Evaluation of Challenges in Human Subject Studies "In-the-Wild" Using Subjects' Personal Smartphones

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Abstract
The experimental setting of Human Mobile Computer Interaction (HCI) studies is moving from the controlled laboratory to the user's daily-life environments, while employing the users' own smartphones. These studies are challenging for both new and expert researchers in human subject studies in the HCI field. Within the last three years, we conducted three different smartphone-based user studies. From these studies, we have derived key challenges that we successfully overcame during their execution. In this paper, we present the outcomes and explain the adopted solutions for the challenges identified in the design, development and execution, and data analysis phases during the user studies. Our goal is to give newcomers and junior researchers a practical view on our conducted studies, and help practitioners to reflect on their own studies and possibly apply the proposed solutions.

Author Keywords
Users study; real environment; personal devices instrumentation; solutions and guidelines.

ACM Classification Keywords
H.m. Information systems: Miscellaneous.

Introduction

Users' own smartphones are the gateways for real world experiments for mobile HCI. The understanding of smartphone users' experience is becoming vital in developing new mobile interaction concepts. Traditional methods that rely on controlled laboratory environment (*e.g.*, simulations, users guided experiments, interviews) are moving towards the real smartphone users' daily-life environments. The successful approach for these experiments requires rigorous design, development, execution, and analysis of the collected results, such that important variables and their correlations and causalities are captured and analyzed. Although, there are general basic methods available for conducting experiments in HCI [6], via *e.g.*, observational studies, the use of personal devices such as user's own smartphones and the involvement of the *real human aspect* can create several challenges that were not yet taken into account.

Since 2010¸ we have conducted three different user studies involving a total of 79 participants from the Pittsburgh (PA, USA) area. In each study, the participants were involved for four consecutive weeks. Each participant contributed with data logged on his/her own Android OS smartphone, used in own, heterogeneous daily-life environments. The goals of the studies were different, but all related to indicating the factors influencing the smartphone users' interaction and experience.

For all the studies, we employed research techniques such as Online Survey, Experience Sampling Method (ESM) [13] and the Day Reconstruction Method (DRM) [11]. Online Survey was used to collect preliminary information about the participants, *e.g.*, demographics, experience with the smartphones, and applications used, as well as some baseline, study-specific information, as subjectively expressed by the users, before their participation in the studies. The ESM keeps a condense diary of events relating to a given phenomena, as it is a short, ad-hoc questionnaire presented to the user, either in an event or time-contingent manner or at random through the day (in 'ad-hoc' manner), to reduce the influence of memory effects on the observed phenomena. The DRM implies that the study participants are interviewed on a regular basis, *e.g.*, weekly, to reconstruct the events and experiences relating to a given phenomena along the 24 hours preceding the interview. This enables to collect more details upon the ESM answers and ground truth from the participants with respect to the research phenomena, as well as to resolve any issues with the collected data (*e.g.*, lost, erroneous). In the following paragraphs, we provide the studies' overview, with the corresponding goals, the particular methods applied (besides the ESM/DRM), and the summary of the results.

Study A ("How far is your phone" study, executed in 2010) [4]: The aim of this study was to determine if the assumption used in ubiquitous computing research, that the mobile phone is always on and at-hand is valid for the smartphones generation (replicating the study presented by Patel, S., *et al.* [12]). It involved 28 participants requiring them to wear a Bluetooth tag to determine how far the mobile device was from his/her owner. An application running on participant's smartphones was collecting Bluetooth logs and other phone and context information. Participants were interviewed weekly to collect the ground truth following the DRM. The results are presented in [4].

Study B (QoE study, executed in 2011) [9]: In this study, the influential factors on the user's perceived Quality of Experience (QoE) on Android OS smartphone were investigated. It involved 29 participants and the data collection was made through the different methods: Online Survey, ESM, and DRM. ESM was used to collect data regarding the user's context, location, mobility, and five-scale MOS (Mean Opinion Score) [3,10] values to quantify QoE where '1' relates to the *bad* perceived quality and '5' to *excellent*, representing the QoE after an application's usage. The ESMs were appearing to the user at random through the day, after an application usage longer than 5 seconds. The results were published in [9].

Study C (Intimacy study, executed in 2012) [in preparation]: This study investigated the relation between the user's current intimacy context and his/her willingness to share personal content. 22 participants were recruited with an online survey, where we asked basic demographic, mobile phone usage, and privacy concerns information. Study participants were required to answer random ESMs through the day that were discussed following the DRM approach. The ESM captured their subjective, ad-hoc perception of intimacy and willingness to share content like current location or video given the context, they were in, while answering the ESM. In addition, contextual information was logged from the participants' smartphone. The preparation for the results of the study is work-in-progress.

In this paper, we provide our experiences while performing the three studies. We aim to help newcomers in the field planning and designing some related studies, while providing a practical view on how to conduct user studies. Our goal is not to cover exhaustively *any* possible event that may occur during a mobile user study, but to provide an overview on a set of challenges that we successfully overcame in our studies. Furthermore, we explain the solutions and guidelines we employed to the most critical challenges that we identified.

Method

We divided the analysis of the studies in five main steps. First, we identified for each of the studies the following four phases: study design, development, execution, and data analysis. Each author of this paper conducted at least one of the studies and was in charge to analyze her/his own study for each phase. Thus, each author proposed a set of challenges that she/he encountered in its own experience for each study phase. In the second step, we agreed upon clusters of the most important challenges that were identified. These were put together following the affinity clustering approach. In the third step, we collected these challenges and identified the ones that were common for the three different studies. As the fourth step, each author independently prioritized all the challenges for her/his own study, along the four study phases. Afterwards, we agreed upon a common focus while providing the employed solutions and guidelines. High priority challenges were treated in more depth than the low priority ones. We present these guideline and solutions in the Discussion section together with the observations upon the methods that we have employed.

Results

Table 1 presents the four study phases and the corresponding challenges that we have identified and

clustered as joint between the studies. Each study indicates if a challenge was present with a grey box and the priority of it defined by the study owner (1 = high priority (red/darker), 2 = normal priority (orange), 3 = low priority (green/lighter). The final column indicates the overall agreed priority of the challenge across the studies, that in turn determines the depth, with which it is treated in the discussion section.

In **Figure 1**, we present an analysis of the specificity of the distribution of challenges in the four study phases for the all three studies. We provide an empirical investigation on how challenges are shared among the three studies by providing the percentage of challenges being: study specific (label: 'specific'); common in two studies ('2 Sim.'); and common in all three studies ('3 Sim.').

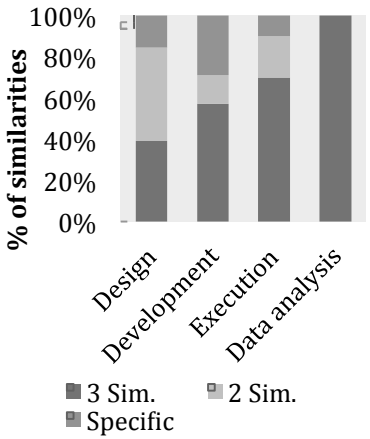

Figure 1. Similarities of challenges in three different user studies, divided between the four study phases.

Discussion: Solutions and Guidelines

The goal of this work is not to provide specific solutions to any kind of challenge the researches may encounter when conducting a user study using subject's personal smartphones "in-the-wild", but to reflect upon a set of challenges and solutions based on the three concrete studies conducted by the authors of this paper in the users' real life environments. As shown in **Figure 1**, when studies are *designed* and *developed*, the set of challenges can be very study specific depending on the goals of the study. For the *execution* and *data analysis* phases the challenges seem to be similar across the set of all the studies.

In this section, we present some solutions and guidelines for the selected challenges in **Table 1**. Due to the space limitations, we cover only the challenges with the highest priority "1" that exist across all the three studies and for each study phase we also cover one challenge specific for each study or a challenge that we believe deserves an in-depth discussion.

Design Phase: (1) *Ethics consent approval*: when designing a study, this is one of the first deliverables. Depending on the country where the study is conducted, the rules may vary. Before proceeding further with the design, it is very important that the ethics committee (*i.e.*, IRB for US) approves the content of the study. Committee observations may ask to change the study method delaying the study, because of its late refactoring. (2) *The enrolment survey*: it should be designed not to reveal the final goal of the study, to not to bias the study recruitment or participation, and at the same time, it must be open enough to involve as many potential participants as possible. The suggestion is to ask indirect questions, *e.g.*, for privacy questions as proposed by Braunstein [2], mostly related to the probable situations that the potential participants encounter daily. (3) *Definition of Variables*: this point is very important and must be treated very early in the design phase, because it defines the set of data that will be collected from the participants and their smartphone. The target definition of the variables influences the *ethics consent*, the procedure on how these variables are collected and by consequence the outcome of the study (in terms of the quality in its results). (4) *Use of the external sensors* (SA only): the challenge was to identify the sensors that could be deployed to replicate the study of Patel [11] as closely as possible; the solution was to contact the original study designers, to borrow sensors used by them, as well as complete the required set with other sensors meeting the hardware/software requirements. Additional challenge was to design of the study such

Ph.	Challenge	Study			P.
		A	B	C	
Design	Ethics consent approval time	2	1	1	1
	Android OS version	2	2	1	2
	DRM items	3	1	2	2
	The enrolment survey	2	1	1	1
	ESM items and scales		1	2	1
	ESM interface		1	3	2
	ESM trigger definition		1	2	1
	Use of external sensors	1			1
	Representative population w/o biasing		2	2	2
	Rewarding participants		2	2	2
	Study replication	1			1
	Target population		1	2	2
	Definition of Variables	3	1	1	1
Development	Developing of specific sensors	1			1
	Data storage	2	3	2	2
	Devices heterogeneity	1	1	1	1
	Efficiency of the logger	1	1	1	1
	QoE instrumentation		1		1
	Recruiting bias	3		3	3
	Study software testing	1	1	1	1
Execution	User cheating vs technical issues		1	2	1
	DRM visualization/interaction	2	1	1	1
	Fix personal bugs	3	1	2	2
	Handling participants' questions	3	1		3
	Par. behavioral change	2	1	3	2
	Participants motivation	1	1	1	1
	Participants privacy	3	1	1	1
	Performance complains	2	1	2	1
	Scheduling interviews		3	2	3
D.A.	Data synchronization	1	2	1	1
	DRM themes	2	1	3	1
	Missing data	1	2	2	2

Table 1. Summary of challenges, Ph. = phases, P. = overall priority, D.A. = data analysis

that it ensures their compliance to study protocol. The solution was to design automated reminders for the users to start wearing the tag in the morning, as well as to design study such that we take time to educate the users along the weekly interviews. This solution was proven to be effective. (5) *Rewarding participants* (SB+SC): the study participants need to receive a reward especially if their participation requires a direct interaction, *i.e.*, answering multiple ESM surveys during the day. In SB they were paid depending on the number of ESM surveys completed. This payment method led to few cheating participants that were answering to ESM surveys with the identical answers or were increasing drastically the number of responses when "pay day" was approaching, or saying that the count of answered survey from our side was not correct. The solution was that we have analyzed statistically the collected data in details, and discarded the outliers. In SC we choose to define a flat rate payment for each week of the study with the possibility to reduce the payment if an insufficient number of ESM surveys was answered; and only the participants that were performing poorly were notified about this policy. In SC was easier to convince participants to increase the collaboration whenever they were performing poorly and the discussions about this matter was much more relaxed and always led to a better contribution from the participants. In addition in SC we were always remembering to participants that they were contributing in answering important scientific questions, that they are very important to us.

Development phase: (1) *Devices heterogeneity*: along all the studies we have employed Android OS, yet in the scope of Android OS, the code of the application must be generic following the Android guidelines (*e.g.*, for interfaces and access to system services), and avoiding performing any device-specific 'hacks'. If 'problematic' devices are encountered at the study launch, it must be evaluated if a device-specific solution is worthwhile (and not influencing somehow the variables important for the study) or better to exclude this device's users from the participation in the study. (2) *Efficiency of the data logger*: the frequency of the data collection on the smartphone and the method to be used needs to be chosen carefully, because they can influence the mobile applications' performance, phone power consumption, and the data storage. The logger must collect the necessary data without jeopardizing the normal use of the participants' smartphone. It is advised to follow all the best Android practices (*e.g.*, for performance, system design, events-based design) when developing the data logger. Consideration of the hardware and software sensors used to collect the data and how these influence the power consumption needs to be observed in advance. (3) *Testing*: it is important to start testing the study application as early as possible. This phase may span over several weeks before the launch of the study depending on the complexity of the smartphone application. The suggestion is to involve trusted testers (*i.e.*, colleagues that usually are not to be involved in the real study) targeting different devices and different characteristics of their users. The testers are going to provide early explicit feedbacks: interface adjustments if ESM is involved, performance issues, *etc*. It will be also possible to test the quality of the data and start to develop the analysis tools needed later (*e.g.*, for DRM interviews visualization and preliminary data analysis). (4) *Developing of specific sensors* (SA only): The challenge was that there was an important part of novel software sensor (i.e., Bluetooth scan sensor)

being developed and critical for the success of the results of the study. At the time of the study, the challenge was that to deal with Android OS unstable Bluetooth interfaces and API. The approach was to contact the lead API developers' forum for a feedback and support, to manage the software reliability and accuracy. The solution was extensively tested and proven to be effective in the field. (5) *QoE instrumentation* (SB only): high QoE sampling rate can cause unnecessary user interruptions, while too few might miss to record important influential factors in the phenomena. QoE samples per day to be asked to the user in minimally obtrusive way, *e.g.*, a user-friendly questionnaire interface is highly encouraged, Event-based ESM questionnaire with context-aware mechanisms as such, the questionnaire does not pop up when the user is accomplishing critical tasks such as using GPS app during driving. Additional challenge is to instrument the phone for capturing important variables capturing the variables influencing the user's QoE (expressed via MOS in ESM). The solution is to capture many possible variables along the user answering an ESM, such that correlations can be derived later, *i.e.*, oversampling is very much suggested for a given, short-periods of time and prove to be effective to capture data relevant for QoE research. (6) *Recruiting bias* (SA+SC): In SA the challenge was to recruit participants with Android OS phones being representatives of general public, wiling to wear an external sensor for the purpose of the study, and not just computer science students, acquainted with technology and willing to wear the sensor. The solution is to post advertisements on a dedicated community website and frame the study as attractive for its participants, without emphasizing the inconvenience of the sensor. We have managed to get a sample of participants, sample from general public including housewife, manual worker and secretary. Instead, in the case of SC the research topic being intimacy context, could lead to the participation of a higher number of female participants [5]. We decided to not provide in any way the word 'intimacy' (or any definition of it) in the study description and entry, recruitment, survey of the study. Participants were notified about the study goal and heard the word 'intimacy' only at the first face-to-face meeting. We obtained a distribution of 10 males and 12 females.

Execution phase: (1) *DRM visualization/interaction*: it is fundamental to find a way to visualize the collected data to be shown to the participants in a meaningful way, during the weekly DRM-based interviews with the users in the lab. The suggestion is to avoid standard, raw data graphs presenting the data quantitatively; most people may not understand them and they do not help to open up a discussion. It is also important to avoid giving to participants too much information on their overall behavior, it may bias them and they may change routines and behaviors based on the results presented. A good visualization will also help to answer the questions for the study first qualitatively, without explicitly asking the participants for the answers, but letting them to go through the DRM by remembering and describing the situations study owner is looking for. (2) *Participants motivation*: the participants must be kept motivated to fulfill the requirements for the study and provide data, without biasing the data results. Motivation can come from monetary compensation, a cultural enrichment, the unexpected ESM questions themselves, and an interesting visualization (as described in the previous point) of the data each week. Participants must feel as they are contributing to

important research questions and that their effort is minimal compared to the benefit that they may gain. If the price for the contribution is minimal, they will be happier while performing the study tasks. The weekly interviews are very important and are the occasion to treat each participant individually, with respect and appreciation. (3) *Participants privacy*: general rules are described in the ethics consent, yet there are additional practical issues such as (a) if the study requires connecting participants' smartphone to a PC, disable any automatic download of personal information (*i.e.*, auto download of personal pictures), (b) no overlapping interview schedule (even for family members participating, unless that is according to the study protocol) or involving third persons outside the study (in particular interviewer must be the same for a given participant over the whole study), (c) do not disclose other participants' opinion and experiences to any participant, do not refer to a particular participant to give examples during interviews, (d) offer the possibility to switch off data collection explicitly on participants smartphones for a limited time when participants require extra privacy. (4) *Performance complains*: this item needs special care, because there is a high probability that the phone performance influences the final results of the study and the motivation of the participant/s. Therefore, if the user has specific performance complains, it may need to be excluded from the study, otherwise the problem needs to be investigated and solved as soon as possible. The study owner shall always meet the expectations of the participants with respect to their smartphone performance. (5) *Fix personal bugs*: the challenge is what to do in case only a participant exhibits a particular bug when running the logger application in his/her phone. During the three studies we have encountered different devices and as well Android OS versions. Some specific phones created strange bugs, such as no data being logged, very high sampling frequency from a specific sensor, very disturbing vibration on notification, etc. Our approach in this case was always to evaluate the cost/benefit for the study on trying to solve the problem. The bug can be easily identified or not, and it can be solved fast or require a lot of work and time. It is necessary to be sure that the solution does not create even more problems in the future, *i.e.*, with other smartphones. In addition is important to consider how the participant is contributing to the study so far to decide if it worth to invest time on her/his problems. To simplify the task from the experiences in SA and SB in SC we were able to leverage the developments in Android OS and to introduce an application auto-update mechanism and an automatic bug report (implemented with ACRA[1]). We were able to know that some bugs were occurring, what was the cause, and what were the phones and Android versions involved. Whenever the application was updated by us, the participants were automatically notified about the update, and could update it themselves, without our assistance. This approach allowed us to solve all the problems in the first week of study assuring the continuous participation of the participants and the reliability of the data collection. As the last though on this point: be aware of battery saving applications that can jeopardize the functionalities of the study logger in unexpected ways! (6) User cheating vs technical issues (SB+SC): this challenge is very related to the nature of studies involving ESM surveys. Some users were showing a very low answer rate and they were justifying that by

[1] http://acra.ch/

saying that they were not notified to answer the surveys. In both studies we solved the problem by logging every time the user was notified of a new ESM survey. We never said to the participants that we were logging that information, and only when necessary we were showing the personal data log, with all the notifications time, to participants that were arguing about their insufficient participation with technical excuses. For both studies once the users were facing the reality they were admitting that they needed to do some extra effort. In SC we had another kind of challenge: we were receiving very few records of data, sampled only in the early morning, from a particular participant. Since our application was starting automatically when the device was switched ON, to our eyes that was like the user was killing our application as soon it started. The participant was arguing that she/he was leaving the application free to run. The user's device, as well its Android OS version, was common among several participants to study SC. All of them were running the application without any problems. After some tests on the particular device we were not able to identify the problem, so our conclusion was that the participant was cheating. When we kindly asked the participant to leave the study, for supposed technical reasons, she/he suddenly remembered that she/he had a third party battery saver application. This battery saver application was killing our application and its service as soon as an energy consumption threshold was passed. This shows how it is often difficult to understand if a participant is cheating or there is a technical problem, especially in the heterogeneous and highly customizable Android world.

Data analysis phase: (1) *Data synchronization*: the format of the collected data should be well designed from the beginning, so that the post processing of the data should not eventually take too much extra effort. It is advised to carefully synchronize data from different sources along the study. This will also help to speed up the DRM visualization and indirectly improve the quality of the DRM interviews. (2) *DRM themes*: DRM is executed in a paper form, but it must be then collected in a digital format and kept separated per participant to lead to a faster data analysis. Themes emerging from the data must be derived based on at least two different coders – at first agreeing upon the themes identified at large. Themes are important to explain particular set of situations (*i.e.*, specific habits emerging from behaviors of the participants) when discussing and leveraging the study results.

Related Work

We identify the following work related to ours. Baraković and Skorin-Kapov [1] present the key aspects and challenges that need to be considered in the field of the QoE management. The authors emphasized the importance of a well-planned extensive subjective study, while describing a well planned subjective tests with main aspects such as the *specification of methodology* to be used; *identification of dependent and independent variables* to be used; *choosing the user test subjects*; *determining the testing scenarios and the environment*; and the *rating scales*. In our research, we follow these schemas additionally giving practical view on the user studies and the corresponding solutions. Earl [7] analyzed the interaction patterns of the users with the smartphone, and has enumerated the most challenging experiences during their large-scale user study: *volatile file systems* (unmounting/mounting the file-system leads to data loss); energy *constraints* (a degradation of the battery

life); *third-party application intervention* (the impact of the battery consumption pattern affects the results); *nonlinear time* (changes to the device clock)*;* and *malicious users*, conducting *file manipulation* (e.g., deleting the files) or *programmatic manipulation* (replaying an existing usage log or running a programmatic manipulation via experimental software). It is stated that the types of attacks depend on the experiment parameters and it is suggested to analyze data early and often to seek for abnormal patterns in every participant's data. We complement the work of Earl [7] with much extended, systematic analysis of the challenges. Ferreira *et al*. [8] present the experiences and the challenges during an application-store (*e.g.*, Google-Play) based large-scale user study: *careful planning and evaluation of time and effort* for the deployment of a research tool; the *number of participants*; *non-biased participants* (age/gender); the *amount of collected data*; the *representativeness of the data*; conducting the study *non-intrusively*. For a user study, the authors introduce a *pilot stage* of a study four months prior to the start of the actual study, where the users have become familiar with the application. This way, they create an extra time to improve and fix any reported problem. For increasing the participation rates in the study, they emphasize the importance of informing the potential participants about what kind of data is being collected and what/how it is going to be used for. According to Serral-Gracià *et al*. [14], it is suggested to answer questions such as *how* to collect *which* information (metrics), and *where* to overcome the main challenges in data acquisition to assess the QoE levels. We complement the work of [8], [14] given our systematic analysis of the challenges, which may be applied in any smartphone-based studies. We add to work of Ferreira, by emphasizing additionally the challenges arriving from physically meeting the participants in the lab for occasional interactions.

Conclusive Remarks

This paper highlights the obtained experiences and the challenges overcame during three different users studies that were conducted by the authors. The outcome of this paper relies on the user studies that were conducted in the users' natural environments, while employing their own smartphones. We first give an overview of the key challenges in design; development and execution; and data analysis phases of the three studies, and next we draft possible corresponding solutions. The key challenges are mostly study-specific in the design phase, and they become more generic towards the data analysis phase. The goal is to provide practical view on such studies, and help practitioners to reflect on their own studies, possibly applying the proposed solutions. Future work area includes systematic research towards development of rigorous methods for conducting human subject studies "in-the-wild", with qualitative/quantitative approaches clearly defined for each study phase and with the overall study goal in mind. Such methods would also enable to assess the quality of the conducted studies and to objectively evaluate the results collected in the future studies.

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