INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN, ICED13
19-22 AUGUST 2013, SUNGKYUNKWAN UNIVERSITY, SEOUL, KOREA

# INSTRUMENTING THE USER: NEEDFINDING BY COMBINING DATA LOGGING AND IMMEDIATE SELF-REPORTING

**Gabriel ALDAZ (1), Martin STEINERT (2), Larry J. LEIFER (1)**
1: Stanford University, United States of America; 2: Norwegian University of Science and Technology, Norway

## ABSTRACT

This paper proposes a quantitative exploration and evaluation method for need finding that may be used in situations where the classical quantitative methods – interviews and direct observation – may not be effective on their own. “Instrumenting the user” combines sensor data logging with periodic, immediate self-reports. The purpose of instrumenting the user is to enable the longitudinal collection and subsequent analysis of data that will aid in the identification of needs that are not apparent to the designer based on prior experience, talking to users, or observing them. When used to generate hypotheses, this quantitative approach retains the open-ended, non-standardized aspects of qualitative methods. A case study from the hearing aid industry illustrates an implementation of the method and explains how instrumenting the user can yield unexpected insights.

*Keywords: design methods, user centred design, human behaviour in design, needfinding, user needs*

Contact:
Gabriel Aldaz
Stanford University
Mechanical Engineering
Stanford
94305
United States of America
zamfir@stanford.edu

# 1 INTRODUCTION

An understanding of user needs is essential for successful product development. The process of studying people to identify their unmet needs is termed needfinding. The literature reveals two basic categories of needfinding approaches: *retrospective* (interviews, questionnaires, focus groups) and *real-time* (various forms of observation, carried out in laboratory settings or in situ). Both kinds of approaches are inherently qualitative methodologies.

We propose a quantitative exploration and evaluation method for needfinding, whereby we "instrument the user"; that is, we fit users with relevant sensor technologies and ask them to provide periodic, immediate self-reports. The purpose of instrumenting the user is to enable the longitudinal collection and subsequent analysis of data that will aid in the identification of needs that are not apparent to the designer based on prior experience, talking to users, or observing them.

This quantitative methodology is founded on the traditional scientific method approach and can be used for hypothesis testing by means of tried-and-tested statistical inter- and intra-subject comparison. A novel application of the same method, the primary focus of this paper, is hypothesis-generating by means of exploring collected data. Observing the necessary contextual siltation of ambiguity during needfining, we retain the open-ended, non-standardized aspects of qualitative methods. Naturally, this method does not preclude our use of classical qualitative needfinding methods. To the contrary, we employ qualitative methods to verify or refute generated hypotheses early on and rapidly, so the results can be quickly integrated into the next prototype iteration.

We illustrate our method with a case study that is, to the best of our knowledge, a unique experimental design in the hearing aid industry. A primary goal of the study was to identify latent user needs by instrumenting hearing aid wearers, and the data revealed interesting results with regards to programs. In hearing aids, programs are settings that can be created for different listening environments. Program changes, along with volume control, are the primary mechanisms for users to adjust their instruments to improve, for instance, hearing comfort or speech intelligibility. The results of the study included the unexpected insight that the participants ($n$=5) did not take advantage of the programs available for their devices even though they consistently expressed a program preference in certain situations. A great deal of engineering effort has been put into the development of programs, and therefore it is both surprising and disappointing that users are not benefitting from them. We hope that these results, if supported by a follow-up study, will provide impetus for a team to re-think the design requirements for advanced hearing technology.

# 2 NEEDFINDING

All products and systems directly or indirectly influence certain user and stakeholder groups (Leifer and Steinert, 2011). Over the last half century, user-centered design (Norman and Draper, 1986) has gained acceptance and is now a leading philosophy in product development. "Know your user" may be an obvious principle today, but user needs were conspicuously absent from the earliest formal design processes. Matchett's Fundamental Design Method from the late 1960s is among the first to explicitly identify user needs (Jones, 1970). Stanford Professors Bob McKim, Rolf Faste, David Kelley, and others coined the term "needfinding" as the process of studying people to identify their unmet needs (Patnaik and Becker 1999).

Although needfinding has been a formal step in numerous design processes for almost fifty years, there are surprisingly few tools available to go about identifying unmet needs. Ulrich and Eppinger (1995) listed "Identify Customer Needs" as the second step in their design process and proposed gathering raw data by interviews, focus groups, and observation. Subsequent methods, such as the IDEO vision of design thinking (Brown, 2008), have tended to reiterate the tried-and-true needfinding tools of interviews and direct observation.

## 2.1 Observation

Observation is repeatedly named as in important activity during the early stages of several important design processes. Naturalistic observation, which takes place in situ, is generally preferred over laboratory observation. The success of major design firms such as IDEO has led to the widespread adoption of naturalistic observation in the needfinding process. The advantages of naturalistic observation compared to retrospective data collection methods in identifying latent user needs include the fact that observation "can produce unadulterated, direct and potentially very rich descriptions of events and their context, because data is captured while the phenomena occur" (Blessing and Chakrabarti, 2009). Despite having numerous advantages, naturalistic observation also has inherent limitations (Patton, 2002, unless otherwise stated).

- Practical and ethical considerations prevent the direct observation of many important behaviors.
- Even when observation is feasible, it necessarily focuses on external behaviors. Thus, limited information is gained on how people are experiencing activities.
- Due to resource constraints, the number of cases that can be studied is generally small. Generalizations to other settings and customers may not be applicable.
- The presence of the researcher, except in the role of complete observer, may alter the customer's behavior in unknown ways (the so-called Hawthorne effect).
- The quality of observation data depends largely on the professional know-how of the researcher.
- Observation is not appropriate if the events of interest are out of reach of the natural senses; that is, they are too distant, too large, too small, too slow, or too fast to be observed directly (Jones, 1970).

## 3 INSTRUMENTING THE USER

To mitigate some of these shortcomings, we propose a quantitative, real-time data collection method that is complimentary to naturalistic observation, and indeed may be preferable to the researcher when one or more of the limitations listed above threaten the validity, reliability, or scope of the data collected.

In its simplest embodiment, the instrumentation required to be used as a needfinding tool comprises one or more sensor nodes and a user interface for recording immediate self-reports (see Section 3.2). The instrumentation may be fixed in the environment (e.g., embedded in a living space, an automobile cockpit, or a movie theater seat). Alternatively, the participant may carry or wear the instrumentation, in which case a mobile Internet device such as a smartphone could serve as a user interface, communicate with sensor nodes via a wireless body-area network, and possibly provide additional sensor inputs. In this article, we focus on wearable sensors, as they are most relevant to our case study.

### 3.1 Data logging using wearable sensors

The idea of using sensors to record unconscious signals emerged in the late 1980s, when Mark Weiser, Chief Technologist of the Palo Alto Research Center (PARC), invented "ubiquitous computing." Weiser (1991), who believed that the most profound technologies are those that weave themselves into the fabric of everyday life, distributed electronic badges to PARC employees that anonymously transmitted their location during work hours. In the late 1990s researchers such as Alex Pentland at the MIT Media Lab linked ubiquitous computing with social network theory, tracking how large wearable sensor data is analyzed to extract subtle patterns that predict future human behavior (Eagle and Pentland, 2006).

Advances in microelectronics have made wearable sensors more reliable and less expensive than ever before. Examples of sensors include physical activity (location, accelerometers, pedometers), physiology (heart rate, respiration rate, galvanic skin response, blood glucose meters), biochemistry (levels of chemical compounds in the atmosphere), and even purpose-built devices (Patel et al., 2012). Therefore, there are exciting possibilities to capture data that would have previously been unimaginable.

### 3.2 Immediate self-reporting

The use of self-reporting, via questionnaires, diaries, and other tools, is ubiquitous in the social sciences, as it enables the collection of significant amounts of data at low cost. The well-documented drawback of self-reporting is the relatively poor accuracy of the data, either by recall error or deliberate falsification. How individuals reconstruct episodic memories calls into question the accuracy of recollected reports of experiences (Yarmey, 1979).

In contrast to traditional retrospective self-report methods, the Experience Sampling Method (ESM) elicits participants to provide an immediate and systematic record of both the context and content of their daily lives at randomized points in time. By sampling an experience the moment it occurs, ESM avoids the memory biases associated with the use of daily diaries or weekly questionnaires. ESM in its current form is credited to psychologist Mihaly Csikszentmihalyi, who devised the methodology in the 1970s to study "flow" (Csikszentmihalyi and Larson, 1987).

In the early days of ESM, participants wore pagers or alarm watches. When signaled, they reported their answers on a form called an Experience Sampling Form, which took only a few minutes to complete. As technology progressed, personal digital assistants (PDAs) were pre-programmed to signal participants at random times. ESM typically scheduled 7-10 signals per day for a 1-week period. Respondents were asked to reply to the signal as soon as possible. Thus, ESM studies were traditionally time-driven, where the signaling cue could occur randomly or at pre-defined times. PDAs also allowed for event-driven sampling, where inferred context or the occurrence of a specific event provided the signaling cue. Researchers at MIT implemented their so-called Context-Aware Experience Sampling (CAES) on a PDA, featuring event-driven sampling. In that study, events of interest were limited to a single, instrumented kitchen (Intille et al., 2002). In general, event-driven sampling can be system-triggered (such as CAES) or participant-triggered (the researcher tells the subject, “when event X takes place, answer the given questions”).

Naturally, mobile phones have now gained popularity for experience sampling. For example, MyExperience is an open-source, Windows Mobile-based software platform that supports studies of mobile technology usage and evaluation (Froehlich et al., 2007). MyExperience expands on the concept of event-based triggers by collecting data from a mobile phone's hardware sensors (for example GSM cells and GPS positions) and software sensors (address book access, SMS usage, phone calls) and providing a signaling cue when certain contexts are present. Thus, MyExperience combines automatic logging capabilities with triggered questionnaires.

## 3.3 Research issues

Instrumenting the user is susceptible to certain limitations, including participant issues (reactivity, privacy, self-selection bias, attrition) and data quality issues.

### *3.3.1 Participant issues*

Participation in a study that lasts weeks or months is inevitably going to influence the behavior of the person who is instrumented. Even if the sensors themselves are non-invasive and unobtrusive, and the computing is transparent to the user, the immediate self-reporting element will be influential.

Usually, a study will aim to get an accurate and complete representation of a participant’s life as it pertains to the issue being investigated. Almost inevitably, however, results will be biased by reactivity, as participants alter their behavior to emphasize some aspects of their lives while concealing others. Participants can, knowingly or unknowingly, selectively decide not to self-report in certain situations. For example, participants may consciously avoid self-reporting while at work, as they may not want to draw attention to their participation in a study regarding hearing loss or some other sensitive subject. Participants may also unconsciously avoid self-reporting as a response to a disruption of their daily routine.

Additionally, the hardware setup itself may not be conducive to self-reporting in certain environments. For example, tasks that are highly visual and require constant attention, such as driving or playing sports, impede participants from performing all but the most basic self-reports.

Longitudinal studies involving wearable computing may also pose serious privacy risks. Depending on the level of instrumentation, these systems may record the actions, locations, preferences, and vital signs of participants. Studies must be designed to safeguard this sensitive data, both during the study and afterwards.

### *3.3.2 Data issues*

Because large quantities of data can now be collected with ease, it is crucial to focus on a particular area of interest. Interesting information tends to be embedded in a mass of irrelevant data, and it requires patience and skill to extract it. The first step should be a consideration of the costs and benefits of the method in the relevant research context. Pilot studies provide preliminary results before significant effort and money have been spent. Secondly, although instrumenting the user is inherently open-ended, it is advisable to formulate one or more hypotheses to guide sensor selection, quantity, and location. Having a hypothesis to test also mitigates the risk that no interesting results will emerge. Lastly, since sensor data alone cannot provide important information such as user intention and perception, the immediate self-reports must be carefully designed with clarity and ease of use as a paramount objective.

## 4 CASE STUDY

This section presents a field deployment to illustrate how instrumenting the user helped researchers with needfinding. The chosen case study is in the field of hearing aids. The hardware comprised a pair of Oticon Intiga hearing instruments, an Android-based Google Nexus One smartphone, and an Oticon Streamer, a commercially available neck-worn device with a built-in microphone that wirelessly links the hearing aids to a mobile phone (see Figure 1). The Streamer serves two primary purposes: it acts as a gateway for the hearing aids, streaming sound from a mobile phone or a digital music player, and it serves as a hearing aid remote control, allowing change of volume and program. Two-way communication between smartphone and Streamer is accomplished via Bluetooth, while one-way communication between Streamer and hearing aids uses low-power Near Field Magnetic Induction (NFMI).

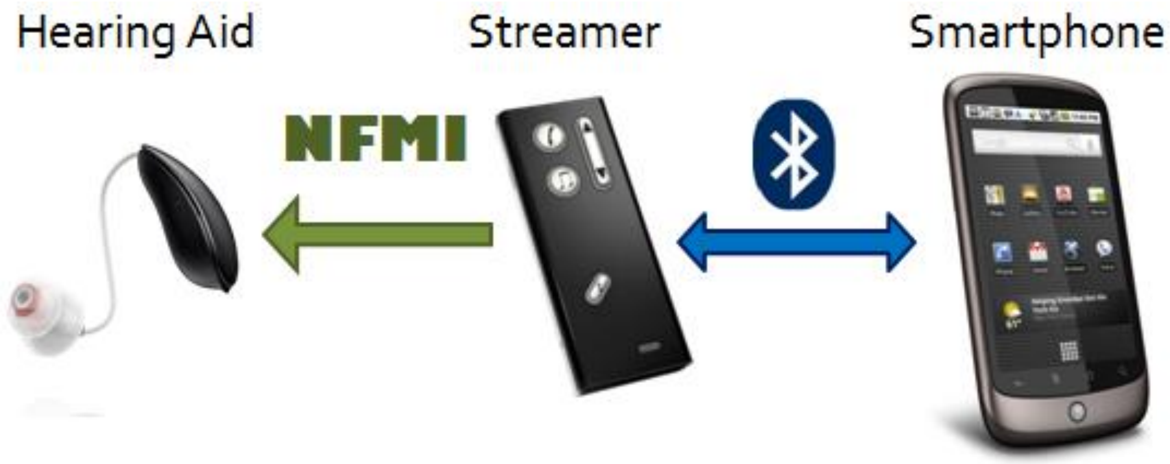


*Figure 1. Case study hardware*

We conducted the case study in Copenhagen, Denmark, with five experienced hearing aid users with medium-to-severe hearing losses and high cognitive skills. Each participant was asked to use the system all day, every day for approximately six weeks, and interact with it using immediate self-reporting.

### 4.1 Hearing aids

Today's advanced digital hearing aids can store several preset programs in their memories that can be created for different listening environments. Typically, there is a general purpose program, one for hearing in noise, and one for listening to music. The hearing aids used for the case study were programmed with Program 1 (P1, General), Program 2 (P2, Music), and Program 3 (P3, Party). Program changes, along with volume control, are the primary mechanisms for users to make adjustments to improve sound quality. Since the Oticon Intiga hearing aid does not have a push button, users must change programs (and volume) by pressing buttons on the Streamer. Audible beeps (for example, three beeps for Program 3) are heard every time there is a change. However, our smartphone interface provided users with an alternate way to change both programs and volume: touch screen buttons that provided visual feedback instead of the standard auditory cues.

### 4.2 Data logging

The system continuously logged data about the user's context: current sound environment, sound level, acceleration, location, as well as time and date. Additionally, the system kept track of hearing aid settings, including current program. Lastly, the system recorded every “button” press on the smartphone screen and every button press on the Streamer. Figure 2 illustrates the two ways participants could choose from to change programs and adjust volume.

### 4.3 Immediate self-reporting

Participants were instructed to give feedback in the form of an A/B test whenever they encountered an interesting listening situation. The A/B test is a standard method of comparing two variants. In the context of this case study, the A/B tests prompted the participant to compare hearing aid settings and choose the one that sounded better in that particular situation. The settings corresponding to A and B were randomized and based on the detected sound environment.


*Figure 2. Program change and volume adjustment, smartphone vs. neck-worn Streamer*

Although participants had the power to trigger test events, the system used its knowledge of current context to decide which settings to present to the participant. If the system detected "*Music*" as the current sound environment, it randomly assigned programs P1 (General) and P2 (Music) to A and B. Similarly, if the system detected a "*Party*" situation (high decibel speech in noise, possibly with music), it randomly assigned programs P1 (General) and P3 (Party) to A and B.  For all other sound environments (such as "*Silence*", "*Noise*", and "*Speech in Noise*"), the system selected other settings that did not directly map to program comparisons.

The A/B test (see Figure 3) functioned as follows: To initiate an A/B test, a participant presses a button on the smartphone, and the application walks her through the process. She starts listening with hearing aid setting A activated. After some time, she presses a button that switches to hearing aid setting B. After more time, the participant can return to listening to A, if in doubt, or proceed to an evaluation screen.


*Figure 3. A/B test screen sequence*

Participants were also asked to provide information about their current sound environment and location as a way to check the inferences made by the system. Participants were told to aim for completing 5-10 A/B tests per day.

### 4.4 Results

As stated above, instrumenting the user can be useful for hypothesis generating. This case study focuses on an insight gained by the open-ended approach: none of the participants made effective use of multiple programs, an important feature of digital hearing aids, even though four out of five subjects expressed a preference when listening to two programs during an A/B test.

It has been shown in the past that hearing aid wearers do not take full advantage of multiple programs. For instance, Nelson et al. (2006) reported on a group of 19 hearing aid users who averaged ten hours per day in the default P1 and less than two hours in P2 and P3 combined. However, the reasons for this are not well explained in the literature.

In the pilot study pre-interview, four of the five participants reported that they seldom changed programs. When asked why not, they cited either an inability to hear the difference between programs or uncertainty about when to switch between them. Participant E reported, “I have owned a Streamer for at least two years, and use it constantly.” Despite this statement, he was incapable of using the Streamer to change programs when asked to. Throughout the pilot study, Participant E never changed program, neither via the Streamer nor the smartphone. Participants A-D averaged close to five program changes per day. When they did change program, they quickly reverted back to the default P1. As illustrated in Figure 4, all five users spent at least 96% of the pilot study in P1.

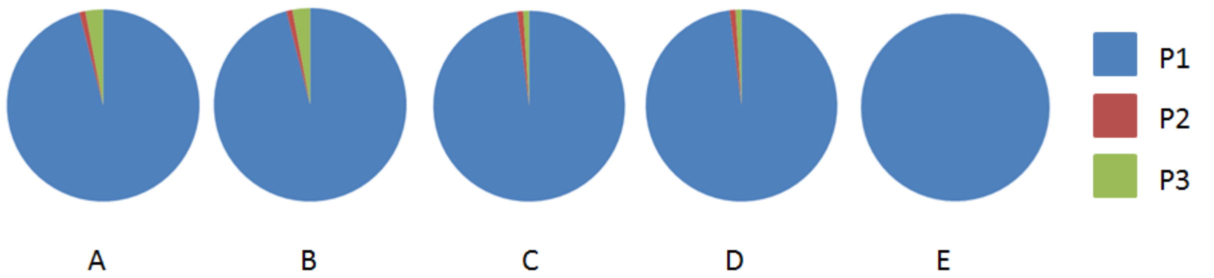


*Figure 4. Percent time spent by Participants A-E in each available program*

Participants reported staying in the default program at least in part because they claimed that they could not hear the difference between programs. The study data showed, however, that four out of the five participants could differentiate between programs in certain listening situations. Recall that participants initiating an A/B test while the system detected the sound environment as “*Music*” were prompted to compare P1 versus P2. If users could not tell the difference, we would expect roughly equal preference for P1, P2, and no difference (same). Figure 5 shows that this is not the case, with the exception of Participant C. The remaining four participants show a clear preference for one program, with two of them consistently choosing their preferred program 100% of the time.

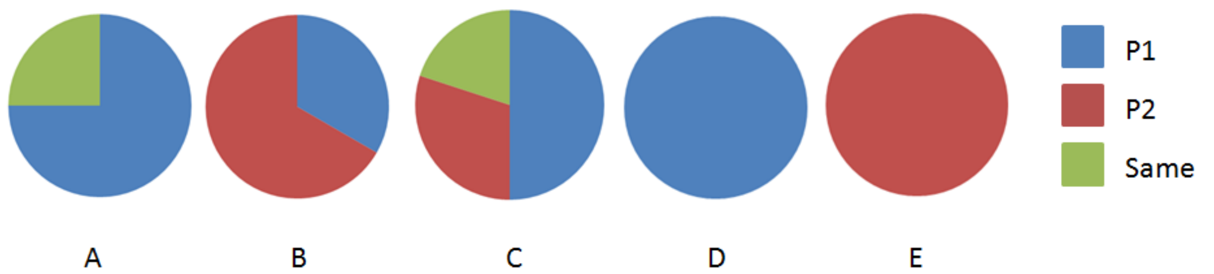


*Figure 5. Percent A/B test preferences for Participants A-E while listening to music (n=4, n=3, n=10, n=3, n=5)*

According to Figure 5, Participant E clearly preferred P2 (Music) while listening to music. However, Participant E never chose to listen to music in P2, and in the post-interview he reiterated that “there wasn't any need to change programs” because he “could not distinguish between them.”

Another challenge hearing aid wearers face in understanding and managing multiple programs is simply knowing their current program. As stated above, on standard hearing aids a program change is accompanied by a corresponding number of beeps. This auditory feedback is ephemeral, and hours later a user may become unsure of what program she is in (unless, of course, she always stays in P1). The pilot study again provided rather unexpected insight into this situation. The smartphones used in the pilot study allowed program and volume change from the home screen. The system recorded every button press on the smartphone screen and on the Streamer. Figures 6 and 7 show, respectively, the relative frequency of program changes and volume adjustments by participant, using the smartphone and Streamer.

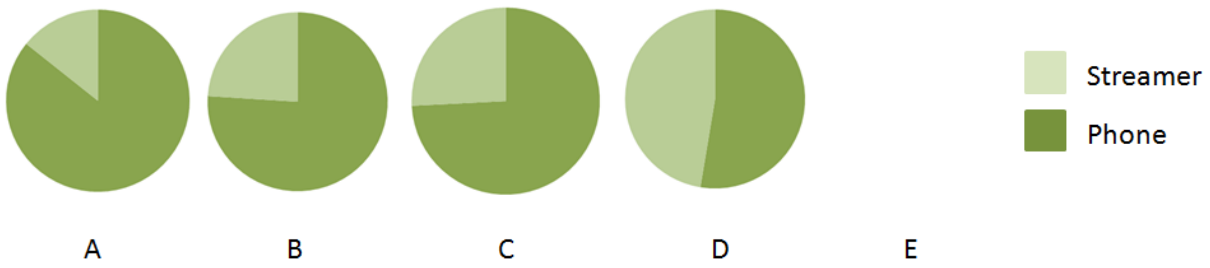


*Figure 6. Percent program changes using Streamer and smartphone (n=77, n=25, n=438, n=95, E did not change programs)*

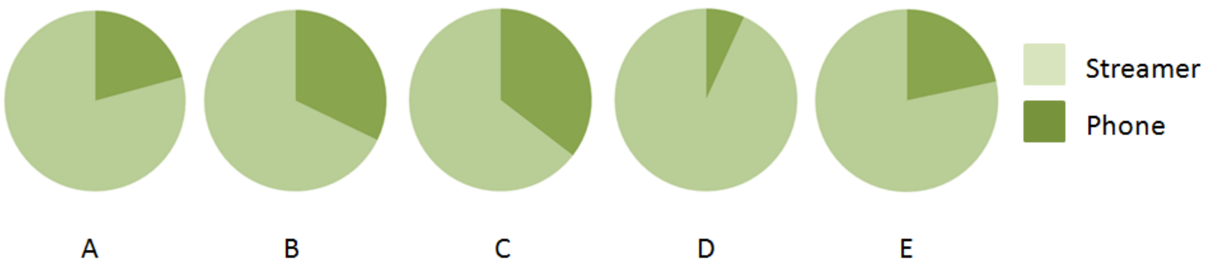


*Figure 7. Percent volume adjustments using Streamer and smartphone (n=631, n=171, n=749, n=681, n=60)*

The four participants who changed programs did so more often with their smartphones (72.0% overall) than with their Streamers (28.0%). All five changed volume with their Streamers (77.7% overall) more often than with their smartphones (22.3%). Why? One theory is that the smartphone provides visual feedback of the current program, both at the time of program change and at all other times. Volume change, on the other hand, is more quickly and effectively accomplished using the neck-worn Streamer, without a need to unlock and access the smartphone. This indicated that the task, not the device, mattered most to the participants.

## 4.5 Research issues

Below is a summary of the participant and data issues that we observed during the study.

### *4.5.1 Participant issues*

There was some evidence of reactivity during the case study. Participants found conversations to be the most difficult everyday situations during which to self-report. In the post-interview, three participants noted that producing and interacting with the smartphone to complete the self-report caused the other person in the conversation to go silent, thus changing the sound environment. Though all three participants denied consciously avoiding self-reporting while talking to others, the data showed that they did not perform as many A/B tests in conversations as the other two participants.

Participants also self-reported in situations that were not representative of their normal lives. In the post-interview, two participants reported going out of their way to find interesting sound environments (for example, a jazz concert they would not normally attend). Sensibly, none of the participants self-reported while driving a vehicle or riding a bicycle. One participant self-reported while walking, and found the interaction with the smartphone to be highly distracting.

With privacy a major concern in the case study, participants were informed of an easily-accessible “privacy button” they could press at any time to stop sensor data collection. Of the five participants, only one made use of this button, and only once for a period of two hours. The lack of usage of the privacy button may indicate a willingness on the part of participants to be continuously monitored, but the sample size is too small to draw broad conclusions.

Participants reacted favorably to the A/B test format, stating that it was clear and intuitive. They typically needed less than two minutes to submit the required information, and four out of the five stated that they liked having control over when they performed an A/B test. Based on this experience,

we advocate event-driven sampling for needfinding (we did not attempt time-driven sampling, so we have no comparative data).
All five participants saw the study through to completion, completing the requisite number of daily A/B tests. The lack of attrition suggests that the test protocol was reasonable and that the subjects took their participation very seriously. In post-interviews, participants stated that they enjoyed having a heightened awareness of their hearing in various environments, and that participant-driven sampling gave them a feeling of empowerment.

### 4.5.2 Data issues

Event-triggered sampling appears to empower the user with the contextual data input and may lead to a higher retention rate and thus to better needfinding data. This gives us reason to believe that the quality of the self-reported data is high. On the other hand, the quantity of relevant data – direct comparisons between two programs – is low. This is partly because we did not know in advance that there would be a dissonance between program usage and perceived differences between programs. Unfortunately, participants only made program comparisons between P1 and P2. A software bug prevented the system from ever detecting a "*Party*" sound environment, and therefore no comparisons were made between P1 and P3.

## 5 CONCLUSION

The case study yielded the unexpected insight that participants were confused by or chose not to employ the multiple programs at their disposal, despite consistently expressing a preference for one program when listening to music. This finding indicates a user need to control hearing aid settings in a different way than the prevalent program change paradigm. Table 2 lists three potential reasons why participants did not make use of multiple programs. The first reason was claiming not to hear the difference between programs. However, in the music listening setting, four out of five participants had a strong preference for either P1 or P2. The notion that users claim not to notice program differences may not relate to hearing in acoustic terms but to the low expectation these users have about whether or not what they have heard is "real". The A/B test forces participants to repeatedly compare two programs in the same sound environment, a task requiring a level of rigor that ordinary users may not employ prior to drawing their own conclusions about the efficacy of different programs.

*Table 2. Reasons for not using multiple programs*

| Reason for not making use of programs | User comments in pre-interviews | Instrumentation data |
|---|---|---|
| Cannot hear difference between programs | Reported by 4 out of 4 | Showed a preference while listening to music (4 out of 5) |
| Unsure of when to change programs | Reported by 3 out of 4 | No data |
| Does not know current program | Not reported | Preferred smartphone for constant visual feedback (4 out of 4) |

The second reason, uncertainty of when to change programs, could not be supported or refuted. A third reason, not articulated by the participants, was their preference for continuous visual rather than ephemeral auditory feedback when changing programs and checking the current program.
Direct observation would probably not have uncovered any of the three reasons given in Table 2. As stated above, observation gives limited information on how people are experiencing certain activities, such as listening to different hearing aid programs. To expand existing qualitative needfinding insights we suggest instrumenting the user by

1. Combining sensor data logging with
2. Periodic, immediate self-reporting

The first gives a significantly better understanding of the contextual environment, especially in longitudinal terms. The latter empowers users to actively contribute data in key contextual situations. In the case study, this resulted in participants having increased awareness of situations and sustained engagement. Perhaps as a result of using participant-triggered sampling in our case study, we did not see the loss of interest and drop-outs that can be associated with traditional, time-triggered Experience Sampling Method. In a sense, participant-triggered sampling allows the user to become part of the development team, thus leveraging to some extent the positive motivational effects of participatory design and co-creation.

## 5.1 Future work

The case study may have identified an unmet user need, but more rigorous work remains to be done. Future user studies will include more program versus program A/B tests in all sound environments (rather than only in "*Music*") to validate our preliminary results. The follow-up study will have a significantly greater number of participants. Ultimately, if the follow-up study continues to support the preliminary results, we hope that a design team will devise a novel method for users to manipulate hearing aid settings, and this method could be submitted for user analysis to verify the design improvement.


## ACKNOWLEDGEMENTS

The authors are indebted to all personnel at Oticon A/S who supported this research, as well as the five pilot study participants. The project was funded by the Oticon Foundation.


## REFERENCES


Blessing, L.T.M. and Chakrabarti, A. (2009) *DRM, a Design Research Methodology*, Springer, London, England.

Brown, T. (2008) "Design thinking", *Harvard Business Review*, vol. 86, no. 6, pp. 84-92.

Csikszentmihalyi, M. and Larson, R. (1987) "Validity and reliability of the experience-sampling method", *Journal of Nervous and Mental Disease*, vol. 175, no. 9, pp. 526-536.

Eagle, N. and Pentland, A. (2006) "Reality mining: sensing complex social systems", *Personal Ubiquitous Computing*, vol. 10, no. 4, pp. 255-268.

Froehlich, J., Chen, M.Y., Consolvo, S., Harrison, B. and Landay, J.A. (2007) "MyExperience: a system for in situ tracing and capturing of user feedback on mobile phones", *Proceedings of the 5th international conference on Mobile systems, applications and services*, New York, NY, USA, ACM Press, pp. 57-70.

Intille, S., Kukla, C. and Ma, X. (2002) "Eliciting user preferences using image-based experience sampling and reflection", *Conference on Human Factors and Computing Systems*, New York, NY, USA, ACM Press, pp. 738-739.

Jones, J. C. (1970) *Design Methods: Seeds of Human Futures*, John Wiley and Sons, London.

Leifer, L.J. and Steinert, M. (2011) "Dancing with ambiguity: Causality behavior, design thinking, and triple-loop-learning", *Information Knowledge Systems Management*, vol. 10, nos. 1-4, pp. 151-173.

Nelson, J., Kiessling, J., Dyrlund, O. and Groth, J. (2006). "Integrating hearing instrument datalogging into the clinic", *American Academy of Audiology conference*, Minneapolis, MN, USA.

Norman, D.A. and Draper, S.W. (1986) *User Centered System Design: New Perspectives on Human-Computer Interaction*, L. Erlbaum Associates Inc, Hillsdale, NJ, USA.

Patel, S., Park, H., Bonato, P., Chan, L. and Rodgers, M. (2012) "A review of wearable sensors and systems with application in rehabilitation." *Journal of Neuroengineering and Rehabilitation*, vol. 9, no. 21.

Patnaik, D. and Becker, R. (1999) "Needfinding: The why and how of uncovering people's needs", *Design Management Journal*, vol. 10, no. 2, pp. 37-43.

Patton, M.Q. (2002) *Qualitative Research and Evaluation Methods*, 3rd ed., Sage, London, England.

Ulrich, K. and Eppinger, S. (1995) *Product design and development*, McGraw-Hill, New York, NY, USA.

Weiser, M. (1991) "The computer for the 21st century", *Scientific American*, vol. 265, no. 3, pp. 66-75.

Yarmey, A.D. (1979) *The psychology of eyewitness testimony*, Free Press, New York, NY, USA.