RAPID RECALIBRATION OF AUDITORY DISTANCE PERCEPTION IN REVERBERANT ENVIRONMENTS Luboš Hládek¹, Beáta Tomoriová², Aaron Seitz³, and Norbert Kopčo^{1,4} ¹P. J. Šafarik University in Košice, Slovakia ²Technical University of Košice, Slovakia GH GENERAL HOSPITAL HIT Health Sciences & Technology ³University of California, Riverside, USA ⁴Harvard Med. School – Martinos Center, MGH, Charlestown, MA, USA 4. RESULTS: EFFECT OF LEVEL ROVE 7. RESULTS: RESPONSE BIAS In rooms, a learning effect often observed: distance B) Kopco et al. (2011), InitR A) Current study, InitR Legend: perception improves with experience xS avg. Individual A) Current study B) Kopco et al. (2011) (Shinn-Cunningham, 2000) 30 A runs R runs A runs R runs Learning process can be disrupted on a short-term excl scale, e.g., if inconsistent D/R cues are presented (Schoolmaster et al., 2004) **Correlation with rove level (Figure 3)**: In/consistency of the overall level cue during initial In both groups and both experiments: exposure to new room influences both distance - some subjects followed level cue in R runs InitR First Last D) Kopco et al. (2011), InitA C) Current study, InitA judgments accuracy, learning (Kopco et al., 2011). despite instructions, ____ - subject whose r exceeded ±0.5 excluded 68 107 165 0.5 ----from further analysis (black lines, 20 - 45%), Target Distance [cm] 0 ----- on average, r<0 in initial runs even for included subjects (thick lines), in particular in -0.5 current study (panel A), Bias in responses (Figure 6): - avg performance approached 0 in later runs. **Prediction: InitR** will perform better than **InitA** (Fig. 1). In both experiments: (Also, see APPENDIX) - in A condition, **InitA** group underestimates Figure 3 Correlation of subject responses with rove level in R distance re. InitR group, Some subjects followed the level runs as a function of the run number. Individual subjects (thin - in R condition, the difference is smaller. -InitR, N = 12 cue even in R runs. lines) and across-subject averages (thick lines) are plotted fo — InitA. N = 11 performance expressed as Average correlation with level is Over time, responses move further away, in the InitR group (panels A, B) and InitA group (panels C, D) of correlation. particular for nearby targets. the current study (panels A, D) and for Kopco et al. (2011) near zero only in second half of (panels B, D). Subjects whose correlation between responses sessions -> possible confound in and rove level exceed ±0.5 on any run were excluded (black results for first half. 0.8 _ lines). 8. SUMMARY AND CONCLUSIONS **5. RESULTS: CORRELATIONS** Subjects improved distance judgments over time in a inferior performance can be: **Correlation with actual dist (Figs 4 and 1)**: new room but the improvement was dependent on In both experiments: initial availability of level cues. A) Current study B) Combined data Figure 1 Effect of the ordering of conditions on - in run 1, performance poor, slightly better for 0.9 — InitR, N = 22 Initial exposure to room with level cue unavailable N = 34 N = 36 accuracy of distance judgments in the initial six runs **InitA** (as expected), – InitA. N = 25 resulted in better performance and learning in both poor later on within the same session), of the Kopco et al. (2011) experiment. Each line - in remaining runs, conditions. - InitR listeners are initially forced to focus on shows performance as a function of run number, **InitR** improves compared to run 1, Hypothesis confirmed: How listeners combine cues separately for the **InitA** and **InitR** groups. ^ ا8.0 ي **InitA** does not improve re. run 1, when judging distance is influenced by which performance varies little across conditions, cues are initially present. **InitR** is better than **InitA**. Performance improvement is mainly due to reduction Difference InitR vs. InitA cannot be explained in response variability. by rove, because rove effect similar across Differences in response biases also observed across groups and small in 2nd half. groups, less consistent with overall performance. inability to ignore level cue. Figure 4 Correlation between the actual and response Room distance as a function of experimental run in the current Small sound-treated lab room, hard walls, carpeted, DISCUSSION Initial exposure to stimuli w/o study (A) and for data combined across the current study ceiling tails, background noise level 35 dBA. The reason why initial availability of level cue causes level cue results in better 2nd and Kopco et al. (2011) (B). Each graph represents one One run subject group. Data from Kopco et al. (2011) shown are half performance than when separately in Fig. 1. Subject informed about stimulus condition (A or R). initial stimuli contain level cue. 80 trials, each speaker used 10 times, random order. Subject indicated heard position by choosing nearest ACKNOWLEDGEMENTS REFERENCES LED above the array of speakers using trackball.

. BACKGROUND

- Several auditory distance cues are known: - overall received sound pressure level or loudness (Warren, 1999),
- in rooms, reverberation, often characterized by Direct-to-Reverberant energy ratio, D/R (Bronkhorst and Houtgast, 1999).
- Amount of reflected energy varies from room to room. Auditory system has to adapt in each room to correctly map D/R to source distance.

2. CURRENT STUDY

- Main question: How does the consistency of the level cue during initial exposure to a new room influence distance judgments in that room?
- A distance localization experiment performed in a single one-hour-long session in a room with little/no previous exposure to subjects.
- Based on results of Kopco et al. (2011), Figure 1 & APPENDIX.
- Spontaneous learning (i.e., no feedback).
- Two run types, differing by the availability of the overall stimulus presentation level cue:
- A: level **fixed** level cue and other cues available.
- **R**: level **roved** from trial to trial only non-level cues. Two groups of subjects:
- **InitR:** Initial run R, **InitA:** Initial run A

Hypothesis

The mechanism that determines how to combine distance cues is influenced by which cues are available during initial exposure to a new room.





3. METHODS

69 normal hearing subjects

Source Stimuli

500-ms-long broadband noise burst. A stimuli:

- fixed presentation level, received level 49-54 dBA, R stimuli:
- received level equalized and roved by +/- 12 dB. Source Locations (Fig. 2)

Nine equidistant speakers, nearest one not used.



Figure 2 Experimental setup. Speakers, hidder under cloth, were used to present stimuli. Listeners used a trackball-controlled LED light array to indicate perceived distance.

- At end of run, subject informed about his/her performance.

Experiment

- One experimental session (1 hour):
- practice run (only light presentation + response),
- 8 experimental runs, R and A interleaved,
- hearing ability test at end. Analysis
- Correlation w/ rove level assessed (Panel 4). Subjects with high correlation excluded.
- Data transformed to logarithmic scale. In correlation analysis, Z-transformed data
- Response biases plotted in % of target distance. All errorbars are SEMs.

(hyperbolic arc tangens) used for significance tests.



In both experiments:

A) Current study

– InitR

<u>ŏ́0.3</u>

<u>2</u>0.2

- InitR better than InitA, except in run 1,

- performance varies little across conditions after run 2.

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6. RESULTS: RESPONSE VARIANCE



Figure 5 Standard deviations in responses as a function of the run number plotted separately for the two subject groups for the current data (A), Kopco et al. (2011) (B), and for combined data from the two studies (C). Std. devs. computed separately for each speaker, then averaged across speakers.

Changes in response variance match the trends observed in correlation coefficient analysis.



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APPENDIX Figure Effect of long-term exposure to a room on performance in R and A conditions. Performance in test runs is plotted for 4 groups of subjects differing by the initial condition (InitA vs. InitR) and by the order of training sessions (R training followed by A training, or vice versa). Sessions performed on different days. Fig 1 shows data from Session 1.

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Figure 6 Estimation of response bias as a function of target location. Current data (A), Kopco et al. (2011) (B). Across-subject average linear fits to the logarithm of the response distance are plotted separately for each subject group (InitR vs. InitA), experimental run (color-coded) and condition (left-hand portion of each panel shows R-run data, right-hand portion shows A-run data).

Response bias differences large across the groups but small across the conditions. Temporal shifts in biases do not correspond to overall

- InitA listeners initially fixate on level cue and are unable to switch to reverberation-related cue when it becomes available (however, **InitA** A performance is
- reverberation and, later on, are able to combine consistent reverberation and level information.
- Note that when exposed to the room over course of days, **InitA** subjects improve the most (Appendix).
- Current results might be influenced by listeners' initial
- If all subjects were considered in current analysis, including the ones who could not ignore level cue, the difference between the groups would disappear.
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APPENDIX

Long-term effects: Poor initial InitA accuracy results in more learning over course of days (Kopco et al., 2011).

