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EDITORIAL / ÉDITORIAL

This issue marks the 40th anniversary of Canadian Acoustics. In recognition of this milestone, John Bradley and Ramani Ramakrishnan have prepared a thoughtful retrospective, complete with commentaries from some of our past Editors. I think it's fair to say that the journal has come a long way since its humble beginnings. As we learn from the Inaugural Editor, the journal was considered by some as "likely to fail within the first two years." The front cover is a compilation of journal covers from the first two years along with covers from the remaining 38. We are using this image in some of our promotional material aimed at increasing membership and submissions (see page 36).

One of my tasks this Winter has been to renew the Editorial board. The collective expertise of the renewed board is deep and covers a formidable array of sub-disciplines (see page 16). The current issue represents a good representation of these sub-disciplines with technical articles spanning Bio-Acoustics, Speech Sciences, Hearing Sciences, and Noise Control.

I hope to see many of you at the International Congress of Acoustics in Montreal, 2-7 June. We will have a table set up that will be staffed by Directors of the Canadian Acoustical Association, including members of the journal's advisory board. Please stop by and share your thoughts on the journal, and tell us how you might like to see it developed over the next 40 years.

Frank A. Russo
Editor-in-Chief

Cette année marque le 40ième anniversaire du journal Acoustique Canadienne. En reconnaissance de cette étape importante, John Bradley et Ramani Ramakrishnan ont préparé avec réflexion une rétrospective des publications antérieures, incluant certains commentaires de nos anciens rédacteurs. Je crois qu'il est juste de dire que le journal a fait du chemin depuis ses débuts modestes. Comme nous avons appris du tout premier rédacteur en chef, le journal était considéré par quelques uns comme étant un « probable échec durant ses premiers deux ans ». La couverture de ce numéro est un collage des couvertures des 40 années passées, et cette image sera utilisée dans certains matériels promotionnels qui auront comme but d'augmenter le nombre de membres et de soumissions (voir page 36).

Une de mes tâches cet hiver a été de renouveler le comité de rédaction du journal. L'ensemble des sous-disciplines représentées dans ce nouveau comité forme une gamme impressionnante de domaines d'expertises (voir page 16). Ce dernier numéro couvre une vaste représentation des sous-disciplines, incluant par exemple des articles techniques qui portent sur la bioacoustique, la science de la parole, la science de l'ouïe, et le contrôle du bruit.

J'espère de voir plusieurs d'entre vous à l'International Congress of Acoustics à Montréal, du 2 au 7 juin. Nous aurons une table gérée par des membres du comité consultatif du journal ainsi que des directeurs de l'Association Canadienne d'Acoustique. Nous vous invitons à visiter nos membres et partager vos opinions du journal et vos suggestions pour ses futurs développements au cours des prochains 40 ans.

Frank A. Russo
Rédacteur en chef

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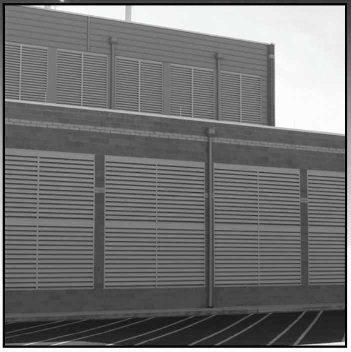

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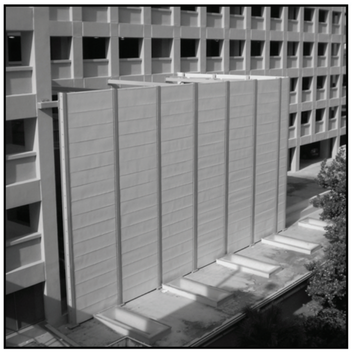

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HISTORY OF CANADIAN ACOUSTICS

JOHN BRADLEY[1] AND RAMANI RAMAKRISHNAN[2]
1 - National Research Council of Canada, Ottawa
2 - Department of Architectural Science, Ryerson University

Canadian Acoustics developed from a news letter called "Acoustics and Noise Control in Canada" (ANCC). ANCC was started in 1973 with Tony Embleton as the first Editor. This was a simple production with photocopied pages hand stapled together, but it did include technical papers as well as news material. Tony Embleton was replaced by Gary Faulkner in 1975 and by Daryl May in 1977. During the years up to 1982, ANCC developed as a useful way for Canadian acousticians to communicate and keep in touch with acoustical activities in Canada.

In 1981 Dee Benwell took over as Editor with plans for ANCC to become a real printed journal that was renamed Canadian Acoustics in 1982. Technical papers were encouraged and reviewed for acceptance for publication in Canadian Acoustics and the current schedule of 4 issues per year was set. Dee Benwell also initiated the format of the front page of Canadian Acoustics with the unique cover art by Simon Tuckett below the table of contents.

After 3 years of being editor she was followed by John Bradley for another 3 years (Jan 1984 to Jan 1987). He built on Dee Benwell's pioneering efforts and encouraged refereed technical publications, book reviews and news about international acoustical events. Being employed at NRC he was able to 'encourage' colleagues to contribute papers to Canadian Acoustics. He also carried out a survey of Canadian acoustical consultants and their areas of expertise which was published in the July 1986 issue. He was followed by Raymond Hétu who did much to continue efforts to strengthen the French content in Canadian Acoustics. He also introduced (1988) the blue title on white paper as the cover format that was used for many years.

In 1990, Hétu was followed by Murray Hodgson, the second longest serving editor. He served for 9 years giving Canadian Acoustics a period of stable growth. He was followed by Ramani Ramakrishnan who has served as Editor for 15 years. During his long reign as editor, Canadian Acoustics has flourished, with improved printing quality, glossy covers, and coloured pictures. There have been special issues of conference papers, invited papers and many other new ventures.

Canadian acoustics is now in its 40th year and can look forward to continuing growth in its quality and the material that it publishes.

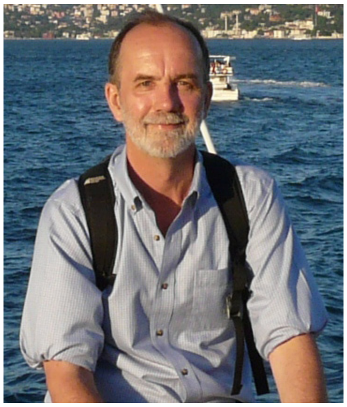
REMINISCENCES OF EDITORS

Dr. Tony Embleton, Editor-in-Chief - 1972-1975

The Canadian Committee on Acoustics (later changed to Canadian Acoustical Association in about 1975) started in 1962. It was literally a committee of about 20 members, almost everyone who was interested in acoustics in Canada at that time. We met once a year, Tom Northwood was chairman and Tony Embleton was the secretary, each for the first three years. The only records were the minutes of the committee. After ten years it was decided that more suitable records should be kept. I became the founding editor of "Acoustics and Noise Control in Canada" as it was first known, and served from 1972 to 1975. I tried to obtain some formal publishing support from the National Research Council, but was turned down on the grounds that the publication was too small (hence likely to fail within two years). So in those early years I typed up somewhere between four and eight pages every three months, photocopied 20 to 40 copies, put a nice coloured cover on them and mailed them out myself. Each issue highlighted one of the acoustics labs in Canada, giving a description of current activities, personnel and list of publications. Usually there were one or two news items of general interest, new ASA Standards, reports of ICA meetings, etc. as well.

Dr. John Bradley, Editor-in-Chief - 1984-1987

My memories of being Editor of Canadian Acoustics (CA) are beginning to fade. I took over from Dee Benwell who had given CA its new name and a serious journal look. I felt a lot of pressure to keep the results of her efforts moving forward. This was not always easy and there were times when colleagues' arms were twisted to contribute papers at the last minute. This was long before convenient desk top publishing and the original was literally cut and pasted together - often into the night of the eve of the monthly trip to the printer. However, the momentum was maintained and CA continued to grow with the efforts of many subsequent contributors to its current impressive status.



Prof. Murray Hodgson, Editor-in-Chief - 1990-1998

My most vivid recollection of my time as Editor-in-Chief relates to the publication of the article, "The Hearing Conservation Paradigm and the Experienced Effects of Occupational Noise Exposure" by Raymond Hétu [Canadian Acoustics/Acoustique Canadienne 22(1) 3-19 (1994)]. On a number of occasions, he and I had discussed this important but controversial work and how to publish it, which I very much wanted to do in Canadian Acoustics. The paper, presenting Raymond's professional analysis of how the world of 'hearing conservation' (HC) deals (or doesn't deal) with the problem, was written as a philosophical treatise as it contained no scientific data. Raymond eventually submitted the paper and I had to have it reviewed...ideally by prominent figures in the field of North American HC. I asked Edgar Shaw at the NRC; he declined, considering that the paper presented an opinion, not scientific facts. I asked Larry and Julia Royster, prominent in American HC, who also declined (and probably later regretted it). I finally got one fairly innocuous but positive review from Margaret Roberts of the Workers' Compensation Board of BC. I published the paper and then did all I could to encourage discussion of it. I sent it to key Americans, including the Roysters; within days they were on the phone threatening to send lawyers after me! In the end I was able to publish a very interesting series of responses to the paper, replies to the responses and replies to the replies, which I now consider essential reading for anyone interested in occupational noise. The paper might have led to a paradigm shift in how we think about preventing occupational hearing loss, had it not been for Raymond's subsequent untimely death.

Prof. Ramani Ramakrishnan, Editor-in-Chief - 1998-2012

My main recollections, during my tenure, are the special issues on underwater acoustics, music acoustics and the vexing issues connected with wind turbine noise. The special issues provided an avenue for the expansion of journal and receive well deserved attention on the international stage. I was also very happy to follow up on Raymond Hétu's efforts to bring more French artticles and we were able to establish a dedicated issue focussing on articles from Francophones. With the assistance of Prof. Chantal Laroche, journal's Associate Editor, the June issue of the journal became the French issue.

Prof. Frank Russo, Current Editor-in-Chief

Only two issues into my tenure, reminiscence is not something that comes to mind when I think about the journal. There is lots of work to do to keep us moving forward in the current world of journal publishing! Nonetheless, I am humbled and inspired by the Herculean efforts of our past Editors. To help navigate new directions for the journal, I have established an advisory board consisting of Jéremie Voix (École de technologie supérieure), Bryan Gick (UBC), and Ramani Ramakrishnan (Ryerson). The advisory board is currently working on a number of exciting initiatives including the move to an electronic submission/review system and related efforts to increase journal exposure and impact. Jéremie Voix has been instrumental in the implementation of the online initiatives; he will also be serving as our next Editor, effective 2014.

ACOUSTIC CROSS-OVER BETWEEN THE EARS IN MICE (*Mus musculus*) DETERMINED USING A NOVEL ABR BASED BIO-ASSAY

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ABSTRACT

Closed-field stimulation of one ear, at high sound intensity, will activate both ears because of bone/soft tissue transmission of the acoustic signal across the skull. In human psychophysics and in clinical audiometry a knowledge of interaural attenuation values is important, particularly when assessing asymmetrical hearing loss or in studies of monaural hearing. Similarly, in testing monaural hearing in experimental animal studies, acoustic cross-over can result in erroneous conclusions about hearing function. The mouse has become a widely used animal model for various types of hearing loss, especially those relating to gene mutations, and also for age related deafness (presbycusis). In the present study we have measured acoustic cross-over in this species using a novel bio-assay technique based on auditory brainstem evoked responses (ABR). We report here for the mouse, an interaural attenuation of 37-45dB for click and 32kHz toneburst

SOMMAIRE

La stimulation de l'oreille unique à haute intensité sonore, en sphère fermée, cause l'activation des deux oreilles dù à la transmission du signal acoustique a travers les tissus mous et l'os du crâne. En psychophysique de l'homme et l'audiométrie clinique, l'atténuation interaural doit être connue dans les études d'audience mono ou de la surdité asymétrique. De même, pour tester l'audition monaurale dans les études expérimentales chez les animaux, la transmission trans-crânienne (aguillage acoustique) peut produire des conclusions erronées au sujet de la fonction auditive. La souris est devenue le modèle animal largement utilisé pour différents types de pertes auditives, en particulier celles qui ont a trait à des mutations géniques, et aussi de la surdité liée à l'âge (presbyacousie). Dans l'étude en question, nous avons mesuré la transmission trans-crânienne (aguillage acoustique) chez cette espèce en utilisant une technique de dosage biologique basée sur les potentiels évoqués auditifs (PEA). Nous rapportons ici chez la souris, une atténuation interaural de 37-45dB pour le clic et le 32kHz pip tonal.

1. INTRODUCTION

In most land vertebrates, acoustic signals in the environment reach both ears by air conduction, and differences in the time and intensity of arrival provide important cues for sound localization. In such free field stimulation, acoustic cross-over between the two ears is of little consequence. If an acoustic signal is presented directly to one ear only, i.e. closed-field stimulation, there is relatively little excitation of the contralateral ear via air conduction. At near threshold levels the activation of only one ear can be confidently assumed, however at high levels of stimulation, there is acoustic cross-over such that acoustic signals can activate both the ipsilateral and contralateral cochleas. This possibility is well appreciated in human audiological evaluations and psychophysical studies. For example in a subject with asymmetric hearing loss, high stimulation levels needed to reach threshold on the hearing-loss side may also stimulate the (lower threshold) opposite ear. This will compromise the accuracy of the audiogram. Clearly, knowledge of acoustic cross-over parameters is important (e.g. Chailkin 1967; Katz 2009). In human auditory evoked potential studies, e.g. auditory brainstem responses (ABR), noise masking of the contralateral ear can be employed to prevent evoked potential contribution from that side (e.g. Studebaker, 1967).

In experimental animal studies it can also be important to be certain that acoustic stimulation (especially if suprathreshold) is delivered to one ear alone with no acoustic cross-over. In some animal studies, experimentally induced damage to one ear is required. Evaluation of this unilateral hearing loss poses similar problems to those aforementioned in human audiology (e.g. Tonndorf, 1966).

The transmission of signal across the skull from one ear to the other has been termed acoustic cross-talk or acoustic cross-over, and is usually measured and expressed as an interaural attenuation in dB. However, the measurement of this attenuation is not straightforward, because the transmission of an acoustic signal from one ear canal, across the skull to the opposite cochlea is complex. The primary mode of acoustic transmission is through bone conduction, but the attenuation of the signal depends much more on the soft tissue interface between the sound source and ear, and also the way in which the opposite cochlea is activated. Thus interaural attenuation can depend on sound transducer type and placement, and the spectral content of the stimulus. In various mammalian species, interaural attenuation will also vary with the bony and cartilaginous structure of the skull, the physical dimensions of the head, and the age of the animal (Tonndorf, 1966).

In the present study, we are concerned with defining acoustic cross-over in the mouse. This species has become the most used mammalian animal model for a range of biological studies. The reason for its growth in popularity is, of course, because its complete genome has been characterized, and can been manipulated to reveal various gene mutations associated with human disease. It is also a well-used animal model because it can be bred easily, and has a short life span thus useful for studies on development as well as age related pathology (including presbycusis).

In this study we employ a bio-assay in which ABR measures of auditory thresholds are recorded before and after unilateral cochlear ablation. When presenting (high level) stimuli to the ablated side, the ABR is generated from the acoustic cross-over to the normal ear. Under clinical settings, masking of the contralateral ear is carried out to prevent evoked contribution from that cochlea (Studebaker, 1967; Katz, 2002). As a control procedure, we also presented masking noise to confirm that ABRs are generated at the contralateral site. Further confirmation was made by ablating the contralateral cochlea.

2. METHODS

The animal species chosen was the CBA/J mouse (*Mus musculus*). Young male adults (6-8 weeks olds) were used. Mice were anesthetised using a Ketamine (150mg/kg) and Xylazine (10mg/kg) combination. An initial dose of 0.1mg/10gm body weight was given intraperitoneally with a half dose given every hour as needed. Mice were used in three experimental groups: a normal ABR control group (n=16), a cochlear ablation group (n=11) and a masking group (n=5). A reproducibility study (n=5) was also conducted over 7 days to ascertain the level of error made by placement of electrodes and the transducer. All procedures were approved by the local Animal Care Committee at the Hospital for Sick Children, following the guidelines of the Canadian Council on Animal Care (CCAC).

Auditory brainstem responses were recorded with electrodes placed in a vertex-to-mastoid (bulla) configuration as illustrated in figure 1. Signals were amplified (1000 X), and filtered (100-1500 Hz; Intelligent Hearing Systems, Smart-EP system). ABR measurements (512 averages) were made to 50μs clicks, and to 32kHz tone pips (2ms rise/fall times) at intensities ranging 10dB to 90dB SPL, delivered to the ear canal in a closed-field. Click stimuli were delivered using a transducer (ER2, Etymotic Research, Illinois, USA) having a spectral peak at around 8-10kHz. The 32kHz tone pips were presented with a high frequency transducer (Intelligent Hearing Systems. Miami, USA) with an effective frequency response out to 40 kHz. The mouse has a relatively high frequency range of hearing, and we have chosen acoustic stimuli in an appropriately high frequency region, i.e. a click with main spectral energy around 8-10 kHz and a 32 kHz tone pip.

In separate control studies, repeat ABR measures were made daily for 7 days to determine measurement error due to placement of electrodes and the acoustic transducer. For ABR click data, threshold measures had a standard deviation of 6.7dB. For ABR to the 32kHz stimulus, threshold measures had a standard deviation of 6.9dB. All ABR recordings were carried out in a sound attenuating room.

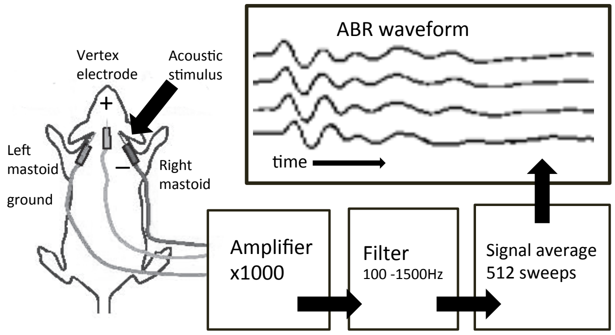

Figure 1. Electrode configuration and system diagram for ABR recording in the mouse.

Baseline ABR measurements, with acoustic stimuli delivered to each ear separately, were taken before any experimental manipulation. Left-side cochlear ablation was carried out by inserting a needle via the ear canal, through the tympanic membrane and middle ear space to pierce the cochlea. The cochlea was then flushed with water to ensure haircell damage by osmotic effects (Harrison *et al.* 1997). ABR measurements were then taken again, with sound presented to both normal and ablated ears. The mouse was allowed to recover and a second set of ABR measurements was made 24hrs later. These are referred to as post-recovery measurements. The final manipulation was ablation of the right cochlea resulting in complete bilateral hearing loss. In the masking group, a similar protocol to that outlined above was followed but instead of a final right-side cochlear ablation, the right ear was masked using broadband noise masker at 80dB SPL.

3. RESULTS

An overview of the ABR acoustic cross-over experiment in one animal is presented in figure 2. This shows ABR waveforms and threshold levels before and after unilateral and then bilateral cochlear ablation. In this example ABRs are evoked by 32kHz tone pip stimuli.

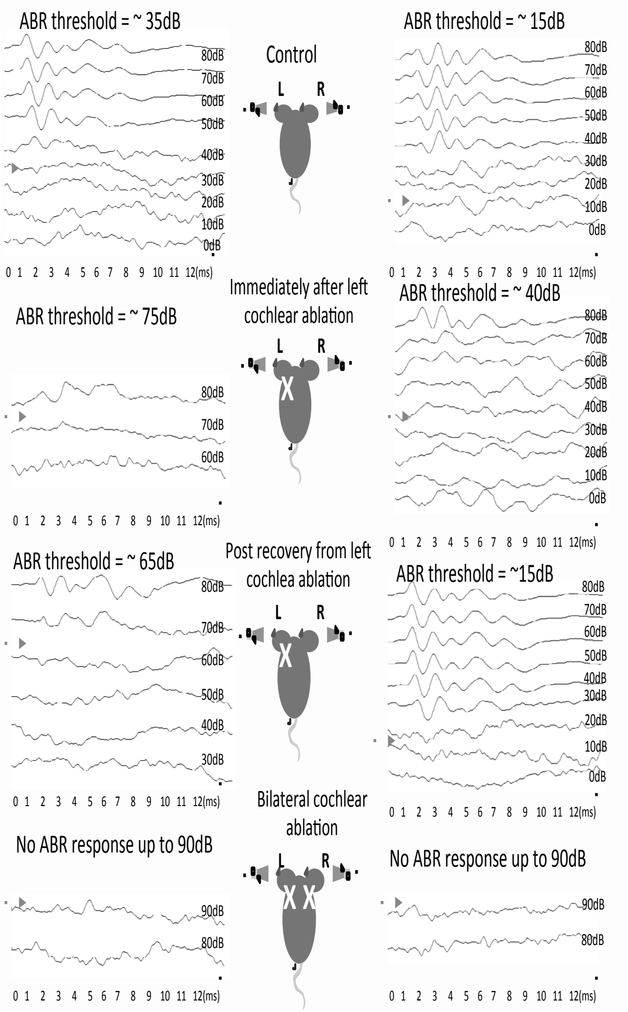

Figure 2. Schematic showing an overview of ABR measures in a mouse during an ablation study. All ABR waveforms are evoked by 32kHz tone pip. Upper panels show baseline ABR recordings to left and right ear stimulation. The approximate ABR thresholds are indicated by the arrow symbols. The next panels down show the immediate effects of left cochlear ablation on ABR waveforms, and then ABR recordings "post recovery" one day later. The lower data indicates that after both left and right cochlear ablation there are no ABR waveforms elicited.

The upper panels show the baseline ABR thresholds for stimuli in left and right ears. In this example there was some initial difference in left versus right ear thresholds. This asymmetry was sometimes found for normal mice but not typically. In any case such initial differences are not important in this study. Immediately after left cochlear ablation, ABR evoked by stimulation of the left ear shows ABR threshold elevation from ~35dB to ~75dB. Interestingly, the ABR to stimulation in the right (undamaged) ear shows a rise in threshold from ~15dB to ~40dB. This threshold returns to its original level of ~15dB a day later (post-recovery). In the left cochlea ABR threshold also drops, in this case to ~65dB at post-recovery. At this point of post recovery, differences between the thresholds in the left and right ear indicate the level of acoustic cross-over. In this example mouse it is 50dB (65dB minus 15dB).

The final manipulations post-recovery, are either noise masking or cochlear ablation of the right ear. These methods remove auditory function of the right ear and can confirm that the ABR evoked by stimulation of the left ear (after left cochlear ablation) was the result of acoustic cross-over. The subject of figure 2 had right-side cochlear ablation that resulted in a loss of any recordable ABR signal as illustrated by the lower panels. Note that for didactic reasons, ABR threshold measures given in figure 2 are approximated (+/- 5dB). In the data analysis that follows, ABR thresholds were derived more accurately using an interpolation procedure. Thus, ABR amplitudes (P2 or P3 waves) were plotted against stimulus intensity and a linear regression, extrapolated to zero amplitude provided the threshold measure.

The pooled ABR threshold data from all animals are represented in figure 3. In all subjects, ABR measures were made to click stimuli and to tone pip stimuli at 32kHz. The top graph (A) shows the ABR thresholds measured by left ear stimulation, before (filled circles), immediately after left cochlear ablation (open circles), and at post recovery (filled triangles). The effects of noise masking of the right ear (filled squares) and right ear cochlear ablation (open triangles) on ABR measures are also indicated. Panel (B) of figure 3 shows plots the ABR thresholds from stimulation of the right ear before (filled circles), immediately after left cochlear ablation (open circles), and at 24 hours post recovery (filled triangles).

With regards to the main aim of the study (the estimation of inter-aural attenuation), after left cochlear ablation all of the ABR responses to left ear stimulation originate from the right cochlear activation as a result of acoustic cross-over. Thus after ablation of the left cochlea the difference between left and right stimulation ABR thresholds is a measure of the acoustic cross-over or interaural attenuation. These values are plotted in figure 4. Because of our finding that the contralateral cochlea is influenced by the unilateral cochlear ablation, we determined interaural attenuation immediately after ablation (black bars) and at 24hrs post-recovery (shaded bars). For the click ABR data there is a 45.3dB value for acoustic cross-over immediately post cochlear ablation, and 40.1dB after a 24 hour recovery. The difference between these values is not significant. For the 32kHz stimulus acoustic cross-over values are 41dB immediately after ablation, and 37.6dB after 24 hours, with no significant difference between values. Comparing interaural attenuation for click versus 32kHz tone stimuli we find no statistically significant difference.

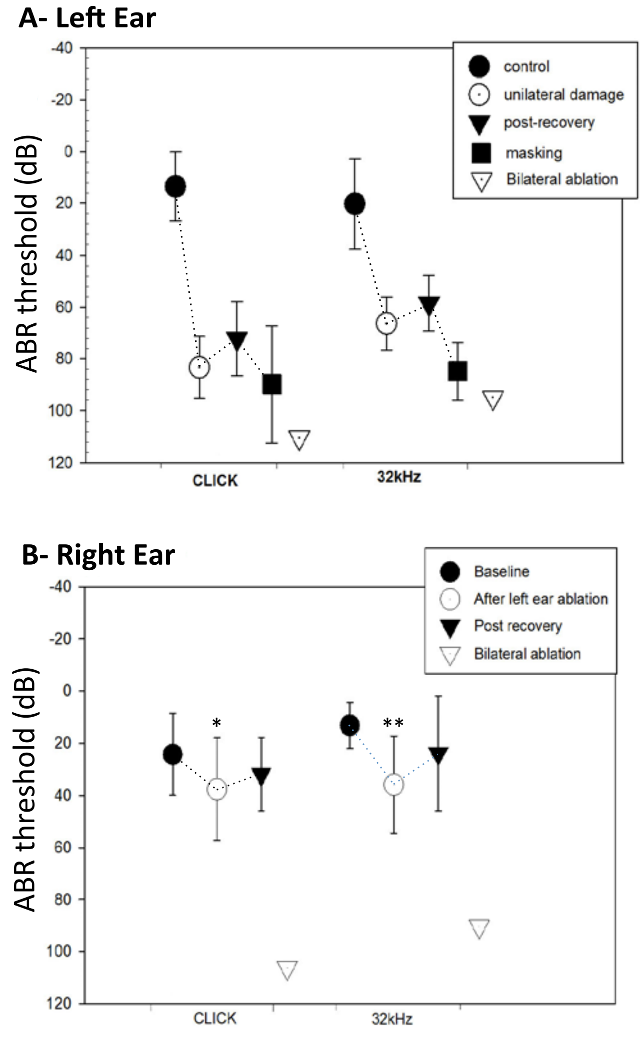

Figure 1. ABR thresholds to clicks and 32kHz tone pip stimulation presented to left ear (A) and right ear (B) before and after left cochlear ablation. Note in plot B, that immediately after ablation of the left cochlea there are significant changes in ABR threshold in the right ear (clicks, *p=0.045; 32kHz, **p <0.001).

Of interest is the finding that after left cochlear ablation, there are significant changes to ABR thresholds when stimulating the undamaged right ear. Thus as indicated in panel B of figure 3, for click and 32kHz tonal stimuli there is a statistically significant elevation in ABR thresholds immediately after cochlea ablation (for clicks, p=0.045; for 32kHz, p<0.001). This indicates that damage to the left cochlea is causing some contralateral effect on the right cochlea so as to elevate ABR thresholds by 10-20dB. We suggest that cochlear ablation results in a transient injury discharge in cochlear afferent neurons, which initiates suppression of the outer haircells in the contralateral ear via the olivo-cochlear efferent pathways (see discussion section below).

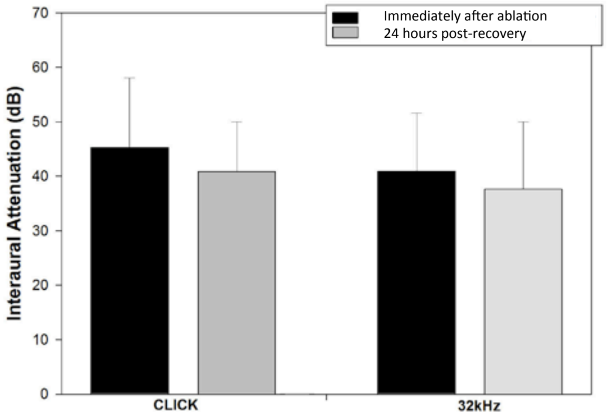

Figure 2. Interaural attenuation (acoustic cross-over) in mice (N=11) derived from ABR thresholds measured immediately after cochlear ablation (black) and at 24hrs post-recovery (light shaded).

4. DISCUSSION

Using the ABR bio-assay technique, the interaural attenuation values are 40-45 dB for click stimuli (spectral dominance at 8-10kHz) and 37-41dB for a 32kHz signal. In general these values for the mouse are lower than measurements in animal species with larger heads. Thus, in humans interaural attenuation is reported in the range of 50-85dB, depending on frequency of acoustic signal and measurement techniques (e.g. Chaiklin, 1967). In the cat, reported values range from 60-80dB (Caird *et al.*1980), in chinchilla: 50-65dB (Arnold and Burkard, 2000), and in rat: 37-75dB (Megerian *et al.* 1996). There is a general reduction in the interaural attenuation with head size that is logical. The trans-cranial signal attenuation through both bone and soft tissue elements will increase in proportion to head size, or more specifically distance between the cochleas.

There are a number of ways in which interaural attenuation can be estimated. Physical acoustic measurement can be made, for example by simply measuring the difference in level of acoustic signals in both ear canals to a unilaterally presented sound. In human subjects, behavioural measures can be employed to judge the relative intensity levels of signals reaching each ear with a unilateral signal presentation, and equivalent objective assays can be made using auditory evoked potential studies. In clinical audiology tests (both behavioural and electrophysiological) where acoustic cross-over can be a confounding factor for estimating hearing thresholds, masking can be employed to "inactivate" one ear. In our bio-assay based on ABR measures in the mouse we can employ cochlear ablation; clearly this is not a method that can be used clinically. We suggest that this method provides a realistic and accurate estimate of functional interaural attenuation. Physical measures sample signals in the ear canal or middle ear in advance of cochlear transduction, and thus do not incorporate any auditory component. The ABR technique of the present study provides an objective and accurate measure of how an acoustic signal presented to one ear can influence the contralateral cochlea.

In the present study we have chosen to add two final "control" steps to the cochlear ablation procedure to confirm that the ABRs measured post ablation are from the contralateral side. In five mice we used noise masking (80dB SPL in the right ear) to interfere with the ability the remaining cochlea to generate a synchronized ABR. This was found to have some effect, i.e. a further 10-20dB ABR threshold elevation. The noise masking was not effective in completely obscuring an ABR signal. The definitive control, in 11 subjects, was ablation of the second ear, after which there were essentially no measurable ABRs.

Of particular interest in these data is the finding that after left cochlear ablation there are changes to threshold sensitivity in right ear. Thus in figure 3, panel B, ABR thresholds are significantly elevated by10-20dB after ablation of the contralateral (left) cochlea. One day after the ablation (post-recovery) thresholds appear to be returning to their baseline levels.

Two sources of possible inaccuracy/error need to be mentioned here. Firstly the threshold determinations for ABRs measured in separate sessions are prone to repeatability error due to slightly different electrode placements and sound source tube fit to the external meatus. We were aware of this, and as reported there were standard deviations of up to 7dB. A second source of variability in the data results from the cochlear ablation itself. The needle puncture and water irrigation of the cochlea can have different time courses of effect. We have observed that some contralateral ABR threshold changes are seen immediately, while some can take more than an hour to develop. These data are not included in the present paper because here we primarily concerned with acoustic cross-over measures, and not these contralateral neural effects. Thus in the present study we report on ABR threshold measures immediately after cochlear ablation, and in some cases the test time-window has not captured the maximal contralateral effect. Most recently we have tracked the time course of these contralateral ABR threshold changes in 12 mice and can be definitive that the ABR thresholds are significantly elevated after ablation of the contralateral

These temporary changes in ABR thresholds in the un-ablated ear are evidence that the cochleas are neurally connected. It is most likely that the ablation of the cochlea results in an injury discharge in cochlear afferent neurons. This neural discharge could result from the direct physical damage to spiral ganglion cells or from excito-toxicity caused by excessive (glutamate) neurotransmitter release from damaged inner haircells (e.g. Pujol *et al.* 1993; Olney and Sharpe, 1969). In any case the nerve will be firing as if there was a high level of acoustic stimulation to the ear. We know that such activation will cause suppression effects to outer haircells of the contralateral cochlea via the olivo-cochlear efferent pathways (e.g. Kimura and Wersall, 1962; Warr and Guinan, 1979; Liberman 1989). This phenomenon is well described in relation to contralateral suppression of otoacoustic emissions (e.g. Collet *et al.* 1990; Maison *et al.* 2000; James *et al.* 2005; Harrison *et al.* 2008).

5. SUMMARY

Using a bio-assay technique based on ABR threshold measures we have derived measures of interaural attenuation for the mouse of 37-45dB. This acoustic cross-over is relatively small compared with species with larger heads, and is for example almost half of the 50-85dB range reported for humans. Auditory researchers using a mouse model should recognize the possibility of acoustic cross-over when using monaural sound stimulation.

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AN INDEX FOR QUANTIFYING TONGUE CURVATURE

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ABSTRACT

This study develops a method of quantifying tongue curvature by modeling the shape of the tongue surface in any anatomical plane using a polynomial approximation. In a validation experiment, the curvature indices of English vowel and consonant sounds were calculated across ten native speakers' productions based on midsagittal ultrasound images of the tongue. Indices confirm substantially higher curvature values for liquids /r/ and /l/ than for all other sounds in the inventory. This method is both more generalized and less dependent upon fixed locations than previous methods, and provides a simple, powerful metric for evaluating shape complexity with applications in areas such as motor development and aeroacoustics.

1. INTRODUCTION

In executing successful speech production, the tongue must often be able to take on quite complex shapes. In disordered or developing speech, speakers may not have achieved fully differentiated control of functionally independent parts of the tongue (see, e.g., Stone et al. 2004 for a discussion of functional tongue regions), limiting their ability to achieve adequate tongue shape complexity, and interfering with the achievement of speech goals (see Gibbon 1999, Cheng et al. 2007). Such is the case, for example, with lingually complex sounds such as the English liquids /r/ and /l/ (see Studdert-Kennedy and Goldstein 2003). Gick et al. (2008) argue that a reduced capacity for lingual shape complexity may account for some of the substitutions for English /r/ and /l/ commonly seen in speech disorders, children's speech, and L2 acquisition. The present study uses the complex tongue shape of these liquids as part of validating a novel method of quantifying tongue shape complexity.

While the complexity of liquid consonants may be easily viewed in the midsagittal plane, other postures appear more complex in the coronal plane (such as the deeply "grooved" shape for /s/; see Stone et al. 1988). Complex tongue curvature is likewise vital in aeroacoustics, where the degree of tongue grooving for sibilants, visible in coronal sections, corresponds with turbulence noise (see Stone et al. 1989).

Tongue shape complexity is not just important in achieving steady-state postures for specific sounds. In coarticulation between any anterior and posterior lingual sounds (as in the temporal overlap of consonants and vowels), different regions of the tongue are independently engaged, resulting in more complex tongue shapes. Noiray et al. (2013) provide evidence linking tongue shape to development, and Zharkova et al. (2012) report less consistency in tongue curvature during coarticulation of /sV/ sequences in children's than in adults' productions. The same presumably applies in longer-distance cases, as where Gafos (1999) treats tongue shape as an independent phonological parameter in understanding consonant harmony.

Despite the many instances where it arises, there have been few attempts to model tongue shape complexity, and fewer to develop practical indices for quantifying it. Stone and Lele (1992) use simple (second-order) shape functions to characterize 3-D tongue shapes and find "shape signatures" that simplify the tongue. Bressmann et al. (2005) use 3-D ultrasound to show that anteriority, concavity, and asymmetry could be used to quantitatively compare normal speakers to one partial glossectomee. While these approaches constitute important contributions to our understanding of tongue shape complexity, they are too data- and labor-intensive to provide practical indices.

A number of methods for quantifying aspects of tongue shape have been proposed in the last decade, although none of these quantify complexity per se, and all have limitations that prevent their being used for this purpose. Iskarous et al. (2003) fit conic arcs to the midsagittal tongue surface, enabling approximation of a variety of rounded shapes. Ménard et al. (2012) use superimposed triangles to extract important midsagittal tongue measures, such as high points or location and acuteness of curvature. Zharkova (2013) uses a tongue dorsum excursion index, a straight line between the ends of the midsagittal tongue curve rising to the highest point, to track variations in tongue shape during production. Whalen et al. (2011) use a similar approach (following a method used by Stone et al. 1988) to measure tongue groove depth in the coronal plane. Most of these previous methods rely upon having either rounded or grooved tongue shapes, but they are not able to quantify differences spanning both simple and complex shapes using a single measure. Further, most methods cannot compare data across different tongue morphologies or sizes, and several methods assume accurate knowledge of landmarks such as the tongue tip and root, which are often the least reliable parts of the tongue to image using ultrasound. These requirements limit the kinds of tongue postures and populations that existing methods can model. One additional approach, the SSANOVA statistical method described by Davidson (2006), also approximates tongue shapes based on edge tracking of ultrasound images. This method is designed to quantify the statistical differences between different tongue shape curves. However, it does not attempt to model the resulting curves, or to quantify degrees of curvature. Furthermore, a fixed probe location relative to the tongue is required, ruling this out as a preferred method for comparing multiple speakers or the same speaker over multiple sessions.

The present study describes an alternative method for quantifying tongue surface shape complexity. This method derives a one-dimensional curvature index from a 7th-order polynomial curve fit to the tongue's surface as imaged in any plane (midsagittal, coronal, or transverse). This method has the advantage of being able to compare tongue shapes that have large variations in curvature along their length, orientation and image quality, and may be recorded from speakers with any range of tongue sizes or orofacial morphologies – an essential feature, as variation in gross tongue shape is associated with many disorders affecting speech.

Figure 1 shows a continuum of idealized tongue surface shapes, with curviness ranging from low (a) to high (d). These are canonical, idealized shapes that are based on observations of midsagittal and coronal ultrasound images from dozens of speakers. Note that the shapes in Figure 1 can represent sections of the tongue's surface in different anatomical planes equally well. For example, if the images represented a midsagittal slice, then shape (a) might correspond to a production of /ə/, whereas shape (d) corresponds to English /r/; if the images were coronal, shape (a) could correspond to /i/ or /ʃ/, whereas (d) corresponds to /s/. After presenting a derivation of the curvature index below, the following sections test the model, first against these idealized shapes, then through a validation experiment exploiting the known lingual shape complexity of the English liquids.

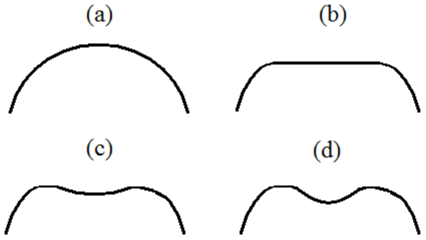

Figure 1. Idealized tongue shapes

2. LINGUAL CURVATURE INDEX

One mathematical formulation of lingual shape is the curvature of a line along the surface of the tongue. That is, one method to quantify lingual shape is to examine the ways in which (and degree to which) the tongue's surface curves upwards or downwards or remains flat in some standard cross-section (midsagittal, coronal, or transverse) of the tongue.

Once a tongue image has been collected and digitized, its surface can be traced either by automatic edge tracking or by a trained analyst placing representative points along its edge by hand. Using MATLAB, the representative points are approximated by a spline curve using a least-squares-fit. After applying the spline tracing to the tongue's surface, the program fits the curve using a 7th-order polynomial fit (function *f* in equation (1)). The first and second derivatives of this function are used to calculate the radius of curvature *r* in equation (2) (at each point along its length), and the total curvature *i,* in equation (3).

The relevant equations are as follows:

$$f = ax^7 + bx^6 + cx^5 + dx^4 + ex^3 + fx^2 + gx + h \qquad (1)$$

where *f* is the polynomial fit to the spline of the tracing and constants *a* through *h* are the coefficients of the fit, and

$$r = (1 + f'^2)^{3/2} / (f''), \qquad (2)$$

$$i = \int_a^b r\,dx, \qquad (3)$$

where *r* is the radius of curvature, *i* is the total curvature, and *a* and *b* are the start point and end point of the spline, respectively.

The total curvature value *i* is referred to as the curvature index (CI) of a given tongue shape. This expression is unitless (that is, it is a ratio of the variation of curvature to the length) and is the same for a given shape, despite being rotated or scaled, such that the CI is essentially probe-location and rotation invariant. We found that the variability of CI values was ±0.04 (approximately 1-2%, due to slight variations in the placement of the points by hand, propagated through the spline and polynomial fits) for the same shape traced by the same judge. Once an image is loaded, it takes less than 30 seconds to manually trace and automatically compute the CI value. The above-discussed properties make this method a fast, reliable, easily-interpretable method of quantifying tongue shape.

Figure 2 shows the range of derived index values for the set of idealized shapes given in Figure 1, as well as values for two actual sample midsagittal tongue shapes.

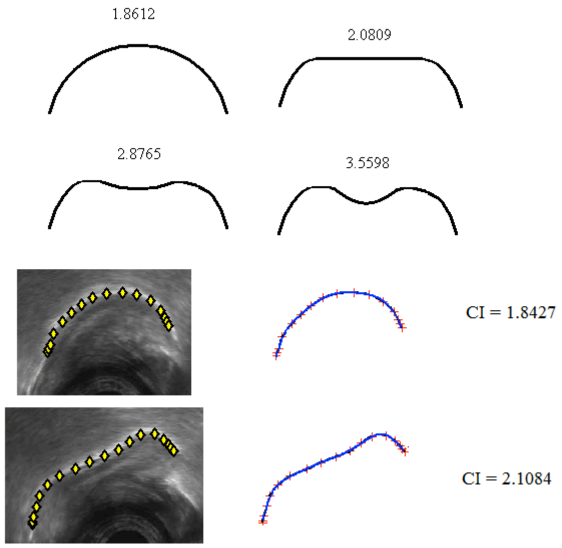

Figure 2. Curvature indices of idealized and recorded tongue shapes.

3. VALIDATION EXPERIMENT: SAGITTAL TONGUE DIFFERENTIATION IN THE SOUND INVENTORY OF ENGLISH

In order to verify the applicability of this index, we conducted a validation experiment using the index to quantify degrees of midsagittal lingual curvature in the sounds of English. This method is able to identify the various sounds as having high or low curvature values and as having a broad or narrow distribution of values.

3.1 Introduction

Past research has shown that certain sounds involve more complex tongue shapes than others, rendering them more difficult for speakers to produce, particularly for L1 or L2 learners and disordered speakers. For example, the late acquisition of English liquids has been ascribed to their having two simultaneous tongue constrictions (see Studdert-Kennedy and Goldstein 2003, McGowan et al. 2004 for /r/; Oh 2005 for /l/), giving them their characteristic shape in the midsagittal plane. This difficulty with producing English liquids relates to motor differentiation, whereby a speaker must learn to segregate and independently control anatomically coupled articulators during the course of motor development (as with the jaw and lower lip; see Green et al. 2000). Being a single muscular hydrostat, the tongue is subject to this same process of differentiation before its independently controllable parts can be separately manipulated for speech (Gibbon 1999). The present validation study uses the CI as a metric for shape complexity (and by extension, lingual differentiation), which is expected to be relatively high for the liquids /l/ and /r/ and relatively low for most other sounds of English.

3.2 Experiment

A study was conducted in which ten adult speakers with no known hearing or speech impairments produced a complete inventory of the sounds (the vowels in a /bVt/ context and consonants in a /aCa/ context) of English.

Participants were seated in a modified ophthalmic examination chair, with four-point head stabilization and a mechanical arm holding an ultrasound probe under the jaw. Midsagittal ultrasound images were recorded using an Aloka Pro-Sound SSD-5000 ultrasound machine. Audio recordings of speakers' productions were also taken.

Stimuli were constructed as follows. Consonants were presented in /aCa/ context; vowels were presented in /bVt/ context. Participants read words from a computer screen that briefly presented each token. Each subject read the prompts for three complete, randomized sets of tokens. In this way, an inventory of relevant sounds was taken, including consonants in context (ara, ala, awa, aga, anga, ana, aya, ata, asha, atha, asa, ada, aza) and vowels in context (boot, bought, bat, bit, beat, but, bet).

Single frames were extracted by pausing the ultrasound video in the middle of the relevant speech segment. Each extracted image provided, as much as possible, a clear midsagittal image of each sound's postural extremum. 15-20 points were manually selected along the surface of each tongue image and were converted into (x, y) coordinates. While it is possible to use fewer points, a 7th order polynomial requires a theoretical minimum of 7 points. The CI value was then calculated for tongue shape using the algorithm described above.

Two-way ANOVAs were used to examine the differences among the curvatures. The sounds were further grouped by manner (liquids, glides, nasals, stops, vowels, and fricatives) to examine the similarities and differences among different categories of sounds.

3.3 Results

The following tables present the CIs for the tongue shapes averaged across subjects, plotted in descending order of median curvature.

Grouping the sounds according to their manner (liquids, glides, nasals, stops, vowels, and fricatives), as shown in Figure 3, two-way ANOVA results indicate a significant effect of manner on the curvature [$F(5, 208) = 7.168$, $p < .0001$]. Specifically, the liquids had a significantly different curvature from all other sounds taken together [$F(1, 212) = 30.25$, $p < .0001$].

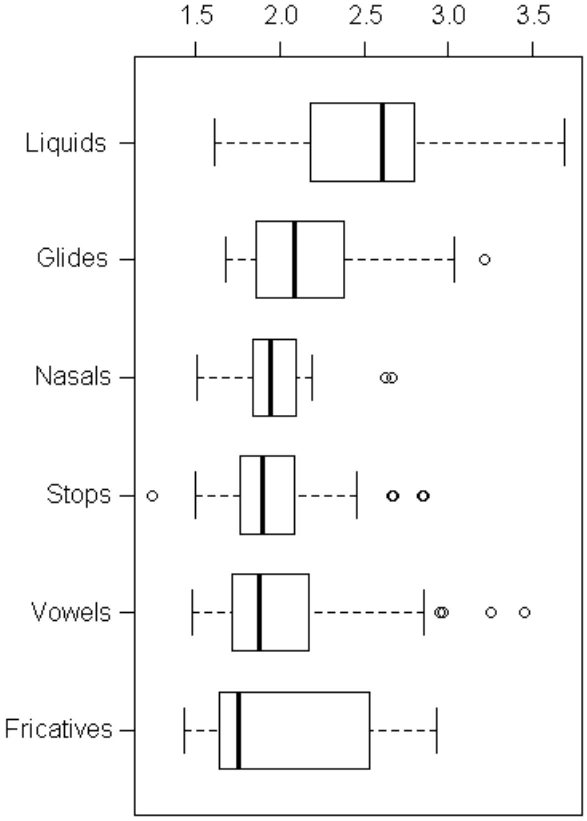

Figure 3. Curvature indices grouped by manner

Taken individually, the CI of /r/ was significantly higher than that of all other sounds taken together, both when excluding /l/ [F(1, 202) = 33.87, p < .0001] and when including /l/ [F(1, 212) = 32.12, p < .0001]. The CI of /l/ was distinct from that of all other sounds taken together (excluding /r/) [F(1, 202) = 5.25, p = 0.0246]. The CI of /l/ was also distinct from that of /r/ [F(1, 18) = 5.95, p = 0.0253]. /l/ was not, however, distinct from all other sounds taken individually. In particular, the CI for /w/ was similar to that of /l/ – and, indeed, all of the velar sounds were clustered at the high end of the scale – presumably due to the curvature introduced by advancing the tongue root for hydrostatic raising of the tongue body. Results by individual sound are given in Figure 4.

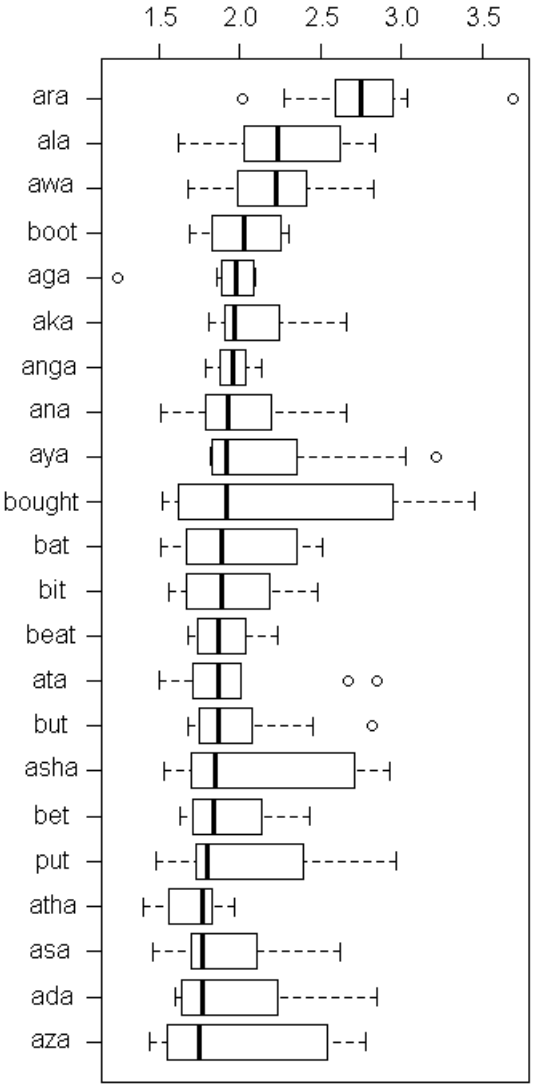

Figure 4. Ordered list of sounds by curvature index, averages within subject.

3.4 Discussion

Our results for the sound inventory of English indicate that the CI accurately differentiates /r/ (by a large margin) and /l/ (to a lesser extent) from the other sounds of English, capturing this known difference in degree of midsagittal tongue curvature.

It is worth noting that both retroflex and bunched tongue shapes appeared in the /r/ productions in our data. These two production variants were approximately equally curvy overall: whereas the retroflexed posture has a locally-high curvature at the tip and a relatively flat shape over the body of the tongue, the bunched /r/ was more curved over its entire length. Our data also indicate some variation in CI values for glides, vowels, and fricatives.

4. CONCLUSIONS

The curvature index thus offers one method of distinguishing more or less complex tongue surface shapes in any measurement plane, distinguishing liquid consonants from other tongue postures. This single metric can potentially be used to examine variation in a variety of speech tasks, such as with sibilant grooving or co-articulation, or to quantify differences in tongue motor differentiation across populations, such as in normal and disordered or developing speakers (see Gick et al. 2008).

In future research, a generalized curvature index of this kind can be implemented to track progress during a course of second language learning, speech intervention or remediation, or to track development of linguo-motor differentiation in normal or disordered populations.

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26.026
2.024

SPEECH INTELLIGIBILITY IN AUTOMOBILE NOISE IN YOUNG AND MIDDLE-AGED ADULTS

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ABSTRACT

Two experiments investigated how automobile noise affects intelligibility of speech signals in both young and middle-aged individuals. In Experiment 1, the effect of automobile noise was compared to speech babble at a number of speech-to-noise ratios. In order to achieve the same intelligibility, the speech-to-noise ratio for the speech babble needed to be substantially greater than the automobile noise. In Experiment 2, middle-aged adults between the ages of 50 and 65 were given the sentences in automobile noise. Even though their hearing acuity was not severe enough to warrant a clinical diagnosis, their performance was significantly worse than the younger adults, particularly for sentences that had few contextual cues. In conclusion, although automobile noise is less damaging than speech babble at typical speech-to-noise ratios, speech understanding for individuals with even small amounts of hearing loss is significantly impacted by the noise. Automobile makers therefore should continue their efforts to reduce the noise levels in cars in order to increase speech intelligibility. [Work supported by Ford Motor Company].

SOMMAIRE

L'effet du bruit ambiant d'une voiture sur l'intelligibilité de la parole chez les jeunes adultes et les adultes d'âge moyen a été étudié à l'aide de deux études. L'expérience 1 comparait l'effet du bruit d'une automobile à un bruit de verbiage pour différent ratios parole-bruit. Les résultats ont révélé que pour atteindre le même niveau d'intelligibilité, le ratio parole-bruit dans le bruit de verbiage devait être considérablement plus grand que dans le bruit de l'automobile. Dans l'expérience 2, des adultes d'âge moyen de 50 à 65 ans écoutaient des phrases en présence du bruit d'automobile. Même si leur acuité auditive n'était pas assez affectée pour mériter un diagnostique clinique, leur performance était significativement plus faible que celle des jeunes adultes et ce, particulièrement pour les phrases avec un faible niveau de prédictibilité. Donc, même si le bruit d'une automobile affecte moins la perception auditive que le bruit de verbiage, la compréhension de la parole est significativement affectée chez les individus souffrant d'une perte auditive même légère. Les producteurs automobiles devraient poursuivre leurs efforts afin de réduire le niveau de bruit à l'intérieur des voitures et améliorer ainsi l'intelligibilité de la parole. [Financé par Ford Motor Company]

1. INTRODUCTION

In 2009, Canadians amassed about 500,000 passenger kilometers (Stats Can, 2010a[1]). Not surprisingly, almost 70% of that distance was accumulated by adults between the ages of 20-65 years. More and more of the time spent in the automobile is occupied with listening to and understanding speech; either instructions from in-vehicle navigation, traffic information or simple conversations among passengers. Misunderstanding directions and/or difficulty in following conversations can result in attention being pulled from the task of driving and can lead to taking wrong turns, annoyance, or even accidents. Thus, it has become increasingly important to measure the effect of automobile noise on speech intelligibility.

1.1 Speech intelligibility measurements in automobile noise

Automobile engineers are understandably very interested in predicting how speech intelligibility is affected by automobile noise (Farina, Bozzoli and Strasser, 2003). A number of reports have measured intelligibility by calculating expected speech intelligibility in a background of automobile noise using already-existing metrics including the Speech Transmission Index (STI) and the Speech Intelligibility Index (SII).

The STI (Steeneken and Houtgast, 1980) models the reduction in intelligibility in noise as a result of a decrease in the intensity of modulation found in the speech signal caused by the noise mixing with the signal. It takes into consideration reverberation, separation of signal and noise and distance of the signals from the receiver. Thus, things like where the noise is coming from and the interior textures

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[1] Statistics Canada defines passenger-kilometres as the sum of the distances traveled by individual passengers (the driver being considered as one of the passengers).

of an automobile are important in calculating this measure. In contrast, the SII uses the spectrum of the speech and noise, as well as information about the listener's hearing threshold to predict intelligibility. Each signal is broken down into a number of bands (up to 20) and each band is weighted in terms of its importance. The importance functions vary depending on the content of the speech and the listener's hearing acuity. Thus, the power spectra of the noise and speech are large contributors to this measure. Both measures are highly correlated with intelligibility of speech under many listening conditions (see Steeneken and Houtgast, 1980 for the STI; ANSI, 1997 for SII).

A recent series of studies has evaluated the effectiveness of these measures of speech intelligibility in different driving environments (Samardzic and Novak, 2011a, 2011b). Samardzic and Novak (2011a) used the STI to measure the effect of different road surfaces, as well as the talker and listener position in the car. They found that the overall sound level did not always predict speech intelligibility. Of most interest here, the frequency content of the background noise, not simply the absolute level of the noise, was an important factor in calculated intelligibility.

In a further study, Samardzic and Novak (2011b) used the SII to generate predictions of speech understanding in an automobile for individuals with typical configurations of age-related hearing loss. The index predicted poor intelligibility for all conditions for the hearing impaired compared to normal hearing listeners. However, for the normal hearing conditions, the SII was lower (worse) for the smooth road condition (which resulted in a great deal of high frequency components in the noise) than the rough road conditions (which resulted in more low frequency energy)–even though the rough road had had higher overall sound pressure levels. The opposite was true for the predictions for hearing-impaired listeners. This was because the SII gives more weight to the important frequencies in speech, which, in turn, is cancelled out by the loss of acuity at those higher frequencies for the hearing impaired. Essentially, the noise is masking frequencies that are already inaudible to the hearing-impaired listeners.

Although these studies show that existing speech intelligibility metrics predict that speech should be harder to understand in an automobile than in quiet, there are few reports directly measuring intelligibility in automobile noise using real human listeners. Although the metrics are quite good, their predictions should be tested with real human listeners.

1.2 Speech Intelligibility in Noise

It has long been known that speech reception performance in noise cannot be predicted from either pure tone thresholds or speech understanding in quiet (see, e.g., Beattie, Barr, and Roup, 1997). In addition, even mild amounts of hearing impairment, as is common with increasing age, magnify this difficulty (Dubno, Dirks and Morgan, 1984). One of the biggest complaints of older adults is that hearing in noisy situations like restaurants and automobiles is difficult, even though they often report little difficulty in quiet conditions.

In order to measure speech intelligibility in noise, Kalikow, Stevens, and Elliott (1977; later revised by Bilger, 1994; Bilger, Nuetzel, Rabinowitz and Rzeczkowski 1984) developed the Speech Perception in Noise test (SPIN; later revised and renamed R-SPIN). We chose to use the SPIN test, rather than one of the many other tests of speech in noise because we were interested in how context might interact with the different types of noise. The test was developed as a screening measure to assess speech perception in noise from both a perceptual (bottom-up) and cognitive (top-down) perspective. In this test, individuals listen to sentences and are asked to report the final word in each sentence. The sentences are presented in a background of multi-talker babble at a single speech-to-noise (S/N) ratio. Half of the sentences in each list have clear contextual cues that allow the listener predict the final word (high-predictability; HP) and half do not (low-predictability; LP). Thus, each individual's performance can be measured when only bottom-up or perceptual information is available, as in the low-predictability sentences, and when both bottom-up and top-down information is available, as in the high predictability sentences. Typically there is a large difference in performance for the two types of lists (Humes, Watson, Christensen, Cokely, Halling and Lee, 1994). This difference illustrates the power of context and top-down processing. Although the test was validated using the single S/N level, it can be transformed into a paradigm using multiple S/N ratios without substantially affecting its validity (Wilson, McArdle, Watts and Smith, 2012).

1.3 Age and speech intelligibility

As we grow older, we experience progressively more difficulty in understanding speech, particularly in situations with background noise (CHABA, 1988; Dubno, Dirks and Morgan, 1984; Sperry, Wiley, and Chial, 1997). Speech understanding in noise starts to decline in the fourth decade even before loss of hearing sensitivity becomes clinically significant (Bergman, 1980). Thus, individuals in their forties and fifties are already experiencing some difficulty in noisy environments. Typically, age-related hearing loss begins in the high frequencies and progressively moves downward to affect lower frequencies. Because of this, low-frequency noises become a greater problem as a person ages and hearing loss progresses, in part because the noise starts to mask the frequencies that do remain audible. Since the noise made by an internal combustion engine is generally loudest in the lower frequencies, it is important to determine whether automobile noise particularly affects speech understanding in individuals with mild hearing losses.

It is well established that, among different types of background noise, meaningful speech noise causes the most disruption in speech intelligibility for both normal hearing and hearing-impaired individuals (Sperry et al., 1997). However, the differential effect of automobile noises on low and high predictable context sentences (reflecting differential contributions of bottom-up and top-down processing) is unknown. Driving is an effortful process and so may take away from cognitive resources that are necessary to use context in understanding speech. Even small amounts of increased effort can have measurable effects on comprehension (Stanley, Tun, Brownell, & Wingfield, in press). In addition, most of the speech heard in the automobile is contextually appropriate; thus allowing us to more comfortably generalize our results to real-world situations.

Thus, the current project measured performance on the Speech Perception in Noise (Revised; R-SPIN; Bilger, et al., 1984) test with the original background noise of multi-talker speech babble and compared it to performance on the same test in a background of automobile noise. In a further experiment, younger and middle-aged drivers were compared to see how age and age-related hearing deficits affect speech intelligibility in the automobile.

2. EXPERIMENT 1

The purpose of Experiment 1 was to compare the SPIN test with the usual speech babble noise to a test using the same sentences but presented -in an automobile noise. We recorded the noise of a Ford Motor Company SUV at 80 mph in the passenger seat of the car. We separated the two channels of the SPIN test and replaced the noise channel with the automobile noise. The question is whether the same level of automobile noise is as disruptive as speech babble for speech understanding even though the frequencies of the automobile noise do not overlap with the speech signal to the same extent as the babble noise.

2.1 Method and Materials

2.1.1 Subjects

Thirty-six normal-hearing college-age Purdue University students between the ages of 18 and 22 participated in this experiment in exchange for partial fulfillment of one of their course requirements. Half were randomly assigned to the babble and half to the automobile noise condition. The design was between subjects because, although the R-SPIN has 8 forms, each pair of forms has the same word in either high or low-context. We tried to minimize the amount of priming of the word for each participant. All individuals tested within the normal range (e.g., ≤25 dB HL at octave frequencies from .25 to 8 kHz (inclusive) on a brief pure-tone hearing screening).

2.1.2 Materials and Design

The materials were adapted from the R-SPIN test (Bilger, et al., 1984). This test contains 200 words distributed as the last words in 200 low-predictability (LP) and 200 high-predictability (HP) sentences. The HP sentences give clear contextual cues about the identity of the final word in the sentences whereas the LP sentences do not. An example of a high predictability sentence is, “The watchdog gave a warning growl.” An example of a low predictability sentence is, “I had not thought about the growl.” Listeners are asked to repeat back the final word in each sentence. Four list pairs, each consisting of two 50-sentence lists, contain the same target word in either a LP or HP sentence. Normally, the R-SPIN is presented with a background of multi-talker speech babble composed of twelve simultaneous voices at a S/N ratio of 8 dB. The validity and reliability of the R-SPIN test have been solidly established (Bilger, et al., 1984; Kalikow, Stevens and Elliott, 1977).

In the present experiment, the R-SPIN test sentences were presented at 70 dB SPL. The background noise was either the original babble or automobile noise recorded in an SUV moving on a road at 80 miles per hour. Automobile noise contains much higher levels of low frequency (< 200 Hz) noise than speech babble. The noise is primarily caused by road-tire interaction and at higher speeds, such as 80 mph, wind noise can also be a problem. Sound transmission into the passenger compartment is controlled and there is sound absorption within the car due to headliners, seats, and carpeting. The noise reduction is more effective at higher frequencies resulting in the spectrum shown in Figure 1 (gray line). Several recordings of automobile noise were examined, all had similar spectral characteristics but there were differences in level. Pilot tests showed that in order to obtain about the same levels of performance we needed to adjust the noise level differently for the two types of background noise. The automobile noise level was varied to create S/N ratios of -10, -8, -5, 0, 5, and 10 dB whereas the speech babble was varied to create S/N ratios of 0, 3, 5, 7, 10, and 12 dB. To be consistent with ratios typically reported with the SPIN test, the S/N ratios were calculated from the unweighted sound pressure levels of the signal (the final word in each sentence) and the background noise (speech babble or automobile noise):

$$SNR = 10\log_{10}\left[\frac{\overline{p_{signal}^2}}{\overline{p_{noise}^2}}\right],$$

where the overbar represents a time average of the squared pressure. All eight versions with 50 sentences each of the R-SPIN test were used in this study. Sentences were presented monaurally in the right ear through headphones in a sound-isolated acoustic chamber.

The average power spectrum of the babble noise and the automobile noise is presented in Figure 1; the un-weighted sound pressure level of both noises is 72.4 dB. This level was chosen for illustration because it was the overall noise level required to meet, on average, a S/N ratio of 0 dB on the last word in the sentences. The playback system was calibrated so that the average level across the entire sentences was 70 dB. As is evident in Figure 1 the majority of the energy in the automobile noise is at low frequencies (below 100 Hz) and in the speech range (200 Hz to 2000 Hz), the babble noise spectrum is always above the automobile noise. Because of people’s lower sensitivity to noise at low frequencies, the automobile noise is perceived as being quieter than the babble noise even though the unweighted sound pressure levels are the same.

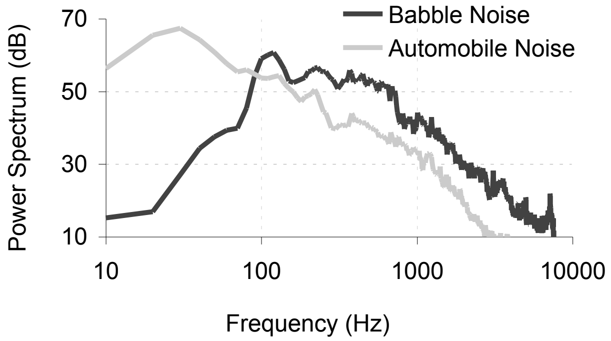

Figure 1. Power spectra of the babble noise (black line), and the automobile noise (gray line). The unweighted sound pressure level for both signals is 72.4 dB.

2.1.3 Procedure

Each subject listened to eight versions of the R-SPIN test (one of the sets of 50 sentences at each S/N ratio) and recorded the last word of each sentence on a form provided for them. The eight lists and six S/N ratios were counterbalanced across subjects in an incomplete Latin square design. No subjects heard the same sentences more than once.

2.2 Results

The percent correct score for the high- and low-predictability sentences with babble noise compared with automobile noise is shown in Figure 2. Each point represents the average score for 18 participants. Error bars indicate standard error of the mean. The small size of the error bars reflects the homogenous performance of the younger adults.

First, the functions look very regular with fairly linear increases in percent correct as a function of S/N ratio in areas of the curve off the floor or ceiling. Second, as expected, there was a substantial difference between the high and low predictability sentences at every S/N level with the low predictability sentences averaging 57% correct (collapsed across conditions) and the high predictability sentences averaging 82% correct. Stated in terms of the S/N ratio, there about a 4-6 dB difference increase in S/N ratio was needed to achieve 50% correct. This is about what has been shown in the past (Pichora-Fuller, 2008). Looking at the differential effect of context for the automobile noise and babble in (for example, at 60, 70 and 80% correct), we see about a 5 dB effect in the babble and the automobile noise for those conditions in which performance is not on the ceiling or the floor.

Finally, it is clear that the babble noise had a greater effect on overall performance than the automobile noise. Comparing performance at 0 dB S/N, there was a difference of 53% for the low-predictability and 44% for the high predictability sentences between the babble noise and the automobile noise. . Thus, at equal unweighted intensities, the babble was having a much greater effect on performance than the automobile noise. Looking at it another way, the S/N ratio needed in order to reach 50% correct is about -8 dB for the automobile noise and about +3 for the speech babble (collapsing across predictability).

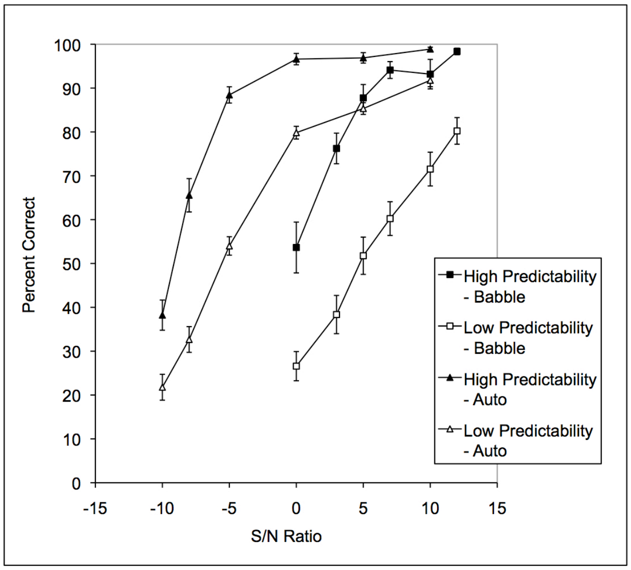

Figure 2. Percent correct word identification as a function of S/N ratio in dB for high and low predictability SPIN sentences in speech babble and automobile noises. Error bars are standard error of the mean.

As mentioned above, in order to achieve the same level of intelligibility as the automobile noise, the S/N ratio based on unweighted sound pressure level needed to be substantially higher for the speech babble. However, we re-calculated the same data in terms of a S/N ratio based on an estimate of loudness (Zwicker and Fastl, 2007). Loudness was calculated over the whole sentences by using the Zwicker time-varying loudness algorithm in the Brüel and Kjaer Sound Quality Software Module. This is based on the German DIN 45631 (2010). The mean value of the loudness over the duration of the last word in the sentence is used in the S/N (Loudness) calculation. Sample average loudness spectra for the three types of signals all normalized to 20 sones are shown in Figure 3. Note that in the he speech range (200 to 2000-3000 Hz) which corresponds to 2.5 to 14-16 Bark, the babble and the speech signal are substantially louder than the automobile noise.

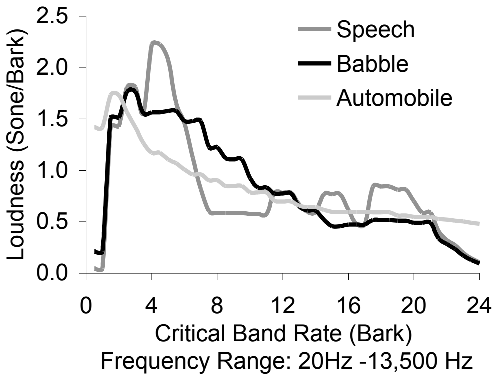

Figure 3. Samples of predicted loudness spectra for speech (dark gray line), babble (black line) and automobile noise (light gray). All of these sounds have been normalized to have a total loudness of 20 sones.

The results of the reanalysis with percent correct as a function of Zwicker loudness is represented in Figure 4. When the data are plotted this way, they demonstrate an interaction of perceived loudness and context (see Figure 4). At equal perceived loudness, the noise has the same effect regardless of the composition of the background noise, provided the context is predictable. However, when context is not present, the physical similarity of the babble to the signal makes the signal more difficult to understand. Thus when top-down information is available, the differences in the physical masking of the stimulus are not relevant—the automobile noise is as detrimental as the babble. However, when the listener must rely solely on the bottom-up perceptual information, the overlap in frequency range of the signal and noise becomes more important.

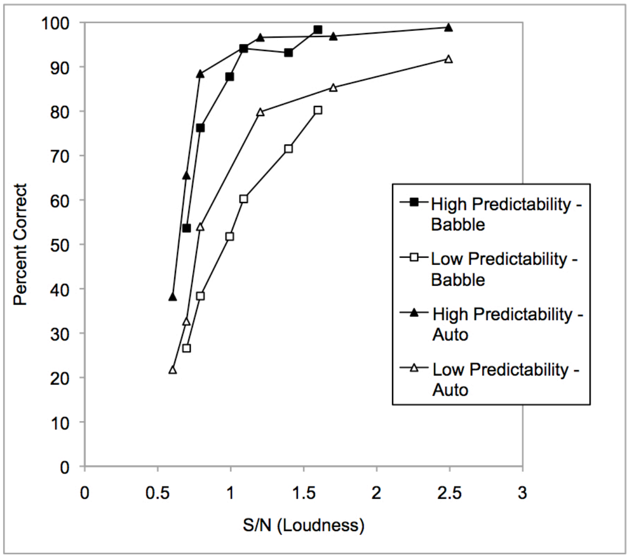

Figure 4. Percent correct as a function of S/N (loudness) for high and low predictability SPIN sentences in speech babble or automobile noise. S/N (loudness) is the ratio of the average of the estimated loudness (Zwicker and Fastl, 1997) over the last words of the sentences to the average estimated loudness of the noise that was playing at that time.

Note also, even though the low frequency components are attenuated in the loudness calculations (which reflects characteristics of the human hearing system), there are still some contributions to the overall loudness from the low frequency critical bands and these contributions are more prominent in the automobile noise. We also looked at other measures of noise level that either attenuate or do not use the low frequency energy, e.g., A-weighted sound pressure level or just the levels in the speech bands. However, use of Zwicker's model to predict loudness and calculate S/N (loudness) yielded the most consistent results when comparing the effects of babble and automobile noise. This indicates that more accurate models of loudness, which include frequency- and level-dependent weighting and masking effects, should be used when examining the effects of noises that have spectral energy distributions that differ to each other and from those of speech signals. For tests with speech and babble noise only, use of unweighted sound pressure levels to determine S/N ratios is appropriate because the signals have very similar spectral shapes, though use of loudness should be considered when the levels of the sentence and the babble noise are very different.

The intelligibility results for the two background noises when plotted against a loudness S/N ratio (Figure 4), rather than over the speech frequency bands (Figure 2) is interesting and requires further investigation.

3. EXPERIMENT 2

Now that we have some sense of how different the automobile noise is from the babble, we can determine how age and mild hearing loss change the effects of automobile noise on understanding speech. In this study, we replicated the automobile noise conditions of Experiment 1 with middle-aged individuals ranging in age from 50-65 years old. Typically, individuals in these age ranges have mild age-related losses that are not severe enough to warrant remediation. However, as mentioned above, there is a substantial amount of data showing that even small amounts of hearing loss affect speech understanding, especially in noise (Dubno et al., 1984; Surprenant, 2007). Given that these individuals make up about 30% of the hours spent in an automobile (Statistics Canada, 2010), it is important to confirm that this holds true in automobile noise, rather than the usual speech babble noise.

3.1 Methods and Materials

3.1.1 Subjects

Eighteen individuals ranging in age from 50-65 years old (13 female; mean: 56.28 years) from the Purdue University community volunteered to participate in exchange for a small honorarium. None of the participants reported taking medication that affected cognitive functioning.

3.1.2 Materials and Design

The materials and design were identical to the automobile noise condition described in Experiment 1.

3.1.3 Procedure

Subjects were first given a brief pure-tone hearing screening at 250, 500, 1000, 2000, 4000, and 8000 Hz. The rest of the procedure was identical to that of the automobile noise condition described in Experiment 1.

3.2 Results

The mean audiometric thresholds are shown in Figure 5. Although none of the participants would qualify as clinically hearing impaired, they all showed some deviation from normal hearing, particularly at the higher frequencies, as is typically found in older adults (Bergman, 1980).

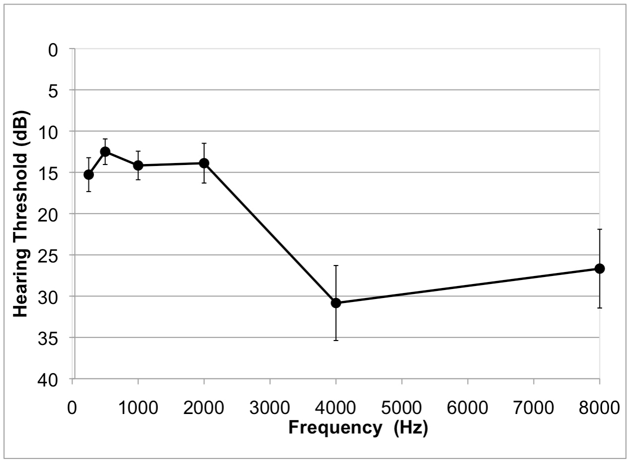

Figure 5. Average hearing threshold (dB HL) as a function of frequency for individuals in Experiment 2. Error bars are standard error of the mean.

The performance-intensity functions of high- and low predictability sentences with automobile noise as the background are illustrated in Figure 6 The data from the younger subjects in Experiment 1 are re-presented for comparison. Each point represents the average score for eighteen participants. Error bars indicate standard error of the mean.

As can be seen in Figure 6, performance for the older group is worse than the younger group, even though their hearing loss is minimal. Because the conditions were run between subjects we can consider them to be different conditions in the same experiment and perform statistical tests (ANOVA) to verify the visual inspection. This observation was confirmed by a 2 (young or middle-aged group) x 2 (predictability) x 6 (S/N level) mixed ANOVA that was performed on the data. There was a main effect of group (*F*(1,34)=1613, mean squared error (*MS*e)=0.71) with the younger (*M*=0.71) outperforming the older (*M*=0.63) group.

There were also main effects of predictability (*F*(1,34)=510, *MS*e=.01), and S/N level (*F*(5,170)=247, *MS*e=5.2). There was no interaction of predictability by group (*F*(1,34_=3.68, *MS*e=0.037) and no interaction of level by group (*F*(5,170)=1.09, *MS*e=0.02) However, there was a significant three-way interaction (*F*(5,170)=4.26, *MS*e=0.42). The three way interaction is due to the finding that the difference between the older and younger group is larger in the low predictability condition than in the high predictability condition but only for the middle (-5, 0, 5) S/N ratios. As mentioned above, performance on the low predictability sentences is considered to be influenced more heavily by bottom-up perceptual information. Thus, even though their hearing would be considered to be clinically normal, they were still more affected by the noise than the younger group. However, they were able to use context to make up for some of that difficulty in the HP condition.

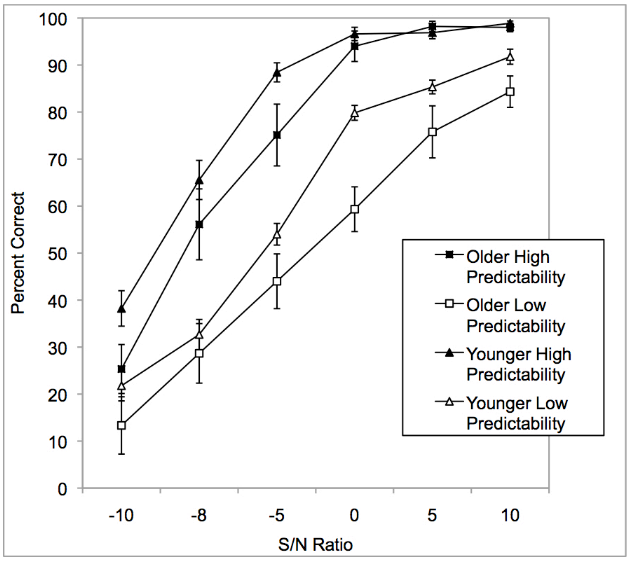

Figure 6. Percent correct word identification as a function of S/N ratio in dB for high and low predictability SPIN sentences in older and younger adults. Error bars are standard error of the mean.

4. DISCUSSION

The data reported here showed that, although speech babble has a greater effect on speech understanding than automobile noise at the same unweighted sound pressure level, the context effect is about the same, indicating that the use of context in a babble condition is no better or worse than it is in a background of automobile noise. When examined in terms of Zwicker loudness rather than unweighted signal to noise ratio, intelligibility is identical in the two noise conditions with predictable context but in the unpredictable context the speech babble continues to be more detrimental than the automobile noise. In Experiment 2, we showed that even a small amount of hearing loss has an impact on speech recognition in noise, particularly when there is little or no top-down or contextual information to support perception.

Recall that Samardzic and Novak (2011b) showed that the SII predicted less of an effect of some road noises for individuals with high frequency hearing loss because the energetic masking of the high frequencies in that noise is having an effect on frequencies that are inaudible to them anyway. The noise used here had more of a low-frequency component to it. Thus, it would be interesting to see whether changes in the automobile noise to include more high frequency components would have as much of an effect on individuals with hearing loss than on those without. The SII would predict that it would not have an effect.

It should also be noted that our participants were merely listening to the stimuli over headphones rather than engaging in a dual task like driving and listening. Samardzic, Novak, and Gaspar (2012) showed that adding the driving task (in a simulator) required an increase of the signal of 3 dB for equivalent performance. Thus, it would be very interesting to see whether the difference between the low and high predictability sentences changes as more higher-level resources are being occupied by the second task of driving. We do know that listening takes away from driving (e.g., Horrey and Wickens, 2006); how much does driving take away from listening?

The current project showed that, although automobile noise is less damaging than speech babble at typical S/N ratios, speech understanding for individuals with even small amounts of hearing loss is significantly impacted by the noise. Automobile makers therefore should continue their efforts to reduce the noise levels in cars in order to increase speech intelligibility.

ACKNOWLEDGEMENTS

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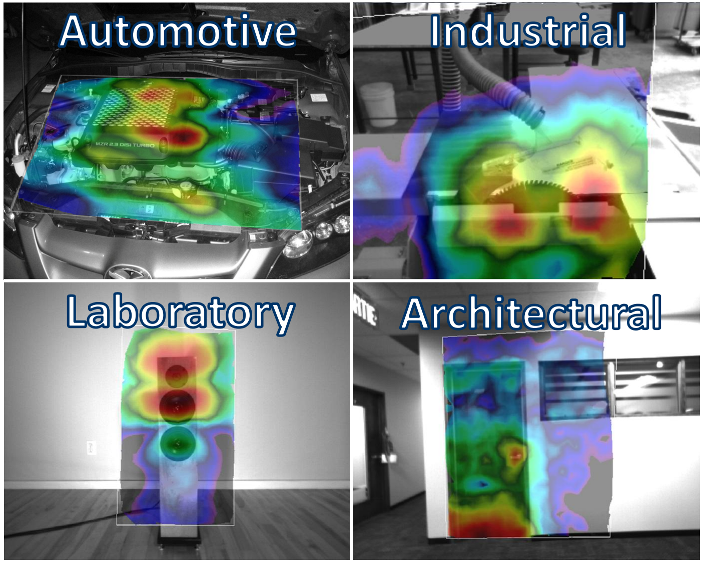
Automotive
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NOISE MAPPING OF AN EDUCATIONAL ENVIRONMENT

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ABSTRACT

The purpose of this study was to perform computer-assisted noise mapping of an educational environment. The computer simulations were performed using SoundPLAN software. An analysis of the acoustic maps generated by the simulations indicates that contributions to the noise levels found on the campus originate mostly from three streets on campus, as well as from the roads surrounding the outer perimeter – the Green Line and the BR-277 highway. The computer-generated acoustic maps show that the noise levels within the campus exceed the limit of Leq = 50 dB(A) established for educational areas, according to the Brazilian standard for noise assessment in communities. Therefore, the noise maps indicate a critical situation of noise pollution on campus. However, despite this negative and concerning situation of noise pollution, the acoustic maps also reveal several "islands of acoustic tranquility" on campus. These "islands" can be observed adjacent to buildings where sound levels range from 45 to 48 dB(A) and from 48 to 51 dB(A), which are indicated in green tones on the acoustic maps.

SOMMAIRE

Le but de cette étude était de réaliser la cartographie du bruit assistée par ordinateur d'un environnement éducatif. Les simulations informatiques ont été effectuées en utilisant le logiciel SoundPLAN. Une analyse des cartes acoustiques générées par les simulations indiquent que les contributions aux niveaux de bruit mesurés sur le campus proviennent principalement des trois rues sur le campus, ainsi que des routes entourant son périmètre extérieur - la Ligne verte et le BR-277 autoroute. Les cartes générées par ordinateur montrent que les niveaux de bruit à l'intérieur du périmètre du campus de dépassent la limite de Leq = 50 dB (A) établie pour les zones d'éducation, selon à la norme brésilienne de bruit environnemental. Par conséquent, les cartes de bruit indiquent une situation critique de pollution sonore sur le campus. Cependant, malgré ces nuisances sonores, les cartes acoustiques révèlent également plusieurs «îlots de tranquillité acoustique» sur le campus. Ces «îlots» peut être observé près des bâtiments où les niveaux sonores s'établissent entre 45 à 48 dB (A) et entre 48 à 51 dB (A) et qui sont indiqués dans les tons verts sur les cartes acoustiques.

1. INTRODUCTION

The rapidly expanding urbanization around the world presents a common factor, which is the aggravation of environmental pollution – of gas emissions, water pollution and noise pollution. The noise that reaches urban populations is generated by various sources, which may be of a simple or complex nature, including the noise generated by transportation systems (road, railroad, air), noise generated by civil construction activities, noise generated by a wide variety of leisure activities such as cultural events, sports events, etc.

Many sectors of society are affected by noise, particularly noise that is generated by vehicle traffic. Traffic noise causes discomfort and irritation, especially during activities that require attention and concentration. In response to the increasing levels of urban and industrial noise pollution, numerous studies have focused on environments intended for activities that involve a cognitive load, such as educational and working environments [e.g. 1-7].

Various studies in different countries have dealt with the problem of environmental noise in educational areas [e.g. 8-13]. However, these studies have not involved the use of computer-assisted noise mapping as a tool for the diagnosis of noise in educational environments.

The buildings on the university campus under study are surrounded by on-campus streets used by cars and buses. The external perimeter of the university campus is surrounded by two expressways with intensive vehicle flows, namely, 1) the BR 277 expressway that links the city of Curitiba to the coastal area of the state of Paraná (southern Brazil), and 2) the Green Line, formerly called the BR 116 highway, which connects the country from north to south. This expressway is currently undergoing an urban transformation to become a major avenue in a new urban scenario in the city of Curitiba [14]. The above-described situation points to the need for and importance of monitoring the sound quality of the university environment – indoor and outdoor - since studies have shown that noisy environments affect the learning process and have negative effects on human health [e.g. 15-19].

The purpose of this work was to generate and analyze the results obtained through computer-assisted noise mapping of an educational environment, in particular a university environment. The environment under analysis is the Polytechnic Center of the Federal University of Paraná, located in southern Brazil. The university campus has a population of about 13,523 people, comprising students, teachers, and administrative staff. The evaluation of noise inside the campus was conducted through in situ measurements of equivalent continuous sound level Leq; noise maps were built using the software Sound Plan-6.2.

2. METHODS

An evaluation was first made of the site plan of the environment in question, using AutoCad R14 software. The measurement points were selected with a view to covering the university campus with its streets and the two major expressways adjoining it – the Green Line and the BR-277 highway - taking into account the topography, the distribution of the buildings, and the entry and exit roads of the campus.

Measurements were taken at 20 points and the duration of each measurement was of 15 minutes, according to the recommendation in the paper by Romeu and collaborators: “Street categorization for the estimation of day levels using short-term measurements” [20]. Figure 1 shows the map of the campus, highlighting the points where the measurements were taken.

The noise generated by vehicle traffic was simulated using SoundPlan version 6.2 software [21], employing the German standard RLS-90 in the calculations for the acoustic modeling of traffic noise [22]. The SoundPlan software works with the following input data to calculate the noise levels generated, for example, on highways: data traffic such as vehicle flows, percentage of light vehicles, road gradients and types of paving, land topography, location and physical characteristics of buildings, etc. [23].

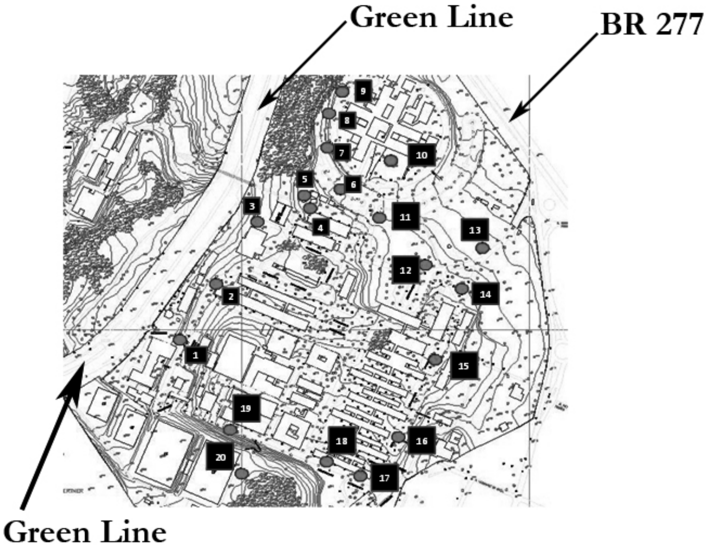

Figure 1. Plan-view highlighting the measured points listed in Table 2, and the two main expressways adjoining the university campus – Green Line and BR 277.

The environmental noise on campus was evaluated according to the criteria of the Brazilian NBR 10151:2000 standard – Acoustics – Noise assessment in populated areas to ensure the comfort of the community [24]. Table 1 lists the external noise levels as a function of the type of land use and period (daytime or nighttime), according to the Brazilian standard NBR 10151.

Table 1. Noise levels according to land use established by the Brazilian standard NBR 10151

	Noise level Leq dB(A)	
Type of Land Use	**Diurnal**	**Nocturnal**
Rural	40	35
Schools, Hospitals	**50**	**45**
Residential	55	50
Commercial	60	55
Industrial	70	60

Figure 2. BK 2260 sound pressure level meter – Measurement point no. 3, facing the Green Line, Leq = 71.7 dB(A) (see Table 2).

Figure 3. BK 2260 sound pressure level meter – Measurement point no. 20, green area of the campus, Leq = 51.4 dB(A) (see Table 2).

3. RESULTS

Table 2 lists the equivalent sound levels measured at each of the 20 points selected for the measurements, as illustrated in Figure 1.

Table 2. Equivalent sound pressure level at each measured point

Measurement Points	**Leq dB(A)**
1	61.4
2	62.3
3	71.7
4	58.7
5	59.0
6	56.2
7	58.3
8	58.2
9	58.1
10	56.1
11	56.6
12	67.3
13	70.5
14	58.9
15	65.9
16	65.6
17	59.0
18	58.7
19	58.8
20	51.4

To prepare the noise maps, the site plan of the university campus was entered into the SoundPlan 6.2 software program [21]. The contour lines were then modeled at every five meters of ground elevation, as well as the buildings containing classrooms and research laboratories. A sound level of 4.6 dB(A) was established as the maximum acceptable difference between the measured values and those calculated for the noise levels, as indicated by Licitra and Memoli [25].

The noise maps for the daytime period were obtained upon completion of the internal calculation routine of the SoundPlan software, and are illustrated in Figures 4, 5, 6 and 7.

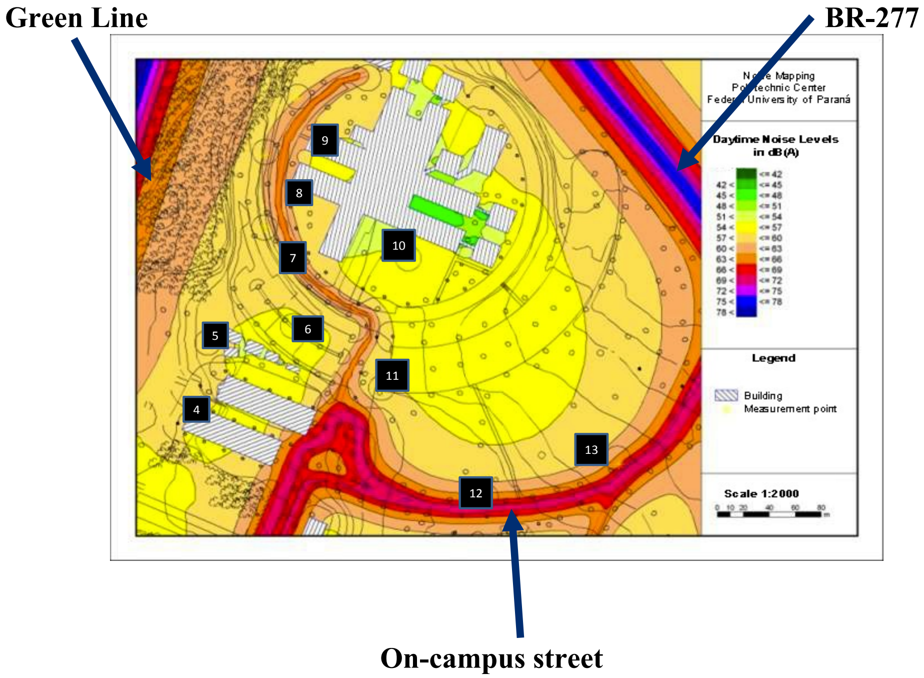

Figure 4. Noise mapping of the area where the classrooms of the Biological Sciences sector of the campus are located, adjoining the BR-277 and Green Line expressways. Identification of the measured points described in Table 2.

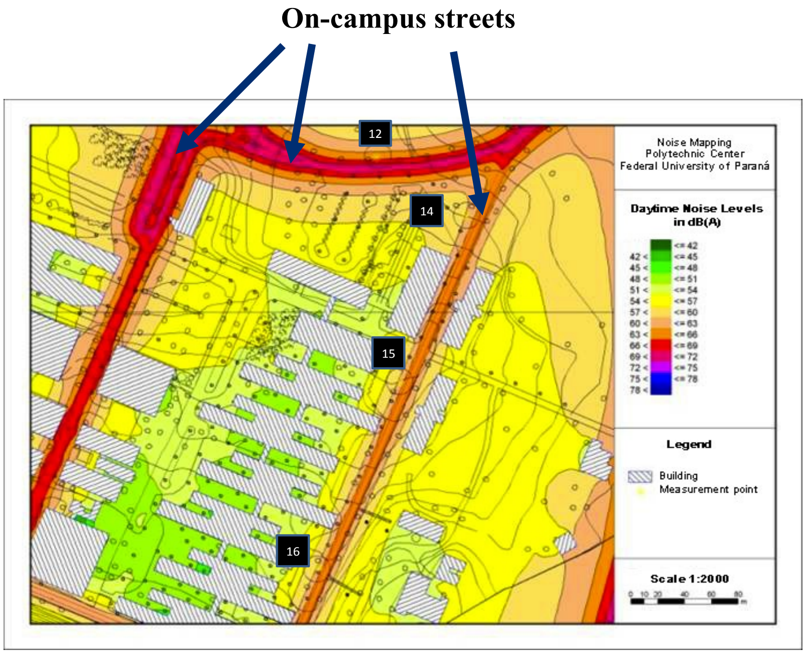

Figure 5. Noise mapping of the classroom buildings of the Technology sector of the campus. The arrows indicate the three major thoroughfares on the university campus. Identification of the measured points described in Table 2.

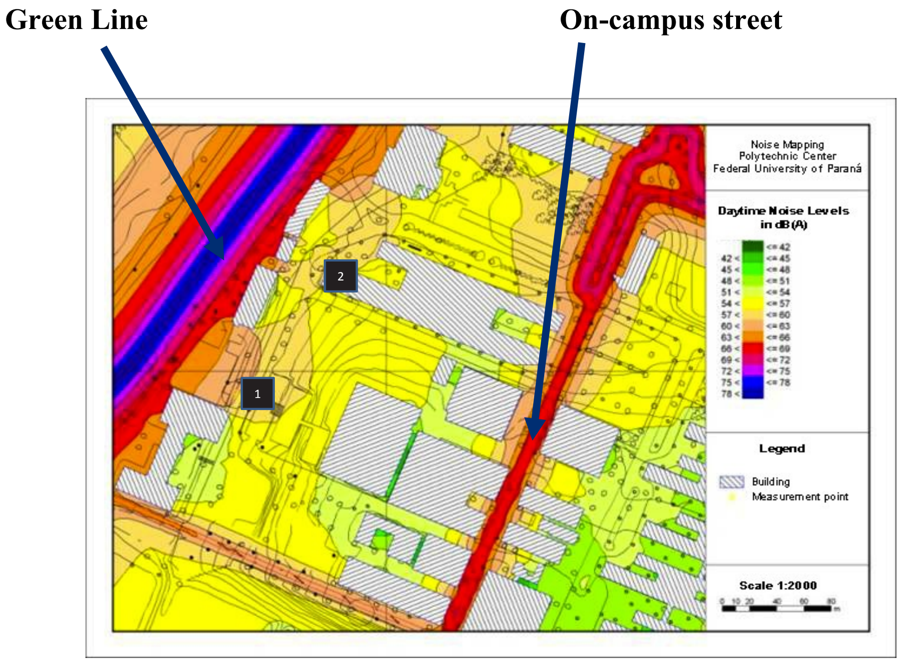

Figure 6. Noise map of the buildings with classrooms and laboratories located adjacent to the Green Line. Identification of the measured points described in Table 2.

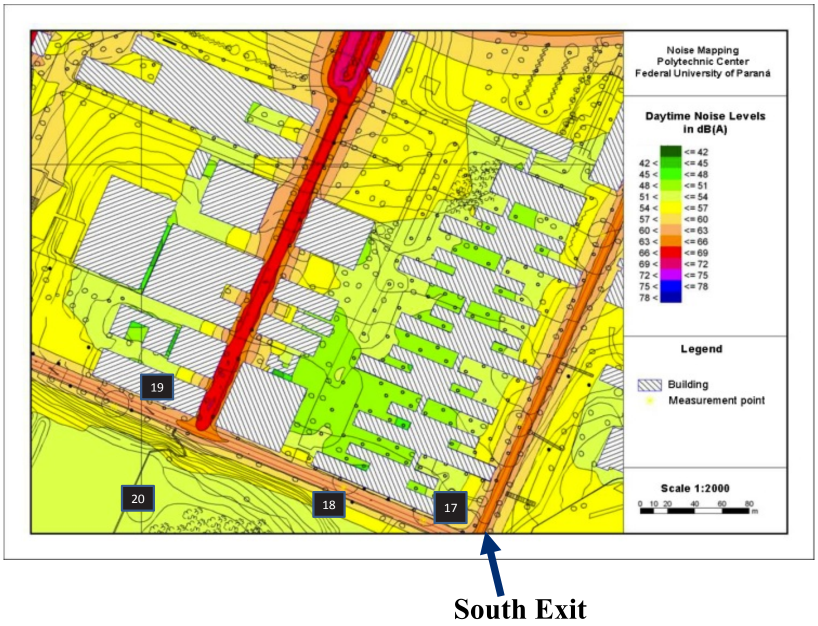

Figure 7. Noise map of the main classrooms close to the south exit from the campus. Identification of the measured points described in Table 2.

4. CONCLUSIONS

Although there are numerous studies on acoustics employing noise mapping, conducted around the world, none have utilized computer-assisted noise mapping in an educational environment [e.g. 14, 23, 26-37].

In 2011, the Journal Applied Acoustics published a special edition on the subject – "Noise Mapping", volume 72, Issue (8) – and none of its 19 articles dealt with noise mapping in Universities. Of these papers, only one has used, albeit en passant, noise mapping to evaluate noise levels in secondary schools of London [38]. In 2013, a book on the theme has just been published - "Noise Mapping in the EU", with 18 chapters, of which none focuses on noise mapping in educational areas [39].

The computer-assisted noise mapping conducted in this study allowed us to understand the problem of noise pollution surroundings and inside the university campus. On the basis of this study, we arrived at the following conclusions and suggestions.

We had assumed that the noise inside the campus would come primarily from the adjoining expressways – the Green Line and BR-277. However, the sound maps indicated that this assumption may be innacurate. The Green Line and BR-277, allied to the campus's three main roads, are the main factors responsible for the noise levels generated on the campus. These levels are explained by the enormous number of vehicles – especially heavy vehicles such as trucks (mainly around the campus), buses and service vehicles, as well as light vehicles such as passenger cars -, that circulate around the campus and inside the campus.

The Brazilian NBR 10151 standard establishes a maximum value of Leq = 50 dB(A) as the criterion for noise exposure in outdoor environments, particularly in educational settings. An analysis of the noise maps indicates that many of the buildings housing classrooms and laboratories are located in areas where noise levels range from 54 to 63 dB(A). Thus, it can be concluded that the noise pollution on campus is a cause for concern. On the other hand, despite this negative and concerning situation of noise pollution, the maps also reveal several "islands of acoustic tranquility" on the campus. These "islands" are located next to buildings where the noise levels range from 45 to 48 dB(A) and from 48 to 51 dB(A), which are indicated in green tones on noise maps 4 to 7.

As a measure to curb the noise pollution to which these buildings are subjected, a suggestion would be to improve the sound insulation of their facades. Zannin and Ferreira [40] demonstrated that the sound insulation – the apparent weighted sound reduction index [41] – measured at the facades of the classrooms of the Technology Sector on this university campus, was = 19 dB. This value is low, considering the requirements of the DIN 4109 for classroom facades, which is = 30 dB [42].

An important administrative solution would be to reduce the vehicle speed limit. This measure was recently implemented and the current speed limit on the Green Line is 70 km/h. To ensure compliance with this speed limit, several radars have been placed along the Green Line. However, at the time this study was conducted the speed limit was not yet in effect. An administrative measure that would further contribute to curbing noise pollution effect would be to aim for the reduction of vehicle emissions (noise and exhaust) by means of compulsory vehicle inspections.

As a form of environmental education, it would be important to conduct awareness campaigns for drivers both inside and outside the university campus, to encourage them to reduce their driving speed and avoid the unnecessary use of car horns. Another instructive measure would be to place signs indicating the existence of a noise sensitive area, i.e., an educational area.

The methodology here employed can be specifically applied to educational environments with layouts similar to that of the campus studied in this paper. In any case, the findings allow us to warn against the error of building educational facilities next to busy highways. In Spain, in the city of Málaga, in the Sixth Iberic Congress of Acoustics, Perea-Pérez et.al. (2010) [43] have shown similar results, from a study conducted inside an University campus also surrounded by highways with great vehicle flow, and whose internal roads also display heavy traffic. Likewise, this Spanish campus also deals with a severe noise pollution problem.

Computer-assisted noise mapping is an important tool for evaluating and interpreting environmental noise, providing information that can be used by public authorities for the mitigation of environmental noise in general, and in particular for educational environments.

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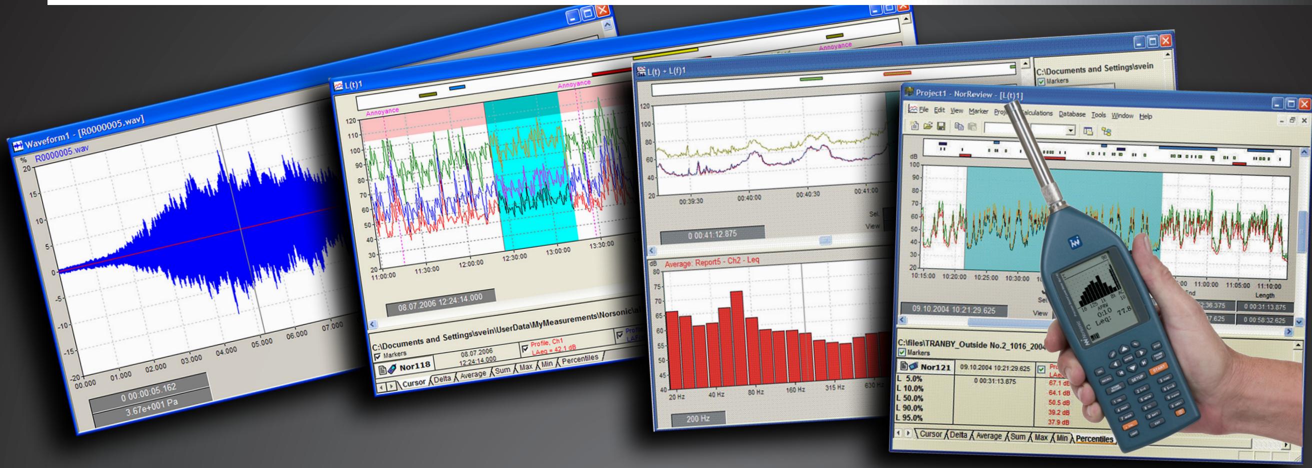


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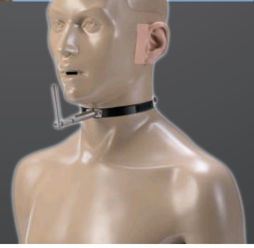

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REVIEW OF MARK CHANGIZI'S *HARNESSED*

Paolo Ammirante
Department of Psychology, Ryerson University, Toronto, Ontario

A recent study used DNA evidence to show that the spotted coat pattern on horses depicted in a 25,000 year old cave painting in France is consistent with a horse genotype found in Paleolithic France [1]. This finding suggests that the painting is a naturalistic depiction, and casts doubt on previous interpretations of the spots as being hallucinated in shamanistic ritual or an early example of "art for art's sake." More broadly, this finding supports the view, held since the ancient Greeks, that much of human culture aims to imitate nature.

In *Harnessed: How Language and Music Mimicked Nature and Transformed Ape to Man* (BenBella Books, 242 pages), Mark Changizi describes why and how he thinks speech and music evolved to "sound like nature." The opening pages reject often-cited hallmarks of Darwinian selection in spoken language and music-making — cultural universality, complexity, effortless and rapid development in infants, and specialized brain areas — on the grounds that our only recently acquired capacity to read shares most of these same hallmarks (p. 3). The central claim is that, by sounding like nature, speech and music "harness" evolutionarily ancient auditory "what" and "where" mechanisms for recognizing and tracking auditory sources and events. As the author puts it: "By mimicking nature, language and music could be effortlessly absorbed by our ancient brains, which did *not* evolve to process language and music. In this way, culture figured out how to trick nonlinguistic, nonmusical ape brains into becoming master communicators and music connoisseurs" (p.11).

So, how do speech and music sound like nature? Changizi — a science writer and Director of Human Cognition at the 2AI lab — is not referring merely to scattered instances of onomatopoeia in speech (e.g., the word "buzz") or programme music (e.g., the nightingale in Beethoven's Sixth Symphony). Instead, he is referring to two particular classes of sound regularities (or what J. J. Gibson called "invariants") that arise from lawful physical events, are stable across habitats and over evolutionary time, and are implicitly known to the listener. In a nutshell, he argues that "speech sounds like solid-object physical events" and "music sounds like people moving." Most of the book is spent detailing these regularities and testing the hypothesis that if language and music evolved to mimic them, then these same regularities should be reflected in statistical trends in language and music corpora.

For example, in Chapter 2, Changizi proposes three basic types of sounds arising from the interaction between solid objects: "hits" (impact sounds), "slides" arising from friction (broadband noise), and "rings" (vibration). Hits, slides, and rings, according to the author, correspond to "the principal three classes of phonemes in human speech" (p.39): plosives, fricatives, and sonorants, respectively.[1] He points out that "the events in our mouths that make the sounds of speech are events involving airflow, not hits, slides, or rings at all. Airflow events in our mouths mimic hits, slides, and rings, the constituents of solid-object physical events" (p. 42). Chapter 2 ends with data showing substantial overlap between the frequency distributions of hits, slides, and their combinations in videos of naturalistic settings (YouTube videos of people cooking, family gatherings, etc.) and the distribution of their corresponding phonemes in a sample of words from eighteen languages.

The case for music sounding "like people moving" spans chapter 3 (on rhythm), chapter 4 (on melody), and an Encore section that follows the Conclusion. The link drawn between the musical "beat" and the sound of human footsteps is substantiated by the proximity of the mean musical tempo to the mean pace of human gait (the Italian medium tempo directive *andante* means "at a walking pace") and similarities between *ritardando* (slowing down at the end of a musical phrase) and deceleration patterns in human locomotion [2]. Uncited in *Harnessed* but potentially relevant are findings [3] that expressive timing variation in music performance contains long range dependencies (*1/f* noise) characteristic of timing variability in human gait [4].

The book's proposed link between pitch perception and sound localization also has some basis beyond the widespread (although not culturally universal [5]) tendency to describe pitch changes in terms of "upwards" and "downwards" movement. For example, interactive effects of space- and pitch-varying sequences on auditory perception have been observed [6], and such sequences activate highly similar brain networks [7]. The book shows that faster tempo piano melodies have a wider *tessitura* or pitch range (pp. 220-222), implying composers' implicit recognition that faster moving objects traverse longer distances. This finding is consistent with studies showing that more widely-spaced tone sequences affect tempo judgment [8] and are reproduced more quickly and with faster finger movements [9-10].

Where I think *Harnessed* falters is in its insistence on a physical basis for the perceptual link between pitch and movement in space. (There is no such basis, for example, for perceptual interactions between numbers and space in common circuits in the parietal lobe [11].) An early suggestion that musical tones engage the vestibular system, eliciting a "corresponding movement experience" in the listener [12], has found little physiological support [13]. Here Changizi implausibly proposes that melodies exaggerate tiny Doppler shifts (beyond conscious detection) that arise from moving human bodies changing direction in space relative to the listener (p. 179). The preponderance of arch-shaped melodic contours in music [14] are thus argued (pp. 170-173) to mimic a typical human "encounter" of veering toward the listener (upshifting) and then away (downshifting). But a more parsimonious account for melodic arch in both human and bird song implicates vocal constraints on the control of subglottal airflow [15]. Moreover, it is difficult to imagine what Doppler-shifted "encounter" might explain other melodic universals not discussed in *Harnessed*, such as the tendency for a large melodic leap to be followed by a smaller leap in the opposite direction (pitch-skip reversal) [16].

Some words of warning: *Harnessed* is not a scholarly book in that it contains fewer citations, references, and endnotes than there are in this review, and no index. Few additional avenues are provided to the non-specialist reader, who may also be thwarted by the book's avoidance of certain established, searchable terms (e.g., declination, speech prosody, pitch proximity, and meter). Music cognition researchers and psychoacousticians may be dissatisfied by the book's isolation from contextual evidence in the scientific literature, and the informally presented data sometimes raise more questions than answers.[2] Still, Changizi's speculative hypothesis is engagingly presented, clearly laid out, and richly detailed. I hope to see aspects of it more rigorously tested and refined in the future.

Notes

1. To my knowledge (I am not a phonetician), Changizi's "principal three classes" are his own. Phonemes are generally classified by features such as manner of articulation. Thus, sonorants (speech sounds produced with continuous airflow) are contrasted with obstruents (speech sounds produced with obstructed airflow), which include both plosives and fricatives.

2. For example, it is claimed that the plot on p. 218 shows a flat distribution of notes across the tessitura for a sample of 10,000 musical themes, which contrasts with other reports of a Gaussian distribution [15-16]. However, there is clearly a "bump" in the middle quintile, the prominence of which is obscured by the scale of the y-axis.

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