Perceptual Auditory Display for Two-Dimensional Short-Range Navigation

Tim Ziemer[1], Holger Schultheis[1]
[1] University of Bremen, Bremen Spatial Cognition Center, 28359 Bremen, Deutschland, Email: ziemer@uni-bremen.de and schulth@uni-bremen.de

Background

Auditory displays for navigation aim at guiding users through multi-dimensional space by means of sound. A general issue in auditory display design is ambiguity due to perceptual interactions of sound parameters that are used to communicate independent, i.e., orthogonal input parameters. Hence, many researchers agree that there is an urgent need to thoroughly consider auditory perception in auditory display design. [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11].

Some psychoacoustic auditory displays have been conceptualized [2, 6, 12, 13]. The latter is our own psychoacoustic auditory display concept. They all aim at mapping physical input parameters like spatial location coordinates to psychoacoustic quantities like pitch, loudness, and timbre aspects such as sharpness, and roughness [14]. However, even though these studies treat the topic well, emphasize current issues, and present promising ideas, they lack experimental evaluation.

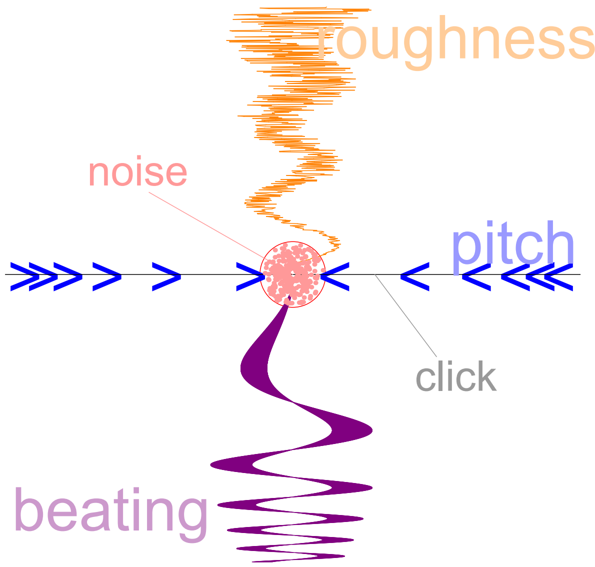

Abbildung 1: Psychoacoustic mapping principle.

Aim and Question

The aim of the present study is to evaluate our psychoacoustic auditory display in an interactive navigation experiment.

Method

In this section the psychoacoustic auditory display is introduced, followed by a description of the experiment. Details on the technical implementation [13, 15], some previous experiments [13, 16, 17, 18] and some deeper insights into the psychoacoustic considerations [13, 15, 18] can be found in the cited literature.

Psychoacoustic Auditory Display

The sonification core of our own psychoacoustic auditory display [13] is depicted in Fig. 1. It maps direction and distance of the horizontal dimension to direction and speed of a Shepard-tone [19] with continuously varying chroma: a target to the right means a Shepard tone with clockwise-moving chroma, which sounds like an infinitely rising *pitch* or glissando. The further to the right, the faster the rise. When the target lies to the left, the chroma of the Shepard tone moves counterclockwise, sounding like a falling pitch. Physically, the sound of an infinitely rising pitch is nothing but a cyclic repetition of the Shepard tone.

The vertical dimension is divided in two halves. A target below sounds increasingly rough, the further down it is. At the target height, the sound is smooth. A target above is represented by beating, i.e., regular loudness fluctuation. The further above, the faster the beating.

To avoid perceptual interactions, the mapping has to be restricted to a certain range: The highest repetition rate of the Shepard tone cycle lies below 10 Hz, so that perceived duration equals physical duration [14, ch. 12]. The same is true for the beating frequency. Since a very slow beating as well as a very subtle degree of roughness are barely audible, the target height is indicated by an additional audible click, which represents the x-axis in a target-centered coordinate system. To represent extended targets, i.e., target regions and not only target points, pink background noise is triggered as soon as the a pre-defined target region is reached. Perceptually, the sonification and the additional click/noise are segregated auditory streams [20], so the presence of the additional elements is recognized but does not affect the sonification.

Experiment

In an interactive experiment 18 novice users find invisible targets, guided by the perceptual auditory display. The experiment setup is described in the following. Details can be found in [15, 18].

First, we gave the candidates an explanation of the auditory display with interactive demonstrators. The explanation was followed by an intermediate multiple-choice test in which they had to assign 10 sonified targets to their corresponding fields on a map with 8 field. To pass the test the candidates had to assign 5 or more sounds correctly and at least 8 had to be assigned to the correct quartile. This explanation plus intermediate test took about 30 minutes.

In the main experiment participants had to navigate to 20 invisible target on a computer screen with a visible cursor, controlled by a computer mouse. The targets were presented successively. 16 targets were presented in random order. Then 4 random targets were repeated. We advised the participants to reach each target as fast as they can and click on it. After each click, the cursor was reset to the center of the screen and the next target was loaded. The size and distribution of the targets are illustrated in Fig. 2.

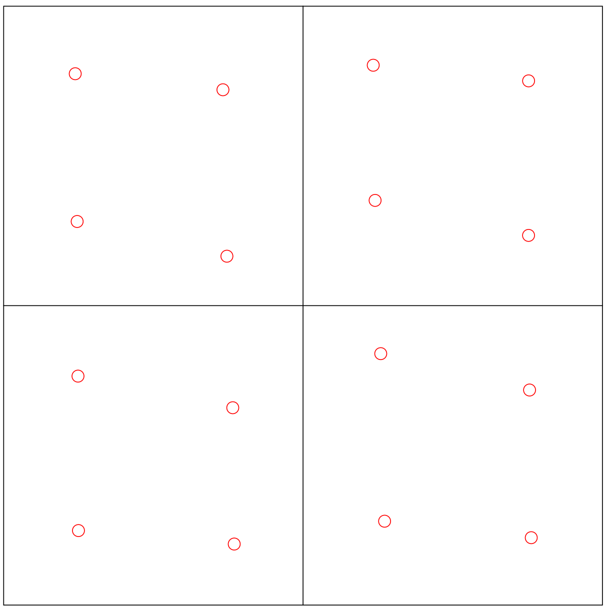

Abbildung 2: 16 targets on a two-dimensional field.

Results

18 out of 25 candidates passed the intermediate test and participated in the main experiment.

On average the participants hit 91.8% of all targets, ranging from 75% to 100%. It took them 20.9 s to reach a target, ranging from 8 to 34 s except for one individual who needed 54 s. When excluding outliers, the mean time to reach a target was 18.8 s.

Typical trajectories are plotted in Fig. 3. It can be observed that some trajectories approximate the shortest path; others approach the target axis-by-axis. Sometimes, oscillations around the target height can be observed. This way the participants repeatedly trigger the audible click, probably to confirm that they are still at the correct height.

After the experiment some participants confessed that they sometimes confused left with right and up with down.

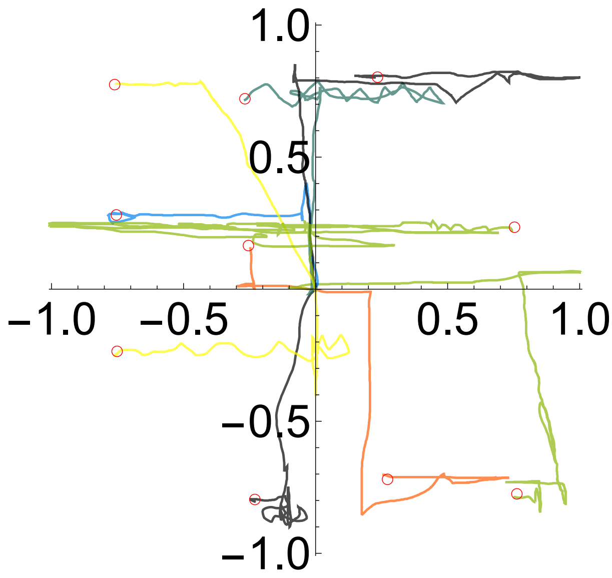

Abbildung 3: Typical mouse trajectories.

Conclusion

In this paper we presented an experimental evaluation of our psychoacoustic auditory display for navigation. Participants were able to find invisible targets reliably and within a fair amount of time and with trajectories that look sorted and more targeted than a random or systematic scan of the whole space. Users were able to approach the target axis-by-axis or on a relatively direct path. Insecure users seem to rely strongly on the click that is triggered at the target height.

Outlook

In its current state the auditory display allows for navigation in a two-dimensional space by mapping orthogonal physical dimensions to parameters in a way that they affect independent psychoacoustic quantities and thus orthogonal perceptual auditory qualities. For the future an implementation of the third dimension in planned. According to the psychoacoustic literature, psychoacoustic quantities auch as brightness/sharpness and fullness [14, 21, 22] seem suitable for to serve as two halves of a third dimension. Potential application areas include surgical interventions [23], piloting [24], or car parking assistance [25].

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