interactions afforded by Heed and the single-purpose nature of Heed compared to the multi-purpose nature of smartphones. In what follows, we describe how these two attributes affected the use of Heed.

We found that the design of Heed was favorable for brief non-disruptive interactions (a.k.a. micro-interactions [17]) which lowered the interaction burden. While the smartphone app required the participants to tap the notification first and then initiate the report, Heed only required the participants to tap once to report. As expected, many participants noted this difference in the interaction as Heed required less time to self-report with and was thus, considered to cause lower interaction burden. For instance, P7 noted that Heed devices offered a smoother interaction as time and effort involved in accessing the interface was less when compared to the phone, "*On the phone, I had to physically open the app. I had to navigate through the screen to get there. With this device, it's just there."* On the other hand, P7 also noted that the phone interface is burdensome because it required the user to move between applications or open the app: *"if I'm using my phone and I need to report... that means I have to leave whatever I'm doing. Or if I'm not using it to do the whole motion of opening it up and everything again."*

The presence of micro-interactions also lowered the access time on Heed as compared to a phone, which made Heed more preferable when participants wanted to report when they were engaged in focused work. Several participants pointed this out and gave different reasons related to Heed's attributes. For example, P17 mentioned that interaction with phone was more complex than Heed, which makes him not want to report using phone when he is working: "*(Heed device) is always turned on and on your face. It's just asking for you to do reports. Just click it, done. A phone is a much more complex device compared to that. On a phone probably, I will not do it… I think for work this (Heed device) is amazing.*"

Another attribute of Heed that participants noted was its single-purpose nature. For instance, P2 highlighted how the single-purpose nature of Heed made it less disruptive for use during work: *"I really like entering on the device like this… (Heed device) is already on my desk, I can see the light flashing sometimes, and if I'm focused on work, it doesn't distract my attention by leading me to check other activities on my phone."* On the other hand, she described the multi-purpose nature of the smartphone as distracting when she was trying to focus on her work *"You know, once you check on the phone, or once your interest is on the phone, you end up checking other stuff on the phone as well."* The multi-purpose nature of smartphone also resulted in situations when user's current activity was too important to be distracted from. For instance, P15 reported ignoring notifications on the smartphone when he was trying to reach his partner or get some work done: *"On the phone it was usually like, "Oh, I see this notification, but I have another thing I need to use my phone for right now so I'm going to ignore it." I'm trying to do something at work or I'm trying to get ahold of my partner or something like that. I would just ignore it, blaze past it and go into whatever task I was doing."*

The social context which showed a greater use of Heed was when participants were alone (Fig 8b). Some participants noted that when they were with friends, they were likely to "zone out" and forget about the existence of the Heed devices. For example, P17 stated that he preferred to use the smartphone when he was with his friends, but he reported much less often in such situations, while he reported using Heed a lot more at work when alone. Moreover, we observed that activities that were reported to be done alone such as "Food" (eating) and "Personal Care" were also reported mostly using the Heed devices (Fig 8a). This further suggests that perceived burden to report on devices may vary based on the activity of the user. While such skewing of self-reports may not be desired by researchers using ESM, the uneven distribution of self-reports across activities also exists for smartphones [6].

6.3 Influence of Device Proximity on Self-Reporting

Situations when users preferred Heed included those when the phone was not available nearby. Several participants pointed out cases when their phone was charging, and Heed happened to be nearby. In P14's case he had to choose between going downstairs or choosing the nearby device: "*I was [watching some TV] on my couch, and the device was on the coffee table and I saw it blinking. And my phone was downstairs. This walking distance is less than going down. I took this device and just recorded from there."* Similar instances of the smartphone not

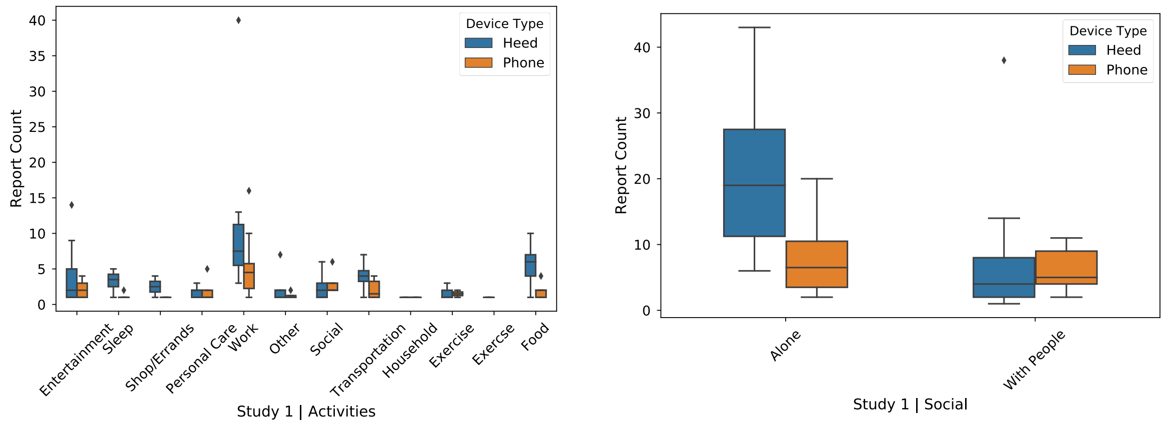

Fig 8. a) (Left) Distribution of reports in Study 1 for each activity. b) (Right) Distribution of reports for the social context reported as being with other people. Reports from Heed devices were found to be higher when participants were alone

being around may also occur when a participant has moved from one place to another: "*Like when I'm at my desk, my phone might be on the bed. But, I tended not to move the [Heed] device around then. So, the device was good then, in such situations.*"

In Study 1, we expected that participants, even while moving around, might find using Heed devices to be more convenient than using smartphones because of the shorter access time. Although we found this to be true in some cases where participants noticed the device in their pocket and were reminded to report, we found that most participants found carrying an extra device for self-reporting to be redundant. For instance, P5 said, *"what makes the device redundant is [that] I'm always having my phone when I'm outside my room, so I just find it like painful to, like, report on a separate thing as opposed to a phone, but then, like, in the bedroom, I'm almost like, I don't sit with the phone in my pocket, so like the [Heed] device is more convenient."* Such anecdotes strengthen our claim that Heed devices were advantageous in certain situations, while Phone is preferred more in other situations. The majority of the participants preferred Heed when they were in one place and smartphones when they were moving. P15 stated this in her own words: "*I think they're really complementary in [the Heed devices] being stationary somewhere and then the phone being the piece if I'm like away for an extended period of time. They're extremely complementary. Where I would probably be less prone to use [the Heed device] is if this was to travel around with me.*"

6.4 Influence of Location on Self-Reporting

To be useful, self-reporting devices must have good coverage of contexts such as location. Our quantitative analysis showed a noticeable difference in reports made in the bedroom and bathroom with the report frequency via Heed being higher than via smartphone (Fig 9). There was high variability in the report frequency among participants across indoor locations. Qualitatively, we found that the visibility of the Heed devices, the size of room, and the space use patterns of the user can be attributed to the variance in the reporting behavior in different indoor locations.

Certain locations favored the use of Heed devices due the relationship between user's space use and the arrangement of artifacts (furniture, appliances, etc.) within that location. For instance, P4 reported that the Heed

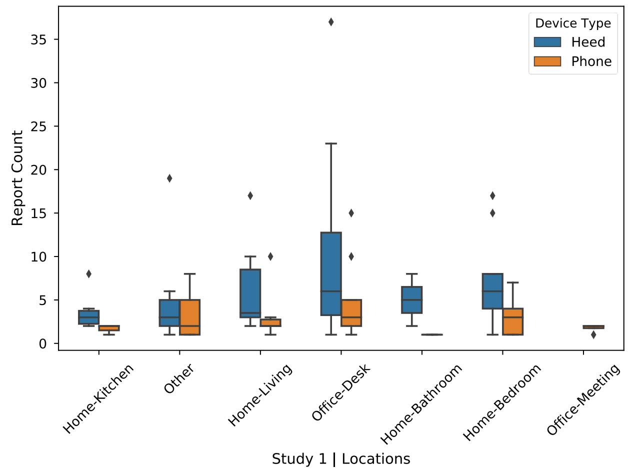

Fig 9. The distribution of reports in Study 1 across different locations. Locations that were not in one of the above categories were categorized as Other.

devices were easy to find when they were in the line of sight: *"The one on my desk is right in front of me just below the monitor, I'm always seeing it. The one in the bedroom is right next to the bed, next to the mirror and I use the mirror … It was in an ideal location, so I always saw it."* In another instance, P2 mentioned that devices were also likely to be found when they were within the peripheral vision: *"Basically I will see it out of the corner of my eye, if I'm looking at my second screen. (I have two screens at home.)"*

On the other hand, the smartphone was reported as sometimes being out of the field of view, which increased reliance on Heed. For instance, P7 found Heed devices more accessible than her smartphone when she was at work, as she would often forget her smartphone in her jacket pocket in another corner of the room: "*Oh, I guess the phone is more often out of the field of view. Sometimes I will leave it in my pocket, in my jacket just leaving it hanging there, not near me but at the corner of the room. Yeah, but the device, the BLE device is always there at the corner of my desk."*

Heed devices were also used more when placed in a frequently accessed space. For instance, P14 mentioned using his device at his desk more as it was placed in an area that was accessed a lot and also had good visibility: "*[Heed device] was on my table… I keep my laptop here, and on the left, these are my snacks and everything else… Having the device in an area where I would generally go to control stuff or probably do something, as I thought that would the most obvious place that I would take notice of the notification, so I kept it there."* Furthermore, spaces that were visited frequently, especially during the transition from one room to another, also made good locations for Heed devices. For instance, P15 said, "*Essentially, I have a little ledge that separates our living room from the hall, but we still have our bedrooms. That ledge also has a staircase next to it, which leads down to my maker space. So, I pass that ledge when I'm at home like 50 times every day, not every hour. So, I'm always walking by it so it's really easy to just always log everything from that."*

A characteristic of the room that was found to influence device preference was the size of the room. It was noted by some participants that it was easier to use Heed in smaller rooms than in larger rooms. For example, P5 noted: *"…especially my living room and kitchen were just much bigger. So, it's hard to have a stationary device [that] I won't remember to see in which case the phone worked better… But then in my bedroom, because it's much smaller and I could see the device from almost any angle and the green light. So, the device worked better in the bedroom."*

We found that users decided to move the Heed device to a more suitable location after having experienced its use in their daily context. For instance, P4 initially decided to move the device to a new place after realizing that the initial placement was not in line of sight *"Actually, it was originally here because I thought if I'm standing here like microwaving something I can see it. [I thought] if I'm sitting here I can see it but it turns out I can't. I moved it here because this is the sink and I can still see it from [where I'm sitting]."*

6.6 Unexpected Social Consequences

In describing their experiences of using Heed, participants noted its social consequences. Several participants mentioned that Heed devices attracted the attention of their friends, family and officemates. In some cases, others would remind the participant to report or reporting on participant's behalf. For instance, P13, who lived with her family, mentioned that the blinking notification on the Heed device turned into a family event: "*One of the times I was outside doing yard work over the weekend, and my partner ran outside with one and was like, "The light is flashing." It was so funny. So the whole family got involved. So I pressed the button and the device was brought back inside.*" In another instance, participants' acquaintances reported on behalf of the participants. For instance, P15's partner noticed the device notification and then reported on her behalf "*Oh, yeah. Actually, one time my boyfriend was in the bathroom and he was like, "Your device beeping." So I actually told him, "Why don't you just report for me so it stop beeping." Yeah. So I just told him, "Why don't you hit the ...," So I basically I told him to choose this option, the one that I was doing."* Here, the participant referred to the "blinking" notification light as "beeping."

In some cases, having novel physical devices created unintended tension and added stress to participants, mainly due to concern about how the devices might be perceived by others. This concern was shared by three participants, all of whom were international students. P11 was hesitant to place the device where everyone could see and instead placed it to the side where it was less noticeable to others: *"[It's an] electronic device. You would see people putting tapes on their webcams these days. People are so conscious of their privacy and all that, so I didn't want them to suspect that I have some device capturing anything in the office."* A similar issue seemed to cause a severe reaction from P6, who was nervous about carrying or using Heed devices in public spaces due to the fear created by the socio-political climate at that time: *"Completely unreasonable, I guess, but I had this panic attack. I just want to remember when was it. I can't remember if it was when I was on the bus, or when I was in the workshop, but I had this moment of a sort of a panic attack. It was me thinking, "I am basically using this conspicuous device and pressing it in the middle of a crowded room, and I am a brown man. Are people going to think I am trying to set off a bomb here? I hope not."* A similar sentiment was shared by another foreign student from South Asia (P5): "*I was being very conscious about was like especially yesterday, I was initially going to take the device on the train, but then like because this is like this handmade device, and like you know, considering that someone freaked out about a bomb scare with like the university professor solving a math equation, I was kind of like a bit worried about carrying it with me."* P5 was worried about openly using the device in the train because of the apprehension that the appearance of the device might lead to it being mistaken for an undesirable and unsafe gadget.

7 DISCUSSION

Our findings show that Heed devices are a viable tool to have in a toolbox of self-reporting approaches as they complemented the use of smartphones for self-reporting in nuanced ways. Such nuances were governed by the context of use of both these tools. While the smartphone was preferred in situations where the user was moving around or already engaged in certain smartphone activities, Heed devices were preferred when the user was at one place for a longer duration of time, and also when the user was engaged in focus work. User's engagement levels indicated they didn't want to be distracted by email or other social communication, which is inevitable on phone but possible on Heed devices.

Additionally, the findings of our study highlighted the effect of certain design choices (Table 1) on the overall use of Heed devices. For example, the minimal form factor and the low-power design of Heed devices allowed users to place them in their surroundings with ease, allowing for the Heed system to be distributed. This revealed participants' preferences for location of Heed devices that could be generalized to many SSR devices; that is, SSR devices are preferable to smartphones when they are in the field of view, within arm's reach, in infrequently visited spaces, and in small spaces.

Similarly, the situated and physical presence of the devices affected the use of Heed devices. Their visibility often triggered users to self-initiate reports via Heed leading to a much higher report frequency in Study 1. That is, the placement of Heed devices affected how aware the users were of the devices and this awareness reminded users to initiate self-reports. The physical visibility of Heed devices also meant that they were visible to user's acquaintances and thus, led to incidents of shared use when friends reported on behalf of the primary user. While such shared use may be considered positive for shared reporting tasks (e.g., family-related tracking), it has the potential to cause privacy-related issues. For example, if the reporting task is related to chronic health conditions, their use of such a device might reveal their health issues when they might not want to.

Our findings have implications for SSR devices, multi-device environments, and lessons for researcher using SSR devices for data collection, which we discuss next.

7.1 Implications for Design of Situated Self-Report Devices

Many themes emerged after characterizing how our participants used the Heed devices and their smartphones to complete the self-reporting tasks. The ways in which they used these devices are indicative of how self-reporting devices should be designed, keeping in mind the actual practices of users. We present these themes as four key lessons to guide the design of SSR devices.

Design or choose self-reporting tools that are suited for your participants

We saw that the patterns and preferences of smartphone use affected when users may choose to respond or ignore notifications or may choose Heed devices over smartphone and vice versa. Such patterns and preferences affect self-reporting and the data that is generated. For instance, if a researcher wants to study the relationship between anxiety and social media using a smartphone-based ESM tool, the self-reporting behavior may be subject to the level of engagement they have in social-media consumption, thus affecting their likelihood of ignoring or attending to the ESM notification. Ignored notifications may be programmed to return, but such behavior of the app may annoy a user, affecting future participation in the study. It is during such situations that SSR devices might complement smartphone use. That is, if the user is deeply engaged in a task on the phone, the low interaction burden and single purpose nature of SSR devices could incentivize the user to report using Heed device without excessively disrupting their task on the phone. Similarly, one may imagine the use of SSR devices in this hypothetical situation - assuming children spend a significant amount of time in their bedrooms, they may be less likely to ignore a particular ambient light on a device soliciting them to touch one of the buttons.

A user's perception of a self-reporting device and constraints to use these significantly affects the preference for that device for self-reporting. For example, in this study, we saw that a disinclination to use phone resulted in using Heed devices more in Study 1. Similarly, mobility constrained the use of Heed devices and participants preferred using smartphone when moving. ESM studies focusing on special populations such as children and elders could consider such preferences and constraints before deploying their tools for ESM studies. For example, doing a study with children may be impossible with smartphones given that smartphone use is often restricted during school hours. However, using an SSR device would allow researchers to solicit information from children on simple constructs in a relatively less intrusive way.

Leverage multi-device strategies for relevant measures

Given the ways in which phone and Heed devices were complementary for self-reporting, in many cases a multi-platform approach may be more desirable for ESM studies. For example, an activity-labeling study, similar to our Study 1, may leverage phones or smartwatches for activities during movement, while it could use SSR devices for indoor activities, especially when the devices are likely to be in the field of view of the user (e.g. on the desk at work, in the bedroom or in the bathroom). These kinds of multi-device self-reporting approaches complement each other.

Multi-platform experiences intend to provide users with the most convenient way to accomplish a task within their current context [13]. For instance, smartwatches work best for people who wear them in situations where taking out a smartphone and navigating through its interface is too much of a burden. The notion of SSR devices intends to build on the multi-platform paradigm, imagining their use specifically for self-reporting tasks. Home assistant devices such as Alexa and Google Assistant are increasingly being adopted in users' homes, and such situated devices may be used as effective SSR devices, offering an avenue for further study.

Allow for flexible placement and re-placement of devices

The use of SSR devices for real-world studies depends greatly on where they are placed in the physical environments of users. SSR devices may be well used when participants expect to spend time in a stationary environment and the devices can be found in frequently accessed or frequently visited spaces. Such placement of the devices can leverage an important advantage of such devices over smartphone; that is, their physical form serving as a reminder to initiate a self-report. Moreover, our findings suggest that users learnt their device placement preferences as the study progressed. SSR device placement may not be perfect initially and hence researchers may allow "pilot" time for their users to better understand their preferences for device placement. Although such constraints may add some burden on the researchers, understanding such constraints for any self-reporting tool can greatly benefit ESM researchers in improving the quality of self-reports. Allowing for the relocation of SSR devices during the course of a study may have methodological implications that would have to be addressed in future studies.

Unintended consequences may or may not have a positive impact on the reporting behavior

The physical presence of SSR devices makes them visible to anyone in the space of the user. This may lead to unintended consequences for the user's reporting behavior. Certain social situations may have positive impacts, as occurred in our study; for instance, the partner of a user may notice a notification on an SSR device and then, in turn, remind the user. A user's acquaintance may even report for the user. Although we mainly saw such positive incidents in our study, it is possible that some of the reports may have been made unintentionally by acquaintances. The ability to know if the user is nearby, using the proximity of a smartphone, is a useful feature in such situations to verify who reported from the device.

The social use of SSR devices is also affected by the socio-political climate around the user and may hinder its intended use. The look and feel of a device may then affect how SSR devices are perceived by users and others around them. Systems could pay specific attention to the form of devices, such as making the look of the device more polished under such circumstances.

7.2 Future Directions

We saw a higher use of Heed devices among participants who made an effort to decrease their smartphone use in their daily life. Our findings strengthen our claim that SSR devices are more suitable for people who are inclined to reduce their smartphone use, such as parents on behalf of their children, or elders. However, we cannot be conclusive about such claims without providing empirical evidence. Future studies exploring the use of SSR devices may be used to understand self-reporting behavior of specific populations.

We also note that Heed devices only hint at the potential of creating personalized self-reporting devices. We can imagine many possibilities that are worth exploring; for instance, a plate may be augmented with low-cost touch sensors [38] to conveniently track what is being eaten. We imagine that creating a wide range of self-reporting tools would make it easier for ESM researchers to choose appropriate ones. Such a toolkit will continue to evolve with new technologies and new opportunities to embed sensors in customized objects. Most studies exploring the use of self-reporting tools focus on quantitative results. We recommend that researchers further delve into qualitative data to extract nuanced user perceptions of self-reporting devices.

7.3 Limitations

Our evaluation of Heed devices with the goal of illuminating the design space for SSR devices has several limitations that may be addressed in future work. A one-week study cannot assess the impact of device novelty. A longer duration is necessary to study the use of Heed once the novelty wears off.

Our emphasis on qualitative analysis allowed us to gain deep insights into the use of Heed devices. Our findings also include results from some basic quantitative analysis. Such results provide us with better insight but are limited due to the small number of participants and the short duration of the study.

We also wish to note some limitations of using Heed for other ESM studies. At present, Heed places an extra burden on researchers to build and maintain the devices, thus requiring extra effort from researchers. Another downside of Heed worth noting is the additional effort required in placing the devices for the participants, as it requires thought and effort to understand participants' spatial patterns. We hope that future studies can develop tools and best practices to accomplish this in an easier way.

We also note that we do not claim an overall lower burden of Heed devices in comparison to smartphones. The app did not take advantage of designs that could have reduced reporting time, such as lock-screen widgets [7] or unlock-gestures [32], which could have decreased the access time. Future studies may further unpack the situated nature of SSR devices separately from the interface elements that lower the burden on users to report.

8 CONCLUSION

In this paper, we presented a design exploration of situated self-reporting (SSR) devices. We designed and built the Heed system, an instantiation of SSR devices that are low-cost, low-power, and have a simple form factor. Overall, we show that Heed devices complemented smartphones in their coverage of activities, locations and interaction preferences. Our findings have implications for the design and use of SSR in self-reporting applications.

REFERENCES

[1] Barbara E. Ainsworth, William L. Haskell, Melicia C. Whitt, Melinda L. Irwin, Ann M. Swartz, Scott J. Strath, William L. O'Brien, David R. Bassett, Kathryn H. Schmitz, Patricia O. Emplaincourt, David R. Jacobs, and Arthur S. Leon. 2000. Compendium of Physical Activities: an update of activity codes and MET intensities: *Med. Sci. Sports Exerc.* 32, Supplement (September 2000), S498–S516. DOI:https://doi.org/10.1097/00005768-200009001-00009

[2] Niels Van Berkel, Denzil Ferreira, and Vassilis Kostakos. 2017. The Experience Sampling Method on Mobile Devices. *ACM Comput. Surv. CSUR* 50, 6 (2017), 93.

[3] Elliot T. Berkman, Nicole R. Giuliani, and Alicia K. Pruitt. 2014. Comparison of text messaging and paper-and-pencil for ecological momentary assessment of food craving and intake. *Appetite* 81, (2014), 131–137.

[4] Chris J. Burgin, Paul J. Silvia, Kari M. Eddington, and Thomas R. Kwapil. 2013. Palm or cell? Comparing personal digital assistants and cell phones for experience sampling research. *Soc. Sci. Comput. Rev.* 31, 2 (2013), 244–251.

[5] Yung-Ju Chang, Gaurav Paruthi, and Mark W. Newman. 2015. A Field Study Comparing Approaches to Collecting Annotated Activity Data in Real-world Settings. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '15), 671–682. DOI:https://doi.org/10.1145/2750858.2807524

[6] Yung-Ju Chang, Gaurav Paruthi, Hsin-Ying Wu, Hsin-Yu Lin, and Mark W. Newman. 2017. An investigation of using mobile and situated crowdsourcing to collect annotated travel activity data in real-word settings. *Int. J. Hum.-Comput. Stud.* 102, (2017), 81–102.

[7] Eun Kyoung Choe, Bongshin Lee, Matthew Kay, Wanda Pratt, and Julie A. Kientz. 2015. SleepTight: Low-burden, Self-monitoring Technology for Capturing and Reflecting on Sleep Behaviors. In *Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '15), 121–132. DOI:https://doi.org/10.1145/2750858.2804266

[8] Eun Kyoung Choe, Nicole B. Lee, Bongshin Lee, Wanda Pratt, and Julie A. Kientz. 2014. Understanding quantified-selfers' practices in collecting and exploring personal data. 1143–1152. DOI:https://doi.org/10.1145/2556288.2557372

[9] Tamlin S. Conner, Howard Tennen, William Fleeson, and Lisa Feldman Barrett. 2009. Experience sampling methods: A modern idiographic approach to personality research. *Soc. Personal. Psychol. Compass* 3, 3 (2009), 292–313.

[10] John W. Creswell. 2013. *Qualitative inquiry and research design: Choosing among five approaches*. Sage.

[11] Mihaly Csikszentmihalyi and Reed Larson. 2014. Validity and reliability of the experience-sampling method. In *Flow and the foundations of positive psychology*. Springer, 35–54. Retrieved May 14, 2017 from http://link.springer.com/10.1007/978-94-017-9088-8_3
[12] Anind K. Dey, Katarzyna Wac, Denzil Ferreira, Kevin Tassini, Jin-Hyuk Hong, and Julian Ramos. 2011. Getting Closer: An Empirical Investigation of the Proximity of User to Their Smart Phones. In *Proceedings of the 13th International Conference on Ubiquitous Computing* (UbiComp '11), 163–172. DOI:https://doi.org/10.1145/2030112.2030135
[13] Jens Grubert, Matthias Kranz, and Aaron Quigley. 2016. Challenges in Mobile Multi-Device Ecosystems. *MUX J. Mob. User Exp.* 5, 1 (December 2016). DOI:https://doi.org/10.1186/s13678-016-0007-y
[14] E. G. Guba and Y. S. Lincoln. 1985. Naturalistic inquiry (Vol. 75). *Beverly Hills CA Sage* (1985).
[15] Joel M. Hektner, Jennifer A. Schmidt, and Mihaly Csikszentmihalyi. 2007. *Experience sampling method: Measuring the quality of everyday life*. Sage.
[16] Javier Hernandez, Daniel McDuff, Christian Infante, Pattie Maes, Karen Quigley, and Rosalind Picard. 2016. Wearable ESM: Differences in the Experience Sampling Method Across Wearable Devices. In *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services* (MobileHCI '16), 195–205. DOI:https://doi.org/10.1145/2935334.2935340
[17] Stephen Intille, Caitlin Haynes, Dharam Maniar, Aditya Ponnada, and Justin Manjourides. 2016. μEMA: Microinteraction-based Ecological Momentary Assessment (EMA) Using a Smartwatch. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '16), 1124–1128. DOI:https://doi.org/10.1145/2971648.2971717
[18] Predrag Klasnja, Beverly L. Harrison, Louis LeGrand, Anthony LaMarca, Jon Froehlich, and Scott E. Hudson. 2008. Using wearable sensors and real time inference to understand human recall of routine activities. In *Proceedings of the 10th international conference on Ubiquitous computing* (UbiComp '08), 154–163. DOI:https://doi.org/10.1145/1409635.1409656
[19] Bob Kummerfeld, Lie Ming Tang, Judy Kay, and Farahnaz Yekeh. 2015. SAL: A Small, Simple, Situated, Ambient Logger. In *Adjunct Proceedings of the 2015 ACM International Joint Conference on Pervasive and Ubiquitous Computing and Proceedings of the 2015 ACM International Symposium on Wearable Computers* (UbiComp/ISWC'15 Adjunct), 403–406. DOI:https://doi.org/10.1145/2800835.2800929
[20] T. Lataster, D. Collip, M. Lardinois, J. Van Os, and I. Myin-Germeys. 2010. Evidence for a familial correlation between increased reactivity to stress and positive psychotic symptoms. *Acta Psychiatr. Scand.* 122, 5 (November 2010), 395–404. DOI:https://doi.org/10.1111/j.1600-0447.2010.01566.x
[21] Neal Lathia, Kiran K. Rachuri, Cecilia Mascolo, and Peter J. Rentfrow. 2013. Contextual Dissonance: Design Bias in Sensor-based Experience Sampling Methods. In *Proceedings of the 2013 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '13), 183–192. DOI:https://doi.org/10.1145/2493432.2493452
[22] Kay A. Lopez and Danny G. Willis. 2004. Descriptive versus interpretive phenomenology: Their contributions to nursing knowledge. *Qual. Health Res.* 14, 5 (2004), 726–735.
[23] Akhil Mathur, Nicholas D. Lane, and Fahim Kawsar. 2016. Engagement-aware Computing: Modelling User Engagement from Mobile Contexts. In *Proceedings of the 2016 ACM International Joint Conference on Pervasive and Ubiquitous Computing* (UbiComp '16), 622–633. DOI:https://doi.org/10.1145/2971648.2971760
[24] Chulhong Min, Seungwoo Kang, Chungkuk Yoo, Jeehoon Cha, Sangwon Choi, Younghan Oh, and Junehwa Song. 2015. Exploring current practices for battery use and management of smartwatches. In *Proceedings of the 2015 ACM International Symposium on Wearable Computers*, 11–18.
[25] William Odom, James Pierce, Erik Stolterman, and Eli Blevis. 2009. Understanding why we preserve some things and discard others in the context of interaction design. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, 1053–1062.
[26] K. O'Hara, M. Perry, and S. Lewis. 2003. Social coordination around a situated display appliance. *Proc. SIGCHI Conf. Hum. Factors Comput. Syst.* (2003), 65–72.
[27] Aditya Ponnada, Caitlin Haynes, Dharam Maniar, Justin Manjourides, and Stephen Intille. 2017. Microinteraction Ecological Momentary Assessment Response Rates: Effect of Microinteractions or the Smartwatch? *Proc ACM Interact Mob Wearable Ubiquitous Technol* 1, 3 (September 2017), 92:1–92:16. DOI:https://doi.org/10.1145/3130957
[28] Abigail Sellen, Rachel Eardley, Shahram Izadi, and Richard Harper. 2006. The Whereabouts Clock: Early Testing of a Situated Awareness Device. In *CHI '06 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '06), 1307–1312. DOI:https://doi.org/10.1145/1125451.1125694
[29] Abigail Sellen, Richard Harper, Rachel Eardley, Shahram Izadi, Tim Regan, Alex S Taylor, and Ken R Wood. 2006. HomeNote: supporting situated messaging in the home. In *CSCW '06: Proceedings of the 2006 20th anniversary conference on Computer supported cooperative work*, 1–10.

[30] Saul Shiffman, Arthur A. Stone, and Michael R. Hufford. 2008. Ecological momentary assessment. *Annu Rev Clin Psychol* 4, (2008), 1–32.
[31] Ghada Abu Shosha. 2012. Employment of Colaizzi's strategy in descriptive phenomenology: A reflection of a researcher. *Eur. Sci. J. ESJ* 8, 27 (2012).
[32] Khai N. Truong, Thariq Shihipar, and Daniel J. Wigdor. 2014. Slide to X: Unlocking the Potential of Smartphone Unlocking. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems* (CHI '14), 3635–3644. DOI:https://doi.org/10.1145/2556288.2557044
[33] M. Weiser and J. Seely Brown. The Coming Age of Calm Technology", Xerox PARC October 5, 1996.
[34] Wikipedia. 2017. Affinity diagram. Retrieved November 12, 2017 from https://en.wikipedia.org/w/index.php?title=Affinity_diagram&oldid=772829913
[35] Jessica A. de Wild-Hartmann, Marieke Wichers, Alex L. van Bemmel, Catherine Derom, Evert Thiery, Nele Jacobs, Jim van Os, and Claudia J. P. Simons. 2013. Day-to-day associations between subjective sleep and affect in regard to future depression in a female population-based sample. *Br. J. Psychiatry* 202, 6 (June 2013), 407–412. DOI:https://doi.org/10.1192/bjp.bp.112.123794
[36] Farahnaz Yekeh, Judy Kay, Bob Kummerfeld, Lie Ming Tang, and Margaret A. Allman-Farinelli. 2015. Can SAL Support Self Reflection for Health and Nutrition? In *Proceedings of the Annual Meeting of the Australian Special Interest Group for Computer Human Interaction* (OzCHI '15), 134–141. DOI:https://doi.org/10.1145/2838739.2838752
[37] Xiaoyi Zhang, Laura R. Pina, and James Fogarty. 2016. Examining Unlock Journaling with Diaries and Reminders for In Situ Self-Report in Health and Wellness. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16), 5658–5664. DOI:https://doi.org/10.1145/2858036.2858360
[38] Yang Zhang, Gierad Laput, and Chris Harrison. 2017. Electrick: Low-Cost Touch Sensing Using Electric Field Tomography. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*, 1–14.
[39] Gartner Survey Shows Wearable Devices Need to Be More Useful. Retrieved November 7, 2017 from https://www.gartner.com/newsroom/id/3537117
[40] Discover the Countries Leading in App Usage. Retrieved May 13, 2018 from https://www.appannie.com/en/insights/market-data/global-consumer-app-usage-data/
[41] BLE Nano. *RedBear*. Retrieved November 13, 2017 from http://redbearlab.com/blenano/
[42] Apache Cordova. Retrieved November 14, 2017 from https://cordova.apache.org/

Received November 2017; revised May 2018; accepted September 2018