Spatial Hearing with Simultaneous Sound Sources: A Psychophysical Investigation

A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy

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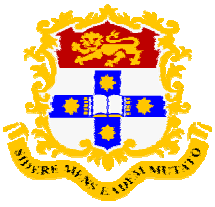

by
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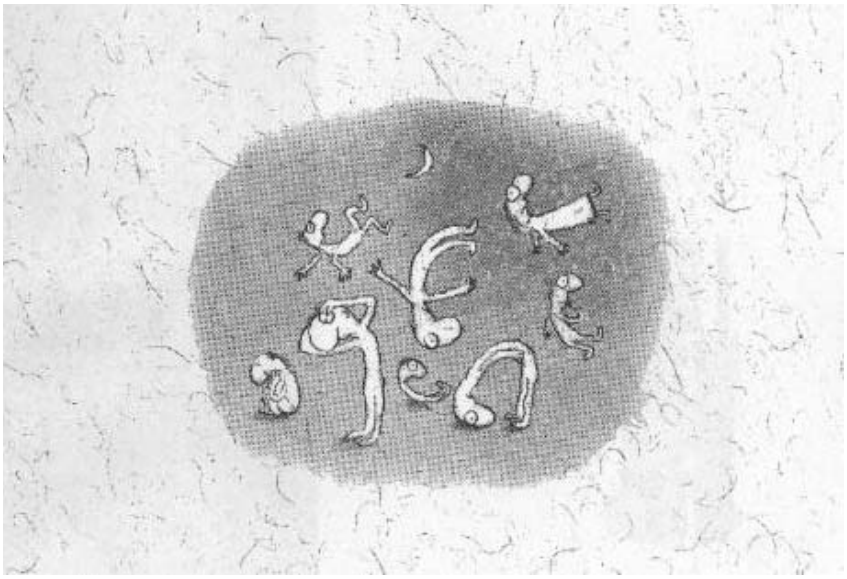

God bless the lost, the confused, the unsure,
the bewildered, the puzzled, the mystified,
the baffled, and the perplexed.
Amen.

- Michael Leunig -

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Abstract

This thesis provides an overview of work conducted to investigate human spatial hearing in situations involving multiple concurrent sound sources. Much is known about spatial hearing with single sound sources, including the acoustic cues to source location and the accuracy of localisation under different conditions. However, more recently interest has grown in the behaviour of listeners in more complex environments. Concurrent sound sources pose a particularly difficult problem for the auditory system, as their identities and locations must be extracted from a common set of sensory receptors and shared computational machinery. It is clear that humans have a rich perception of their auditory world, but just how concurrent sounds are processed, and how accurately, are issues that are poorly understood. This work attempts to fill a gap in our understanding by systematically examining spatial resolution with multiple sound sources.

A series of psychophysical experiments was conducted on listeners with normal hearing to measure performance in spatial localisation and discrimination tasks involving more than one source. The general approach was to present sources that overlapped in *both frequency and time* in order to observe performance in the most challenging of situations. Furthermore, the role of two primary sets of location cues in concurrent source listening was probed by examining performance in different spatial dimensions. The binaural cues arise due to the separation of the two ears, and provide information about the lateral position of sound sources. The spectral cues result from location-dependent filtering by the head and pinnae, and allow vertical and front-rear auditory discrimination.

Two sets of experiments are described that employed relatively simple broadband noise stimuli. In the first of these, two-point discrimination thresholds were measured using simultaneous noise bursts. It was found that the pair could be resolved only if a binaural difference was present; spectral cues did not appear to be sufficient. In the second set of experiments, the two stimuli were made distinguishable on the basis of their temporal envelopes, and the localisation of a designated target source was directly examined. Remarkably robust localisation was observed, despite the simultaneous masker, and both binaural and spectral cues appeared to be of use in this case. Small but persistent errors were observed, which in the lateral dimension represented a systematic shift *away* from the location of the masker. The errors can be explained by interference in the processing of the different location cues. Overall these experiments demonstrated that the spatial perception of concurrent sound sources is highly dependent on stimulus characteristics and configurations. This suggests that the underlying spatial representations are limited by the accuracy with which acoustic spatial cues can be extracted from a mixed signal.

Three sets of experiments are then described that examined spatial performance with speech, a complex natural sound. The first measured how well speech is localised in isolation. This work demonstrated that speech contains high-frequency energy that is essential for accurate three-dimensional localisation. In the second set of experiments, spatial resolution for concurrent monosyllabic words was examined using similar approaches to those used for the concurrent noise experiments. It was found that resolution for concurrent speech stimuli was similar to resolution for concurrent noise stimuli. Importantly, listeners were limited in their ability to concurrently process the location-dependent spectral cues associated with two brief

speech sources. In the final set of experiments, the role of spatial hearing was examined in a more relevant setting containing concurrent streams of sentence speech. It has long been known that binaural differences can aid segregation and enhance selective attention in such situations. The results presented here confirmed this finding and extended it to show that the spectral cues associated with different locations can also contribute.

As a whole, this work provides an in-depth examination of spatial performance in concurrent source situations and delineates some of the limitations of this process. In general, spatial accuracy with concurrent sources is poorer than with single sound sources, as both binaural and spectral cues are subject to interference. Nonetheless, binaural cues are quite robust for representing concurrent source locations, and spectral cues can enhance spatial listening in many situations. The findings also highlight the intricate relationship that exists between spatial hearing, auditory object processing, and the allocation of attention in complex environments.

Declaration

This thesis describes original work carried out in the Department of Physiology at the University of Sydney. I certify that all material in this thesis which is not my own work has been identified and that no material has previously been submitted and approved for the award of a degree by this or any other University.

Virginia Best
April 2004

Portions of this work have appeared in the following publications:

V. Best, A. van Schaik, C. Jin and S. Carlile (2004). "Sharing auditory space: Sound localisation in the presence of a concurrent masker." Acta Acustica united with Acustica (special issue on Spatial and Binaural Hearing) (submitted).

V. Best, A. van Schaik and S. Carlile (2004). "Separation of concurrent broadband sound sources by human listeners." Journal of the Acoustical Society of America 115(1):324-336.

V. Best, A. van Schaik and S. Carlile (2003). "Two-point discrimination in auditory displays." Proceedings of the 9th International Conference on Auditory Display, Boston, USA, pp. 17-20.

V. Best, A. van Schaik and S. Carlile (2003). "Spatial effects on the segregation of sounds in virtual auditory space." Proceedings of the 8th Western Pacific Acoustics Conference, Melbourne, Australia, p. 1090M.

V. Best, A. van Schaik and S. Carlile (2002). "The perception of multiple broadband noise sources presented concurrently in virtual auditory space." Proceedings of the Audio Engineering Society 112th Convention, Munich, Germany.

C. Jin, V. Best, S. Carlile, T. Baer and B. Moore (2002). "Speech Localization." Proceedings of the Audio Engineering Society 112th Convention, Munich, Germany.

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