Azimuth-and-Elevation vs. Azimuth-Only Light-Pointer Method for Auditory-Localization Studies

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Introduction

Using a light pointer in order to indicate hearing-sensation positions is an established method for psychoacoustic localization experiments (e. g. Lewald and Ehrenstein 1998, Seeber 2002, Völk et al. 2013) and audiological studies (e. g. Weißgerber et al. 2015). Different setups are possible, some addressing the horizontal direction only, while keeping the light point at constant height ("azimuth only"), others allowing two-dimensional, horizontal and vertical, light-point movements ("azimuth and elevation"). It is the aim of this contribution to compare the horizontal-direction results for "azimuth only" with those of "azimuth and elevation" for a simple exemplary localization experiment.

Setup and Procedure

Serving as the sound sources, two broadband loudspeaker boxes (Bose Video RoomMate) were positioned with the geometrical centers of their drivers at ear-canal height at about ±1.9° azimuth in front of the subjects seated in an empty, darkened, reverberant laboratory. In order not to reveal any visual information about the sound sources and their positioning, a projection screen (1.2 m high and 1.6 m wide, acoustically transparent according to THX cinema standards) was positioned between subjects and loudspeakers, 20 cm away from the loudspeakers. The distance between the subjects' heads and the loudspeakers was selected to 2.35 m, clearly beyond the room's critical distance. The sound sources and the subjects' heads were separated from all reflective surfaces by at least 1.5 m.

The light point was realized as a white circle (diameter visible to the subjects $\approx 0.1°$) against black background by a video projector, on the screen in front of the loudspeakers. In the darkened room, this procedure left only the light point on the dark screen visible. A custom computer program automatically controlled the experiment including sound synthesis (44.1 kHz, 32 Bit floating point), audio playback (16 Bit, RME Fireface 400), video output (1024 × 768 pixels), and all hardware components. The participants were given control over the light point position (azimuth only or azimuth and elevation, depending on the condition) by a trackball computer interface, aiming at proprioception decoupling (cf. Seeber 2002).

The subjects were instructed to position the light point using the trackball device at the perceived location of the sound. No time limit was applied. After finishing the adjustment, the subjects had to push a button on the trackball device, which started the next adjustment. The initial light-point position was selected randomly within the screen area in azimuth (condition "azimuth only", elevation fixed at the height of the sound-source centers, which is ear-canal height), or independently in azimuth and elevation (condition "azimuth and elevation").

Subjects and Stimuli

A sample of 13 randomly selected, normal hearing, unpaid volunteers (less than 15 dB HL at standard audiometric frequencies; 11 male, 2 female; age between 22 and 30 years, median 26) conducted the experiment twice, once with the light point fixed at ear-canal height (condition "azimuth only"), once with variable elevation ("azimuth and elevation"). Five of the subjects had previously participated in localization experiments, the same five subjects regularly take part in psychoacoustic experiments.

Each subject evaluated a broadband uniform-exciting-noise pulse (UEN according to Fastl and Zwicker 2007, 700 ms impulses, 5 ms Gaussian slopes, 300 ms pause) 20 times per loudspeaker and condition, in individually randomized order. The pulse remained active during each adjustment process and was interrupted for 1 s between the adjustments. Both loudspeakers were calibrated so that the stationary UEN windowed to generate the pulse for the actual task elicited 75 dB SPL at the listening position, in absence of the subject. The calibration was carried out with a free-field equalized, pressure-sensitive microphone oriented towards the respective loudspeaker.

Results: Duration

On average, the subjects required about 20% more time to conduct the experiment in the condition with variable elevation ("azimuth and elevation"), compared to "azimuth only" (5.5 vs. 4.6 minutes, cf. table 1). Also the quartiles differ by 10% to 20% between the conditions. Inter-individual differences up to almost a factor 5 occurred in the condition "azimuth only", compared to almost a factor 7 for "azimuth and elevation".

Percentile	0%	25%	50%	75%	100%
Azimuth only	2.5	3.6	4.6	7.0	12.2
Az. & Elev.	3.2	4.0	5.5	8.2	22.0

Table 1: Statistics of the experiments' duration (in minutes) for the conditions "azimuth only" vs. "azimuth and elevation" (Az. & Elev.), calculated per condition over all 13 subjects.

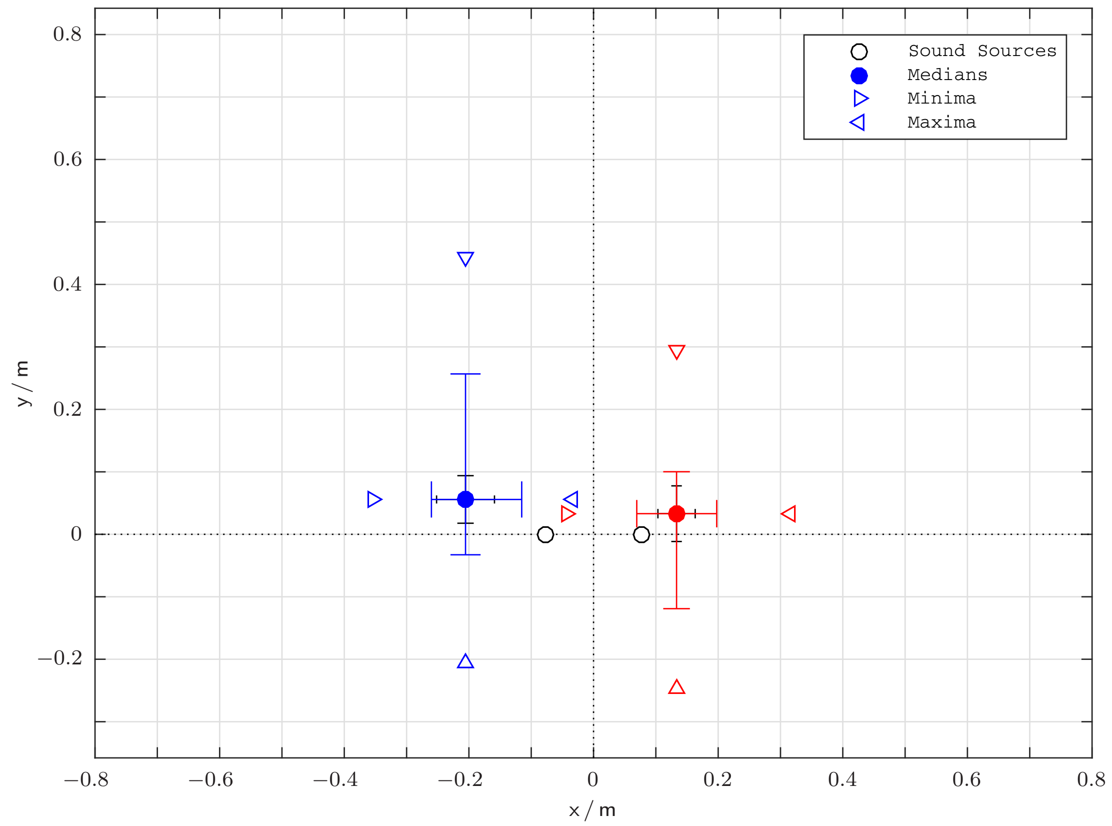

Figure 1: Results of the localization-by-light-pointer experiment for the condition "Azimuth and Elevation". The open black circles indicate the sound-source centers, the filled circles the medians of the individual arithmetic-mean values (blue: left source, red: right source). Also shown are the corresponding quartiles (colored bars) and maxima/minima (triangles). The average intra-individual inter-quartile ranges are indicated symmetrically around the filled circles by black bars.

Results: Statistics and Symbols

The results were individually averaged (arithmetic mean) on a linear metric position scale over the 20 repetitions per sound source, separately in horizontal and vertical direction. Inter-individual medians and inter-quartile ranges as well as maxima and minima were then calculated over the individual averages. The medians are shown in the figures by symbols (filled circles for the condition "azimuth and elevation", crosses for "azimuth only"), the quartiles by horizontal/vertical bars. Maxima and minima are marked by triangles, with one corner pointing towards the corresponding median. Colors indicate the data for the left (blue) and right (red) sound source.

In addition, the medians of the intra-individual inter-quartile ranges were calculated. These are indicated by black bars, positioned symmetrically around the corresponding medians of the individual averages.

The sound-source positions (x/y = ±7.8 cm/0 cm, representing ±1.9°/0° at the subjects' position) are indicated by open black circles, drawn around the geometrical centers of the loudspeaker drivers. The visible area in the figures is proportional to the size of the projection screen.

Results: Azimuth and Elevation

Figure 1 shows the results for the condition "azimuth and elevation". On average, the left sound source, located at −7.8 cm/0 cm (x/y, black open circle) was localized at −20.5 cm/5.6 cm (blue filled circle). The right sound source, positioned at 7.8 cm/0 cm, was localized on average at 13.3 cm/3.3 cm (red filled circle). In azimuth and elevation these coordinates correspond to −5.0°/1.4° (azimuth/elevation) and 3.2°/0.8°, with the sound sources located at ±1.9°/0°.

One-factorial analysis of variance (ANOVA) of the data for the y-coordinate (linear height in meters) indicates a significant main effect of the factor sound source (left or right, [$F(1,12) = 6.59$; $p = 0.0328$]). The inter-quartile ranges of the individually-averaged results (blue/red) amount to 14.5 cm/29.0 cm (x/y) for the left and 12.8 cm/22.0 cm for the right sound source, corresponding to 3.5°/7.0° (az/el) and 3.1°/5.3°, respectively.

The average intra-individual inter-quartile ranges (black) resulted to 9.3 cm/7.6 cm (x/y) for the left sound source, and 6.0 cm/8.9 cm for the right. In terms of azimuth and elevation, this corresponds to 2.3°/1.9° and 1.5°/2.2°.

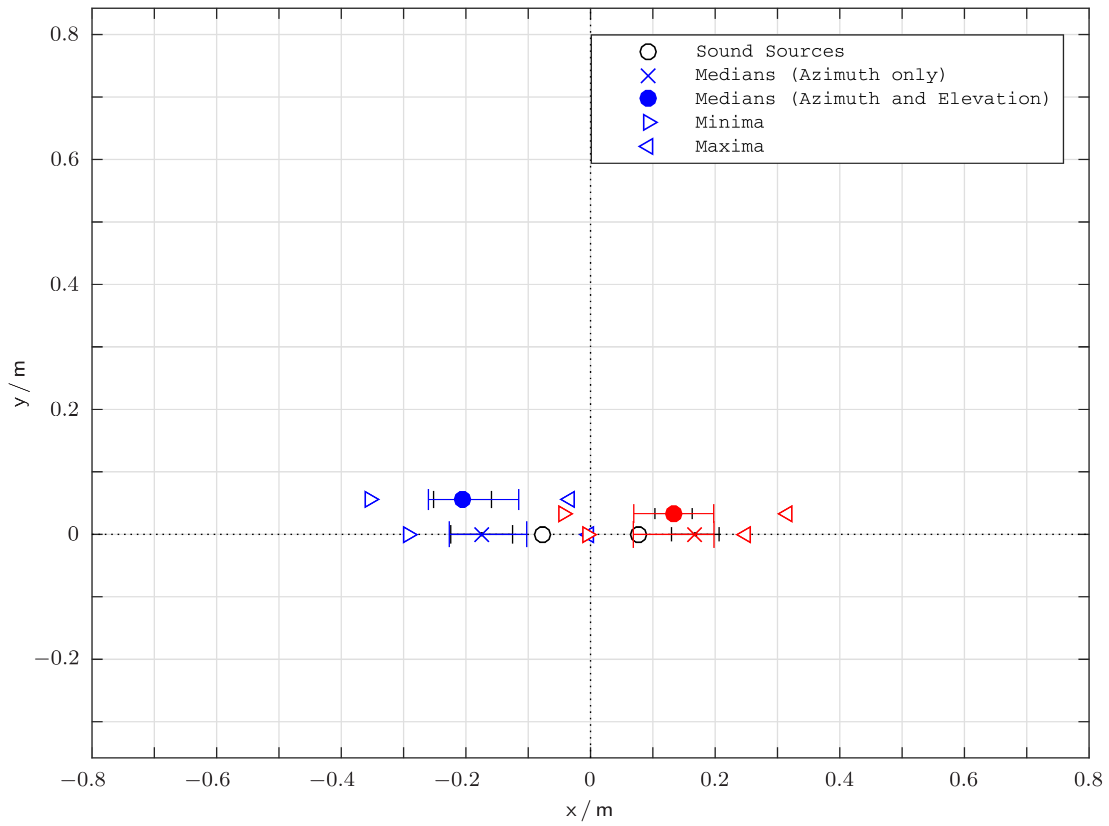

Figure 2: Results of the localization-by-light-pointer experiment for the conditions "Azimuth only" (crosses) and "Azimuth and Elevation" (filled circles; only horizontal results are shown). The open black circles indicate the sound-source centers, the filled symbols the medians of the individual arithmetic-mean values (blue: left source, red: right source), with quartiles (colored bars) and maxima/minima (triangles). The average intra-individual inter-quartile ranges are indicated by black bars.

Results: Azimuth Only

Figure 2 shows the results for the condition "azimuth only". On average, the left sound source, located at −7.8 cm (black circle), was localized at −17.5 cm (blue cross), the right source, located at 7.8 cm, at 16.8 cm (red cross). In azimuth, this corresponded for the subjects to −4.3° and 4.1°, respectively, with the sources at ±1.9°.

The inter-quartile ranges of the individually-averaged data resulted inter-individually for the left sound source to 12.4 cm (blue) and for the right source to 12.9 cm (red), corresponding in azimuth to 3.0° and 3.2°. Intra-individually, average inter-quartile ranges of 9.9 cm and 7.6 cm were found (black), representing 2.4° and 1.9°.

For comparison purposes, figure 2 contains the x-direction results for the condition "azimuth and elevation" (filled colored circles, reprinted from figure 1). Two-factorial analysis of variance (ANOVA) indicates for the horizontal direction a highly-significant main effect of the factor sound source (left or right, $[F(1,12) = 68.5;\ p < 0.01]$), but not of the factor condition ($[F(1,12) = 2.45;\ p = 0.1435]$). Also, ANOVA indicates no significant interaction between these factors ($[F(1,12) = 0.77;\ p = 0.3963]$).

Discussion and Conclusions

Regarding the absolute localization results, a tendency was observed for the magnitudes of the azimuth and elevation judgments to exceed the magnitudes of the source azimuths and elevations, regardless of the condition, that is regardless of the input method. In other words, with the sound-source positions as a reference, the hearing sensations were indicated more laterally and higher.

Taking into account the not specifically controlled, reverberant environment, it is not clear or easily predictable whether the expected hearing-sensation positions should coincide with the sound-source positions. Room influences are indicated by the significantly different height results for the equally-high sound sources. Furthermore, also earlier studies show comparable tendencies towards hearing-sensation azimuths and elevations exceeding those of the sound sources in their magnitudes (for example Völk et al. 2008, 2009), even for experiments in anechoic conditions (e. g. figure 3 of Lewald and Ehrenstein 1998).

As the actual localization results were not the major focus here, it is considered sufficient for the purpose and conclusions of this study to verify that the results are plausible. This is the case qualitatively comparing the ratings collected in this study to the actual source positions and to earlier studies. Therefore, setup and procedure are considered a valid basis for the following conclusions.

The primary purpose of this study was comparing two implementations of a light-pointer method for auditory-localization studies. The comparison was implemented by conducting the same experiment with the same participants in two conditions, namely the implementations with (“azimuth and elevation”) and without elevation judgment (“azimuth only”). The latter was carried out with the light-point at constant elevation (at ear-canal height, which was also sound-source height). While this method shows the obvious disadvantage of not producing elevation results, it may be advantageous in terms of a faster procedure or regarding the difficulty of the task. Additionally, the condition “azimuth only” has been the method of choice for most earlier studies using the light-pointer method (e. g. Lewald and Ehrenstein 1998, Seeber 2002, Völk et al. 2013, Weißgerber et al. 2015). For that reason, the comparison of the conditions, which to the authors best knowledge has not been carried out before, is relevant also to those earlier studies. As the conventional light-pointer method is necessarily limited to directions within the listener’s field of view and no distance judgments, it is applied only in scenarios that can tolerate these restrictions. If the respective scenarios may also tolerate the further restriction to the horizontal direction only, the condition “azimuth only” may be advantageous.

Looking at the results of the present study, the observed increase in average experimental duration by about 20% for the condition “azimuth and elevation”, compared to the condition “azimuth only” (cf. table 1), may indicate that the task of adjusting the light point in two dimensions is more difficult for the participants or requires more effort than the adjustment of the horizontal direction only. As expected, this result proves that, at least when using setup and instructions of this study, the procedure implemented according to the condition “azimuth only” is more time efficient than the procedure implemented according to the condition “azimuth and elevation”. This reduction of experimental time, however, can only be considered an advantage if the results are identical or comparable.

In the present study, the procedures “azimuth and elevation” and “azimuth only” did not produce significantly different average hearing-sensation-position estimates regarding the x-coordinate (horizontal direction, left sound source -5° vs. -4.3°, right sound source 3.2° vs. 4.1°, cf. figure 2). This result is confirmed by ANOVA, which indicates no significant main effect of the factor condition. The similarity between both horizontal-direction data sets is further supported by the inter-quartile ranges of the individual averages, which resulted for the left sound source to 12.4 cm (“azimuth only”) vs. 14.5 cm (“azimuth and elevation”), respectively 3° vs. 3.5°, from the participants’ perspective. This data for the left sound source shows a tendency towards increased inter-individual variation. However, the results for the right sound source, namely 12.9 cm vs. 12.8 cm or 3.2° vs. 3.1° contradict this tendency, while confirming the similarity of the data sets. Descriptively speaking, the accuracy of the “typical subject’s” results is similar for both conditions.

The precision of the “typical subject’s” results (if existing) is indicated by the average intra-individual inter-quartile range. For the left sound source, this average amounts to 9.9 cm (“azimuth only”) vs. 9.3 cm (“azimuth and elevation”), respectively 2.4° vs. 2.3°. The precision is similar for both conditions, with a tendency towards smaller values for the condition “azimuth and elevation”. This tendency (as well as the similarity) is also visible for the right sound source, with values of 7.6 cm vs. 6 cm or 1.9° vs. 1.5°. Therefore, the results of the present study indicate a somewhat higher precision of the “typical subject’s” result for the condition “azimuth and elevation”.

Summary

This study aimed at comparing the horizontal-direction results of an auditory-localization experiment using a light-pointer method between the conditions “azimuth only” (with the light point fixed at the sound-source elevation) and “azimuth and elevation” (with the light point to be adjusted in azimuth and elevation).

On average and regarding accuracy (inter-individual variance), the horizontal-position results agree well between both conditions (maximum deviation of averages 0.9°, of accuracies 0.5°). Regarding the precision (intra-individual variance), a tendency towards somewhat (0.1° to 0.4°) smaller values (higher precision) for the condition “azimuth and elevation” was observed.

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