Distance perception of objects using visual-to-auditory sensory substitution: comparison of conversion methods based on sound intensity and envelope modulation

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INTRODUCTION

- **Sensory substitution devices convey spatial information for the blind** (Kristjánsson et al., 2017).

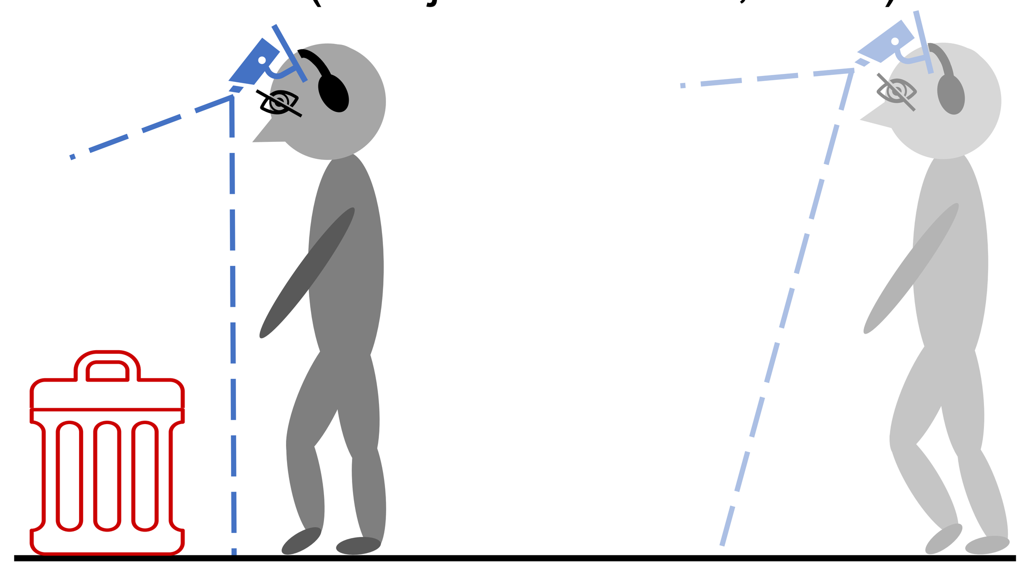

Figure 1: A blind visual-to-auditory SSD user approaching an obstacle (red). The camera (blue) is filming the front space.

- **Intensity is a major acoustical cue for auditory distance perception** (Zahorik et al., 2005).

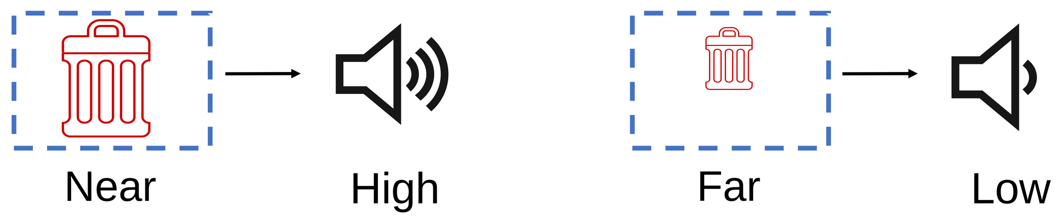

Figure 2: The view of the camera and the corresponding heard sound. Sound intensity increases as the obstacle get closer.

- **Envelope amplitude modulates the "audio-visual bounce inducing effect"** (Grassi et al., 2019 ; Sekuler et al.,1997).

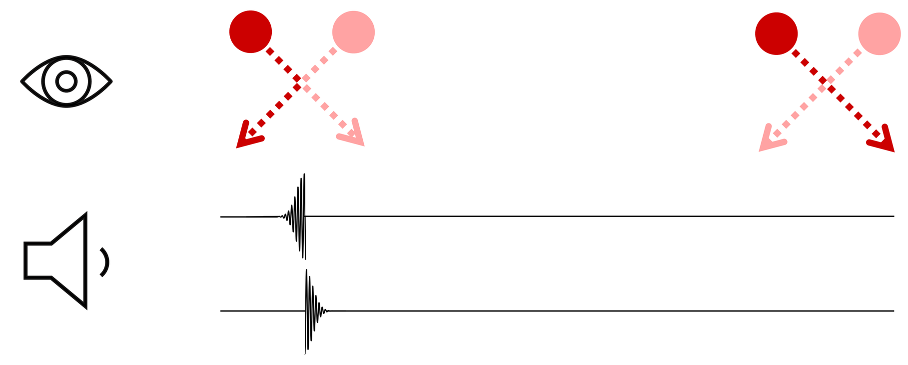

Figure 3: The audio-visual bounce inducing effect. The two identical visual stimuli are perceived as bouncing (left) instead of streaming (right) when a sound is played simultaneously or just after the stimuli impact. The effect is more pronounced when the sound is percussive.

Does a percussive effect improve distance perception in the context of visual-to-auditory substitution ?

ENCODING SCHEMES

11 sighted blindfolded participants practiced a familiarization for both distance encoding schemes in a virtual environment.

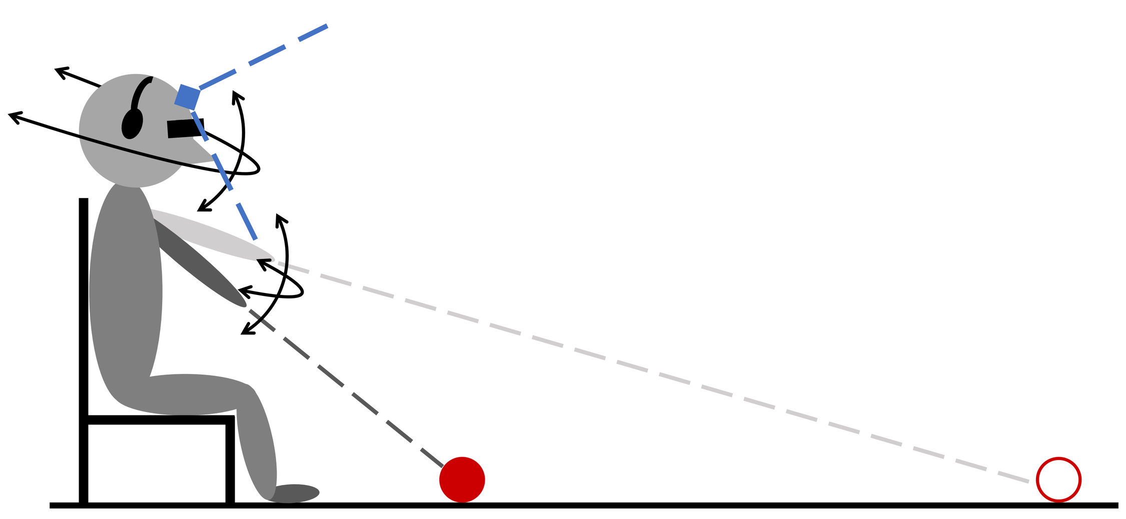

Figure 4: The active audio-motor familiarization method. After a 120-seconds sighted guided familiarization, participants practiced a 60-seconds blindfolded unguided active familiarization.

Video frames are converted into soundscapes composed of mixed stereophonic auditory pixels.

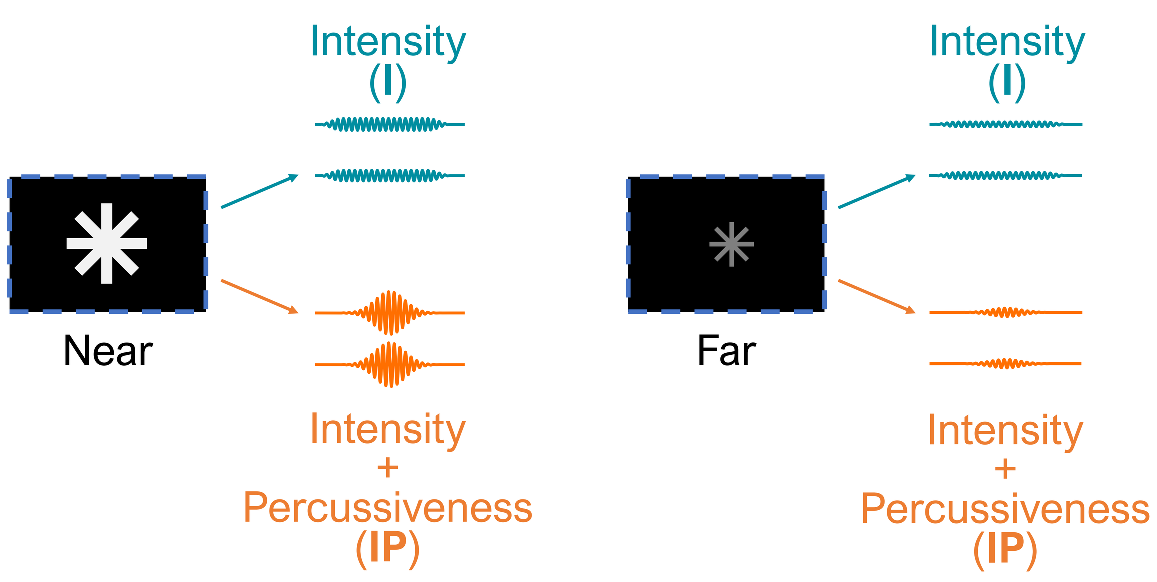

Figure 5: Examples of stereophonic auditory pixels as a function of target distance for the both tested distance encoding schemes: intensity modulation (I, top), and intensity and percussiveness modulation (IP, bottom). Elevation was conveyed through pitch modulation: 250 Hz (low elevation) to 1492 Hz (high elevation). Auditory pixels were convoluted with Head-Related Transfer Functions so azimuth was conveyed through binaural cues.

DISCRIMINATION TASK

Preliminary results suggest comparable distance discrimination scores to others sensory substitution devices (Richardson et al., 2019). **Distance discrimination scores are not significantly different between the two encoding schemes.**

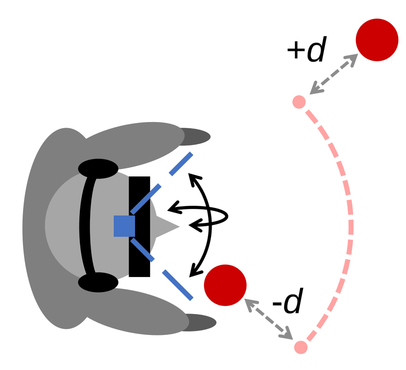

Figure 6a: The distance discrimination task method (3-down/2-up staircase method).
The two targets (red filled circles) were placed relatively to the reference locations (little pink filled circles) at 80 cm ± *d* from the participant. Initial tested distance *d* was 50 cm. Staircase steps were -15 cm, ± 5 cm and ± 2.5 cm. The distance discrimination score was computed as the mean of *d* in the last two trials.

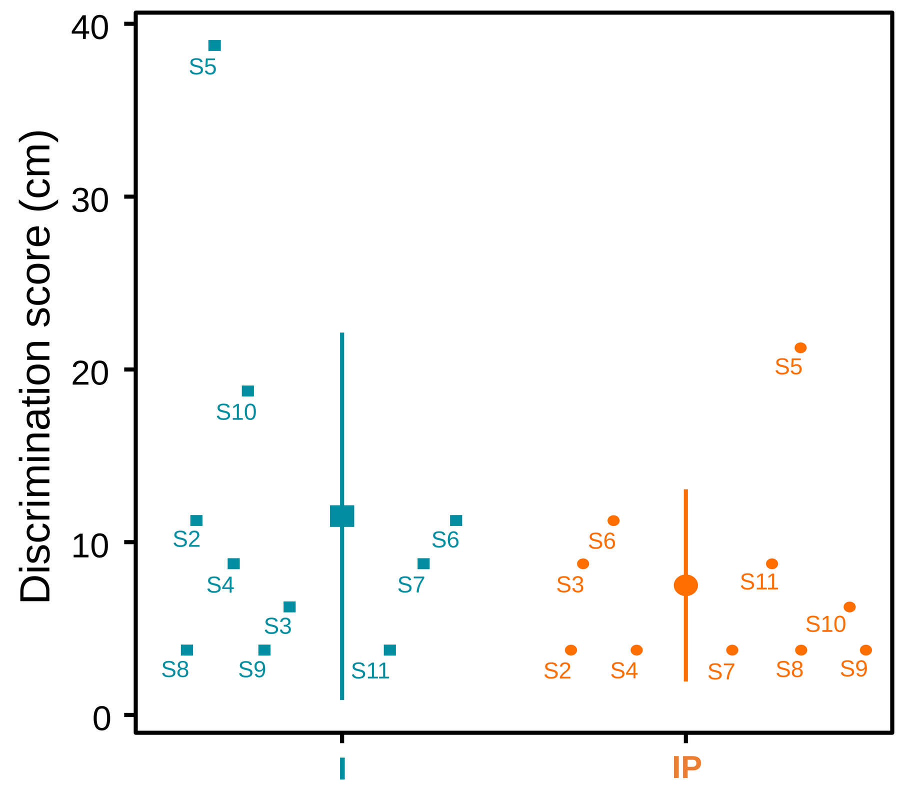

Figure 6b: The distance discrimination task results. Distance discrimination score as a function of distance encoding schemes. The average scores and the participants' individual scores are depicted.
Error bars represent standard deviation.
10 participants (age: M = 27.2, SD = 3.58, 4 female).
Encoding: [$F_{(1,9)} = 3.27$, $p = 0.100$, $\eta_p^2 = 0.270$].

LOCALIZATION TASK

Preliminary results show a great ability to perceive distance with both encoding schemes. They suggest a higher accuracy in distance perception when the encoding scheme combined intensity and percussiveness modulation.

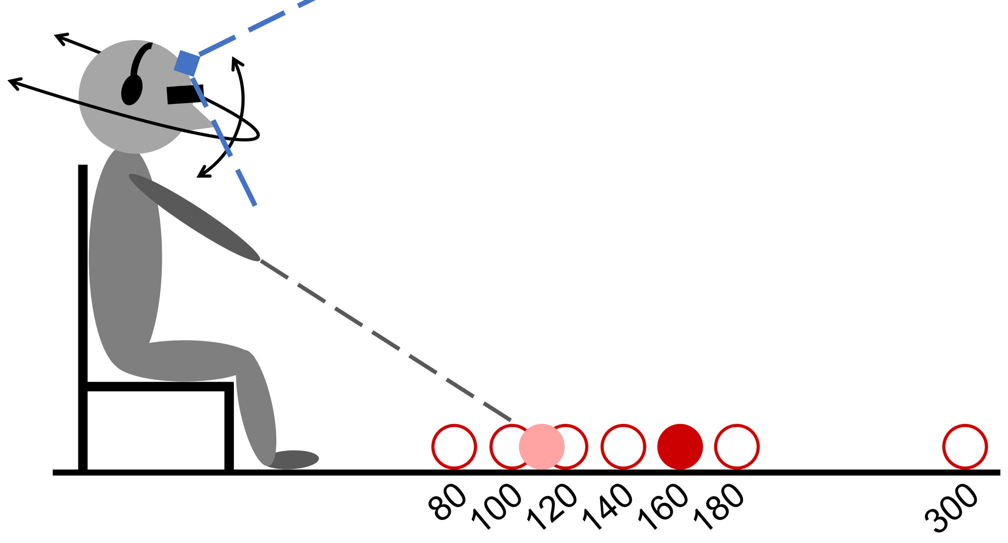

Figure 7a: The distance localization task method (pointing method).
The target (red filled circle) was placed at 7 distances (red circles) from 80 cm to 300 cm. The perceived distance (pink filled circle) was recorded with a tracked pointing tool.

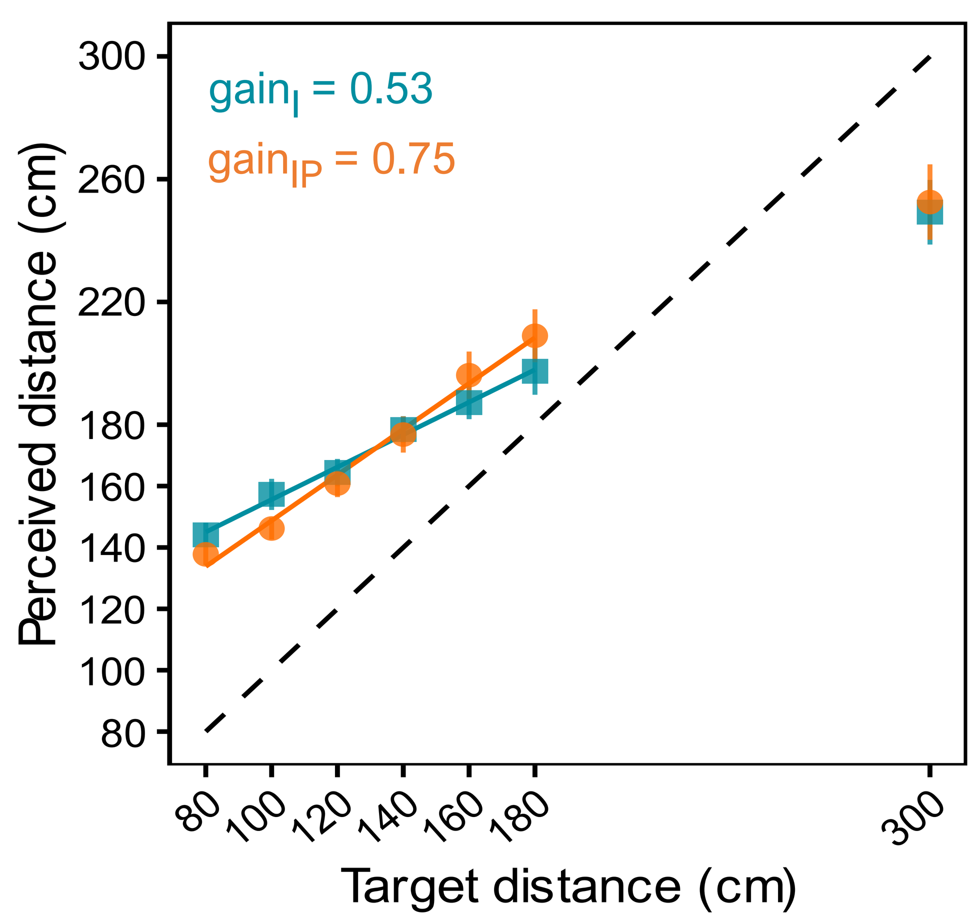

Figure 7b: The distance localization task results. Perceived distance as a function of target distance with both encoding schemes.
Error bars represent standard deviation. Estimated trends (solid lines) for the 6 nearest distances and the optimal trend (black dashed line) are displayed.
10 participants (age: M = 26.7, SD = 3.33, 4 female).
Distance: [$F_{(1,827)} = 232.08$, $p < 0.001$, $\eta_p^2 = 0.220$].
Encoding: [$F_{(1,827)} = 6.44$, $p = 0.010$, $\eta_p^2 = 0.008$].
Distance × Encoding: [$F_{(1,827)} = 6.71$, $p = 0.010$, $\eta_p^2 = 0.008$].
$gain_I = 0.53$, $gain_{IP} = 0.75$, $t_{(827)} = 2.59$, $p = 0.010$, $d = 0.523$.

DISCUSSION

- **Distance of near objects is overestimated and distance of far objects is underestimated.**
- **The percussiveness of the sound might improve distance perception through a perceptual effect (impact-similar) and an attentional effect** (Grassi et al., 2019).

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