CHRONOROOM CLOCK: PERIPHERAL TIME AWARENESS THROUGH SOUND LOCALIZATION

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ABSTRACT

Our auditory perception skills enable us to selectively place one auditory channel in the center of our attention while monitoring others in the periphery. Furthermore, we are able to accurately localize sound sources. In this paper, we present Chronoroom Clock, an auditory display that unobtrusively provides information about the current time based on the direction the audio is coming from, enabling people to monitor it in the periphery of their attention. Evaluation of a prototype version of this design indicates that the used audio may indeed shift to the periphery of the user's attention.

1. INTRODUCTION

Imagine an early morning at home. You just had breakfast and are listening to the news on the radio before you leave for work. While the coffee machine is on, birds are singing outside, you hear your neighbour on the left leaving, your partner making a phone call in the other room and even though it is early, there are traffic sounds to be heard from a nearby street.

In many everyday situations, multiple auditory sound sources can be heard simultaneously. This soundscape may provide us with information, such as the time of the day, the traffic or the activity of our neighbours. Interestingly, we usually do not intentionally have to listen to such information to be aware of it; we know it without consciously attending to it. Furthermore, in the midst of all these information sources, we are perfectly able to focus attention to the news on the radio without being distracted by the other sound sources.

This cognitive ability is commonly referred to as the 'cocktail party effect' [1], enabling us to selectively place one auditory channel (e.g. the radio) in the *center* of our attention, while monitoring others in the *periphery* of our attention. This monitoring provides us with awareness of 'what is going on around us' [2], but can also enable shifts in attention. When something potentially relevant happens in an unattended channel, for example when your partner mentions your name while on the phone, this will most likely attract your attention [3]. In such a case, a channel that previously resided in the periphery of the attention shifts to the center.

In recent years, digital technologies have started to play an important role in our everyday lives. Accessing digital information typically takes place in the center of the attention, for example by looking at screens. Sounds used in modern technology settings are generally designed to attract people's attention, for example in the form of an alarm, reminder or ringtone. However, when the digital technologies that are becoming more pervasive in everyday life can only be accessed through information displays such as screens and alerting sounds, we are at risk of being overburdened with information.

Inspired by our natural way of monitoring information, Weiser and Brown [4] envisioned *calm technology*; "technology that engages both the center and periphery of the attention and in fact moves back and forth between the two" [4, p. 82]. This enables us to monitor information in the periphery of our attention and only focus on it when desired, which we think enables new technologies to better fit into our everyday lives. Given the previously described cocktail party effect we see audio as a particularly interesting modality for calm technology. Since we do not have to look at the source to perceive sound [5], audio is naturally used as a peripheral information display. Furthermore, being surrounded by sounds all the time has made us very skilled perceivers. For example, humans seem able to accurately localize sound sources [5].

The broad aim of our research is to study how we can leverage human attention skills as well as auditory perception abilities in interaction with technology. Although several examples exist that use audio as calm technology, we are particularly interested in studying how such designs can be implemented in and be valuable during everyday life. In this paper we present the preliminary design and evaluation of the Chronoroom Clock; a design that uses subtle sounds to give users a better feeling for the time, and thereby support daily patterns, based on the direction this sound is coming from.

2. RELATED WORK

Although Weiser and Brown's [4] vision of technology being calm and unobtrusive seems far from the way we interact with everyday technologies, several research examples aim at presenting auditory information in the periphery of the attention.

One of the first examples of calm technology is 'Dangling Wire' [4]; a strand of wire hanging from the ceiling that moves depending on the amount of data transfer through the Ethernet cable in an office. As a result, an ongoing soundscape makes office workers aware of the network activity. Another well-known example is 'Audio Aura' [6], which uses background auditory cues to provide office workers with information such as the status of the printer or the availability of colleagues.

Other examples leverage human sound localization abilities in calm technology. 'Nomadic radio' [7], for example, uses spatial audio to inform users of incoming emails. 'ONTRACK' [8] uses sound localization to subtly direct pedestrians toward their destination. In line with the context of use of both these systems, audio is provided via a headset. A different example is 'Birds Whispering' [2], which generates bird sounds at quiet places in an office, to create an awareness of the surroundings.

3. SOUND LOCALIZATION

As is evident from the scenario described in the introduction, multiple simultaneous sound sources form the soundscape of our everyday life. We are not only able to distinguish these sources; we can also accurately locate them. For example, when we hear one of our neighbours leaving home, we immediately know if it is the neighbour on the left or on the right-hand side.

The fact that we have two ears allows us to pick up directional information from incoming sound streams [9]. This ability is largely researched in the area of 'spatial hearing' [10], and more specifically referred to as sound localization [11]. For our design activities, we considered it important to acquire a hands-on feeling of the practical applicability of the sound localization capabilities of our users. We therefore set up an explorative study with 10 participants. In this study we positioned a blindfolded participant on a rotatable chair in a middle of circular track for a model train. The radius of this circular track was around two meters. We let the model train drive around the track and instructed the participant at random moments to point toward the current location of the train, see Figure 1. As a result we found that all participants were able to locate the train, with an accuracy of about 10 centimeters. We also noticed that participants quickly improved their accuracy after a few tries. This indicates that people are accurate in localizing sound sources in a room, which is also known from theory [11]. Furthermore, they quickly improve their abilities once they get used to a particular sound source.

Figure 1. Exploring human sound localization abilities.

4. CHRONOROOM CLOCK DESIGN

The broader aim of our research is to study the design of systems that provide auditory information in the periphery of the user's attention. Although such information may not be urgent, it is important that the information that is made audible is relevant to the user. The design we present in this paper is inspired by the observation that many people regularly check the time on devices like their watch or cell phones. It seems highly relevant to many to always have an impression of the approximate time as well as their planning and agenda. In order to fulfill this need however, we often have to consciously grab our mobile phone or look at our watch. We therefore think that it would be interesting to make information about time audible. If this is done unobtrusively, the information can reside in the periphery of the user's attention, facilitating overall awareness of it. Furthermore, it may be focused on in the center of the attention when a more precise knowledge of the time is needed.

4.1. Time and Sound Localization

To facilitate awareness of time, we propose a design concept named the Chronoroom Clock, which can be installed in a living room or workspace. The Chronoroom Clock is designed as a strip on the walls that makes a full circle around a room, see Figure 2. This strip contains many small piezo speakers lined up next to each other. An unobtrusive sound is produced by one speaker at the time. This speaker produces the sound for a few minutes, after which the sound is produced for a few minutes by the speaker next to it. After that the next speaker produces the sound, and so forth. This way, the sound goes clockwise around the room once in 24 hours. The exact number of minutes the sound is played by one speaker depends on the total number of speakers, which can differ based on the size of the room. However, we envision a minimum number of 720 speakers, which would mean that every speaker is active for two minutes. When using speakers with a diameter of 3 cm, the 720 speakers of the Chronoroom Clock could fit in a room of 7 by 4 meters.

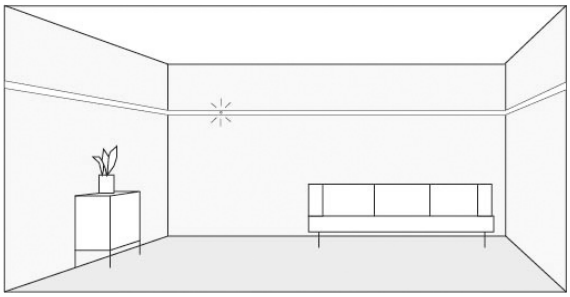

Figure 2. Illustration of the Chronoroom Clock setting

Apart from speakers, the Chronoroom Clock also contains LED lights: one with each speaker. Each LED will light up when the accompanying speaker is active, as a visual aid that gives more precise information in addition to the sound. The strip of the Chronoroom Clock is engraved with small numbers reflecting the exact time. When lit up by the LED, these numbers will be brighter than the rest of the material, giving more precise information in a subtle way, as seen in Figure 3.

The Chronoroom Clock is meant to be installed in a room where the user spends most his time, such as a living room or workspace. Rectangular rooms measuring more than 22 meters around are most suitable. Since we have seen that people are rather accurate at localizing the source of a sound, having the Chronoroom Clock in your room will likely enable you to link time to location in this room. After having this clock installed

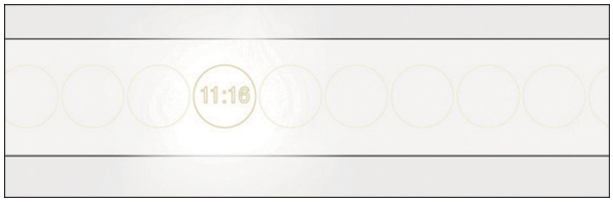

Figure 3. Detail illustration of the Chronoroom Clock

for a number of days, one may start recognizing patterns. For example one may learn that the sound comes from near the bookshelf during breakfast, from left to the plant when coming home and from above the cupboard when going to bed. Such knowledge may not only provide awareness of the time itself, it may also support daily patterns. For example one may learn that when the sound is approaching the left corner of the room, it is time to leave or the train will be missed. In addition, it may provide valuable insights when daily patterns are not followed, for example when coming home later than usual, one may notice that indeed the sound is already meters passed the plant.

4.2. Subtle Reminders

The idea of a system that links time to location allows for several additional options related to time. A rather common functionality of a clock is the ability to set a reminder. In line with the calm technology approach of the Chronoroom Clock, we think an interesting option could be a 'subtle reminder function'. When for example you want to set such a reminder at 09:00 h, you touch the Chronoroom Clock at the location corresponding to 09:00 h. The LED at this location will light up in a different color, indicating that the reminder has been set, see Figure 4. When 09.00 h approaches, the sound of the clock slightly changes. At exactly 09.00 h, a short distinct reminder sound will be heard once.

Subtle reminders can be set to remember non-urgent things, such as remembering to turn on the news or to take out the trash. When used to the Chronoroom Clock, one will likely notice the sound change, similar to the way one notices his own name mentioned in an unattended conversation. Since the reminder sound is not more obtrusive than the regular clock sound (described below), it is expected not be perceived as distracting. The reminder may be missed when working in concentration. However, given the low urgency, this should not be a problem.

4.3. Sound Design

The sounds produced by the Chronoroom Clock should be unobtrusive so that they can be monitored in the periphery of the attention. Furthermore, users should be easily able to localize these sounds. To find the right sound design for the Chronoroom Clock, we created several sounds using a number of physical objects and materials. These sounds, which differed in pitch, volume and rhythm, were recorded and played back in an open workspace. Each sound design was informally evaluated with the students working in this space.

The sounds that were easiest to locate, were semi-continuous sounds, ideally melodies, that incorporated a relatively broad spectrum [11]. On the contrary, the sounds that were perceived as least obtrusive were sounds that consisted of short intervals of ticking or buzzing. We therefore selected a sound design that consisted of a murmur of ticking and tingling sounds, created with a metal cheese grater rubbed against a metal spoon. Users perceived this sound as friendly and natural. See [12] for a video with sound of the prototype.

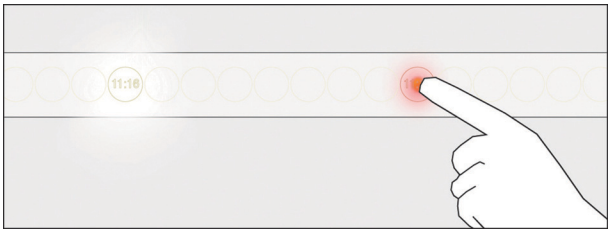

Figure 4. Illustration of the 'subtle reminder function'

4.4. Prototype

To enable a user evaluation of the Chronoroom Clock concept, we developed a working prototype. Since we were most interested in evaluating the concept of time awareness through sound localization, this prototype did not include the previously described subtle reminder function.

The Chronoroom Clock concept is to contain up to 2880 units consisting of a small speaker and an LED; one for each half minute in 24 hours. However, to perform an informal evaluation aimed to study if users are able to monitor the time based on the location of which sound is coming from, we built a prototype that featured only 16 such units, see Figure 5. These units were connected to an Arduino [13] controller and an MP3 player. The units were located on the walls of a simulated living room environment, distributed evenly around the room. See [12] for a video of the prototype.

5. USER EVALUATION

In this paper we have presented the Chronoroom Clock, a clock designed to convey audible information about the time based on the location this sound is coming from. To evaluate how people experience the Chronoroom Clock, we set up an informal formative user evaluation using the above described prototype.

5.1. Evaluation Setup

For this user evaluation we recruited one male and two female participants of 22, 24 and 55 years old. Two participants experienced the Chronoroom Clock in a simulated living room environment, whereas one experienced it in her own home.

Since the design is intended to be perceived in the periphery of the attention, we let our participants experience the Chronoroom Clock for a period of 2:40 hours while performing another task. The participants, who each participated separately, were therefore asked to bring some reading material to the evaluation session. During the evaluation, the participants were asked to stay in the room in which we installed the prototype,

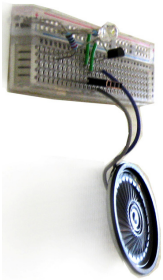

Figure 5. One unit of the Chronoroom Clock prototype.

and to focus their attention on reading. Two participants brought a book and one brought a laptop.

For the evaluation, we programmed the Chronoroom Clock prototype in such a way that each unit would produce sound and light for 10 minutes, before the next unit would become active. This way, the sound would go around the room in 2:40 hours, enabling the participants to experience the sound coming from all angles. At the start of each evaluation session, we explained the working of the prototype in detail. During the sessions, we made sure that the participants had no access to devices that informed them of the current time, other than our prototype. For example, we temporarily disabled the time indicated on the laptop of one of our participants. See Figure 6 for an impression of the setup of the user evaluation.

After the 2:40 hours had passed, we conducted an open interview with each participant. This interview focused on the Chronoroom Clock sounds as well as the participant's awareness of time. Furthermore, we asked if participants thought the design would be valuable in their everyday lives.

5.2. Findings

During the evaluation, our participants were either reading a book or working behind a laptop. Although all participants said that they could clearly hear the sounds made by our prototype, none of them felt distracted by the sounds. Two participants mentioned that when they were concentrated on reading or working, they sometimes forgot about the sounds. Although this only happened for short periods of time, clearly the sound was not in the center of the attention at those moments. This might indicate that the sounds made by our prototype can indeed shift to the periphery of the attention.

During the 2:40 hours of each session, the sound was produced by each unit of the Chronoroom Clock prototype for 10 minutes. All three participants mentioned that they clearly noticed when the sound moved from one speaker to the next. However, they did not experience this as distracting, instead it made them aware of the fact that 10 minutes had passed. Possibly due to this, the participants said that during the entire evaluation they felt that they always had a rather good impression of how much time had passed since the start of the session. One participant however mentioned that she would be better able to estimate the current time when the sound would travel one circle in 12 or 24 hours rather than 2:40 hours, as that would be more natural. However, she also mentioned that it would always take a certain learning period before she would accurately be able to use the Chronoroom Clock.

Figure 6. Impression of the user evaluation

All participants associated the sounds of the Chronoroom Clock to nature, which they found positive or friendly. The participant who experienced the prototype in her own home said that she always needs background noise in her living room. Normally she turns on the TV or radio, but mentioned that she could imagine the sounds of our prototype replacing this need. She experienced them as pleasant background sounds.

Regarding our question if participants would find the Chronoroom Clock valuable in everyday life, we found varying answers. One participant, who preferred not having to think about the time when he is at home, mentioned that he would like it in an office or meeting context but not in his living room. Another participant, who said she is very punctual, saw great value in having this at home. However, she mentioned that she would want it to be more detailed than the prototype, which displays the time in portions of 10 minutes. She felt that if she would have a Chronoroom Clock in her home, she would less often have to think about the time.

Although the previously described 'subtle reminder' function was not included in the prototype nor discussed with the participants, adding a reminder function was mentioned multiple times in the interviews. One participant suggested connecting the Chronoroom Clock to her digital calendar to share meetings and appointments.

6. DISCUSSION

In this paper, we have presented the Chronoroom Clock, an auditory display designed to give users a better feeling of time and support everyday patterns, by leveraging sound localization abilities. In this section we will further discuss this concept as well as the process of designing and evaluating it.

To evaluate the Chronoroom Clock concept, we developed a prototype consisting of 16 speaker-units. Although this prototype contained far fewer speakers than the strip of speakers we envision for the actual concept, it enabled us to create the experience of the sound going around the room. However, due to the large distance between the units as a well as the long period of 10 minutes one unit was active, the transition between two speaker-units was not very smooth. As a result, the participants consciously noticed the transitions. Nevertheless, even with this simplified version of the concept, we have seen that participants sometimes shortly forgot about the sound, which may indicate it shifting to the periphery of the attention. Furthermore, our participants felt that they always had a rather good impression of how much time had passed since the start of the evaluation. These promising results give us the impression that a more sophisticated version of the Chronoroom Clock could indeed provide people with peripheral awareness of the current time as we intended.

In the user evaluation performed with the Chronoroom Clock prototype, each participant experienced the prototype for 2:40 hours. Although we already found interesting results in this short period of time, it was not enough to fully evaluate the concept of peripheral monitoring of time. Furthermore, for practical reasons the sound in our prototype travelled around the room in 2:40 hours instead of 24 hours. Installing the

system in someone's home for a period of a few weeks would enable evaluating the long-term value of this design. It could for example be expected that experienced users will be able to know the time more accurately, potentially in the periphery of their attention. Furthermore, the Chronoroom Clock design is intended to support daily patterns, by enabling people to link everyday events to certain locations in the room, which was not evaluated in the current study. Further research would be needed to evaluate such effects of the Chronoroom Clock.

The 'subtle reminder' function of the Chronoroom Clock was not evaluated. However, our participants did suggest using the Chronoroom Clock for reminders. Although such functionality could be useful in one- or two-person households, it may be confusing when more people use it simultaneously. In multi-user settings, the sounds and colors of subtle reminders could be personalized to different users.

The Chronoroom Clock is an auditory display that leverages human sound localization abilities. Although some related examples are known of auditory displays based on sound localization (e.g. [7, 8]), most these examples require the user to wear headphones. While it is possible to create directional sound without using headphones, such technologies (e.g. suround sound or Vector Base Amplitude Panning [14]) generally require the user to remain at a fixed distance between the sound sources. Though useful for applications such as computer games, such technologies are less suitable for systems like the Chronoroom Clock, which have to be accurately perceivable from any location in the room.

The solution we provide, using numerous small speakers, may not seem an obvious one given the availability of more sophisticated technologies. However, given the low costs of the components needed for the Chronoroom Clock (e.g. piezo speakers are inexpensive when bought in large quantities), we think it makes a valuable solution that can steadily function in everyday environments. Furthermore, the physicality of the design creates interesting affordances. Since the Chronoroom Clock is a strip on the wall of a room, the exact length of the strip will differ in different rooms. This means that in larger rooms, more speaker-units could fit on the strip, making the resolution of the clock higher. Additionally, the layout of each room will be different, which will make each implementation of the clock personalized to the room it is in. The fact that the user can decide where to locate the clock, for example on the walls or on the ceiling, could add a decorative function as well.

7. CONCLUSION

This paper presents Chronoroom Clock: an auditory display designed to provide peripheral awareness of the time by leveraging human sound localization abilities. Informal qualitative evaluation of a prototype version of this concept has indicated that even in a short period of time, the sounds produced by the design seem to shift to the periphery of the attention at moments.

With the increasing pervasiveness of computing technology, digital information can be everywhere nowadays. Leveraging perception abilities that people use to interact with the physical world, enables such technologies to seamlessly fit into our everyday life. The simplicity of the Chronoroom Clock design allows it to be relatively easily implemented in everyday situations.

8. ACKNOWLEDGMENT

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