

**Auditory Temporal Processing Ability and the
Development of Speech, Language and Reading:
Implications for Children with Auditory
Neuropathy Spectrum Disorder**

By

Aseel Al-Meqbel

Dip Pharmacology, B.S Audiology, M.S Audiology

Audiology, Centre for Language Sciences, Linguistics Department, Faculty of Human
Sciences, Macquarie University, Sydney

&

The HEARing Cooperative Research Centre (CRC)

This thesis is presented for the degree of

Doctor of Philosophy (PhD) in Audiology

April 2011

DEDICATION

This work dedicated to my mother's spirit

Who raised and supported me through my entire life

She was always my safety net, who brought me to safety when I thought I was falling

Contents

<i>List of tables</i>	<i>vi</i>
<i>List of figures.....</i>	<i>vii</i>
<i>Abstract.....</i>	<i>ix</i>
<i>Statement of candidate</i>	<i>xi</i>
<i>Acknowledgements</i>	<i>xii</i>
<i>Thesis organization</i>	<i>xiv</i>
Chapter 1 Review of the literature	1
1.1 Auditory neuropathy spectrum disorder (ANSO): An auditory temporal processing disorder	2
1.2 Cortical auditory evoked potentials: Electrophysiological methods.....	8
Chapter 2 Current state of knowledge: The consequences of auditory temporal processing disruption on speech, language and reading development of children with Auditory Neuropathy Spectrum Disorder	17
2.1 Introduction	19
2.2 Relationship between auditory temporal processing ability and speech perception.....	26
2.3 Relationship between auditory temporal processing ability, language and reading	30
2.4 Conclusion.....	36
Chapter 3 Auditory cortical temporal processing abilities in young adults.....	41
3.1 Introduction	43

3.2	Method.....	49
3.2.1	Participants	49
3.2.2	Procedure.....	50
3.3	Results	56
3.3.1	/da/ vs. / ta/	56
3.3.2	/ba/ vs. /pa/	56
3.3.3	Speech-in-noise	56
3.3.4	Amplitude-modulation (AM) of broadband noise.....	57
3.4	Discussion.....	58
3.4.1	Voice-onset-time	58
3.4.2	Speech-in-noise	60
3.4.3	Amplitude-modulated broadband noise	62
3.4.4	Conclusion.....	64

Chapter 4 Cortical auditory temporal processing abilities in elderly

	listeners.....	71
4.1	Introduction	73
4.2	Methods	78
4.2.1	Participants	78
4.2.2	Procedure.....	78
4.3	Results	84
4.3.1	Voice-onset-time	84
4.3.2	Speech-in-noise	85
4.3.3	Amplitude-modulation (AM) of broadband noise.....	85
4.4	Discussion.....	86
4.5	Conclusion.....	90

Chapter 5 Auditory cortical temporal processing abilities in school- aged children with normally developed hearing, speech, language and reading skills: Implication for children with Auditory Neuropathy Spectrum Disorder	98
5.1 Introduction	100
5.2 Method	103
5.2.1 Participants.....	103
5.2.2 Stimuli.....	104
5.2.3 Behavioural procedure	106
5.3 Results	109
5.3.1 Behavioural measures	109
5.4 Discussion	111
5.5 Conclusion.....	117
 Chapter 6 Future direction and conclusions	 124
6.1 Summary of findings.....	125
6.2 Implications, future directions of study	127
6.3 The recommended test battery for the evaluation of children with temporal processing disruption	128
 References.....	 136

List of tables

Table 1. The magnitude of temporal disruption in individuals with ANSD versus dyslexics	38
Table 2. Details of the stimuli, stimulus type, VOT and formant frequency	66
Table 3. Behavioural test procedures used for speech, language and reading assessments.....	118
Table 4. Children's results from the behavioural measures (Mean, SD)	119
Table 5. Recommended objective and behavioural test battery for evaluation of children with temporal processing disruption	129

List of figures

Figure 1. Varying magnitudes of TMTF thresholds at 10 Hz for 14 children between 48 and 120 months of age with ANSD (from Rance et al., 2004), separated into those with good and poor speech perception (CNC phoneme score), and 6 children with dyslexia between 100 and 175 months (from Lorenzi et al., 2000).	38
Figure 2. Thresholds of gap detection for adults with ANSD (from Michalewski et al., 2005) and children with dyslexia (from Van Ingelghem et al., 2001) compared to adults and children (120–144 months) without ANSD or dyslexia.....	39
Figure 3. Grand average cortical waveforms measured at Cz for /da/ vs. /ta/ (A) and /ba/ vs. /pa/ (B) for 10 normally hearing adults. C. Mean (\pm stdev) of N1 latency for /da/ compared with /ta/ and /ba/ compared with /pa/. D. N1 latency as a function of voice-onset time.	67
Figure 4. A. Grand average cortical waveforms at Cz electrode N1 latency as a function of SNRs for 10 normally hearing young adults. B. Mean (\pm stdev) N1 latency for signal-to-noise ratios from +20 dB to -10 dB.	68
Figure 5. Individual cortical waveform at Cz electrode for five levels of modulation depths (100, 75, 50, 25 and 0%). A: Cortical auditory evoked potential (CAEP), B: Acoustic Change Complex (ACC).	69
Figure 6. Grand averaged waveforms for older listeners recorded from electrode Cz in responses to /da/ vs. /ta/ speech stimuli.	92
Figure 7. Grand averaged waveforms for younger and older normal-hearing listeners recorded from electrode Cz in response to A: /da/; B: /ba/; C: /ta/; and D: /pa/ speech stimuli.....	93

Figure 8. Grand averaged waveforms for A: older and B: younger normal-hearing listeners recorded from electrode Cz in responses to five SNRs conditions.	94
Figure 9. Mean (\pm stdev) of temporal modulation transfer function (TMTF) using 16 Hz in younger group versus older group.	95
Figure 10. Grand averaged waveforms for A: older normal-hearing listeners, B: younger normal-hearing listeners recorded from electrode Cz in response to three levels of amplitude modulation for both conditions.....	96
Figure 11. An example of differences between older and younger normal-hearing listeners recorded from electrode Cz in response to 100% AM.	97
Figure 12. Individual cortical waveforms from A: a child aged 6 years, B: a child aged 9 years in response to /da/ vs. /ta/.	120
Figure 13. Single individual cortical waveforms recorded at Cz in responses to three SNRs levels (20 dB SNR, 0 dB SNR and g -10 dB SNR) in a child aged 6 years..	121
Figure 14. Individual cortical waveforms for a child aged 8 years recorded from electrode Cz in response to 100% and 0% AM for A: CAEP and B: ACC, C: Mean (\pm stdev) N2 latency for amplitude-modulation from 100% to 0%, D: Mean (\pm stdev) N2 latency for amplitude-modulation from 100% to 0% when it follows the BBN.....	122
Figure 15. Mean (\pm stdev) N2 latency in both groups for each stimulus.....	129
Figure 16. An example of auditory cortical auditory responses as a function of +20 dB SNR in three different groups (young adults, older adults, school-aged children).....	133
Figure 17. An example of cortical auditory response as a function of AMBBN at 100% in three different groups (young adults, older adults, school-aged children).....	134

Abstract

Auditory Neuropathy Spectrum Disorder (ANSD) is classified by normal cochlear mechanical function but severely degraded neural synchrony. The auditory system relies on high levels of neural synchrony for processing timing (temporal) cues which are critical for speech perception (particularly in degraded conditions) and normal speech, language and reading development. Unlike most sensorineural hearing losses, speech perception ability in ANSD appears to be correlated with the magnitude of temporal disruption rather than spectral disruption (measured either through the pure tone audiogram or estimated by frequency-specific auditory brainstem responses; ABR). Because ANSD is mostly diagnosed in infants through newborn hearing screening programs, objective tests of temporal processing are needed. The current study focused on the development and evaluation of objective tests of temporal processing for children.

Specifically, the aims of the present study were to:

- identify the likely types of disruptions that occur to speech perception, language and reading abilities in young children with abnormal temporal processing, and the magnitude of disruption that can affect these skills;
- develop and evaluate objective measures of temporal processing in normally hearing adults to provide sensitive measures of assessing different auditory temporal processing abilities;
- evaluate the applicability of these objective measures to normally hearing children (aged 5-12) with normal speech, language and reading abilities and to

normally hearing older adults with poor temporal processing abilities (aged 64–80 years).

This study provides normative data for objective temporal processing measures, which ultimately can be used to evaluate temporal processing abilities in children with ANSD unable to provide behavioural responses. Because of the heterogeneous nature of the disorder and co-morbidity of other medical problems in this population, research in this area is limited. Nonetheless, developing a greater understanding of this problem is critical to improved management of children diagnosed with ANSD and other temporal deficits.

Statement of candidate

I certify that the work in this thesis entitled “Auditory Temporal Processing Ability and the Development of Speech, language and Reading: Implications for Children with Auditory Neuropathy Spectrum Disorder” has not previously been submitted for a degree nor it been submitted as part of requirement for a degree to any other University or institution for a degree other than Macquarie University.

I also certify that the thesis is an original piece of research and it has been written by me. Any help and assistance that I have received in my research work and the preparation of the thesis itself have been appropriately acknowledged.

In addition, I certify that all information sources and literature used are indicated in the thesis. The research presented in this thesis was approved by Macquarie University Ethics review committee, reference number <HE28NOV2008-D06222> <30 January 2009>

Signature

Aseel Al-Meqbel

27 April 2011

Acknowledgements

First and foremost, I would like to express my deepest gratitude to my principal supervisor, Dr Catherine McMahon for her unwavering support academically and personally. You are a true treasure, and finishing this thesis would not have been possible without your understanding, gentle motivation and dedication to my success. She taught me many valuable things. She taught me the importance of performing work carefully. Her support and care gave me self confidence and encouraged me to work diligently to expand my knowledge in audiology and electrophysiology. I have learned a lot from her research perspective and professionalism. You have had a dramatic influence on my scientific thinking, problems solving and attitude to word research.

I would like to extend my gratitude to my associate supervisor, Professor Linda Cupples, for her constant support and feedback and encouraging my progress throughout this journey; I really appreciate your answering my questions over and over, Linda.

Importantly, I would like to thank all the children and their families who took the time out to come and participate in my research.

I also wish to thank the young and old adult participants who participated in this study for their generous contribution of time and energy.

A special thanks to my Dad, the smartest man I know, whose guidance and wisdom carried me through the most difficult stages of my work.

I offer my most sincere thanks and gratitude to my amazing and loving family, younger sister and brother who have never stopped encouraging me to grow both academically

and personally, and for always being available. Especially I would like to thank my lovely younger sister Fajer for her encouragement and support during this work. I was lucky to have the wonderful support of her and my younger brother Ali; you are such amazing and lovely siblings. I love you both so much.

Finally, I would like to gratefully thank the Kuwait University for financially supporting my scholarship in Australia and the Kuwait cultural office in Canberra for their continuous support, and being always there for all Kuwaiti students in Australia.

I promise to do my best and to give back even a little portion of that debt and support from my home country Kuwait.

Thank you - I love you all

Thesis organization

This thesis was designed to be a thesis by publication. Four of the six chapters will be submitted to international journals or have formed part of oral presentations at Macquarie University and other national and international conferences during the PhD candidature. This section provides an outline of the thesis.

Chapter 1 is a literature review of two main literatures: a review of a type of hearing disorder known as auditory neuropathy spectrum disorder (ANS), an auditory temporal processing disorder, and a review of the cortical auditory evoked potentials (CAEPs) as an electrophysiological method to study the auditory system at the cortical level.

Chapter 2 (Paper 1) has been prepared for submission to *Ear and Hearing*. It is a review article that discusses the consequences of auditory temporal processing on speech, language and reading development. The paper draws its conclusions from populations diagnosed with language learning disorders (LLD), such as dyslexia and specific language impairment (SLI), who were also characterized by an auditory temporal processing disruption and where we have assumed that the disruption is more centrally located than in ANSD, which is characterized by disrupted synchrony of the primary afferent nerve as indicated by the poor morphology or absent ABR. In addition, these findings motivated us to question whether ANSD children with auditory temporal processing deficits share similarities in the language and reading disruptions to dyslexic and SLI populations. This particular area has not been fully investigated and little is known regarding language and reading development in school-aged children with ANSD. While it was the initial aim of the current study to address this, the challenges of

recruiting individuals with ANSD without additional medical complications or with only milder forms of hearing loss did not permit an in-depth analysis of this disordered population. Instead, this study focuses on the development of a protocol for evaluating speech perception, language and reading abilities in children with ANSD; the development and evaluation of electrophysiological tests of temporal processing in “two normally hearing populations” and young adults and school-aged children (with age-appropriate speech, reading and language abilities) – and the application of these tests of temporal processing in a normally hearing population (older adults) with disordered temporal processing.

Chapter 3 (Paper 2) has been partly presented at the Audiology Australia XIX National Conference 2010, Sydney, Australia and has been prepared for submission to the journal *Clinical Neurophysiology*. The aim of this paper was to study whether cortical encoding of temporal processing ability could be measured objectively (electrophysiologically) in young adults with normal hearing using three temporal processing paradigms: voice-onset-time, speech-in-noise and amplitude-modulation-detection of 16 Hz broadband noise. The N1 latency of the cortical auditory evoked potential (CAEP) was used as a measure of temporal processing.

Chapter 4 (Paper 3) has been prepared for submission to the journal *Clinical Neurophysiology* and will be presented in part at the XXII IERASG Biennial Symposium, 26–30 June, 2011, Moscow, Russia. The aim of this study was to test whether the above three temporal processing paradigms are sensitive to evaluate the disrupted temporal processing in elderly listeners with normal hearing (age-related-temporal processing deficit). The N1 latency was used as a measure of temporal

processing, and we compared elderly results with previously evaluated young adult listeners with normal hearing (see Chapter 3).

Chapter 5 (Paper 4) has been prepared for submission to the journal *Clinical Neurophysiology*. The aim of this paper was to determine whether, in normally hearing school-aged children, the N2 latency of the cortical auditory evoked potential (CAEP) could be used as an objective indicator of temporal processing ability where the N1 peak is not present in the cortical waveform.

Chapter 6 presents a summary of all three studies and discusses the implications of the research, possible future research directions and recommended test battery for the evaluation of children with disrupted temporal processing followed by the main references.

Author's contribution to the papers:

- Responsibility for the experimental design and procedure (e.g., develop and generate the stimuli, setting up the equipment, calibration, trouble shooting)
- Conduct of experiments (e.g., participant recruitment and testing)
- All data analysis (statistical analysis, graphing and results interpretation)
- Write-up of all papers.

Co-authors' contributions:

- Initial study design and revisions
- Editorial input
- Advice about interpretation of data.