The effects of aircraft noise on the auditory language processing abilities of English First Language primary school learners

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INTRODUCTION

Auditory processing difficulties may cause scholastic difficulties (Cacace & McFarland 1998) and research has shown that chronic noise exposure can have a negative effect on some auditory processing skills (Maxwell & Evans 2000) which, in turn, may impact on children's scholastic performance. However there has been very little research on the effect of long term aircraft noise exposure on the auditory processing skills of children when hearing thresholds are within normal limits. Airports are notoriously noisy environments and already in 1974, Crook & Langdon demonstrated that noise levels within schools near airports in London peaked at or above 70 dBA with at least one out of every four flights. Therefore, this study sought to investigate the effects of long term aircraft noise exposure on the auditory language processing abilities of English First Language primary school learners attending schools in Durban, South Africa since processing problems may manifest as difficulties with reading, spelling or other learning problems.

Auditory Language Processing

Auditory Language Processing (ALP) occurs beyond the peripheral auditory system and requires an intact peripheral auditory system to transmit the signal along the auditory pathway to the brain where it passes from the auditory nerve to the cochlear nucleus (CN), then continues to the superior olivary complex, through to the lateral lemniscus to the inferior colliculus. The signal continues through to the medial geniculate body of the thalamus and then reaches the auditory cortex (Phillips 2007; Katz et al. 1992) where it is processed. The processing of language is the ability to attach meaning to an auditory signal using linguistic knowledge and tends to occur in the temporal lobe, more specifically Heschel's Gyrus, Angular Gyrus as well as Broca's area. Primary, secondary and tertiary zones of the brain progressively attach meaning to the auditory signal (Richard 2001). Poldrack et al. (2001) investigated the neural basis of auditory processing in comparison to phonological processing and they found that a subset of the left inferior frontal regions involved in phonological processing in reading are also sensitive to acoustic features within the range of comprehensible speech. Thus, we can see that there is an overlap in the processing of auditory and language signals and cannot always be distinguished as separate entities.

Signs and symptoms of an auditory language disorder

An auditory language processing disorder is characterized by difficulties in the interpretation of acoustic signals. The signs and symptoms can vary considerably, depending on the degree of the disorder and the individual child affected (Geffner & Ross-Swain 2007). Auditory processing problems can manifest in several ways, where, in some instances, a person with an auditory language processing disorder

(ALPD) is aware of his/her difficulty with listening and understanding signals that is exacerbated by some situations or environments, such as in noise. However, with others, the actual difficulties that arise from ALPD are more subtle, such as disturbances with learning, language, spelling, reading, socializing and problem solving skills (Bellis 2002). Bellis (2007) estimated that half of all children identified with a learning disorder exhibit an auditory processing disorder and auditory processing disorders are estimated to occur in 2–3 % of children (Martin & Clark 2003). Therefore, children in the vicinity of airports may have an even larger chance of developing an ALPD.

Noise causing cognitive, psychological and health problems

Aircraft and road traffic noise can impact on cognitive tasks as demonstrated in a study in the Netherlands, Spain and the United Kingdom by Stansfeld et al. (2005) which showed that chronic aircraft and road traffic noise could impair cognitive development in children, specifically reading comprehension. Similarly, in Los Angeles, it was shown that there were approximately 300 over-flights daily peak sound readings in these schools were 95 dBA. This study showed that the children in the noisy schools, compared to the matched quieter schools were more likely to give up before time, more likely to fail on a cognitive task, and more likely to have higher blood pressure (Cohen et al. 1980). Therefore, these studies show that noise can have adverse effects on learning and it appears necessary to look specifically at AP effects as there appears to be a dearth of literature in this aspect.

Classroom acoustics

Environmental and aircraft noise can contribute to a poor signal to noise ratio and poor listening conditions within classrooms, where, as Palmer (1997) points out, children can spend up to 45 % of their school day engaged in listening activities. In South Africa there are no national standards for classroom acoustics, simply noise level recommendations. Typical school buildings and classroom layouts vary between countries in ways that are often related to material resources. Many schools in South Africa have been described as large, dilapidated and unwieldy classrooms with limited recourses. In some schools, learning takes place in prefabricated buildings with very thin walls; while other schools, although made of brick buildings, have poor acoustics such as thin windows and doors, and limited posters and carpets to absorb the sounds which does not at all help to achieve an acceptable S/N ratio for the children to learn. Although the layouts and environments are important, it is necessary to make accommodations depending on budget and recourses (Higgins et al. 2005), which is a common issue in South Africa. The promotion of health is what nations should aspire to, rather than solely provide treatment, such as therapy. Consequently, it has been proposed that causative variables can be identified and accommodated by suggesting preventative implementations improve the S/N ratio in the classroom, and assist in preventing ALPDs (Levi 2005).

Therefore, because of the recognized effects of noise on learning and the high levels of noise near airports, it became apparent to study the effect of noise on particular aspects of auditory processing to better understand the impact of noise on these auditory processing skills since compromised auditory language processing skills can have an impact on classroom learning.

METHODOLGY

The aim of this study was to investigate the auditory language processing abilities of English First Language (EFL) learners who attend aircraft-noise-exposed schools and learners who attend non-aircraft-noise-exposed schools in Durban, South Africa.

Context of the study

The results shared here form part of a larger Master of Arts in Audiology project. It is also related to the RANCH-SA (Road Traffic and Aircraft Noise and Children's Cognition and Health-South Africa) project conducted in the Departments of Psychology, Education (Geography discipline) and Speech Pathology and Audiology at the University of the Witwatersrand.

Research design

The current study utilized a non-experimental, cross sectional and descriptive design, as well as a post-hoc design.

Ethical considerations

Permission to conduct this study was granted by the University of the Witwatersrand's Human Ethics Research Committee (protocol number 2008ECE94). Information sheets and consent forms were sent to the parents or caregivers of the learners, as well as verbal assent was obtained from the learners themselves. Participants who failed the hearing screening or who were identified with auditory processing deficits during the data collection phase were referred for further assessment. Teachers were also provided with strategies to implement in the classroom to help these learners. Confidentiality of the results in the write-up of the study was assured.

Participants

In order to investigate the auditory processing abilities of children exposed to aircraft noise, participants from four schools were grouped according to whether they attended the noisier schools or the quieter schools. Learners from two schools exposed to high intensities of aircraft noise formed the one group while the other group consisted of learners from two schools exposed to considerably less noise, not located in close proximity to the airport. The noisy schools were broadly matched to the quieter schools on the basis of socio-demographic characteristics to reduce subject variability between schools. Criteria for participation in the study included continued attendance at the school from grade one and hearing levels within normal limits when screened by an audiologist. In addition, only the learners from grade six through to grade seven were eligible to participate in this study in order to see the long term effects of chronic airport noise exposure. Only English First Language (EFL) learners were included in this study as the tests are standardized on first language English speaking children and to preclude any reliability and validity issues from second language English speakers who attend the four selected schools. Learners with pre-established learning difficulties were excluded from this study.

Auditory processing measurement instruments

Verbal working memory, auditory discrimination, phonological awareness and phonological memory are important skills for academic learning. These areas were thus selected to be the focus of this research.

This study utilized the following subtests to investigate children's auditory processing abilities:

- Subtests of the Test of Auditory Processing Skills (TAPS) (Verbal Working Memory and Auditory Discrimination) (Gardner 1985)
- Subtests of the Phonological Assessment Battery (PhAB) (Phonological Awareness) (Frederickson et al. 1998)
- The Dollaghan and Campbell Non-word Repetition Task (Phonological Memory) (Dollaghan & Campbell 1998).

The TAPS is an assessment tool developed to measure a child's functioning in various areas of auditory perception and include auditory discrimination, auditory number memory-reversed and auditory sentence memory. The Rhyme and alliteration tests are subtests of the PhAB which was designed to asses phonological processing. The Dollaghan and Campbell Non-word Repetition Task involves 16 non words, ranging from CVC's to CVCVCVCVC's. The aim of the non-word repetition task is to assess phonological memory in a non-biased manner with regard to language proficiency and vocabulary.

Procedure and protocol

1. Pilot study

The auditory language processing instruments (TAPS, PhAB, non-word repetition task) underwent a pilot study at a public sector school which was demographically matched to the sample schools. All the tests proved reliable for the population being tested, apart from the spoonerism test which was, therefore, excluded from the testing procedure. No modifications were necessary on the other tests.

2. Data collection

Hearing screening:

Hearing screening included otoscopy (Heinz mini otoscope), tympanometry (GSI 38 tympanometer) and screening pure tone audiometry (GSI screening audiometer). Cut-off screening levels were at 20 dB HL at 500 Hz, 1kHz, 2kHz and 4kHz. Learners who failed in audiometric screening (two or more frequencies in at least one ear), in tympanometry or otoscopy were referred for further assessment and were excluded from further auditory processing assessment.

Noise measurements:

A SVAN 955 type one sound level meter was used to measure noise. The average sound levels (LEQ), as well as maximum and minimum sound levels were recorded.

Auditory language processing assessment:

Tests were conducted with the children on an individual basis throughout the school day by two audiologists.

Data analysis

These research data were scored and analyzed with various methods to ensure accurate interpretation of the individual tests. Various tests, such as Pearson's chi-squared tests, Fisher's exact test were used on the auditory discrimination, auditory number memory and auditory sentence memory tests, and three-way ANOVA were used on the non-word repetition task, rhyme and alliteration subtests, while descriptive methods were also utilized with the means of tables and figures. In order to compare the significance of the auditory discrimination, auditory number memory and auditory sentence memory, the strength of association (Cramer's V test) was calculated.

RESULTS

The results are summarized hereafter.

Table 1: Noise levels and hearing screening results

	School A (noisier)	School B (noisier)	School C (quieter)	School D (quieter)
Noise levels	69.9 dBA	63.5 dBA	55.3 dBA	54.4 dBA
Percentage of learners who failed the hearing screening	27.9 %	27.1 %	5 %	23.4 %

The results of the chi-squared and Fisher's exact test can be observed at the p<0.05 level, as well as the strength of the positive association (see Table 2).

Table 2: Summary of the chi-squared tests, Fisher's exact test and Cramer's V tests conducted for the auditory discrimination, auditory number memory, and auditory sentence memory subtests

Relationship	**Auditory test**					
	Auditory discrimination		**Auditory sentence memory**		**Auditory number memory**	
	Calculated X^2 (p-value) with Cramer's V	***Scores of ≥12 years in noisy vs. quieter schools***	***Calculated X^2 (p-value) with Cramer's V***	***Scores of ≥12 years in noisy vs. quieter schools***	***Calculated X^2 (p-value) with Cramer's V***	***Scores of ≥12 years in noisy vs. quieter schools***
Noisy vs. quiet schools	2.03 (0.155)	51 % in noisy versus 63 % in quieter	15.1 ** (<0.001) 0.34 moderate association	54 % in noisy versus 85 % in quieter	10.8 ** (0.001) 0.29 moderate association	25 % in noisy versus 53 % in quieter
Grade 6: Noisy vs. quiet schools	5.38 ** (0.020) 0.30 moderate association	11 % in noisy versus 38 % in quieter	13.9 ** (<0.001) 0.49 relatively strong association	33 % in noisy versus 81 % in quieter	4.61 (0.032)*	0 % in noisy versus 16 % in quieter
Grade 7: Noisy vs. quiet schools	0.19 (0.666)	82 % in noisy versus 86 % in quieter	3.66 (0.056)	71 % in noisy versus 89 % in quieter	13.7 ** (<0.001) 0.44 relatively strong association	44 % in noisy versus 86 % in quieter

* Fisher's exact test was not significant at p= 0.05
** Significant results (quieter schools performed better than noisy schools)

The overall effect of noise on the non-word repetition, rhyme and alliteration task can be observed from ANOVA measures (see Table 3).

Table 3: The results of the analysis of variance analyzing the non-word repetition task, rhyme and alliteration tests at the p<0.05 level

Relationship	**Auditory test**		
	Non word repetition	**rhyme tests**	**alliteration test**
	Calculated ANOVA (p-value)	***Calculated ANOVA (p-value)***	***Calculated ANOVA (p-value)***
Noisy vs. quiet schools	p=0.020	p < 0.001	p < 0.001

DISCUSSION

From these results, it appears evident that aircraft noise affects the auditory language processing skills investigated in this study. Hindrances of auditory processing abilities, can affect multiple areas, such as learning, literacy, numeracy, and in turn, social and psychological factors.

According to Wepman (1960), most auditory discrimination skills should be developed by eight years of age, or by the end of grade three. Learners in this study were already in grade six and seven and appeared to show auditory discrimination difficulties. A weakness in auditory discrimination skills can be problematic as it can hamper educational development, such as with further learning: if learners struggle to distinguish sounds, they may have difficulty learning the phonemes which is an important aspect of reading (Wepman 1960).

The reduced scores in the rhyme and alliteration tasks may also suggest that the learners in this study may be at risk for reading difficulties since, as Bryant et al. in Lonigam et al. (2000) found, there is a link between learning and literacy development as it has been found that the sensitivity to rhyme leads to awareness of phonemes, which in turn is related to reading.

Similarly, the decreased performance in areas such as auditory memory may impinge on learning during class as the learner may find it difficult to retain the information presented in class and may also have difficulties with sequencing. Therefore, learning in a noisy environment can hinder the development of ALP skills, and could result in academic difficulties which may also have social, psychological and emotional consequences if the learner struggles at school.

The importance of working memory is further discussed by Lee et al. (2004) when they describe how working memory contributes to early arithmetic performance and mathematical development. Also, the reduced number memory and sentence memory scores (related to working memory) observed in this study, can further affect mathematical development. In South Africa, a country where there are low levels of reading and numeracy (Taylor et al. 2003), the addition of noise to an already disadvantaged community may again intensify this problem.

South Africa already feels the burden of health issues within a context of poverty. It is reported that there are approximately 5.3 million people infected by HIV/AIDS in South Africa (Lubbe 2008). HIV/AIDS can place children at a risk for chronic otitis media, and thus fluctuating hearing loss, and may cause neural hearing difficulties too (Larsen in Khoza 2009). More so, the Committee of Inquiry into a Comprehensive Social Security System for South Africa found that between 45 and 55 % of all South Africans live in poverty (Martin & Rosa 2002). Therefore, it would suggest that placing vulnerable learners who attend noisy schools may be at even greater risk for ALPD since the noise may compound the other matters.

CONCLUSION

Auditory language processing difficulties have been identified in both noisy and quiet schools although more problems were identified in noisy schools. The ALP data from aircraft noise exposed schools can be extrapolated to schools exposed to other types of excessive and continuous noise which suggest some recommendations for education. One of the recommendations could suggest the need to motivate for the provision of speech-language therapy and audiology services within mainstream schools, as well as informing educators about auditory language processing difficulties. Similarly, it would be beneficial to improve the acoustic design of new classrooms to enhance the listening of learners as well as the sound treatment of existing classrooms since, by adjusting some measures of the existing design in the classroom, classroom acoustics can be improved (Edwards 2002). Lastly, the results of this research aim to motivate for a change of legislation for more appropriate specifications with regard to zoning of schools away from noisy areas and the standardization of acceptable noise levels. In South Africa, a country with developmental challenges, where successful education is seen as a hope for future development, addressing factors which can compound learning difficulties, such as auditory language processing difficulties brought on by environmental noise, may provide opportunities for successful learning.

However, despite these recommendations, it is important to heed the advice from Higgins et al. (2005) when they suggest that in a changing world, no design solution will last forever, and thus, on-going research and involvement is always necessary for on-going support and change.

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Overview of research into sleep disturbance due to noise in the last three years

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INTRODUCTION

It is well established that noise can disturb sleep and if this disturbance is severe and frequent enough it can lead to significant fragmentation and sleep deprivation which seriously affects our physical and mental health. In the early days of modern sleep research there was a considerable emphasis on understanding the importance of the type and structure of sleep in terms of its electro-physiologically defined sleep stages and the nature of recovery sleep following sleep deprivation (Dement & Greenberg 1966). However, it is unclear how the well documented deleterious effects of these early sleep deprivation studies can be applied to environmental noise disturbed sleep (Zaharna & Guilleminault 2010) as the typical level of environmental noise is usually not severe enough to produce the same degree of sleep deprivation and/or fragmentation as the early experimental studies were designed to provoke significant outcomes.

Nonetheless, it has been clearly established that we can have autonomic responses to noise at low levels that do not produce wakefulness (Muzet 2007), as well as responses that could be described as minor fragmentation which includes shifts to lighter sleep stages, movement and/or brief wakefulness which are frequently associated with limb and body movement (Ollerhead et al. 1992). In addition, there is clear evidence that night-time noise has been associated with cardiovascular disease (Jarup et al. 2008) and stroke in the elderly (Sorensen et al. 2011. What is lacking is evidence of a clear pathway that directly links noise (at ecological levels) and disturbed sleep with cardiovascular disease.

One factor that makes it difficult to determine clear dose response relationships for these autonomic and minor sleep fragmentation responses to noise is that they also occur naturally in the absence of noise and any other obvious external agent. The dilemma has been how to establish an acceptable point at which the additional reactions to noise results in clear negative health endpoints (Brink et al. 2009). Adding to the dilemma is the large number of uncontrolled non-auditory factors e.g. annoyance, work and psychosocial stress, and personal characteristics e.g. noise sensitivity, that are known to affect our sleep and reaction to noise.

TRANSPORTATION NOISE

The last 3 years has seen continued interest in the effect of transportation noise on sleep. This has been driven mainly by the continued and planned expansion of aviation and high speed trains, which is considered to develop faster than noise suppressing technology. The future predictions for air-travel volumes indicate considerable growth and increased noise which outweighs the reductions due to quieter jet aircraft and other noise mitigation measures (Girvin 2009). The main focus of research into noise disturbed sleep over the last couple of decades has been in Europe. This has in part been a consequence of the realization of the European Noise Directive (END) which required governments to provide detailed noise maps of urban