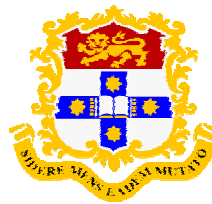


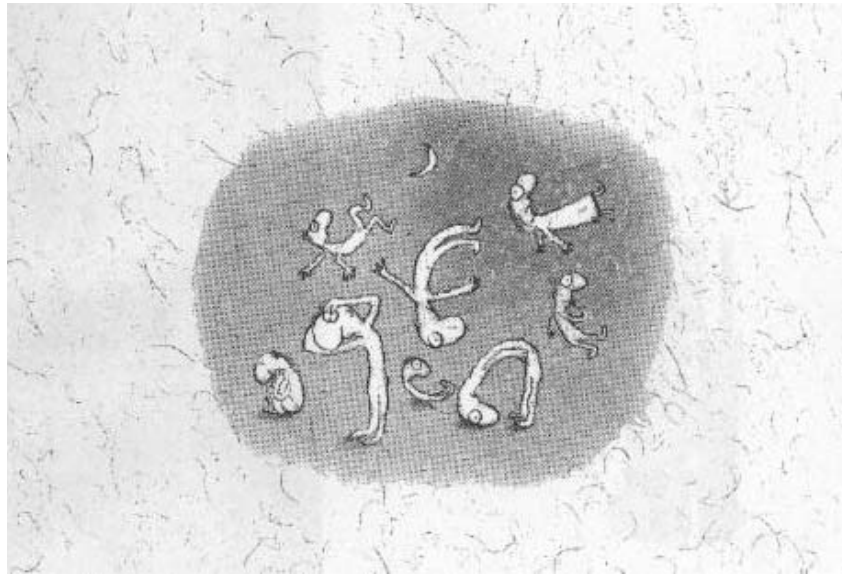
# Spatial Hearing with Simultaneous Sound Sources: A Psychophysical Investigation

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

Faculty of Medicine,  
The University of Sydney.  
April 2004.



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 -

## Acknowledgements

I would first like to acknowledge and thank my supervisors, Simon Carlile and André van Schaik, for absolutely everything. Simon's enthusiasm, wisdom, and knack for story-telling first got me excited about ears, kept me inspired, and will stay with me always. I am grateful for his unfailing belief in me. The opportunities and responsibilities he gave me have made me so much stronger and I thank him for making me do things I didn't think I could do! André's contribution to this work (and my character) has been enormous. From the very start he excused my naivety and trusted my ability to understand and learn. He shared with me the brilliant things he was doing and, more importantly, thinking. Working with André has made me a more critical thinker, a clearer communicator, and a much better anagram unscrambler. Above everything, I treasure how effortlessly we blended work with fun and how often we read each others minds. André, heel hartelijk dank voor allehulp.

A most important aspect of this work was the amazing environment it took place in, and I most affectionately acknowledge all in the Auditory Neuroscience Lab. A special thanks must go to Johahn Leung, for taking me under his wing when I arrived in the lab, and for being there with friendship and support ever since. Jogi was the one who always had the answer I needed, but always made sure I worked for it so that I would learn something. My warmest thanks also to Craig Jin for his ideas, his advice, and his unrivalled ability to get things moving. Craig's fascination with everything took this work down many important avenues, and his famous suspicions averted many disasters! I also want to thank Ben Dickson, whom I felt I had known for years as soon as he arrived in the lab. It was wonderful to share an office with him, as well as the sometimes rocky PhD road, some good and bad music, and a lot of laughs.

My friends are the ones who have always kept me balanced and smiling, and I thank them all wholeheartedly. I am especially grateful to them for accepting those periods of distraction where I completely forgot how to be fun. A (fully) special thank you to Sarah-Jane, for a million things that I needn't mention because she just *knows*. And to Haydn, who faced the writing-up stage with me, for inspiring me to finish through his determination and energy, his love and care, and that great big smile. Finally, I would like to acknowledge my beautiful family for their undemanding love and quiet encouragement. I am truly the luckiest person in the world to have them. I dedicate this thesis to them, but want to assure them that they are not obliged to read past this page! xo

# 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 9<sup>th</sup> 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 8<sup>th</sup> 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 112<sup>th</sup> Convention, Munich, Germany.

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

# Table of contents

<b>Chapter 1: Sound localisation .....</b>	<b>1</b>
1.1 Overview .....	1
1.2 Organisation of the auditory system .....	1
1.2.1 The ear.....	1
1.2.2 Basic coding strategies.....	3
1.2.3 Central auditory pathways .....	4
1.3 Auditory spatial processing.....	6
1.3.1 Interaural time differences .....	7
1.3.2 Interaural level differences.....	10
1.3.3 Spectral cues .....	12
1.3.4 Externalisation and distance perception.....	20
1.3.5 Space maps in the auditory system .....	21
1.4 Human spatial performance .....	23
1.4.1 Absolute localisation.....	24
1.4.2 Relative localisation.....	27
1.5 Aims and overview .....	28
<b>Chapter 2: The experimental environment.....</b>	<b>31</b>
2.1 Subjects .....	31
2.2 The spatial co-ordinate system.....	31
2.3 Testing facilities .....	33
2.3.1 Anechoic chamber.....	33
2.3.2 Soundproof Room.....	35
2.4 Localisation paradigm.....	35
2.4.1 Basic testing procedure .....	35
2.4.2 Localisation training .....	37
2.4.3 Analysis of localisation performance.....	37
2.5 Individualised virtual auditory space .....	38
2.5.1 The use of virtual auditory space .....	38
2.5.2 Measurement of directional transfer functions .....	39
2.5.3 Stimulus delivery .....	42
2.5.4 Validation of VAS .....	42
2.5.5 Spatial interpolation of DTFs.....	43
<b>Chapter 3: Auditory two-point discrimination.....</b>	<b>45</b>
3.1 Introduction.....	45
3.2 Previous studies of auditory spatial resolution.....	46
3.3 Approach.....	47
3.4 Experimental methods.....	48
3.4.1 Subjects and task.....	48
3.4.2 Stimulus configurations .....	49
3.4.3 Data analysis .....	51
3.4.4 A note on response criteria, training and controls.....	51
3.5 Experiment 1: Broadband stimuli .....	52

3.5.1	Stimuli .....	52
3.5.2	Results .....	54
3.5.3	Discussion .....	56
3.6	Experiment 2: Effect of removing single components of the ITD .....	60
3.6.1	Stimuli .....	60
3.6.2	Results .....	61
3.6.3	Discussion .....	64
3.7	Experiment 3: Effect of removing ITD components in combination .....	65
3.7.1	Stimuli .....	65
3.7.2	Results .....	65
3.7.3	Discussion .....	67
3.8	General discussion .....	68
3.8.1	Subject performance .....	68
3.8.2	A consideration of ITD sensitivity .....	70
3.8.3	ITD extraction and interaural coherence .....	72
3.8.4	ITD as a cue in other situations .....	74
3.8.5	Ineffectiveness of spectral cues in a mixed signal .....	75
3.9	Conclusions .....	76
<b>Chapter 4: Sound localisation in the presence of a concurrent masker .....</b>		<b>77</b>
4.1	Introduction .....	77
4.2	Previous studies of concurrent localisation .....	78
4.2.1	Pushing effects .....	78
4.2.2	Pulling effects .....	79
4.2.3	Other studies .....	79
4.2.4	A reasonable hypothesis? .....	80
4.3	Approach .....	81
4.4	Experimental methods .....	82
4.4.1	Subjects and task .....	82
4.4.2	Stimulus configurations .....	83
4.4.3	Data analysis .....	84
4.5	Experiment 1: Influence of simultaneity and duration .....	85
4.5.1	Stimuli .....	85
4.5.2	Results .....	87
4.5.3	Discussion .....	96
4.6	Experiment 2: Influence of stimulus characteristics .....	99
4.6.1	Stimuli .....	99
4.6.2	Results .....	99
4.6.3	Discussion .....	107
4.7	General discussion .....	109
4.7.1	Comparison with the literature .....	109
4.7.2	Relation to models for localisation bias .....	109
4.7.3	Segregation and localisation cue processing .....	112
4.7.4	A note on attention .....	115
4.8	Conclusions .....	115
<b>Chapter 5: Speech localisation .....</b>		<b>117</b>
5.1	Introduction .....	117
5.2	Previous studies of speech localisation .....	119

5.3	Experimental methods.....	120
5.3.1	Subjects and task.....	120
5.3.2	Speech stimuli.....	121
5.3.3	Data analysis.....	121
5.4	Experiment 1: Speech localisation.....	122
5.4.1	Conditions.....	122
5.4.2	Results.....	123
5.4.3	Discussion.....	127
5.5	Experiment 2: Influence of high-frequency level.....	132
5.5.1	Conditions.....	132
5.5.2	Results.....	132
5.5.3	Discussion.....	137
5.6	General discussion.....	138
5.7	Conclusions.....	139
<b>Chapter 6: Spatial performance with concurrent speech sources .....</b>		<b>140</b>
6.1	Introduction.....	140
6.2	Experiment 1: Location discrimination with paired speech sources.....	141
6.2.1	Experimental methods.....	141
6.2.2	Results.....	144
6.2.3	Discussion.....	148
6.3	Experiment 2: Speech localisation in the presence of a concurrent speech masker.....	151
6.3.1	Experimental methods.....	151
6.3.2	Results.....	152
6.3.3	Discussion.....	155
6.4	General discussion.....	156
6.5	Conclusions.....	159
<b>Chapter 7: Spatial factors aiding speech segregation .....</b>		<b>160</b>
7.1	Introduction.....	160
7.2	Experimental methods.....	162
7.2.1	Subjects and task.....	162
7.2.2	Speech materials.....	162
7.2.3	Stimulus configurations.....	163
7.2.4	Stimulus conditions.....	163
7.2.5	Testing procedure.....	164
7.2.6	Data analysis.....	165
7.3	Results.....	166
7.3.1	Same talker condition.....	166
7.3.2	Different talker condition.....	169
7.3.3	Median vertical plane configurations.....	169
7.4	Discussion.....	171
7.4.1	Performance with co-located stimuli.....	171
7.4.2	Advantage of binaural separation.....	172
7.4.3	Advantage of median plane separation.....	172
7.4.4	Types of masking and voice/space interactions.....	176
7.5	Conclusions.....	177

<b>Chapter 8: General discussion.....</b>	<b>178</b>
8.1 Summary of findings.....	178
8.2 Discussion of findings.....	179
8.2.1 Binaural cues and concurrent source perception.....	179
8.2.2 Spectral cues and concurrent source perception .....	180
8.2.3 The relationship between localisation and segregation.....	181
8.2.4 Practical relevance of results.....	183
8.3 Key areas for further research .....	184
8.3.1 Neurophysiology .....	184
8.3.2 Behavioural research.....	186
 <b>Bibliography .....</b>	 <b>188</b>