Avoid the Use of Audio? Evaluating the Influence of Sound in a Large Display Multi-User Scenario

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Figure 1. The three experimental conditions of our study evaluating the influence of videos with audio in a multi-user setting: both participants read a text (C1), one participant watched a video while the second read a text (C2), each participant watched a video (C3).

ABSTRACT

Today's interactive wall displays are large enough to accommodate two or more simultaneously interacting users. Multiple users might retrieve multimedia content from public information screens at the same time, either together or in parallel without interfering with each other. We conducted two lab studies on the influence of sound in a multi-user scenario. In our first lab study we simultaneously showed two different videos with audio and measured the objective and subjective information perception. This was compared to both participants reading text. While the objective information perception remained similar, the subjective information perception decreased. In a second lab study we evaluated the influence of auditory icons in a multi-user scenario on distraction and awareness about the second user's activities. Auditory icons increased awareness but also distraction. Based on the results of our studies, we recommend the use of audio on wall displays when users explore a wall display application together. Only in case multiple users work in parallel on focused tasks sound should be omitted.

ACM Classification Keywords

H.5.2 Information interfaces and presentation (e.g., HCI): User Interfaces

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Author Keywords

Large Screen; Multi-Touch; Multi-User; Public Display; Wall Display; Audio; Information Perception.

INTRODUCTION

Today information applications running on (interactive) wall displays are quite common in public places. As wall displays are large enough to enable simultaneous interaction of several co-located users [3, 16], multiple users interacting with one display are not uncommon. One example for such a display is the CityWall application in Helsinki (display width of 2.5m) which was mostly interacted with by pairs [12]. Another multi-user wall display installation is "The Cube" [13]. In contrast to the CityWall, the Cube also includes audio output for videos.

Concerning the usage of audio in a public display application, several recommendations exist within related work. Somervell et al. [14] recommend:

> "Avoid the use of audio. Audio is distracting, and on a large public display, could be detrimental to others in the setting."

This recommendation is part of their usability heuristics for large screen information exhibits. The recommendations were developed using scenario based design. Similarly, Maguire [10] suggests to use sound at a public information kiosk only at very low level as "users will not wish to draw attention to themselves when interacting with a system". Due to the public situation and its lack of privacy, adults are already inhibited in their interaction with the wall display [15]. This negative effect could be increased due to audio output.

However, audio output cannot only be distracting but also be beneficial in multi-user environments. For example sound

can be exploited as an additional sensory channel to transmit supplementary information, e.g. concerning the activities of another user [5] hence raising awareness.

The aim of our work is not to support or contradict Sommervell's or Maguire's general recommendations. Rather we advocate a more differentiated view of audio usage in a multi-user scenario in order to take the versatile character of audio into account. A large variety of different types of audio exist, for example music, speech, auditory feedback (positive or negative), notifications, etc. In two lab studies we evaluated two different usages of audio, namely the audio stream of news videos and auditory feedback. In both studies we looked into both possible effects of audio in multi-user settings – audio as a distraction and audio as a benefit to information perception or awareness. The contributions of our work are

- a confirmation of the Cocktail Party Effect in a multi-user wall display setting with loudspeakers,
- but also measuring an additional objective information perception from a competing audio source,
- a disclosure of a discrepancy between the subjective and objective information perception when listening to competing audio sources and
- showing an increase in awareness about the second user's activities when using auditory icons in a wall display application.

RELATED WORK

In the following we present research concerning the influence of multiple simultaneous audio streams (Cocktail Party Effect) as well as the usage of audio in multi-user settings in general.

Cocktail Party Effect

The human ability to focus on one conversation while background noise and competing conversations occur, is called Cocktail Party Effect (e.g. [1]). Listening to several competing audio channels was already researched by Cherry [2]. The participants of his study received two different audio channels via headphones, one audio channel per ear. The evaluation showed that people are easily able to concentrate on one audio channel but cannot provide any information on the second one. In our studies we use loudspeakers and not headphones and also measure the objective information perception for both audio sources. Additionally, we measure the subjective information perception in order to see whether it matches the objective results.

Loudspeakers in Multi-User Settings

Morris et al. [11] compared the output of music either individually via headphones or via shared loudspeaker in a multi-user tabletop setting. The task of the participants was to relate songs to images in order to create a soundtrack for a movie. For their specific use case individual headphones proved to be more suitable as it was rated better by the participants, and lead to more communication. As we focus on a public setting, we do not want to rely on headphones (e.g. due to risk of damage/theft, hygiene) and solely use shared loudspeakers. In our first study we evaluate speech audio and not music. Morris et al. provide an assumption regarding speech audio: if the spoken information match the information on the screen (as it is the case for videos) it might not be "overly distracting". Our first study will clarify this assumption.

Another comparison of headphones vs. shared loudspeaker in a group setting was done by Fencott & Bryan-Kinns [4]. In their study participants had individual screens and the task was to compose a song. They found headphones to be suitable for focused individual work but at the same time the feeling of involvement with the group was reduced for some participants. Therefore, the authors recommend loudspeakers for open, collaborative work and headphones for focused work. It remains unclear if these results also apply to a wall display application when using speech audio. As we do not want to rely on headphones, is it better to completely avoid audio for focused work at a wall display?

Audio Feedback

Hancock et al. [6] evaluated the influence of audio feedback in a multi-user tabletop setting. Using one shared loudspeaker, they found that audio not linked to a person's own actions negatively influences the processing of information about their own interactions. In a second study every participant had their own speaker which resulted in improved identification of the person causing the sound but reduced attention to the group. In our second study we use directed sound output which is a combination of Hancock et al.'s settings: everything is still hearable (comparable to one shared loudspeaker) but louder for the person who caused it (comparable to an individual loudspeaker).

A study with desktop computers was conducted by Gaver [5]. Each of the two participants worked on one PC. Comparing two experimental conditions (sound/no sound for all screen events), Gaver found that audio resulted in increased shared problem solving as well as increased commenting and awareness of the second participant's events. In our second study we also measure awareness concerning the second user's activities and will determine whether an increase in awareness does also occur in a wall display setting, where awareness is already provided by seeing the second user's interaction.

STUDY 1: MULTI-USER VIDEOS WITH AUDIO STUDY

Information on public displays can be presented as text, pictures, animations and/or videos. Huang et al. [8] showed, that people rated video opposed to text or images to be more attractive as well as that videos caused longer gazes at public displays. Therefore, videos seem to be a suitable media type for public displays. But shall we turn on the sound? The research question of our first lab study was: What is the influence of videos with audio on the participants subjective and objective information perception in a multi-user scenario?

Hypotheses

Related to our research question we formulated the following four hypotheses:

H1 Simultaneous play back of two different videos with audio negatively influences the subjective information perception.

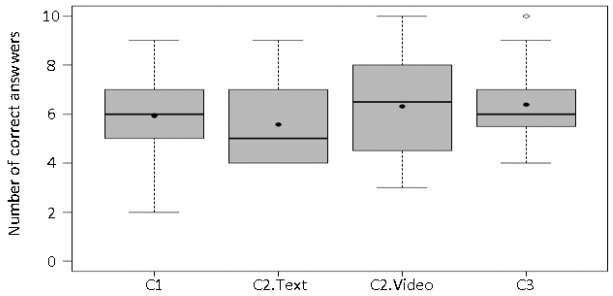

Figure 2. Objective information perception from the own source (max=10, N(C1, C3)=24, N(C2.Text, C2.Video)=12, whiskers=1.5*IQR). The black circles represent the mean values.

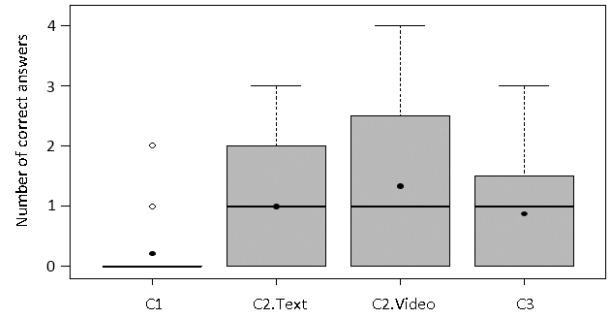

Figure 3. Objective information perception from the neighbor's source (max=5, N(C1, C3)=24, N(C2.Text, C2.Video)=12, whiskers=1.5*IQR). The black circles represent the mean values. For C1 (text only) participants were mostly not able to perceive information from the neighbor's source.

H2 Simultaneous play back of two different videos with audio negatively influences the objective information perception.

The following two hypotheses concern an experimental condition during which one participant watches a video with sound, while the second one reads a text.

H3 The subjective information perception of a participant reading a text is negatively influenced by the play back of a video with audio from another participant.

H4 The objective information perception of a participant reading a text is negatively influenced by the play back of a video with audio from another participant.

Based on the hypotheses, subjective and objective information perception are the dependent variables and the display format of the information (text, video) is the independent variable. H1 and H3 will be answered with a questionnaire containing questions regarding the subjective impression. H2 and H4 will also be answered with a questionnaire but using questions concerning the visual and auditive content of the text/video.

Design & Method

The experiment was conducted in a lab with a 65" 4k-screen supporting multi-touch interaction. Two participants took part in the experiment simultaneously with each assigned a designated half of the screen. The participants had marked positions in front of the screen to ensure comparability of the results. Both participants had one speaker assigned for their audio. The speakers were located under the screen with maximum horizontal spacing and we used the same moderate audio volume throughout the experiment. In order to reduce side effects, the necessary interaction with the screen was reduced to a minimum, namely paging the text.

The experiment consisted of three conditions (cf. Figure 1):

Condition 1 (C1) Baseline condition in which both participants read a text.

Condition 2 (C2) Participant 1 watched a video while the second one read a text.

Condition 3 (C3) Each participant watched a video.

We chose text as baseline condition, as it is the common method to convey information on a wall display. The task for each condition was to gather as much information as possible, different text and videos were used for the different conditions. The text consisted of 400-500 words and appeared in newspapers, the videos had a duration of 2-3 minutes and were aired in a reputable German newscast.

We used a within-subject-design and the order of the three conditions was counterbalanced using a latin square. After each condition the participants answered three questions about their subjective information perception, and then fifteen questions about facts from the information source to determine objective information perception. The questions concerning the subjective information perception of the participants had to be answered on a five-point scale and were the following:

Q1 The system enabled me to fulfill my task with focus.

Q2 I was able to gather and recall information from my source of information.

Q3 I was distracted by my neighbor and his/her interaction respectively.

The fifteen questions to determine objective information perception were divided in the first ten about their own source of information and then five questions about the other participant's source. As answer format we chose multiple-choice with four given answer possibilities (including the correct one) and a "don't know" option. The knowledge questions for the videos concerned spoken as well as visual information.

Participants

In total we had 24 participants (23 male, one female) with seven aged between 18 and 22 years, 16 aged between 23 and 27 years and one aged between 33 and 37 years. All of the participants were students with 22 having a science or technical background and two with a background in social science.

Results

In the following we elaborate on the results. Figure 4 shows the results of the subjective information perception, while Figure 2 and Figure 3 contain the objective results.

Subjective Results

In order to answer H1 we have to analyze the subjective results, comparing the baseline condition C1 with C3. According to the answers of the questionnaire displayed in Figure

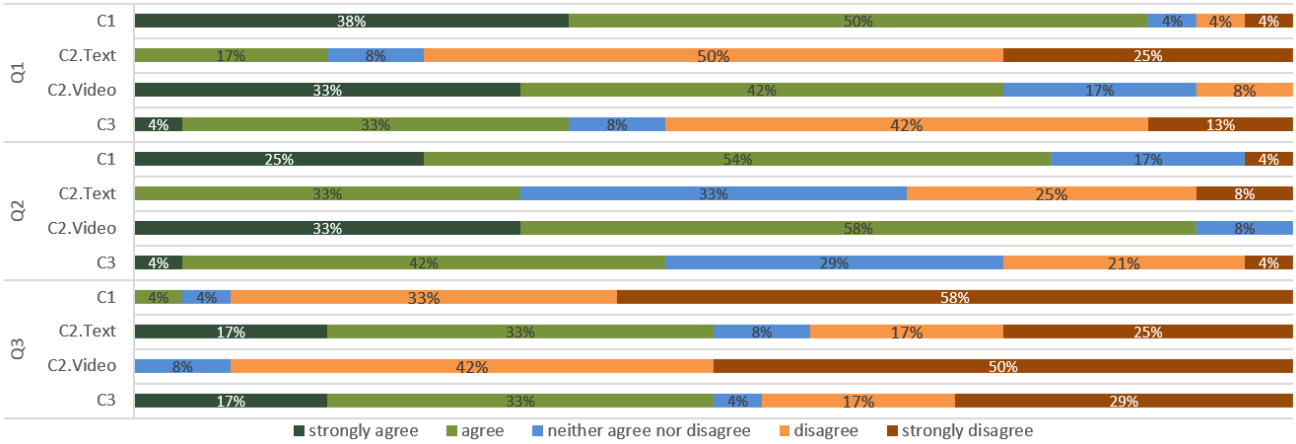

Figure 4. Subjective information perception (N(C1, C3)=24, N(C2.Text, C2.Video)=12)

4 the participants were less able to focus (Q1): for C1 88% (strongly) agreed and for C3 37% (strongly) agreed. According to a paired-samples t-test this difference is significant ($t(23)=-5.01$, $p<.0005$). Furthermore, they were subjectively less able to recall information from their own information source (Q2: (strong) agreement C1=79%, C3=46%). The difference between C1 and C3 concerning Q2 is also significant ($t(23)=-3.19$, $p<.005$). Distraction (Q3) significantly ($t(23)=3.87$, $p<.0005$) increased in C3 (50% (strongly) agree) compared to C1 (4% agree). Thus, we accept H1.

In order to answer H3 we compared the answers of the participants reading text in C2 with their answers from the baseline condition C1. Once again participants felt significantly less able to focus (Q1) ($t(11)=-4.51$, $p<.0005$) and their feeling of disturbance (Q3) significantly increased ($t(11)=2.68$, $p<.05$). Our participants subjectively recalled less information (Q2) in C2 than in C1 ($t(11)=-3.32$, $p<.05$). Thus, we also accept H3.

Objective Results

H2 and H4 will be answered by analyzing the objective results (see Figure 2). We found no significant difference between the number of correct answers for the three conditions. Thus, we have to reject H2 and H4: we found no evidence that an additional audio source influences the objective information perception in our study.

Looking at the results concerning the objective information perception from the neighbor's source (cf. Figure 3) we see that participants were able to answer on average between 0.88 and 1.33 out of five questions correctly when a video was played (C2, C3). A one-way repeated measures analysis of variance (ANOVA) reveals a significant difference ($F(2,46) = 6.28$, $p<.005$) between the three conditions. A follow-up Tukey HSD test shows a significant difference between C1 and C2 ($p<.01$). So, the usage of one video enabled the participants to recall significantly more information from the second information source.

Limitations

One problem of our first study was the selection of the information, namely rather recent news articles and videos. We cannot eliminate that some questions might have been answered with prior knowledge by well-informed participants, other questions might have been answered correctly by chance. Moreover, we did not specifically differentiate between questions concerning the visual or spoken information in the videos, nor did we compare audio or video only. The socio-demography of our participants reveal a gender imbalance, almost all of them are male. This is particularly problematic as men are better than women in localizing sounds within several competing sound sources [17].

STUDY 2: MULTI-USER AUDITORY FEEDBACK STUDY

In our second study we chose another type of audio, namely auditory feedback, as our aim in this paper is to account for the versatile character of audio. We decided to enrich an existing multi-user multi-touch wall display application with auditory icons which are

> "[...] environmental sounds (like taps, scrapes, etc.) designed to convey information by analogy with everyday sound-producing events." [5]

The goal of auditory icons is to convey information almost unconsciously and to distract as little as possible. The aim of our second study was to evaluate awareness as a possible positive and disturbance as a possible negative effect of auditory icons in a multi-user scenario.

Hypotheses

Based on the results of our first study that audio from the second participant distracted and disturbed the participant we formulated the following hypothesis:

H1 Auditory icons caused by another participant are distracting.

Hancock et al. [6] found an increase in awareness regarding group activities when using auditory feedback which lead us to the following hypothesis:

H2 Auditory icons increase awareness about the activities of the second user.

Based on these hypotheses the subjective feeling of distraction as well as awareness are our dependent variables and the usage of audio feedback (on/off) is our independent variable. Both hypotheses will be checked using a questionnaire.

Design & Method

The experiment was conducted in a lab with a 65" 4k-screen supporting multi-touch interaction. We used an updated version of the CommunityMirror application [9] (see Figure 5), which is a typical example of a multi-user information application running on an interactive wall display. This multi-user multi-touch application displays information particles of different types (eg. publication, person). The particles move horizontally in both directions with various velocity. On touching an information particle it stops and changes into a detail state, displaying more content.

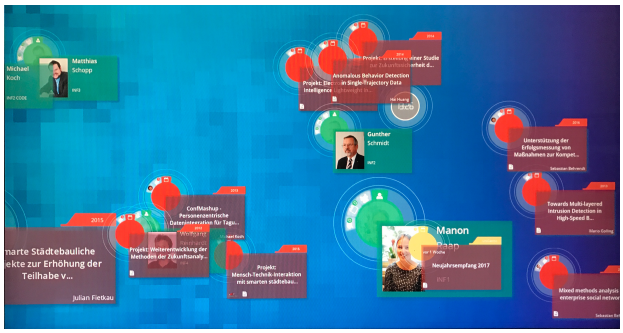

Figure 5. GUI of the CommunityMirror application.

For the purpose of our study we enriched the application with eight different auditory icons providing both positive and negative feedback. In particular we used auditory icons for throwing a particle, zooming a particle, reaching the maximum zoom level and for each opening of the three different particle types. In case the user touched the background, a piano note representing the position on the screen was played. The intention of the piano sound was to provide negative feedback as this touch gesture had no effect. We used directed sound output on the TV loudspeakers and the volume was set to 60dB. The directed sound output, i.e. a touch on the right half of the screen was played louder on the right loudspeaker, enabled a simplified mapping of the location of the occurrence.

The experiment began with an interactive tutorial in order to accustom the participants to the application. After a general introduction of content and functionality of the CommunityMirror, the participants got the chance to explore the capabilities of the application themselves. During the tutorial the sound was muted. This was followed by two experimental conditions, one with enabled sound notifications and one without. The order of the conditions was counterbalanced. Each condition consisted of two phases: First one phase with two individual tasks for each participant (task phase). And then a free exploration phase during which the participants were able to interact freely with the application. Tasks were simple and not checked for correctness. The only purpose was to make the participants interact with the application and to invoke the sounds. An example for a task was: "Enlarge one particle of your choice and scale it down again". Tasks were printed and handed over to the participants. After each condition a questionnaire with open and closed (five-point scale) questions had to be answered. The relevant questions for answering our hypotheses were the following:

Q1 Did you feel distracted by the activities of your experiment partner? [not at all ... very much]

Q2 How well were you able to notice the activities of your experiment partner? [very good ... not at all]

We also inquired the number of perceived sounds and used semantic differential for an evaluation of the sounds in general (distracting...helpful), each auditory icon (confusing...explanatory) and the volume (too loud...too soft).

Participants

In total we had 22 participants (10 male, 12 female), aged between 19 and 34 years (M=22.3, SD=3.9). Three of the participants had previous experience with the CommunityMirror application. More than half of the participants (13) have sound notifications enabled on their devices.

Results

Analyzing the results of the questionnaire provides answers to our hypotheses.

Distraction

The replies for Q1 concerning distraction are summarized in Figure 6 (top). Generally, the answers indicate rather low distraction, none replied with "very much". Nevertheless, we see an increase from two replying with little when sound was muted to five (task phase) respectively four (free exploration phase) when auditory icons were present. The difference between the two phases is not significant. Therefore, we summed up the results and compared sound and mute. The difference is significant according to a paired-samples t-test ($t(43)=3.38$, $p<.005$), thus we accept H1.

Awareness

Concerning H2, the answers are depicted in Figure 6 (bottom). When sound was muted, the awareness was rather low with only four (task phase) respectively six (free exploration phase) rating awareness very good or good. With sound this increases to ten (task phase) respectively nine (free exploration phase). According to a paired-samples t-test the difference between the two phases without sound is significant ($t(21)=-1.82$, $p<.05$), the awareness is greater during the free exploration phase. There is no difference between the two phases with sound. Once again adding up the answers of the two phases, the awareness is significantly greater with auditory icons according to a paired-samples t-test ($t(43)=-3.64$, $p<.005$). Thus, we also accept H2.

Auditory Icons

The mean number of perceived sounds was M=4.95 (Min=3). Three participants were able to identify all eight different auditory icons. Figure 7 shows the number of replies (x-axis) for the general assessment of the sounds. We see a slight tendency towards distracting which underlines the previous finding that sounds are distracting in a multi-user scenario.

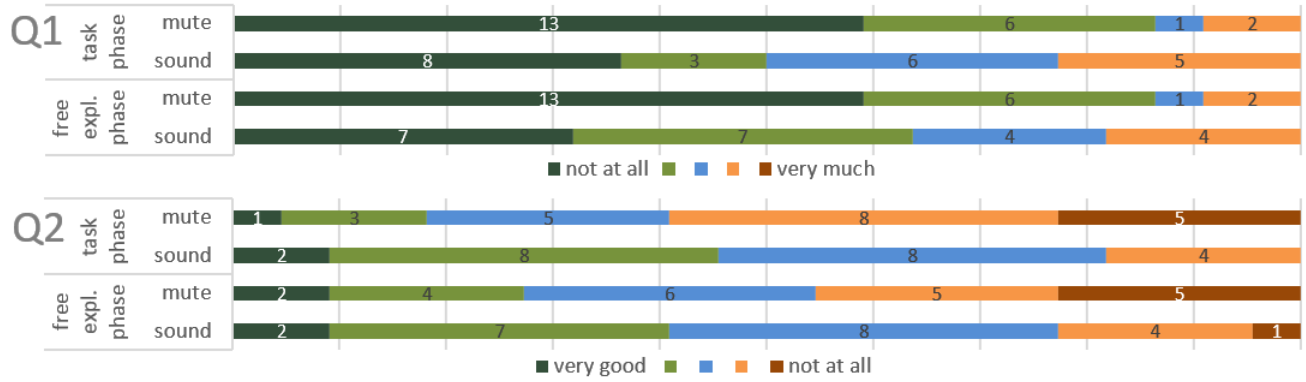

Figure 6. Answers to Q1 and Q2 (N=22).

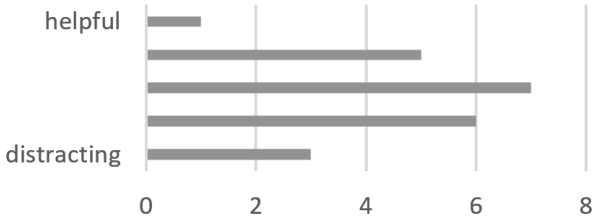

Figure 7. Judgment of the sounds in general (N=22).

The used auditory icons were mostly rated neutral to explanatory, just one (reaching the maximum zoom level) was mostly rated confusing. Therefore, our choice of auditory icons was acceptable. The most striking auditory icons were the piano and the bird chirping (used for twitter particles). The volume was perceived as loud (10) or too loud (4) by our participants, only eight rated it as neutral.

Limitations

The volume of the audio output was rated too loud by our participants which might have distorted the results towards greater distraction. In a future study a comfortable volume has to be determined. Only three participants noticed all auditory icons which indicates that we used too many auditory icons for the study which increased the cognitive load and likely also influenced the results.

DISCUSSION

Consistent with the Cocktail Party effect the objective information perception concerning the own source of information remained similar throughout the three conditions of our first study. But our participants were able to recall at least some information from the second audio source. In particular, they recalled significantly more information concerning the second information source when one video was played opposed to only textual information. In C2 both participants could read text (visual impression) and listen to the audio of the video at the same time, exploiting two sensory channels and thus explaining this result. Furthermore, we found a discrepancy between the subjective and objective results: while the objective information perception of the own source of information remained similar, the subjective information perception dropped with the addition of a sound source. Participants had the impression to recall less while this was objectively not the case. This feeling was likely caused by a decreased ability to focus and an increase in distraction.

An increase in distraction caused by audio output was also measured in our second study, despite the use of a different type of audio, namely auditory icons. But the measured distraction was generally on a rather low level. At the same time, we found a positive effect of audio feedback, namely an increase in awareness. This confirms the results found by Gaver [5] in a remote PC setting. Audio is one possibility for multi-user wall display applications to raise awareness above the already given level provided by observing the second user.

CONCLUSION AND FUTURE WORK

Both lab studies showed that audio in a multi-user setting is distracting and according to the results of our first study the subjective information perception decreased with the use of at least one audio source. Audio is therefore not suitable for focused tasks of several users working in parallel. However, at a public information display where several people interact together in an exploratory and/or playful manner, and consistent with the recommendation by [4], we conclude that sound can be used as the disadvantages are smaller and several advantages appear. Our studies showed an increase in awareness of the others activities and an increase in objective information perception of the second audio source.

For future work the use of audio should be evaluated in a field study with careful choice of the volume. In the field, environmental sounds will have a strong influence and the effects on awareness might decrease. Listening to more than one audio source requires concentration and it would be interesting to measure the cognitive load with a standardized questionnaire like the NASA Task Load Index [7]. This might deliver a distinct explanation for the subjective impressions.

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