SonicAIR: Supporting Independent Living with Reciprocal Ambient Audio Awareness

HANIF BAHARIN, Universiti Teknologi MARA
STEPHEN VILLER, The University of Queensland
SEAN RINTEL, Microsoft Research Cambridge

Sonic Atomic Interaction Radio (SonicAIR) is an ambient awareness technology probe designed to explore how connecting the soundscapes of friends or family members might reduce the isolation of seniors living independently. At its core, SonicAIR instruments kitchen activity sites to produce an always-on real-time aural representation of remote domestic rhythms. This article reports how users in two pilot SonicAIR deployments used the sounds as resources for recognizing comfortable narratives of sociability. Used alongside telecare monitoring, such technologized interaction might enable older people to engage in community-oriented soundscape narratives of shared social responsibility.

Categories and Subject Descriptors: H.5.m [**Information Systems**]: Information Interfaces and Presentation (i.7); Miscellaneous

General Terms: Human Factors

Additional Key Words and Phrases: Ambient awareness, phatic technology, social presence, domestic, soundscapes, earcons, telecare, independent living

ACM Reference Format:
Hanif Baharin, Stephen Viller, and Sean Rintel. 2015. SonicAIR: Supporting independent living with reciprocal ambient audio awareness. ACM Trans. Comput.-Hum. Interact. 22, 4, Article 18 (July 2015), 23 pages.
DOI: http://dx.doi.org/10.1145/2754165

1. INTRODUCTION

People often describe sound not by using the characteristics or properties of the sound, but in terms of the events that produced it. Whether the sound is a real-time recording of an actual sound event or an artificial sound representing a virtual event, we are able to form narratives of social purpose that go beyond what is directly experienced [Gaver 1989, 1993]. This article unpacks the compositional and interpretative achievement of sonic intersubjectivity afforded by a domestic technology probe called the SonicAIR. SonicAIR was inspired in part by the Oleksik et al. [2008] "Appliance Cube" proposal for a sonic intervention into the domestic soundscape. SonicAIR is an always-on reciprocal ambient awareness system designed to reduce the isolation of seniors living independently by connecting them with the soundscape of a remote friend or family member. SonicAIR senses instrumented kitchen activities in a local location and plays sonified representations of those activities in a remote location.

The authors gratefully acknowledge scholarship support for the first author from the Biasiswa Yang Di-Pertuan Agung, managed by Public Service Department of Malaysia.
Authors' addresses: H. Baharin, Computer Science, Universiti Teknologi MARA, Malaysia; email: ahmadhanif@perlis.uitm.edu.my; S. Viller, School of Information Technology & Electrical Engineering, The University of Queensland, Australia; email: viller@itee.uq.edu.au; S. Rintel, Human Experience and Design, Microsoft Research, Cambridge, UK; email: serintel@microsoft.com.

ACM 1073-0516/2015/07-ART18 $15.00
DOI: http://dx.doi.org/10.1145/2754165

This article reports on two pilot SonicAIR deployments. Rather than evaluating the viability of SonicAIR, we were interested in participants' accounts of how individual signals generated by actions from the remote other were learned as resources for social understandings. We found that participants treated the signals as notes in a score of reciprocity of perspectives, taking the form of stories of remote domestic rhythms that were integrated into the monitored background of the local soundscape. We argue that the probe shows how such technologized interaction supports independent living through affording the opportunity to recognize comfortable narratives of sociability with remote others.

The independent living context is of particular interest because strong social ties have been shown to positively affect health outcomes for seniors and contribute to longevity [Cohen 2004; House et al. 1988; Umberson and Montez 2010]. While seniors living independently may have increased self-esteem, there is a concomitant danger that independence may slide into isolation and lead to negative health outcomes. Ironically, this isolation may be exacerbated by telecare technologies that support independent living and decrease healthcare costs associated with ageing populations [Smith and Maeder 2010]. This raises the puzzle of how we can get the benefits of both telecare and independent living while maintaining strong social ties. There have been a number of studies showing that ambient awareness technologies can support independent living [Caine et al. 2011; Dadlani et al. 2011; Demiris et al. 2005; Huber et al. 2012], and we follow in their footsteps by proposing that socially oriented ambient awareness technologies might be deployed in parallel with medically oriented telecare technologies. Used alongside telecare as part of a deliberate attempt to provide a textured experience of computer-mediated living [Harper 2010], such affordances might be a resource for older people to engage in shared social responsibility.

We begin by reviewing some prior research on social presence and lean signaling technologies for awareness, and describing our approach. We then discuss how sound matters to domestic awareness, especially for seniors, and why it might be an appropriate mode for exploring how ambient awareness connects domestic soundscapes. This leads to a description of the SonicAIR pilot: the technical outline, deployments, and data collected. We report our findings in terms of the accounts provided by participants and follow the findings with a discussion of how the accounts reveal the development of reciprocity of perspectives. We finish with some speculations about how this pilot might provide direction for future awareness design.

2. AWARENESS AND TECHNOLOGY

2.1. Technology, Social Presence, and Awareness

The field of Computer-Mediated Communication (CMC) has explored social presence as a central concept since its inception. Most work stems from variations on Social Presence Theory [Short et al. 1976], which proposes at base that richness of communicative mode has a direct effect on interlocutors' achievement of social goals. Over time, various waves of CMC research have argued back and forth about how channel richness interacts with other factors such as time, experience, and motivation [e.g., Walther 1996], and of course we are now moving through generational shifts in comfort with textual messaging. O'Hara et al. [2014] demonstrate that the social metaphor of "dwelling" better typifies user engagement with one another in WhatsApp than simply communicating via a lean text channel, such that social presence is less about richness as it is about the shared sense of a place of production.

Prior Human-Computer Interaction (HCI) research has explored lean awareness from the perspective of designing lean signaling technology contexts. Ambient presence technologies are those designed to unobtrusively sustain attentional awareness

between noncolocated parties by affording continuous peripheral indicators of connection [Mankoff et al. 2003; Wadley et al. 2013]. Phatic technologies are those designed to sustain remote relationships between noncolocated parties by affording lightweight reciprocal communication in which the fact of exchange itself is more important than the quality or quantity of information exchanged [Vetere et al. 2005, 2009].

Ambient presence technologies and phatic technologies both have awareness as their core affordance [Vetere et al. 2009], trading on a sociotechnical engagement in which awareness shades into connectedness [Dey and De Guzman 2006]. In social presence research, this shading is related to the "threshold of co-presence" [Biocca and Harms 2002, p. 13] – that moment when "automatically and without effort, a thing, technology, is suddenly perceived as somehow being, a mediated other", or rather, following Goffman [1961], two moments "(1) when individuals sense that they are able to perceive others, and (2) when others are able to perceive them" [Biocca and Harms 2002, p. 13]. Biocca and Harms [2002, pp. 11–12] propose that the reciprocal nature of social presence has three increasingly complex levels of coherent subjectivity: perceptual, subjective, and intersubjective. These levels are proposed as hierarchically indicative of the richness of social presence, and are intended to be a step towards measurability.

Our interests intersect with Vetere, Biocca, and their respective colleagues. Phatic technology and ambient awareness technology research are serious attempts to shift design from information to connection [Vetere et al. 2009, p. 178]. Modern social presence research notes that social presence is phenomenologically variable within any given interaction [Biocca and Harms 2002; Biocca et al. 2003]. Nevertheless, we are concerned about premature attempts to predetermine the boundaries between passive and active senses of ongoing connectedness. We take the position that the tropes of connection portrayed in prior research privilege technological signaling and an artificial separation of cognitive states for the purpose of arms-length measurability, over exploring how such signals are *recognized* by people as fitting into their ordinary understandings of the reciprocity of perspectives.

Reciprocity of perspectives is a central tenet of Ethnomethodology that Garfinkel [1984, 2002] developed from Schutz [1972]. "Schutz suggests that actors engaged in coordinated actions with others will assume the socially standardized and shared nature of their knowledge and will seek actively, if unconsciously, to sustain it" subject to the assumed limits of shared biographic circumstances [Heritage 1984, p. 77]. While this is a cognitivist concept, Garfinkel proposed that it be researched as a constitutive feature of interaction – what is done by people to make order observable and reportable – as opposed to a normative or regulative feature of interaction – assuming rules mark our proper conduct and searching for variations on stability [Heritage 1984, p. 83].

We believe that it is important to document the fundamentals of recognizable reciprocity of perspectives as a learned coconstituted social phenomenon. It is from such documentation that later operationalization may be possible.

Our approach to exploring awareness technologies follows phenomenological approaches to HCI research that focuses on how participants treat technology as a resource for coconstituting meaning [e.g., Button 1993; Suchman 1987] and do so in ways that orient their unique experiences [Harper 2010; Orlikowski 2008]. For communication technologies, Hutchby [2001, 2003] calls this an exploration of technologized interaction. Technologized interaction refers to communication in which users treat technology as materially framing but not causally determining social action. Hutchby and Barnett [2005] and Rintel [2013a, 2013b, 2015] explored technologized interaction in semantically rich media contexts such as mobile telephony, text messaging, and video-calling, but the concept has not yet been applied to ambient awareness technologies. However, given the premise that technology is a resource for making meaning, this approach is ably suited to exploration of ambient awareness. We turn, then, to

prior research into audio awareness technologies as a means of setting up the purpose of the SonicAIR pilot study.

2.2. Awareness and Soundscapes

Perhaps because visuality dominates postliterate societies, many awareness technologies have been designed around presence displays using the visual field [Consolvo et al. 2008; Consolvo et al. 2004; Erickson and Kellogg 2000]. As Wadley et al. [2013] note, awareness technologies can be created to draw attention through either visually appealing form factors [Abowd et al. 2002] or embedding them in objects of common visual attention such as clocks, chairs, and photograph or mirror frames [Brown et al. 2007; Dey and De Guzman 2006; Riche and Mackay 2007]. In terms of affording ambient awareness, however, visual technologies have the major drawback of requiring a line of sight. While it can be argued that mobile ambient technologies may overcome this visual drawback through high availability and likelihood of being in a peripheral attention space when not in direct use [Marcus and Chen 2002; Wadley et al. 2013, 2014], it is clear that sound is well suited to ambient awareness that extends beyond the line of sight. Sound is also useful for multitasking because it lends itself to ambient attention, communicating "large amounts of information quickly, heralding imminent events or signifying ongoing processes, and carrying powerful associations" [Oleksik et al. 2008, p. 1427]. It is, of course, limited by factors such as volume, perceptual disambiguation, and the hearing of the proposed user.

Most audio awareness technologies take their starting point from the Soundscape approach of Schafer [1977] which argues that instead of trying to solve noise problems after they occur, society should relearn how to actively listen to that soundscape and actively design an acoustically pleasing environment. However, unlike Schafer who sees technology as the culprit for the creation of a "schizophonic" society, HCI research has followed the Acoustic Communication Theory of Truax [2001], which proposes that technology can help to create a more acoustically meaningful world though soundscape composition. Soundscape composition involves producing sets of sounds that are fitted to the relevant soundscape but also, when relevant, distinct enough from the background to be used as resources for summoning memories and sparking the imagination of the listener.

We noted earlier that Gaver [1989, 1993] found that people describe sound not by using the characteristics or properties of the sound, but in terms of the events that produced it. In the work context, Alexanderson and Tollmar [2006] SpaceNav took up this concept and used captured sounds from "hotspots" in a factory and replayed them elsewhere in real time to provide a sense of the overall work context. By contrast, both Mynatt et al. [1998] and Kilander and Lönnqvist [2001] detected information about the work environment and represented it sonically to provide intuitive contextual awareness. The WISP system of Kilander and Lönnqvist [2001], for example, used the sound of birds to denote how many coworkers arrived in the building; the more people, the more birdsong could be heard.

2.3. Domestic Soundscapes

The most thorough treatment of the relationship between domestic soundscape and technology is that of Oleksik et al. [2008]. The domestic soundscape, they found, has both a rich and a carefully managed sonic environment: "sounds within the home have layers and levels of meaning resting upon them. These meanings are contingent upon both the contexts in which the sounds are received and the personal associations with which those sounds are bound" [p. 1423]. Household members routinely monitor sounds to keep abreast of the progress of the day and occurrences in the house and beyond [Oleksik et al. 2008].

On the basis of these findings, Oleksik et al. proposed several sonic interventions that would enable the management of sonic intersubjectivity. The most interesting of these for our purposes is the Appliance Cube. An Appliance Cube would have an image representing a different active domestic appliance on each face of the cube (e.g., washing machine, running bath, kettle boiling). Each appliance would be instrumented with a microphone whose output could be relayed wirelessly to the cube. The upward-facing side of the cube would play the recorded real-time sound of that appliance continuously while the other faces would indicate events at or near the other instrumented appliances. This device could be "used to sense and relay sounds throughout the home, allowing family members to monitor remote events in the home through sound when they are beyond the range of hearing" [p. 1427].

The domestic soundscape contains sounds which are unmediated (opening and closing doors, pull out of and into driveways, and the like) and mediated (radio, television, music players, computers, and the like). Mediated sounds are used for far more than their obvious directly informational functions (e.g., listening to the news) [Tacchi et al. 2002]. Broadcast radio in the domestic context "can be seen to fill 'empty' space and 'empty' time with a familiar routine ... [and] it can be seen to provide a frame, not only for social interactions in Goffman's sense, but also for avoiding, or making up for, a lack of social interactions" [Tacchi et al. 2002, p. 25]. Seniors traditionally make up a large proportion of the radio audience, especially for news and talk radio [Santhanam et al. 2012] and are used to "filling their day" with the routine of radio [Tacchi et al. 2002]. An audio-based awareness intervention, then, seems well suited to the context of supporting seniors living independently.

3. SONICAIR: SONIC ATOMIC INTERACTION RADIO

We developed the SonicAIR [Baharin and Mühlberger 2009] to explore how metaphorically "atomic" lean individual sound cues could be treated by users as aggregately constitutive of a connection shared between two locations [Baharin et al. 2008]. The name is also a nod to SonicFinder [Gaver 1989] which was one of the earliest systems to use auditory icons to represent activities.

A SonicAIR installation was comprised of two homes augmented with reciprocal technologies. Each SonicAIR consisted of a Mac Mini with a 3G broadband modem, Arduino board, and reed sensors. Reed sensors and magnets were attached to kitchen activity sites (appliance doors, drawers, or cabinets). When the sensors were actuated, a signal was sent to the Mac Mini via the Arduino and an application (written in the Processing programming language) updated a local (private) Twitter status with a code corresponding to the activity. Each SonicAIR unit monitored the Twitter feed of the other SonicAIR unit and played the corresponding auditory icon when the Twitter feed indicated that a sense had been triggered. Sampled sounds and musical sounds were used rather than live sound streams to reduce bandwidth requirements as well as anxiety over surveillance. Using magnets and reed sensors meant that the detection was robust as long as there was no mechanical failure. Latency depended on the internet connection and the Twitter service, but given the nature of the signals being sent, latency issues were not a significant factor.

Figure 1 shows a SonicAIR in the process of being set up, with the wires of a reed switch attached to a refrigerator door being attached to the Arduino Board in the SonicAIR's enclosure). Figure 2 shows a completed SonicAIR setup in place on a kitchen bench. Figure 3 shows the signaling process of a SonicAIR deployment. If the father in House A opened his microwave door, the SonicAIR in his daughter's House B would play the sound sample representing this activity. The process would be reversed if the daughter used her microwave.

Fig. 1. SonicAIR deployment, setting up reed switches.

Prior to the deployment of SonicAIR in their homes, all senior participants were interviewed to develop a general idea about their sense of independent living, paying particular attention to their individual soundscapes. Before installing SonicAIR, mutual agreement of sensor placement was important because we wanted to maximize SonicAIR engagement but did not want the participants to feel that the sensors and wires were impeding their daily routine. Despite some visible wires, the participants did not feel that the sensors were intrusive. They reported that they did not think they "used" SonicAIR, rather they were just going about their daily lives.

3.1. Iterative Sonification

While sensor placement was negotiated and set prior to the study, the nature of the sonification used for each deployment was more negotiable. The accuracy of earcons has been considered of primary importance in other work [for example, Bikaki and Floros 2011; Brewster 2003; Zhao et al. 2008], but the goal of the SonicAIR technology probe was similar to that of WISP [Kilander and Lönnqvist 2001], in which accuracy was less important than intuitive understanding. Further, since the goal was not strict evaluation of this technology, we allowed for some iterative refinement of sonification driven by the experiences of the participants.

We started all participants with denotative samples, in which a prerecorded sample of the actual sound produced by an activity was used to represent that activity. For example, opening a cutlery drawer was represented by a sample of rattling cutlery and the drawer's mechanism sounds. The denotative sample was intended to maximize the rapid identification of the remote activity as specifically domestic. However, some participants (Lucy, Mary, Josephine) soon reported difficulty disambiguating local sounds and samples emanating from the SonicAIR. To counter this ambiguity, we initially

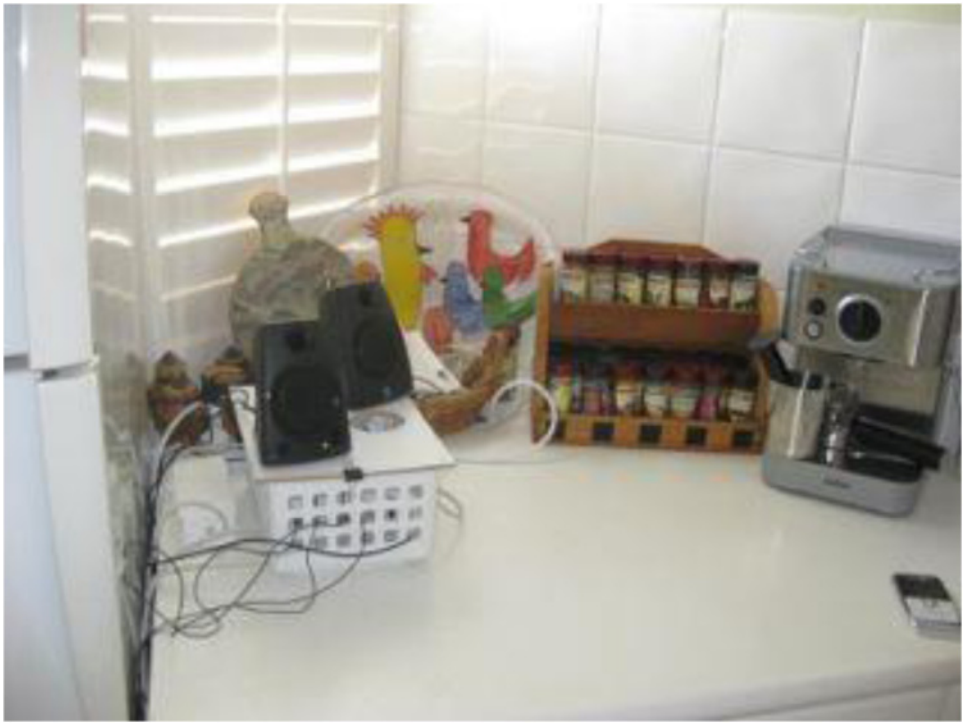

Fig. 2. SonicAIR deployed.

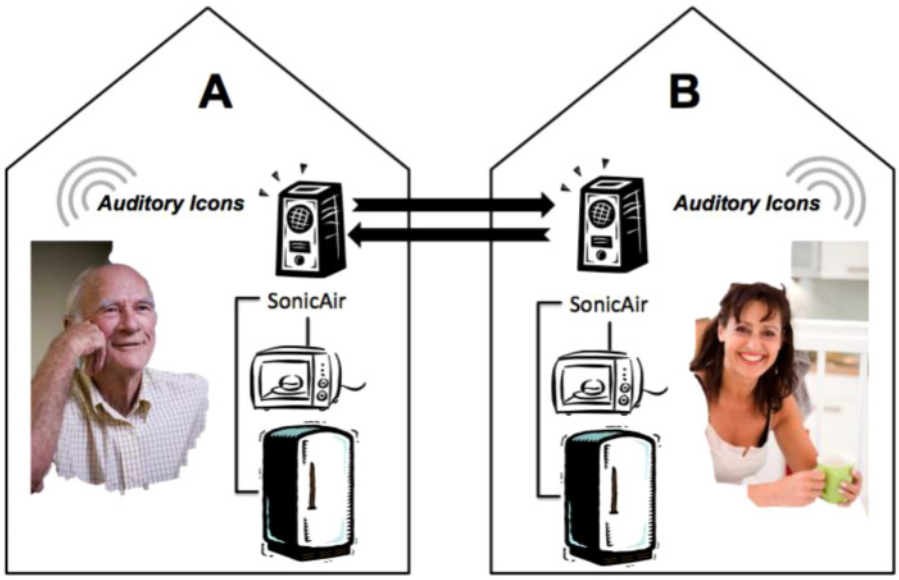

Fig. 3. SonicAIR process scenario.

tried combining earcons and denotative samples. Earcons are the representation of information using abstract musical sounds [McGookin and Brewster 2004]. However, when these participants missed the prefacing earcon, they experienced the same ambiguity as for the denotative samples. For these participants, alternative realistic but nonambiguous samples were used. For example, a sample of soft clanging bells was played when a pantry door sensor was triggered, as it connoted other door-opening moments (such as entering shops). Realistic samples rather than abstract samples or musical phrases were used because they could connote some aspect of the remote action without total simulation. Participants thus ended up with a variety of cues throughout the deployment, which will be mentioned later when relevant.

3.2. Method

SonicAIR was piloted in two separate deployments, each lasting a total of five to six weeks. Five people were involved, representing three dyads in two pairs of homes.

The first deployment was in the homes of a pair of friends, Lucy and Janet for three weeks. Lucy, 67 years old, lived in a two-bedroom apartment. She was fit and active with no serious illness and regularly walked to her art classes. Janet, 79 years old, was Lucy's friend. When Janet was healthier, she had attended art classes with Lucy. Two weeks into the deployment, Janet had a fall in her house and decided not to continue after returning from hospital. Lucy was interested in continuing, so she introduced us to another friend, Mary, who was an active 60 year old recent retiree living in a detached house. This pair of friends used SonicAIR for a further four weeks.

The second deployment was a family pair. Rosanne, 70 years old, lived in a town house and, other than a back problem, was healthy and active. She asked her younger daughter, Josephine, to be her coparticipant. Josephine, in her 30s, lived alone in a one-bedroom apartment and worked irregular hours. This family pair used SonicAIR for five weeks.

Future research will seek more generalizable patterns across larger deployment groups and explore the link between connected remote soundscapes and health outcomes. All participant names in this article have been pseudonymized.

3.3. Data Collection

We deployed the SonicAIR in the manner of typical HCI ethnographic field studies of technology probes [Hutchinson et al. 2003]. Data took the form of participant interviews taken at several times over the deployment, participant diaries, some in-home observation, and researcher diaries and technical logs. Analysis focused on gathering qualitative perspicuous examples of how SonicAIR *afforded accounts of recognizability* rather than on generalizable uses or measurable evaluations [Harper and Taylor 2009].

Diaries: In the first deployment (Lucy with Janet/Mary), the participants were each given a blank diary and requested to reflect on being able to hear the sounds from SonicAIR. In the second deployment (Roseanne with Josephine), the diaries provided stimulus questions designed to encourage more detailed entries.

Twitter logs: Since SonicAIR used Twitter to relay information between participants, the Twitter feeds were logged to link participant diary narratives with objective sensor information.

Logbook: The primary researcher kept a project logbook to reflect on the challenges of the deployment. This was especially helpful for troubleshooting issues such as the need to modify the sonification in response to participant feedback. Data from the Twitter logs and the researcher logbook were used to corroborate the accounts from the participants and give a more complete view of the participants' experience.

Interviews: We aimed to conduct an interview once a week for the duration of the deployments but the number of interviews completed varied depending on the participants' situations. Overall, we conducted a dozen interview sessions. In the first

deployment, when Lucy was connected with Janet, each was interviewed once. When Janet was hospitalized, Mary became Lucy's coparticipant. Mary was interviewed twice and Lucy once, separately, and they were both interviewed together once. In the second deployment, Roseanne was interviewed three times, Josephine two times and they were both interviewed together once.

4. FINDINGS: ACCOUNTS OF CONNECTED DOMESTIC SOUNDSCAPES

4.1. Adding to the Expectable Soundscape: From "possums at the screen door" to "it didn't worry me"

Domestic soundscapes are a mixture of expected and unexpected sounds, but unless people have a contextual reason for treating sound as remote, all sounds are treated as local. Some unexpected sounds are easily explained away as not domestically relevant, such as passing emergency vehicle sirens, while others may trigger investigation if they seem close or are of a type that exceeds the threshold at which they may be treated as background [Oleksik et al. 2008]. The participants in this study first had to learn how to understand the SonicAIR sounds as emanating from the appliance rather than another local source. Part of this learning process involved telephoning one another over the first few days to "check" that sounds had been played at the remote end. SonicAIR was designed as an entirely passive player of triggered sounds from the remote location and did not include feedback to indicate successful or unsuccessful transmission.

When Lucy first heard the SonicAIR, it played the crashing metallic denotative sound sample representing Janet's cutlery drawer being opened. Lucy initially did not recognize the denotative nature of the sound as it was not connected to her own activity, did not recognize that the sound had come from SonicAIR, and did not recognize it as indicating Janet's action.

> **Lucy:** Well, I sort of looked around and I couldn't see anything and I went to the door to look out to see if it was [. . .] no, I really wondered what had happened. And then I think when I heard it the second time, I thought, well that sounds more like cutlery.

When Roseanne first heard SonicAIR, she was in her living room watching TV. Like Lucy, she knew the unexpected sound was not connected to her present activity, so she initially attributed the sound to a local physical source rather than her remotely connected coparticipant. She attributed the sound to the common Australian evening event of marsupial possums making noises in or around the house (in much the same way as mice, rats, raccoons, nesting birds, and the like).

> **Roseanne:** I guess it happened in the evening, which will be a normal time for Josephine. But first time I was not expecting it. I didn't immediately realize that it was her opening the fridge. Because to me it sounded that a very scratchy sound that I have heard here on the screens outside with possums shaking them or they've jumped down from somewhere and grab on. [. . .] Then five minutes later I heard it again and I was absorbed watching a program on TV. So I kept watching but the second time I think I actually got up and then it hit home that [it was SonicAIR].

Even though the sound from SonicAIR caused Roseanne to feel anxiety about whether possums were making mischief around the house, after a couple of days she felt that she was accustomed to the sound (albeit still considering it unpleasant).

> **Roseanne:** And I probably got a bit more comfortable with the sound [. . .] But I guess after a couple of days you start to get adjusted. And it shows, you know, the more accustomed you get the more you can cope with things.

On the other hand, the denotative samples did not confuse Janet. She attributed this to the fact that she heard noises all around her house all day long, be it from the traffic or from her neighbors whose houses are very close to hers. She turned her radio on almost all the time when she was home, somewhat covering those sounds. The uniqueness of the denotative samples stood out for her as not part of this soundscape and thus she attributed them to SonicAIR.

Janet: Well [the sounds] weren't frightening. Well, once you said we were hooked up like that, I knew some noise would be coming through. But once I realized where it was coming from, it didn't worry me.

Even in Janet's response, though, we see that the formulation of the problem was becoming accustomed to the sound source more than the link to the coparticipant.

A similar issue was found in terms of descriptions of the sound preferences. Lucy (who experienced both singular denotative samples and combined earcons and denotative samples) particularly liked the earcons that preceded the samples, but treated them as sounds with their own value rather than sounds for which the value was an indication of a remote participant's action.

Lucy: [. . .] I just heard these funny sounds, I mean, there's nice music to start with, which I quite like. I quite like the music sound and I think I probably, I don't think I, I certainly hadn't woken up to the fact that there were two other sounds as well. It was the music that I listened to most, I think.

When Roseanne's SonicAIR sounds were changed to connotative samples to reduce ambiguity, she commented that she liked the sound of clanging bells because it brought back nostalgic memories – her own memories, not memories connected to the remote other.

Roseanne: It's the water. The water's okay but the chimes. Now it's interesting, it has a much nicer effect on me. The sound you use is important I think. The chimes are sort of for me, uplifting. Maybe the sound more like the cows, the bell ringing on the cows and I've had lovely times in Europe with the cows (laugh) and their bells and so it's just yeah, it sounds special.

When SonicAIR was installed for Janet, she was told that SonicAIR would produce sounds but the specific sounds were not explained so that we could see how she would attribute meaning to them. She reported enjoying trying to guess what the sounds were; she likened this to a program she heard on the radio where the listeners called in to guess "mystery sounds" played by the station. Despite not being told what the sounds specifically meant, it was important to Janet that she developed her own attribution of a remote action to a sound. Lucy also said that knowing the different sounds would help to deduce more information about the remote other.

However, sound differentiation and meaning were less important to the other participants. Mary and Josephine reported that the specific sound mattered less than its occurrence in time. While it was difficult for Mary to differentiate the sounds from SonicAIR, Josephine could not tell the difference at all, because she did not pay attention to each individual sound. Roseanne did not know until during the exit interview that Josephine's SonicAIR did not make the same sounds as hers. She could tell the different sounds apart (pouring water and clanging bells) but she could not remember what actions each sound represented since her SonicAIR used connotative samples.

4.2. Hearing the Rhythm of Coparticipant's Routine: "There's Lucy, you know"

After learning to treat SonicAIR sounds as emanating from the appliance, participants began monitoring the sounds as socially relevant.

Roseanne and Josephine kept their diary devotedly. In the first few entries, they both referred to the SonicAIR sounds as "sound" or "noise". They did not differentiate between samples nor did they associate the sounds with their remote coparticipant. However, in later entries, they referred to the sounds in terms of agentive action, such as "Mom doing something in her kitchen".

In interview responses, some participants stressed the link between the sound and the remote participant, but not the specific activities. When asked what she thought of the sounds from SonicAIR, Janet responded as following.

> **Janet:** Well, I'll say "Oh, yeah, that's that," and I suppose I didn't put down I just heard noise. I didn't distinguish between which items she was using. I thought, "Oh that noise. It's just Lucy using something in her kitchen".

Similarly, after two weeks of having SonicAIR in her kitchen, Mary reported her reaction when she heard the sound as "There's Lucy, you know". Reciprocally, for Lucy, the sound from SonicAIR was not just Mary opening a microwave or refrigerator door but steps in the process of having a meal.

> **Lucy:** I usually hear sounds sort of in groups, and then you'd think somebody's having a meal or something like that.

After Roseanne's SonicAIR sounds were changed to connotative samples to relieve her anxiety about possums, she reported both a link to the remote coparticipant and some specificity of action.

> **Roseanne:** Yeah I think well [Josephine] is home and is getting something out of the fridge or the pantry. I think she said the water was the fridge.

Participants' accounts changed not only to include agentive links for specific incidents but also indications that rhythmic information heard over hours or days was treated as awareness of the remote participant's domestic routines, as in this example from Janet describing SonicAIR as providing a window to Lucy's daily life.

> **Janet:** Well I thought I better make a note of what time or something it was. Yeah, I didn't really hear lots of noise. Yeah, it's mainly when she was in her kitchen, same sounds, that I – yeah. But it was just at certain times in the morning, some in the middle of the day, some in the evening. Because she goes out a lot. She's never always there.

Writing in her diary may have been a contributing factor that made Janet recognize that there is a rhythm to SonicAIR's sound, but as shown later in the deployment with Roseanne and Josephine, even without writing in the diary the participants could relate the sounds of SonicAIR to certain times. Lucy was also aware that she heard sounds every morning, but because she was half-asleep she was not sure if it was the birds or Janet. While she may have been mistaken about the actual cause of the sounds, the confusion also indicates an acceptance of sounds representing the remote other.

> **Lucy:** And then I mean, I think I probably did hear it occasionally, when I think back, early morning when I was half awake, and probably thought it was just the birds on the roof scratching around or doing something. Because they do scratch around or make scratching noises on part of the roof at times.

For Lucy, SonicAIR was a window on learning about the moment-to-moment aspects of her friend Janet's domestic routines. For the mother–daughter pair of Roseanne and Josephine, however, SonicAIR was a way of confirming presupposed understandings of each other's routines – or claimed lack thereof.

Josephine: Just let me know really. But like it wasn't like I was discovered something new about Mum's patterns that I didn't already suspect [laugh].

Roseanne: I don't think that I really discovered anything new but it's probably reinforced my idea of her lifestyle if you like or her behavioral pattern. I sort of feel Josephine doesn't have a regular-

Josephine: -structured life.

It is telling to note that Roseanne here talks about the continuous monitoring of SonicAIR as rich enough to provide an "idea" or a "feel" for Josephine's "lifestyle" – moving well beyond descriptions of individual sounds and into a gestalt contexture of a revealed remote soundscape. Narratives about coparticipants often took the form of hearing sounds and then describing what the sound "meant", but it was also apparent that such accounts depended on shared knowledge which was then back-filled with evidence from the SonicAIR sounds.

Janet: Well I thought well she's busy in the kitchen. She's either in a rush this morning or she's, because she's got to be out somewhere. Because I know in myself that she had to be out. On certain days she has to be at an art class at a certain time. And knowing Lucy, she's always late, so everything's done in a – [hurry].

For Roseanne, hearing the SonicAIR sounds from Josephine's end after a period of no sound led to a narrative of Josephine returning home.

Roseanne: I was probably home, or late evening, or from late afternoon and hadn't heard her. And then I heard her come in and I heard her twice five minutes apart.

The SonicAIR did not actually provide a sound trigger for Josephine entering her home, only of kitchen activities, so Roseanne's claim to have heard Josephine "come in" is an extension of reciprocity of perspectives: combining a comparison of the assumed meaning of an absence of sounds all day together with the newly occurring sounds that would require someone (presumably Josephine) being in the house.

Similarly, one day Mary helped Lucy to pack her furniture so that Lucy's house could be painted. Late that night, when the SonicAIR produced a sound, Mary reported thinking "Oh, Lucy must be still packing". While this meaning of the sound is based on shared knowledge, "packing" is just one of many reasons that the Lucy may have been opening a drawer or cupboard at that time. Nevertheless, Mary found comfort in being able to treat packing as a recognizable narrative regardless of its veracity.

4.3. Changing Behavior Based on Inferred Sonic Intrusion: Settling for Cold Milk

Once participants started associating individual sounds and then rhythms of sounds with remote others, they also started to consider the potential sonic intrusion by one another – what it might mean to cause loud noises at the remote end, especially at normatively quiet times of diurnal domesticity.

Three of the five participants in the SonicAIR deployment changed their behavior because they did not want to trigger the associated sound in the homes of their remote coparticipant. Lucy changed her behavior only for the first week of her deployment, but for Mary and Roseanne the change persisted until the fourth and fifth weeks of deployment, respectively. For the first week of deployment, Lucy stopped opening her

fridge at night and did not heat her milk in the microwave because Janet usually went to bed early. Indeed, on the basis of the SonicAIR deployment, Janet mildly accused Lucy of being up too late at night.

Mary started to avoid storing her food items in the pantry if she thought she would need them later, saving her from repeatedly opening her pantry door and thus triggering repeated sounds. Similarly, instead of taking each item only when needed, Roseanne began to plan which items to take from her fridge when she was cooking. She would collect them all at once when she opened her fridge door and put them on her kitchen counter. When she finished cooking, she would return them all to the fridge again at one time. The participants changed their behavior because they wanted to accommodate or respect their coparticipant's routine. All the participants had some knowledge of their coparticipant's routine. For example, Janet could describe Lucy's routine:

> **Janet:** Perhaps, I know perhaps it's wrong if you know someone's vaguely. . . there. . . what they get up to each day. So you know when they should be in their kitchen or they should be in the. . . making those noises. Where, perhaps, if it was someone that I didn't know. She goes out to art Saturday and Wednesday and then does something else another day. [. . .] You've got these ideas, you know where she is on certain days. So is that wrong? Well, perhaps, if you knew it was someone you didn't know, I don't know.

Mary and Janet knew that Lucy was an evening person. Meanwhile, Lucy knew that Janet and Mary were morning people. Therefore, when Mary prepared her breakfast early in the morning she was conscious that her activity might disturb Lucy's sleep. Mary tried to be "quiet" as if she was colocated with Lucy because of the intrusive nature of the sound.

> **Mary:** I did think that a few times getting my breakfast at 5.30 and I thought ah maybe sort of quiet and then I thought well I can't be [laugh] and yeah it sort of went through my head.

4.4. Active Communicative Adjacency: "I'll open the fridge to let her know I'm at home"

At the beginning of deployments, on occasion, participants would engage in more active communicative action than simply monitoring, a form of communicative adjacency that started as a summons – answer-style mutual signaling of awareness that could shade into a playful game of 'tag'.

In the first week of the mother–daughter pair deployment, Roseanne's SonicAIR did not function consistently. After three days without any sound from SonicAIR, the first time Roseanne heard a sound she deliberately opened her fridge door so that Josephine could hear her too, in an attempt to let Josephine know that her machine was operational. In the second week, when correct operation was no longer an issue, Roseanne started to intentionally trigger a sensor when she heard a sound relayed from Josephine's end. Josephine did not have a stable routine because she was studying and working part-time. Roseanne also led a very active life, filling her week with planned activities outside the house. Both coparticipants were mostly away from home during the day. However, Roseanne monitored Josephine's relayed sounds and, on the basis of her narrative that a sound meant that Josephine was "returning home", triggered the same sensor as she heard from Josephine's end to "tell" Josephine that she was home too.

> **Roseanne:** You know, oh, oh, you know, she's just come home. She hasn't heard me all day. And I'm finished with it but I'll just do it this once. Yeah, yeah so you know I'm here too.

Roseanne and Josephine went one step further than signaling mutual awareness. Log data showed that there was a form of back-and-forth signaling between Roseanne and Josephine that went beyond simply 'I'm home'—'I'm home too'. Roseanne described the act of deliberately opening a fridge door as playful. Only the mother–daughter pair engaged in this form of back-and-forth communicative 'tag'. Roseanne speculated that if she were connected with a friend using SonicAIR, the experience of hearing the sound would not be as meaningful as with her daughter and might not engender such play. Indeed, the friend pair Mary and Lucy did not engage in such activity.

4.5. Behavioral Interdependency: "She can't sleep. . . I'll get up myself"

While Mary and Lucy did not engage in quite direct communicative action, they did engage in mutual action. Each reported an instance of behavioral interdependency. When Mary heard the SonicAIR produce fridge and microwave sounds at about 1:00 a.m., she developed a narrative in which Lucy could not sleep by virtue of comparison between the absence of her own and Lucy's sounds at that time and assumptions about the normative diurnal rhythms of sleeping and waking. Mary then reported reflecting on her own wakefulness and decided to engage in the activity of watching television.

> **Mary:** I suppose that I have read my book, and then I probably woke up about one, although I'm not sure what [the sound] was, and I thought, oh, she can't sleep [laughs]. I'll get up myself and I'll turn the TV on.

Similarly, Lucy developed a narrative of 'Mary having a meal' when she heard a succession of sounds from SonicAIR. However, she also went further on some occasions. When asked whether her actions were dependent on Mary's actions, Lucy responded that although she knew Mary might not be making a drink, she might treat the narrative as a trigger to make herself a drink.

> **Lucy:** I think sometimes it might make me go and have another. . .an extra drink or something like that I suppose. I mean I have wondered that because I can hear her and I think well I haven't had a drink or something for a while and I might make another drink. I think I've done that sometimes.[. . .] sometimes I think, well I mean she might not be making a drink but I think well I haven't had any.

Behavioral interdependency thus involved treating the cues of the remote other as a resource for reflecting on ones' own behavior and then enacting a locally relevant activity that could be treated as paralleling the narrative of the remote activity. The two behaviors were interdependent but not mirrors, echoes, or communicated, and they were also not reliant on the ability or need to verify the accuracy of the narrative of the remote activity. Indeed, only one person engaged in the interdependent activity as a conscious participant.

5. DISCUSSION: STORIES OF RHYTHM

The accounts of SonicAIR deployment participants above show them engaging in forms of technologized interaction. SonicAIR's sounds, brute and effectively unverifiable as to their motivating actions, were nevertheless used by participants as a resource for enacting a range of mutual social assumptions. This mutuality was a personally-oriented-to sense of reciprocity of perspective with the remote partner rather than a materially active connection. It was also for the most part not a deliberate and conscious communicative exchange.

5.1. The Discovery of Awareness

Our findings about the early period of the trial were that the participants had to first appreciate that the SonicAIR sounds emanated from the SonicAIR appliance rather than another local source, and then connect those sounds to their remote partner in a threshold moment of copresence.

The first issue, learning to hear sounds as emanating SonicAIR, was partially a reaction to denotative sonification. The sounds were not of the local participants' own direct activity and were similar enough to those which might unexpectedly occur in the local soundscape (such as things falling over or animals scratching at a screen door) that they were easily explained away as background or at least able to be let pass – a figure/ground problem. A combination of physical investigation and personal reflection led the users to realize that SonicAIR could produce sounds "on its own". The next step in this process was to become accustomed to the fact of SonicAIR's unexpected sounds, even before attributing this to the activities of another social being. There was, then, a need to orient to the existence of a technologically instantiated connection, and then build a special sense of mutuality on that orientation.

When bare denotative samples were replaced with combined earcons and denotative samples, the sounds of SonicAIR were more recognizable as emanating from the device especially because their musical earcon introductions were treated as interesting/valuable additions to the existing local soundscape. Similarly, connotative samples, such as clanging bells, were treated as interesting/valuable additions to the local soundscape because they triggered nostalgia (albeit unexpectedly from our perspective).

It is interesting to note that recognizing that there were different sounds, and that different sounds were ostensibly conveying signals about different remote actions, was of limited importance to all participants bar one. We might attribute this to an early learning phase but most of the participants reported not knowing the difference between sounds even by the end of their trial.

All participants reached a threshold moment of mutuality after just a few days, as indicated by a change in descriptions of sounds in both diaries and interviews. Specifically, sounds became identity categories for social others, such as "there's Lucy" or Josephine is "returning home". Again, the ability to recognize the categorized identity of a social other from sounds played by SonicAIR is a precondition to further mutuality. The difference, of course, is that the recognition that the sounds are those of a social other is not that of a focused encounter [Goffman 1961], but rather more akin to the recognition of a distant other by sight or an unseen other by sound. As Oleksik et al [2008, p. 1422] found, domestic listening involves multiple levels of monitoring sounds in the domestic soundscape as being of foreground or background importance. "Listening out" for others who are making sounds not directed at oneself is part of this monitoring, and assuming one recognizes the sounds of the other then it is clearly relevant to a sense of relationship and belonging.

5.2. Reciprocity of Perspectives

It seems that the threshold of mutuality was triggered by the recognition of temporality – when sounds occurred and the patterns of those sounds – and quickly shaded into the kind of reciprocity of perspectives that is assumed in many social contexts. The recognition of the importance of rhythm – both sequences of sounds and sounds in the context of the diurnal routines of domestic life – required developing narratives combining foreground and background hearing [Oleksik et al. 2008, p. 1422]. Foregrounding occurred in the sense that as the SonicAIR sounds were heard they presumably took some conscious effort to connect to a remote social other, but backgrounding also occurred because the sounds were meaningful but not directly relevant to the local activity.

Many participants reported hearing sounds in groups and then reporting on those groupings as intentional activities of the remote other, specifically having a meal, and, given the time of day, the particular meal that it would be. These accounts were often more than just individual actions, they were narratives about activities (about packing, for example) based on a combination knowledge about the other, the timing of sounds, and a deliberate change of attention from hearing to monitoring. These narratives were never reported as being verified or not, indicating that the veracity of these narratives was less important than the ability to create them. This has potentially important ramifications for ambient awareness, both good and bad. The good, of course, is that, as Vetere et al. [2009] note, the leanness of the information does not correlate with its significance. On the other hand, the potential for misrecognized narratives certainly does need to be taken into account, especially if there is the possibility of ambiguity that could affect wellbeing, as in the case of this kind of technology being deployed in parallel with telecare technologies.

Further, the participants talked about the sounds that they triggered as if they were present in the other's space, but when asked if they felt like they were living with their coparticipant, they disagreed. The connection between the two locations, then, was treated as distinctly remote even while it was a socially meaningful representation of the other. Ambient presence was thus in no way an illusion of presence. Mutuality was, as noted earlier, more a sense of parallel domestic soundscapes than combined domestic soundscapes.

The reciprocity of perspectives extended to decisions about how activities in the local environment might impact on the remote environment. It would appear that the timeliness and rhythmic nature of SonicAIR's sounds outweighed their apparent informational leanness. This matches Oleksik et al. [2008, p. 1423] finding that participants were very concerned to manage the volume levels in domestic soundscapes – negotiating their own preferences and the perceived preferences of others. That SonicAIR users might change or constrain behaviors (such as gathering ingredients from a cupboard in a batch rather than individually) to not adversely impact one another indicated involvement and caring. Just how stable and how relevant such changes or constraints may be is, of course, an issue for future research, but it is certainly indicative that always-on ambient awareness technology may indeed provide sufficient resources for social connection.

This is, then, an interesting twist on the accessibility of the remote other. The remote other was, in fact, materially accessible. Participants could deliberately trigger a sound in the other's house (we will discuss the deliberate use of this shortly) but in terms of phatic communion, the technology did not provide a way for feelings of mutual care to be mutually negotiated through the exchange of these sounds. The participants would have had to use another medium, presumably the telephone, to discuss this. However, while the participants did report telephoning one another to check that SonicAIR was operating on occasions, they did not report talking to one another about their mutual feeling of intrusion, even though they reported feeling it or wanting to avoid the other feeling it.

5.3. Interaction

Participants developed two variations on interaction using the SonicAIR system: communicative adjacency and behavioral interdependence. When we designed SonicAIR we wondered whether communicative adjacency might occur, but behavioral interdependence was a surprise – and a reminder that technology design works best when it provides a platform for social resourcefulness rather than attempting to tie users down to presupposed activities.

The mother–daughter pair engaged in communicative adjacency, deliberately triggering the playing of sound at the remote location after hearing a sound triggered by the remote other. This practice, which when asked about the pair described as both "letting her know I'm there" and "playful", was not an intended use of SonicAIR as SonicAIR was designed to be more of a passive ambient awareness device rather than a direct interaction device. It is clearly indicative of a deeper engagement with mutual awareness, somewhat close to an active monitoring. It points to a possible future situation in which long-term users of ambient awareness technologies might develop routines for signaling everyday continuity of life-as-normal, as well as taking the extra step of deliberately calling one another when expected rhythms are not heard or unexpected sounds are heard. Such behaviors would be a valuable social monitoring system to support independent living both within and outside the telecare context.

The second form of interaction was that of behavioral interdependence. In principle, this is less interactive than communicative reciprocity, but we think it is the most interesting finding in terms of supporting social presence in the independent living context. As discussed earlier, behavioral interdependence was the process of speculating about the narrative of remote sound production and, on reflection, deciding to take action oneself that might parallel the remote narrative action. There was no attempt to make the remote coparticipant aware of the local action, but it was clearly interdependent because choices were made based on considering a social other. This interdependent behavior was not quite indicative of belonging to a particular community or ties between oneself and the social other, but engaging in it was a personal reminder of belonging. As with communicative reciprocity, this could well be a valuable behavior supporting independent living if it occurred in long-term uses of this form of technology. Providing awareness resources for behavioral interdependence may potentially be exploited as a way of ensuring natural mutual reinforcement of behaviors that promote physical wellbeing – movement, hydration, taking medicine and the like – while also promoting the social benefits of wellbeing as communally generated.

6. DESIGNING FOR RHYTHM

The ability to both produce and detect rhythm is innate in humans [Winkler et al. 2009]. According to Sacks [2008], bonding among people as the result of music as a social activity, for example in concerts or in some religious rituals, is achieved through rhythm. At music concerts, the rhythm enables the crowd to mimic and synchronize with one anothers' behavior. This is called entrainment, which is "the synchronization of a biological, internal, regular oscillator with an external, periodically recurring event" [Knight 2009, p. 82]. Synchronization of rhythmic actions is used to create a sense of communion, for example in marching, dancing, and some religious rituals. While external entrainment is usually observable when audiences listen to music, such as swaying and foot tapping, Knight [2009] suggested that oratory performance, such as political speech, although they do not have "high enough periodicity *levels*" to induce physical entrainment, may have used rhythm in speech for example, to stress on syllables in time, to create communion for the purpose of persuasion. Auer and Di Luzio [1992] found extensive rhythms in mundane spoken interaction. While rhythm in music and speech is easily discernable because of the quick tempo and the short time span needed to notice it, we speculate that with extended exposure to domestic soundscape rhythms via SonicAIR may have the ability to link to internal entrainment.

6.1. Design for Systematicity over Objectivity

According to Thomas [2008], sonification should be objective (facilitating accurate communication or correct interpretation), systematic (there should be a systematic way the data affects the change in sound), and reproducible (the same data yield the same

sound; and representation of different data is possible). SonicAIR technically provided these affordances but our findings show that, except for Janet, participants did not pay much attention to individual sounds coming from SonicAIR. In fact, they used the rhythms of the sounds to validate their prior knowledge or assumed knowledge about their coparticipant's actual circumstances or commonsense knowledge of what kitchen activities would be undertaken at what time. Indeed, other totally nonobjective sonification systems have also been shown to allow participants to develop narratives about their sounds [Brazil and Fernström 2007].

It would seem that sonification designed to support ambient awareness should emphasize systematicity over objectivity. Users are already sensitized to listen for and make meaning from patterns, and those meanings will be socially conditioned. That being said, there is clearly also the potential for problems in terms of the annoyance of repetition [Ferguson 2013]. Repetition of sounds to create rhythm is crucial for the creation of narrative, but how much repetition is too much? Clustering procedures may be needed to prevent annoyance within high-use periods, or the ability for users to choose their own granular interest in hearing all the triggered sounds. This would be especially important if such awareness systems were deployed in groups larger than dyads [Erickson and Kellogg 2000]. Similarly, damping abilities such as 'do not disturb' periods may be needed to allow users to avoid disturbance when it is not desirable. However, that may constrain the utility of such a system to provide potentially useful, even life-saving, information about unexpected events.

6.2. Design for Variety, Activity-Orientation, and Feedback

Although our participants mostly did not distinguish between different sounds, they did have varied responses to denotative and connotative versions, and the prefacing (or not) with earcons. The participants reported evaluations of the icons that had more to do with personal feelings of enjoyment or nostalgia than our proposed meanings. As such, again given that objectivity may be less important than systematicity, we suggest that users be provided with a range of sounds to choose from. This might also help with the repetition problem, as repeated versions of preferred sounds are likely to be less annoying.

Investigation is also needed into designing sonification that avoids startling users. Having low-level pulses promptly followed by increase in pulse can reduce startled reactions to auditory signals. Guidelines such as those of Patterson [1990], Gygi and Shafiro [2010], or Mynatt [1994] should be applied carefully to fit the context of using sonification to awareness without startling or annoyance.

What is important, and would need to be more objectively provided, is feedback on the transmission–reception success or failure. Our participants were somewhat confused and anxious about whether or not their actions were triggering sounds at the remote location, sometimes because they do not know if the technology was working and sometimes because they were concerned about the incompatibility of routines of the merged soundscapes. At the risk of complicating the leanness of an ambient awareness system, then, there may be some call for either visual or auditory feedback.

7. CONCLUSION

As hypothesized by the Appliance Cube design sketch [Oleksik et al. 2008] we found that SonicAIR users incorporated a propensity for domestic monitoring with the ability to generate *comfortably recognizable narratives about remote lives*. Comfort here refers to the developmental process of comfort with the technology and how that shaded into the comfort taken from monitoring and intersubjectively engaging with the social assumptions about domestic lives lived in parallel, if not together. Rather than attending to the specific actions that the different sounds represented, the participants attended

to the sustained rhythms of their coparticipants' actions in the kitchen as represented by SonicAIR. They used these rhythms together with knowledge about their coparticipants' everyday lives to account for the sounds as narratives of everyday life. They also used these rhythms as reminders of their own ritual and opportunistic domestic needs.

The value of ambient awareness technologies is that, designed well, they allow users to develop complex narratives based on reciprocity of perspective and, by extension, a sense of coconstituted mutual social connection. This has parallels with the argument made by Benedict Anderson that "all communities larger than primordial villages of face-to-face contact (and perhaps even these) are imagined. Communities are to be distinguished, not by their falsity or genuineness, but by the style in which they are imagined" [Anderson 2004, pp. 5–6]. The importance of imagined community has long pervaded definitional and evaluative debates about online/virtual community. Rheingold [2000], Castells [2010], and boyd [2009], have all argued against claims of inauthenticity about virtual communities by proposing that all communities are effectively imagined connections built around quasi-objects [Bingham 1999] and shared practices [Baym 1999]. Whatever form these may take, "tools, stories, corpses, or bulletin board contributions, the quality which identifies them remains the same: "the power to catalyse social relationships" [Bingham 1999, p.257].

The lean signals from SonicAIR did not require, cajole, or force users to develop particular or preplanned narratives of social understandings. The participants chose how to understand, acknowledge, admit, and even be constrained by one another by treating the signals as indicative of social rhythms – usually those of diurnal domestic cycles, sometimes those unique to the particular pair. Once such a technology can be incorporated as part of the quotidian order, then we believe that a valuable social quality will tend to follow.

Of course, in the study deployments SonicAIR only allowed for one-to-one location connections. Given our interest in the fine details of how individual soundscapes could be manipulated to incorporate awareness of a remote other, having many-to-many connections was beyond our scope. A significantly more sophisticated design would be required to enable the actions of three or more locations to be distinguished from one another. Such a design, though, would support an expanded coconstitution of the meshed social connections of community. This could be physically instantiated through SonirAIR devices with enclosures and sounds designed to be harmonious in the aggregate. A row of birds, for example, could represent friends and family and be 'tuned' to produce a pleasing choral soundscape.

As noted in the Introduction, telecare is seen as having a significant impact on reducing the cost of healthcare and improving the quality of life of the elderly. Third generation telecare enables remote detection of older people's activities with the aim to provide reassurance to concerned parties and as preventive measures. Therefore, we argue that, in the future, ambient awareness technology could be installed alongside telecare and make use of existing infrastructure that enables remote monitoring. This may be difficult if the existing infrastructure is a closed propriety system that prevents add-on by third parties. We suggest that activity or lifestyle monitoring systems may be developed to be akin to personal computer operating systems, which allow applications to be installed as add-ons. Audio-modal technologies can be used alongside telecare as a resource for older people to maintain social contact in their home; comfortably recognizing a soundscape narrative of shared social responsibility.

ELECTRONIC APPENDIX

The electronic appendix for this article can be accessed in the ACM Digital Library.

ACKNOWLEDGMENTS

The authors are grateful to the study participants for their time and assistance throughout the deployments of SonicAIR into their homes. We are grateful to Rod Watson and Wendy Kellogg (as ToCHI editor) for their excellent guidance, and our reviewers for their invaluable critiques and suggestions throughout the submission process.

REFERENCES

Gregory D. Abowd, Elizabeth D. Mynatt, and Tom Rodden. 2002. The human experience. *IEEE Pervasive Computing* 1, 1 (Mar. 2002), 48–57. DOI: http://dx.doi.org/10.1109/MPRV.2002.993144

Petter Alexanderson and Konrad Tollmar. 2006. Being and mixing: Designing interactive soundscapes. In *Proceedings of the 4th Nordic Conference on Human-computer interaction: Changing Roles*. Oslo, Norway, ACM Press, New York, NY, 252–261. DOI: http://dx.doi.org/10.1145/1182475.1182502

Benedict Anderson. 2004. *Imagined Communities: Reflections on the Origin and Spread of Nationalism*. Verson, London.

Peter Auer and Aldo Di Luzio (Eds.) 1992. *The Contextualization of Language*. John Benjamins, Amsterdam, Netherlands.

Hanif Baharin, Romiza Md Nor, and Ralf Mühlberger. 2008. It's the thought that counts: Content vs. Contact. In *Proceedings of the 20th Australasian Conference on Computer-Human Interaction: Designing for Habitus and Habitat*, Cairns, Australia, ACM Press, New York, NY, 235–238. DOI: http://dx.doi.org/10.1145/1517744.1517753

Hanif Baharin and Ralf Mühlberger. 2009. Utilising the open channel created by telecare: Acoustic communication analysis of radio sounds at home. In *Proceedings of the 21st Annual Conference of the Australian Computer-Human Interaction Special Interest Group: Design: Open 24/7*, Melbourne, Australia, 23–27 November 2009, J. Kjeldskov, J. Paay and S. Viller (Eds.), ACM Press, New York, NY, 281–284. DOI: http://dx.doi.org/10.1145/1738826.1738874

Nancy K. Baym. 1999. *Tune in, Log on: Soaps, Fandom, and Online Community*. Sage, Thousand Oaks, CA.

Athina Bikaki and Andreas Floros. 2011. An rss-feed auditory aggregator using earcons. In *Proceedings of the 6th Audio Mostly Conference: A Conference on Interaction with Sound*, Coimbra, Portugal, ACM Press, New York, NY, 95–100. DOI: http://dx.doi.org/10.1145/2095667.2095681

Nick Bingham. 1999. Unthinkable complexity? Cyberspace otherwise. In *Virtual geographies: Bodies, Space and Relations*, M. Crang, P. Crang and J. May (Eds.) Routledge, London, 244–260.

Frank Biocca and Chad Harms. 2002. Defining and measuring social presence: Contribution to the networked minds theory and measure. In *Proceedings of the 5th Annual International Workshop on Presence*, Porto, Portugal, F. R. Gouveia and F. Biocca (Eds.), 7–36.

Frank Biocca, Chad Harms, and Judee K. Burgoon. 2003. Toward a more robust theory and measure of social presence: Review and suggested criteria. *Presence: Teleoperators and Virtual Environments* 12, 5 (Oct. 2003), 456–480. DOI: http://dx.doi.org/10.1162/105474603322761270

Danah boyd. 2009. Why youth (heart) social network sites: The role of networked publics in teenage social life. In *Macarthur Foundation Series on Digital Learning – Youth, Identity, and Digital Media Volume*, D. Buckingham (Ed.) MIT Press, Cambridge, MA, 26, 119–142.

Eoin Brazil and Mikael Fernström. 2007. Investigating ambient auditory information systems. In *Proceedings of the 13th International Conference on Auditory Display (ICAD 2007)*, Montreal, Canada, Jun. 26–29 2007, W. L. Martens (Ed.), Schulich School of Music, McGill University, http://www.music.mcgill.ca/icad2007/documents/ICAD2007proceedings.pdf, Last accessed: 9 December 2014.

Stephen Brewster. 2003. Nonspeech auditory output. In *The Human-Computer Interaction Handbook: Fundamentals, Evolving Technologies, and Emerging Applications*, J. A. Jacko and A. Sears (Eds.) L. Erlbaum Associates Inc., Mahwah NJ, 220–239.

Barry Brown, AlexS Taylor, Shahram Izadi, Abigail Sellen, Joseph 'Jofish' Kaye, and Rachel Eardley. 2007. Locating family values: A field trial of the whereabouts clock. In *UbiComp 2007: Ubiquitous Computing*, Lecture Notes in Computer Science Volume 4717, J. Krumm, G. Abowd, A. Seneviratne and T. Strang (Eds.) Springer, Berlin Heidelberg, 354–371. DOI: 10.1007/978-3-540-74853-3_21

Graham Button (Ed.) 1993. *Technology in Working Order: Studies of Work, Interaction, and Technology*. Routledge, London.

Kelly E. Caine, Celine Y. Zimmerman, Zachary Schall-Zimmerman, William R. Hazlewood, L. Jean Camp, Katherine H. Connelly, Lesa L. Huber, and Kalpana Shankar. 2011. Digiswitch: A device to allow older adults to monitor and direct the collection and transmission of health information collected at home

Journal of Medical Systems 35, 5 (Oct. 2011), 1181–1195. DOI: http://dx.doi.org/10.1007/s10916-011-9722-1

Manuel Castells. 2010. *The rise of the Network Society: The Information Age: Economy, Society, and Culture*. Wiley-Blackwell, Chichester.

Sheldon Cohen. 2004. Social relationships and health *The American Psychologist* 59, 8 (Nov. 2004), 676–684. DOI: http://dx.doi.org/10.1037/0003-066X.59.8.676

Sunny Consolvo, Predrag Klasnja, David W. McDonald, Daniel Avrahami, Jon Froehlich, Louis LeGrand, Ryan Libby, Keith Mosher, and James A. Landay. 2008. Flowers or a robot army?: Encouraging awareness & activity with personal, mobile displays. In *Proceedings of the 10th International Conference on Ubiquitous Computing (UBICOMP 2008)*, Seoul, Korea, ACM Press, New York, NY, 54–63. DOI: http://dx.doi.org/10.1145/1409635.1409644

Sunny Consolvo, Peter Roessler, Brett E. Shelton, Anthony LaMarca, Bill Schilit, and Sara Bly. 2004. Technology for care networks of elders. *IEEE Pervasive Computing* 3, 2, 22–29. DOI: http://dx.doi.org/10.1109/mprv.2004.1316814

Pavan Dadlani, Panos Markopoulos, Alexander Sinitsyn, and Emile Aarts. 2011. Supporting peace of mind and independent living with the aurama awareness system. *J. Ambient Intell. Smart Environ.* 3, 1 (Jan. 2011), 37–50. DOI: http://dx.doi.org/10.3233/AIS-2011-0094

George Demiris, Cheryl L. Shigaki, and Laura H. Schopp. 2005. An evaluation framework for a rural home-based telerehabilitation network *Journal of Medical Systems* 29, 6 (Dec. 2005), 595–603. DOI: http://dx.doi.org/10.1007/s10916-005-6127-z

Anind K. Dey and Edward S. De Guzman. 2006. From awareness to connectedness: The design and deployment of presence displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Montréal, Québec, Canada, ACM Press, New York, NY, 899–908. DOI: http://dx.doi.org/10.1145/1124772.1124905

Thomas Erickson and Wendy A. Kellogg. 2000. Social translucence: An approach to designing systems that support social processes. *ACM Trans. Comput.-Hum. Interact.* 7, 1 (Mar. 2000), 59–83. DOI: http://dx.doi.org/10.1145/344949.345004

Sam Ferguson. 2013. Sonifying every day: Activating everyday interactions for ambient sonification systems. In *International Conference on Auditory Display (ICAD 2013)*, Lodz, Poland, 77–84, http://icad2013.com/paper/10_S3–2_Ferguson.pdf.

Harold Garfinkel. 1984. *Studies in Ethnomethodology*. Polity Press, Cambridge, UK.

Harold Garfinkel. 2002. *Ethnomethodology's Program: Working out Durkheim's Aphorism*. Rowman and Littlefield, Boston Way, ML.

William W. Gaver. 1989. The sonicfinder: An interface that uses auditory icons. *Human-Computer Interaction* 4, 1, 67–94. DOI: http://dx.doi.org/10.1207/s15327051hci0401_3

William W. Gaver. 1993. How do we hear in the world? Explorations in ecological acoustics. *Ecological Psychology* 5, 4, 285–313. DOI: http://dx.doi.org/10.1207/s15326969eco0504_2

Erving Goffman. 1961. *Encounters: Two Studies in the Sociology of Interaction*. Bobbs-Merrill, Oxford, UK.

Brian Gygi and Valeriy Shafiro. 2010. From signal to substance and back: Insights from environmental sound research to auditory display design. In *Proceedings of the Sixth International Symposium on Computer Music Modeling and Retrieval: Auditory Display*, Jan. 2010, S. Ystad, M. Aramaki, R. Kronland-Martinet and K. Jensen (Eds.), Springer Berlin Heidelberg, 306–329. DOI: http://dx.doi.org/10.1007/978-3-642-12439-6_16

Richard H. R. Harper. 2010. *Texture: Human expression in the Age of Communications Overload*. MIT Press, Cambridge, MA.

Richard H. R. Harper and Stuart Taylor. 2009. Glancephone: An exploration of human expression. In *Proceedings of the 11th International Conference on Human-Computer Interaction with Mobile Devices and Services*, Bonn, Germany, ACM Press, New York, NY, 1–10. DOI: http://dx.doi.org/10.1145/1613858.1613890

John Heritage. 1984. *Garfinkel and Ethnomethodology*. Polity Press, Cambridge, UK.

J. S. House, K. R. Landis, and D. Umberson. 1988. *Social Relationships and Health Science* 241, 4865 (Jul. 29, 1988), 540–545.

Lesa Lorenzen Huber, Kalpana Shankar, Kelly Caine, Kay Connelly, L. Jean Camp, Beth Ann Walker, and Lisa Borrero. 2012. How in-home technologies mediate caregiving relationships in later life *International Journal of Human-Computer Interaction* 29, 7 (Jul. 2013), 441–455. DOI: http://dx.doi.org/10.1080/10447318.2012.715990

Ian Hutchby. 2001. Technologies, texts and affordances. *Sociology* 35, 02 (May 2001), 441–456. DOI: http://dx.doi.org/10.1017/S0038038501000219

Ian Hutchby. 2003. Affordances and the analysis of technologically mediated interaction: A response to Brian Rappert. *Sociology* 37, 3 (Aug. 2003), 581–589. DOI: http://dx.doi.org/10.1177/00380385030373011

Ian Hutchby and Simone Barnett. 2005. Aspects of the sequential organization of mobile phone conversation. *Discourse Studies* 7, 2 (May 2005), 147–171. DOI: http://dx.doi.org/10.1177/1461445605050364

Hilary Hutchinson, Wendy Mackay, Bosse Westerlund, Benjamin B. Bederson, Allison Druin, Catherine Plaisant, Michel Beaudouin-Lafon, Stéphane Conversy, Helen Evans, Heiko Hansen, Nicolas Roussel, Björn Eiderbäck, Sinna Lindquist, and Yngve Sundblad. 2003. Technology probes: Inspiring design for and with families. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Ft. Lauderdale, FL, ACM Press, New York, NY, 17–24. DOI: http://dx.doi.org/10.1145/642611.642616

Fredrik Kilander and Peter Lönnqvist. 2001. A weakly intrusive ambient soundscape for intuitive state perception. In *Proceedings of the Workshop on Continuity in Future Computing Systems, Library and Information Services*, Rutherford Appleton Laboratory, Chilton, UK, J. Doherty, G. M. Massink and M. D. Wilson (Eds.), The Central Laboratory of the Research Councils, http://people.dsv.su.se/~peterl/publications/kilander-lonnqvist.pdf, Last accessed: 9 December 2014.

Sarah Knight. 2009. Marching to the same beat: Entrainment and persuasion. In *Proceedings of the 2nd International Conference of Students of Systematic Musicology*, Ghent, Belgium, Nov. 18–20 2009, IPEM – Institute for Psychoacoustics and Electronic Music, Ghent University, 81–84, http://www.ipem.ugent.be/sysmus09/files/Sysmus09_webproceedings.pdf, Last accessed: 9 December 2014.

Jennifer Mankoff, Anind K. Dey, Gary Hsieh, Julie Kientz, Scott Lederer, and Morgan Ames. 2003. Heuristic evaluation of ambient displays. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Ft. Lauderdale, Florida, USA, ACM Press, New York, NY, 169–176. DOI: http://dx.doi.org/10.1145/642611.642642

Aaron Marcus and Eugene Chen. 2002. Designing the PDA of the future. *Interactions* 9, 1 (Jan. 2002), 34–44. DOI: http://dx.doi.org/10.1145/503355.503356

David K. McGookin and Stephen A. Brewster. 2004. Understanding concurrent earcons: Applying auditory scene analysis principles to concurrent earcon recognition. *ACM Trans. Appl. Percept.* 1, 2, 130–155. DOI: http://dx.doi.org/10.1145/1024083.1024087

Elizabeth D. Mynatt. 1994. Designing with auditory icons: How well do we identify auditory cues? In *Proceedings of the Conference Companion on Human Factors in Computing Systems*, Boston, Massachusetts, USA, ACM Press, New York, NY, 269–270. DOI: http://dx.doi.org/10.1145/259963.260483

Elizabeth D. Mynatt, Maribeth Back, Roy Want, Michael Baer, and Jason B. Ellis. 1998. Designing audio aura. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Los Angeles, California, USA, ACM Press, New York, NY, 566–573. DOI: http://dx.doi.org/10.1145/274644.274720

Kenton P. O'Hara, Michael Massimi, Richard H. R. Harper, Simon Rubens, and Jessica Morris. 2014. Everyday dwelling with whatsapp. In *Proceedings of the 17th ACM Conference on Computer Supported Cooperative Work & Social Computing*, Baltimore, Maryland, USA, ACM Press, New York, NY, 1131–1143. DOI: http://dx.doi.org/10.1145/2531602.2531679

Gerard Oleksik, David Frohlich, Lorna M. Brown, and Abigail Sellen. 2008. Sonic interventions: Understanding and extending the domestic soundscape. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*, Florence, Italy, ACM Press, 1419–1428. 10.1145/1357054.1357277

Wanda J. Orlikowski. 2008. Using technology and constituting structures: A practice lens for studying technology in organizations. In *Resources, Co-evolution and Artifacts*, M. S. Ackerman, C. A. Halverson, T. Erikson and W. A. Kellogg (Eds.) Springer, London, UK, 255–305.

Roy D. Patterson. 1990. Auditory warning sounds in the work environment [and discussion]. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.* 327, 1241, 485–492. DOI: http://dx.doi.org/10.2307/55320

Howard Rheingold. 2000. *The Virtual Community: Homesteading on the Electronic Frontier*. MIT Press, Cambridge, MA.

Yann Riche and Wendy Mackay. 2007. Markerclock: A communicating augmented clock for elderly. In *Human-Computer Interaction – Interact 2007*, C. Baranauskas, P. Palanque, J. Abascal and S. Barbosa (Eds.) Springer, Berlin Heidelberg, 408–411.

Sean Rintel. 2013a. Tech-tied or tongue-tied? Technological versus social trouble in relational video calling. In *Proceedings of the 2013 46th Hawaii International Conference on System Sciences*, Wailea, HI, 7–10 Jan. 2013, IEEE 3343–3352. DOI: http://dx.doi.org/10.1109/HICSS.2013.512

Sean Rintel. 2013b. Video calling in long-distance relationships: The opportunistic use of audio/video distortions as a relational resource. *The Electronic Journal of Communication/La Revue Electronic de Communication* 23, 1 & 2 (Special issue on Videoconferencing in practice: 21st century challenges), http://www.cios.org/EJCPUBLIC/023/1/023123.HTML, Last accessed: 9 December 2014.

Sean Rintel. 2015. Omnirelevance in technologized interaction: Couples coping with video calling distortions. In *Advances in Membership Categorisation Analysis*, R. Fitzgerald and W. Housley (Eds.) Sage, London, UK, 123–150.

Oliver Sacks. 2008. *Musicophilia: Tales of Music and the Brain*, Revised and Expanded Edition. Vintage, New York, NY.

Laura Houston Santhanam, Amy Mitchell, and Tom Rosentiel. 2012. Audio: How far will digital go? In *The State of the News Media 2012: An Annual Report on American Journalism*, T. Rosentiel and A. Mitchell (Eds.) The Pew Research Center's Project for Excellence in Journalism, Washington, DC, http://www.stateofthemedia.org/2012/audio-how-far-will-digital-go/, Last accessed: 9 December 2014.

R. Murray Schafer. 1977. *The Soundscape: Our Sonic Environment and the Tuning of the World*. Destiny Books, Vancouver, BC.

Alfred Schutz. 1972. Common-sense and scientific interpretation of human action. *Phaenomenologica, Collected Papers I* 11 (Jan. 1972), 3–47. DOI: http://dx.doi.org/10.1007/978-94-010-2851-6_1

John Short, Ederyn Williams, and Bruce Christie. 1976. *The Social Psychology of Telecommunications*. John Wiley, New York, NY.

Anthony C. Smith and Anthony J. Maeder (Eds.) 2010. *Global Telehealth: Selected Papers from Global Telehealth 2010 (gt2010)*: *15th International Conference of the International Society for Telemedicine and Ehealth and 1st National Conference of the Australian Telehealth Society*. IOS Press, Amsterdam, Netherlands.

Lucy A. Suchman. 1987. *Plans and Situated Actions: The Problem of Human–Machine Communication*. Cambridge University Press, Cambridge.

Jo Tacchi, Kelly Askew, and Richard Wilk. 2002. Radio texture: Between self and others. In *The Anthropology of Media: A Reader*, K. M. Askew and R. R. Wilk (Eds.) Blackwell, Malden, MA, 241–257.

Hermann Thomas. 2008. Taxonomy and definitions for sonification and auditory display. In *Proceedings of the 14th International Conference on Auditory Display (ICAD 2008)*, Paris, France, P. Susini and O. Warusfel (Eds.), IRCAM, 1–8, http://nbn-resolving.de/urn:nbn:de:0070-pub-20172352, Last accessed: 9 December 2014.

Barry Truax. 2001. *Acoustic Communication*. Greenwood, Westport CT.

Debra Umberson and Jennifer Karas Montez. 2010. Social relationships and health: A flashpoint for health policy. *Journal of Health and Social Behavior* 51, 1 suppl (Nov. 2010), S54–S56. DOI: http://dx.doi.org/10.1177/0022146510383501

Frank Vetere, Steve Howard, and Martin Gibbs. 2005. Phatic technologies: Sustaining sociability through ubiquitous computing. In *Proceedings of the First International Workshop on Social Implications of Ubiquitous Computing (CHI 2005 Workshop)*, Portland, OR, http://www.vs.inf.ethz.ch/events/ubisoc2005/.

Frank Vetere, Jeremy Smith, and Martin Gibbs. 2009. Phatic interactions: Being aware and feeling connected. In *Awareness Systems*, P. Markopoulos, B. De Ruyter and W. Mackay (Eds.) Springer, London, 173–186.

Greg Wadley, Frank Vetere, Liza Hopkins, Julie Green, and Lars Kulik. 2014. Exploring ambient technology for connecting hospitalised children with school and home. *International Journal of Human-Computer Studies* 72, 8–9 (Aug.–Sep. 2014), 640–653. DOI: http://dx.doi.org/10.1016/j.ijhcs.2014.04.003

Greg Wadley, Frank Vetere, Lars Kulik, Liza Hopkins, and Julie Green. 2013. Mobile ambient presence. In *Proceedings of the 25th Australian Computer-Human Interaction Conference: Augmentation, Application, Innovation, Collaboration*, Adelaide, Australia, ACM Press, New York, NY, 167–170. DOI: http://dx.doi.org/10.1145/2541016.2541080

Joseph B. Walther. 1996. Computer-mediated communication: Impersonal, interpersonal, and hyperpersonal interaction. *Communication Research* 23, 1 (Feb. 1996), 3–43. DOI: http://dx.doi.org/10.1177/009365096023001001

István Winkler, Gábor P. Háden, Olivia Ladinig, István Sziller, and Henkjan Honing. 2009. Newborn infants detect the beat in music. *Proceedings of the National Academy of Sciences* 106, 7, 2468–2471. DOI: http://dx.doi.org/10.1073/pnas.0809035106

Haixia Zhao, Catherine Plaisant, Ben Shneiderman, and Jonathan Lazar. 2008. Data sonification for users with visual impairment: A case study with georeferenced data. *ACM Trans. Comput.-Hum. Interact.* 15, 1, 1–28. DOI: http://dx.doi.org/10.1145/1352782.1352786

Received April 2012; revised December 2014; accepted March 2015