DOI: 10.61782/fa.2023.0851

EFFECTS OF MONAURAL SPECTRAL CUES ON SOUND LOCALISATION DURING SMALL HEAD MOVEMENTS

Glen McLachlan[1] **Piotr Majdak**[2*] **Jonas Reijniers**[1]
Michael Mihocic[2] **Herbert Peremans**[1]
[1] Department of Engineering Management, University of Antwerp, 2000 Antwerp, Belgium
[2] Acoustics Research Institute, Austrian Academy of Sciences, 1040 Vienna, Austria

ABSTRACT

Spatial listening in natural situations is facilitated by a constant deployment of head movements, affecting both spectral and interaural timing cues, both of which the auditory system uses to infer spatial information about the auditory environment. In particular, the contribution of dynamic spectral cues is still poorly understood. We conducted a series of experiments investigating the effects of head rotations (up to 10° in yaw or pitch) in order to disentangle the contribution of static and dynamic cues in the process of human sound localisation. Our results confirmed previous findings that even small yaw rotations provide a remarkable decrease in the front-back confusion rate, whereas pitch rotations do not show much of an effect. Further, our results provide new evidence that, in the presence of dynamic interaural cues, spectral cues improve sound localisation performance, even if they are just static. The localisation performance was not affected by dynamic spectral cues, irrespective of whether they agreed or conflicted with dynamic interaural timing cues. This indicates that human listeners utilise the spectral cues in the static listening conditions, but do not necessarily rely on the dynamic spectral cues to localise sounds, at least not during small head movements.

Keywords: *auditory modelling, spatial hearing, spectral cues, interaural cues, dynamic cues.*

***Corresponding author*: piotr.majdak@oeaw.ac.at.*

1. INTRODUCTION

Head movements have repeatedly been shown to improve sound localisation [e.g., 1] leading to increasing interest in the influence of head movements on the localisation performance. Unfortunately, modelling active sound localisation is more complex than its passive counterpart. The three major acoustic cues for sound localisation are the interaural time difference (ITD), interaural level difference (ILD), and monaural spectral shape (MSS) cues. When listening to a static sound source without head movements, ITDs and ILDs contribute to the sound localisation in the lateral dimension and listener-specific MSS cues to the sound localisation in the sagittal planes [e.g., 2]. In a dynamic environment, the acoustic cues change over time and have a dynamic counterpart: dynamic ITD (dITD), dynamic ILD (dILD) and dynamic MSS (dMSS) cues. Listeners seem to be more sensitive to binaural cues than to spectral cues, although they all can be perceivable within small head rotation ($\pm 10°$) [3]. Unfortunately, it is still unclear how this affects localisation performance. Moreover, active listening requires a separate movement model to complement the acoustic model [4]. This demands insights on the vestibular and motor systems and the way that humans coordinate these systems in conjunction with the auditory system.

In this study, we investigated which dynamic cues are responsible for the effects of small head movements on sound localisation. The hypothesis was that dITD is the dominant dynamic acoustic cue and has a profound effect in conditions missing MSS cues. Further, we expected that dMSS cues do not affect localisation performance when MSS cues are available.

2. METHODS

We tested normal-hearing subjects in a condition with loudspeaker-based stimulation (free-field) and three conditions with headphone-based stimulation: full, flat, and frozen. The full condition considered listener-specific head-related transfer function (HRTFs) measured as in Majdak *et al.* [5]. The flat condition considered these HRTFs but flattened between 1 and 16 kHz as in Baumgartner *et al.* [6]. The frozen condition used these HRTFs with all cues available while the head was stationary, but considered only ITD changes when the head rotated.

We tested three types of head rotations: static, yaw rotation, and pitch rotation. The rotations were single-sided. In the static conditions, head movements were restricted by instructing the subjects to keep their head aligned with the reference position. The subject was asked to point to the perceived sound localisation, as in Majdak *et al.* [5]. In the dynamic localisation experiment, subjects were instructed to make a specific one-sided rotation around either the yaw or the pitch axis, as soon as they heard the stimulus onset. Each subject underwent acoustic training to get familiar with the equipment and task, and to reach a baseline localisation performance.

Localisation performance was assessed by the lateral and polar precision errors (LPE and PPE), and front-back confusions (FBC) rate (in %). The performance was analysed using a linear mixed-effects model. The statistical significance was considered below the levels of p of 0.05 as significant.

3. RESULTS & CONCLUSIONS

The results showed no additional benefit of small head rotations on both lateral and polar localisation precision. Yaw rotations did significantly reduce the front-back confusions, pitch rotations did not. This can be explained by the contribution of dynamic ITD cues because these effects were most prominent for stimuli without the MSS cues, but remained even when these cues were available. In the frozen condition, which provided the actual static and dynamic ITD cues, but ”froze” the MSS cues to those from the initial head orientation, PPEs were at similar levels for both types of rotation, without any significant difference between the full and frozen conditions. This suggests that our subjects did utilise the static MSS cues but were insensitive to their dynamic changes.

Our findings aim at helping further development of the proposed model of active directional sound localisation [4]. More details on the results and methodology, accompanied by figures and statistical analyses, will be provided in the conference presentation.

4. ACKNOWLEDGMENTS

This research was supported by the Research Foundation Flanders (FWO) under Grant no. G023619N, the Agency for Innovation and Entrepreneurship (VLAIO), and the European Union (EU, project “SONICOM”, grant number 101017743, RIA action of Horizon 2020).

5. REFERENCES

[1] F. L. Wightman and D. J. Kistler, “Resolution of front–back ambiguity in spatial hearing by listener and source movement,” *The Journal of the Acoustical Society of America*, vol. 105, no. 5, pp. 2841–2853, 1999.

[2] P. Majdak, R. Baumgartner, and C. Jenny, “Formation of three-dimensional auditory space,” in *The Technology of Binaural Understanding*, J. Blauert and J. Braasch, Eds., Berlin, Heidelberg: Springer, 2020, ISBN: 978-3-030-00385-2. [Online]. Available: https://doi.org/10.1007/978-3-030-00386-9_5.

[3] K. Saberi and D. R. Perrott, “Minimum audible movement angles as a function of sound source trajectory,” *The Journal of the Acoustical Society of America*, vol. 88, no. 6, pp. 2639–2644, 1990.

[4] G. McLachlan, P. Majdak, J. Reijniers, and H. Peremans, “Towards modelling active sound localisation based on bayesian inference in a static environment,” *Acta Acustica*, vol. 5, p. 45, 2021.

[5] P. Majdak, M. J. Goupell, and B. Laback, “3-D localization of virtual sound sources: Effects of visual environment, pointing method, and training,” *Attention Perception and Psychophysics*, vol. 72, no. 2, pp. 454–69, Feb. 2010.

[6] R. Baumgartner *et al.*, “Asymmetries in behavioral and neural responses to spectral cues demonstrate the generality of auditory looming bias,” *Proceedings of the National Academy of Sciences*, vol. 114, no. 36, pp. 9743–9748, 2017.