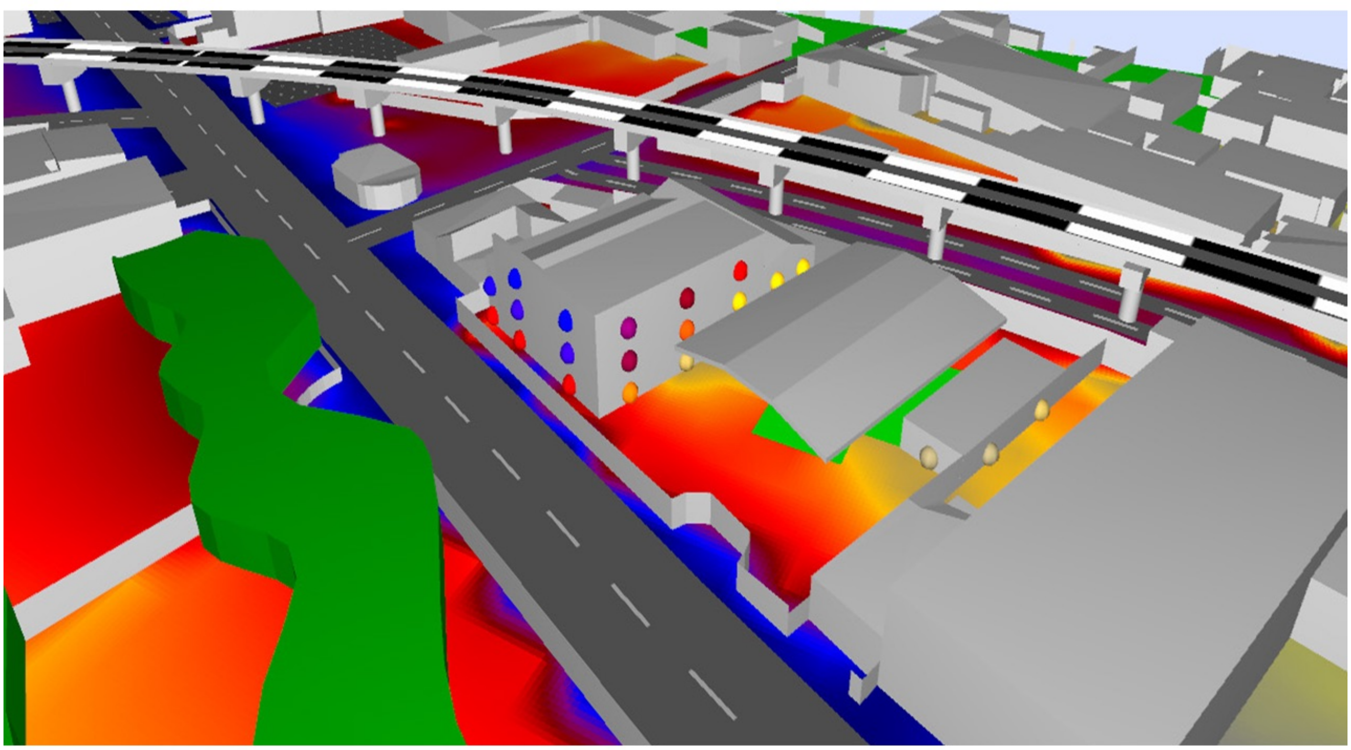
ISSN 0711-6659

canadian acoustics
acoustique canadienne

Journal of the Canadian Acoustical Association - Revue de l'Association canadienne d'acoustique

MARCH 2018 MARS 2018
Volume 46 - - Number 1 Volume 46 - - Numéro 1



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Canadian Acoustics is published four times a year - in March, June, September and December. This quarterly journal is free to individual members of the Canadian Acoustical Association (CAA) and institutional subscribers. Canadian Acoustics publishes refereed articles and news items on all aspects of acoustics and vibration. It also includes information on research, reviews, news, employment, new products, activities, discussions, etc. Papers reporting new results and applications, as well as review or tutorial papers and shorter research notes are welcomed, in English or in French.The Canadian Acoustical Association selected Paypal as its preferred system for the online payment of your subscription fees. Paypal supports a wide range of payment methods (Visa, Mastercard, Amex, Bank account, etc.) and does not requires you to have already an account with them. If you still want to proceed with a manual payment of your subscription fee, please use the application form from the CAA website and send it along with your cheque or money order to the secretary of the Association (see address above). - Canadian Acoustical Association/Association Canadienne d'Acoustiquec/o JASCO Applied Sciences2305–4464 Markham StreetVictoria, BC V8Z 7X8 Canada - - - secretary@caa-aca.ca - Dr. Roberto Racca

Acoustique canadienne est publié quantre fois par an, en mars, juin, septembre et décembre. Cette revue trimestrielle est envoyée gratuitement aux membres individuels de l'Association canadienne d'acoustique (ACA) et aux abonnés institutionnels. L'Acoustique canadienne publie des articles arbitrés et des rubriques sur tous les aspects de l'acoustique et des vibrations. Ceci comprend la recherche, les recensions des travaux, les nouvelles, les offres d'emploi, les nouveaux produits, les activités, etc. Les articles concernant les résultats inédits ou les applications de l'acoustique ainsi que les articles de synthèse, les tutoriels et les exposées techniques, en français ou en anglais, sont les bienvenus.L'Association canadienne d'acoustique a sélectionné Paypal comme solution pratique pour le paiement en ligne de vos frais d'abonnement. Paypal prend en charge un large éventail de méthodes de paiement (Visa, Mastercard, Amex, compte bancaire, etc) et ne nécessite pas que vous ayez déjà un compte avec eux. Si vous désirez procéder à un paiement par chèque de votre abonnement, merci d'utiliser le formulaire d'adhésion du site de l'ACA et de retourner ce dernier avec votre chèque ou mandat au secrétaire de l'association (voir adresse ci-dessus). - Canadian Acoustical Association/Association Canadienne d'Acoustiquec/o JASCO Applied Sciences2305–4464 Markham StreetVictoria, BC V8Z 7X8 Canada - - - secretary@caa-aca.ca - Dr. Roberto Racca

Contents - Table des matières


Outdoor Noise Control
Community friendly solutions for chillers and cooling towers
• Customizable solutions featuring independently tested products
• On grade and rooftop applications
• Proven design and performance of noise reduction with low system pressure loss since 1958
Cooling Tower Barrier Wall System
Central Energy Plant Louvers
Equipment Yard Noise Control
KINETICS Noise Control
1-800-684-2766 | www.kineticsnoise.com | canadiansales@kineticsnoise.com

Editor's note: changes and challenges
Éditorial : changements et défis

Let's plan a fantastic 2018

Every January 1st, I like to express some desires. This year, I could not start the year without thinking to the great responsibility I have been given. So, I thought about what I dream for *Canadian Acoustics* in 2018, and here are my three desires:

1) *More papers, more quality and (may be) an Impact Factor*. While Canadian Acoustics is in good shape and several activities and plans exist, I would like to enforce my vision. With the support of all the Canadian acousticians, I hope to increase the visibility and diffusion of our journal. Last year we started by expanding the Editorial Board of the journal, with new members to bring new energy for the new challenges we have. We are now working on obtaining an impact factor in order to bring more international recognition. With the intent to keep alive the discussion about the equilibrium point between the strong scientific robustness of the journal and its capability to connect all the Canadian acousticians and to offer a space to host more announcements and news, we want to increase the content of our journal. So please submit your new research!

2) *Practitioners corner*. We all want to make *Canadian Acoustics* the reference guide for all acousticians in Canada and around the world (as proved by the increasing number of international submissions we receive). The main content of the journal is represented by the refereed scientific articles we receive. However, the journal also includes news and items on all aspects of acoustics and vibration, information on research, reviews, news, activities, and discussions. Papers have sometimes looked at applications, as well as reviews and shorter research notes to testify the diversity and depth of our contents. In this context, I work to find a balanced equilibrium between journal technical content and contributions and useful information for practitioners. With the objective of enlarging the readership of the Journal and to allow the non-academic members to voice their activities and achievements, we decided to publish every issue one or two short (two-pages) articles, containing every day, practical cases or experiences in a dedicated section called *"The practitioners corner"*. Articles should follow the pattern of Problem & Solution. The inclusion of illustrations, such as graphs and photographs is highly recommended. The main request I

Planifions une fantastique année 2018

Chaque 1er janvier, j'aime exprimer quelques souhaits. Cette année, je ne pouvais pas commencer l'année sans penser à la grande responsabilité qui m'a été confiée et à ce dont je rêve pour l'*Acoustique Canadienne* en 2018. Voici mes trois souhaits :

1) Davantage de publications, davantage de qualité et (peut-être) un facteur d'impact. Même si l'*Acoustique Canadienne* est en bonne santé et que plusieurs activités et projets sont prévus, je souhaiterai consolider ma vision. Avec l'appui de tous les acousticiens canadiens, j'aimerais augmenter la visibilité et la diffusion de notre journal. L'année dernière, nous avons commencé par élargir le comité de rédaction de la revue avec de nouveaux membres, apportant un souffle nouveau pour affronter les défis qui nous attendent. Nous travaillons actuellement à l'obtention d'un facteur d'impact qui nous permettrait de susciter davantage de reconnaissance internationale. Nous voulons augmenter le contenu de notre revue en poursuivant la discussion sur l'équilibre entre sa rigueur scientifique et sa capacité à connecter tous les acousticiens canadiens, en leur offrant un plus grand espace de partage d'annonces et d'actualités. N'hésitez pas à présenter vos nouveaux résultats de recherche !

2) *Le coin des praticiens*. Nous cherchons tous à faire d'*Acoustique Canadienne* la référence pour tous les acousticiens canadiens et internationaux (comme en témoigne le nombre croissant de soumissions internationales reçues). La majorité du contenu de la revue sont les articles scientifiques (révisés par un comité de lecture) que nous recevons. Cependant, le journal comprend également des nouvelles et des articles sur tous les aspects de l'acoustique et des vibrations, des informations sur la recherche, des activités et des discussions. Les articles portent sur des applications, mais aussi des critiques de livres ou des notes de recherche plus courtes, témoignant ainsi de la diversité et de l'ampleur de du contenu du Journal. Dans ce contexte, je travaille à trouver l'équilibre entre le contenu technique et les contributions et informations utiles pour les praticiens. Dans le but d'élargir le lectorat du Journal et de permettre aux membres non universitaires de présenter leurs activités et réalisations, nous avons décidé de publier dans chaque numéro, dans une section dédiée appelée "Le coin des

have for such contributions is that papers should contain limited information regarding the author's company, since the *Corner* is not intended to convey commercial messages or advertisements. The content of the submission will be reviewed by the Editorial Board to ensure its adequacy for the Journal. Authors are encouraged to submit manuscripts to myself, mentioning that the submission is intended for the Practitioner's Corner.

3) *Special issues together with Regional issues*. We will host a special issue later this year about Audiology and Neuroscience. This will be the first of a series of special issues, which we aim to promote to increase the attractiveness towards our journal and to better organize its content. Your contribution will be more than welcome! Meanwhile, moving forward, please share with us your own ideas and suggestions for a special issue in 2019. Acoustics is a broad subject matter that employs hundreds of specialists across the country in diverse fields, so any suggestion is valid. Meanwhile, we are not forgetting our valuable tradition of “regional” special issues, which aims to offer an opportunity to individuals, groups, and companies located around major cities in Canada to show case their chosen areas of specialty. Next issue, in June (2018), we plan to have a special issue for Vancouver (and the province of British Columbia at large). So if you are from this area, please submit your contribution soon as we are already finalizing this issue. For any question, related to this special issue please feel free to contact any one of the guest editors: Sasha Brown (Sasha.Brown@worksafebc.com), Maureen Connelly (Maureen_connelly@bcit.ca), or Roberto Racca (Roberto.Racca@jasco.com).

Finally, I would take the opportunity to report you that the first meeting of the new 2018 Initiative about Local Chapters of the CAA took place on November 23 (2017) at Ryerson University. A Panel discussion about Acoustic Issues and the Building Code, was followed by a lecture of Marshall Chasin titled “Musicians and the Prevention of Hearing Loss”.

As you see, many initiatives are taking place and we hope 2018 will be busier than ever.

I wish you a pleasant reading.

Umberto Berardi,
Editor-in-chief.

pratiquants", un ou deux courts articles (de deux pages) présentant des expériences ou des cas pratiques. Les articles doivent être présentés suivant une démarche « Problème & Solution » et les illustrations, graphiques et photographies, y sont fortement recommandées. La principale exigence pour ces articles consiste à limiter au minimum les informations concernant la compagnie de l'auteur, le *Coin des praticiens* n'étant pas destiné à véhiculer des annonces publicitaires ou tout autre message commercial. Le contenu de la soumission sera examiné par le comité de rédaction pour assurer son adéquation avec la revue. Les auteurs sont encouragés à soumettre leur manuscrit au rédacteur en chef de l'*Acoustique Canadienne* par courriel, en mentionnant que la soumission est destinée au *Coin des praticiens*.

3) *Numéros spéciaux et numéros régionaux*. Dans le courant de l'année, nous publierons un numéro spécial sur l'audiologie et les neurosciences. Ce sera le premier d'une série de numéros spéciaux, que nous promouvrons, pour renforcer l'attrait pour notre journal et mieux organiser son contenu. Votre contribution sera plus que bienvenue ! En attendant, n'hésitez pas à partager avec nous vos idées et suggestions pour un numéro spécial en 2019. L'acoustique est un vaste sujet qui emploie des centaines de spécialistes à travers le pays dans divers domaines, toute suggestion sera valable. Parallèlement, nous n'oublions pas notre précieuse tradition de numéros spéciaux «régionaux», qui a pour but d'offrir aux individus, groupes et entreprises situés dans les grandes villes du Canada une opportunité de présenter leur(s) spécialité(s). Le prochain numéro, en juin (2018), sera un numéro spécial sur Vancouver (et la province Colombie-Britannique). Ce numéro étant en train d'être finalisé, si vous êtes de cette région, n'hésitez pas à soumettre votre contribution rapidement. Pour toute question relative à ce numéro spécial, n'hésitez pas à contacter l'un des rédacteurs invités: Sasha Brown (Sasha.Brown@worksafebc.com), Maureen Connelly (Maureen_connelly@bcit.ca) ou Roberto Racca (Roberto.Racca@jasco.com).

Finalement, je profite de l'occasion pour vous informer que, dans le cadre de la nouvelle initiative de 2018 sur les sections locales de la CAA, la première réunion a eu lieu le 23 novembre 2017 à l'Université Ryerson avec une table ronde sur les enjeux acoustiques du code du bâtiment, suivie par une conférence de Marshall Chasin intitulée «Les musiciens et la prévention de la perte auditive».

Comme vous pouvez le constater, de nombreuses initiatives sont en cours, en espérant que 2018 soit plus occupée que jamais.

Bonne lecture.

Umberto Berardi,
Rédacteur en chef

Scanning Electron Microscopy Of The Basilar Papilla Of The Lizard (*Anolis Carolinensis*)

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Résumé

Le lézard est un modèle utile pour l'étude de la biophysique de la fonction auditive périphérique, notamment parce qu'il possède un organe auditif relativement simple par rapport à la cochlée mammalienne. Pour bien comprendre les mécanismes de l'oreille interne, une description précise et détaillée de l'anatomie est nécessaire. À cette fin, nous décrivons la morphologie et la disposition des cellules ciliées le long de la papille basilaire de l'espèce de lézard *Anolis carolinensis*, telle que révélée en utilisant la microscopie électronique à balayage. Nous fournissons également des détails sur les méthodes d'obtention et de préparation d'échantillons pour le microscope électronique.

Mots clefs : labyrinthe des reptiles, papille basilaire, anolis.

Abstract

The lizard is a useful model for study of the biophysics of peripheral auditory function, not least because it has a hearing organ that is relatively simple compared to the mammalian cochlea. To fully understand inner ear mechanisms, an accurate and detailed description of anatomy is required. To that end *w*e describe morphology and arrangement of haircells along the basilar papilla of the lizard species *Anolis carolinensis*, as revealed using scanning electron microscopy. We also provide details of the methods for obtaining and preparing specimens for the electron microscope.

Keywords: reptile inner ear, auditory papilla, anoles.

1 Introduction

In biological studies of hearing mechanisms, a wide range of animal models has been used. For studies relating the human condition, the mammalian cochlea has has been widely studied, however many non-mammalian vertebrates have an ear structure that appears to be more simple and thus suitable for understanding some basic principles of auditory signal detection [5, 8]. Reptiles in particular have highly evolved inner ear structures and excellent hearing, and within this group the lizards (Lacertilia) have been used in a number of studies of auditory function. In many respects the lizard is an excellent animal model for elucidating biophysical principles of peripheral auditory function. The inner ear is easily accessible and the cochlea equivalent, the basilar papilla, has a less complex structure compared to the mammalian organ of Corti. There have been studies of the variations in hearing sensitivity and frequency range between different lizard types and this animal has been used to study middle and inner ear mechanisms [e.g. 2, 3, 7, 11]. In the present study, we describe some anatomical features of the lizard Anolis carolinensis (fig 1). This species is useful as a model in many scientific studies due to their low cost in breeding and also because the entire genome has been sequenced [1]. The Anolis is particularly useful because it exhibits robust otoacoustic emissions [2, 3, 4].

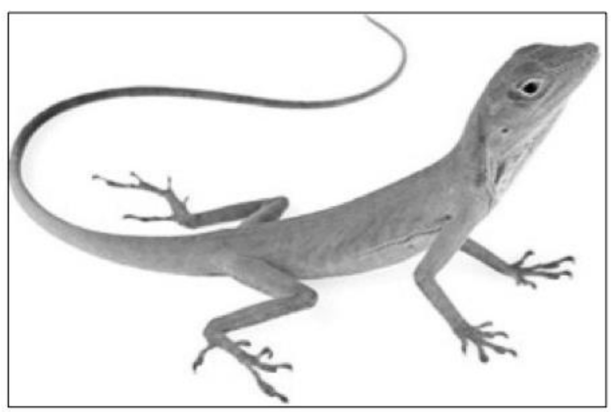

Figure 1: The anolis lizard.

In order to fully understand inner ear function, detailed study of the anatomy and morphology of the sensory epithelium is required. There have been useful descriptions of the anatomy of the basilar papilla using light microscopy, not least the comprehensive studies by Wever [11]. However to obtain an accurate analysis of stereocilia bundle

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structure and the geometric arrangement of haircells, scanning electron microscopy (SEM) is perhaps the best technique available. There have been SEM studies of the inner ear in various lizard species [e.g. 7, 10] but no clear description of the basilar papilla of *Anolis carolinensis*. Furthermore there has been no detailed description of the methodology for obtaining and preparing specimen for SEM study. We provide these methods here, and discuss some aspects of basilar papilla haircell arrangements as revealed using scanning microscopy.

2 Methods

2.1 Inner ear specimen preparation

To prepare the *Anolis carolinensis* lizard for electron microscopy the subject is deeply anesthetized. A 1-2 ml solution of 2.5% gluteraldehyde in sodium cacodylate buffer is injected through the tympanic membrane into the middle ear. Immediately after, the head of the lizard is removed and placed in a solution of the same fixative at 4°C overnight. Once fixed, the head is washed in phosphate buffered saline **(**PBS**)** and then dissected under a microscope to remove the inner ear. This is achieved by surgical removal of the lower mandible to expose the mandibulo-hyoid muscle. This muscle is cut away to expose the boney structure housing the inner ear. The view of structures is schematically represented in figure 2B.

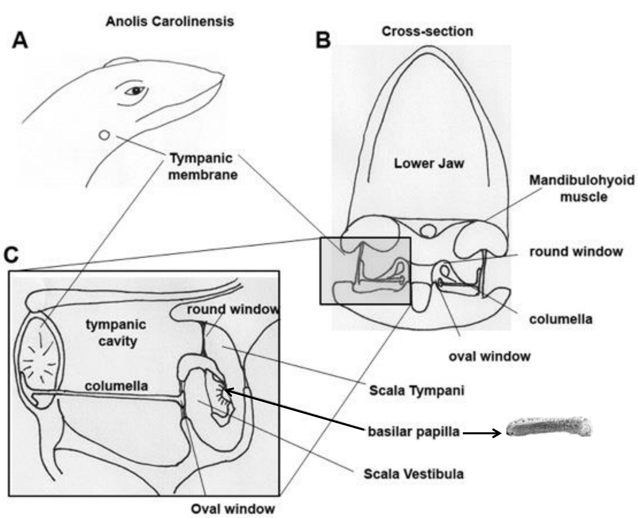

Figure 2: Anatomical landmarks to locate the inner ear of the lizard, and the position of the basilar papilla. Adapted from Wever [11].

From this position, the middle ear columella bone (the equivalent of the mammalian middle ear ossicles) can be seen connecting the tympanic membrane to the oval window (Fig 2B, C). With this exposure the inner ear round window can also be located. At this time, all surrounding tissue is removed, before gently pulling away the columella to expose the oval window of the inner ear. Cacodylate buffer is then flushed through the round window using a 30G needle. The sample is immersed in sodium cacodylate buffer at 4° C overnight.

The following day, the sample is washed in fresh sodium cacodylate for 15 mins. The inner ear is flushed via the round window with 2% buffered osmium tetroxide, 2-3 times using a 30G needle, and then immersed in a solution of 2% buffered osmium tetroxide for 1.5 hours. The specimen is then briefly washed in cold PBS and is ready for a gradual dehydration process.

The sample is submerged and gently shaken for 15 mins in, sequentially, 35%, 50% and 70% solutions of ethanol. Once the dehydration process begins, the specimen should not be exposed to air. Removing most of the fluid from the glass vial, but leaving some to cover the sample can achieve this. The vial is then filled with the next ethanol strength solution. Once the sample is submerged in 70% ethanol, further dissection can be made to open the inner ear and expose the basilar papilla. With very fine forceps, the bone surrounding the round window is gently chipped away in the direction of the oval window, thereby opening up the bony structure of the inner ear. This will expose the tissue that forms a basilar membrane-like structure to which the basilar papilla is attached (fig. 2C). Very gently, this small (and fragile) organ can be removed and transferred to a vial of 90% alcohol on a shaker. The specimen is then further dehydrated in 90% and 95% ethanol for 15 mins each and then washed in 100% ethanol three times for 15 mins. Rinses are done in the same manner as before without exposing the sample to air.

2.2 Scanning electron microscopy

For electron microscopy the basilar papilla specimen undergoes critical point drying, whereby all moisture is removed from the sample by replacing water with liquid carbon dioxide at very high pressure and temperature. The specimen is then mounted on a stub, and gold sputter-coated. This creates a conductive layer of metal on the specimen that reduces thermal damage and improves the electron signal in the microscope. The basilar papilla is imaged at high resolution (5 kV accelerating voltage; magnification 200X) using the Hitachi 3400 microscope (Hitachi, Ltd., Chiyoda-ku, Tokyo, Japan).

3 Results and discussion

An image of the whole basilar papilla is shown in figure 3. Such whole specimens are often obtained, but on occasion there can be breakage. Because the sensory epithelium is not a coiled cochlear structure, apex to base descriptions are not useful. Here we use dorsal–ventral co-ordinates as adopted by Wever [11] and others. In figure 3, dorsal is left, and ventral is right. The length of the organ is 3.5 mm and the width of the haircell-bearing region is about 400 µm.

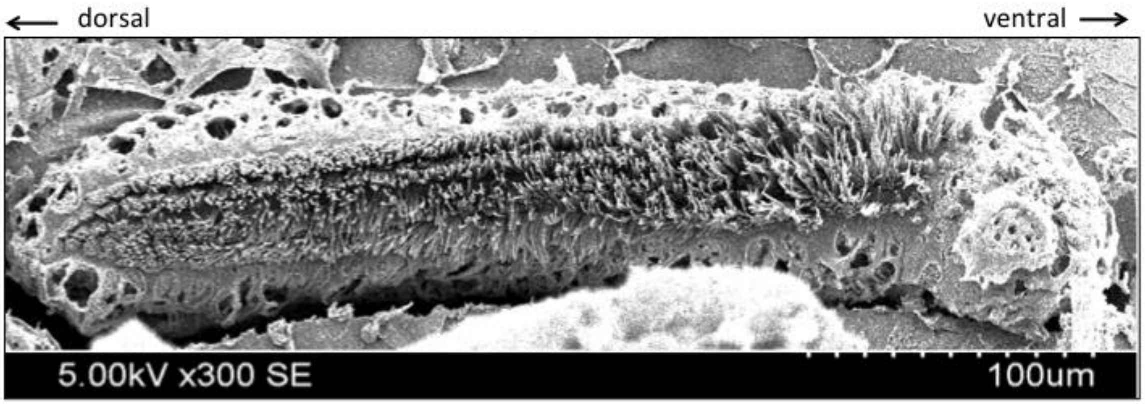

Figure 3: Scanning electron image of the whole basilar papilla of the lizard (Anolis carolinensis). In this image, the dorsal region is to the left, ventral to the right.

The organ has two distinct regions, with a long tapering dorsal section having four rows of haircells, and a ventral section showing evidence of a tectorial membrane structure (see discussion below). The dorsal region, making up 85% of the papilla has, almost uniformly, four rows of haircells. Figure 4 shows the close packing of stereocilia in individual haircells in the dorsal region of the papilla. Each haircell has a bundle of about 50 stereocilia with length gradation, the longest being towards the midline of the papilla.

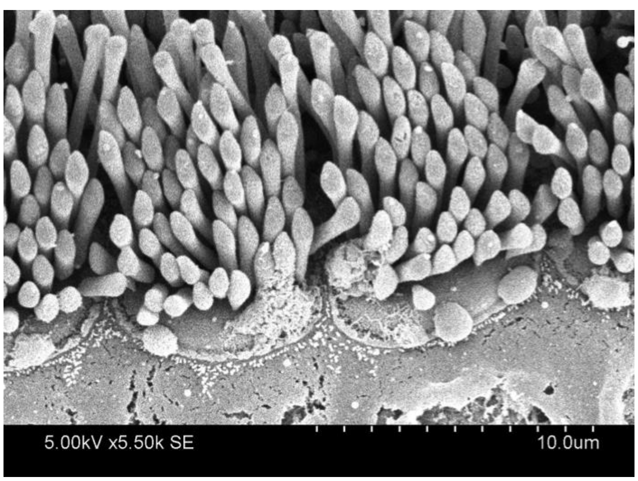

Figure 4: Stereociliar bundles of individual haircells in the dorsal section of the basilar papilla.

Along most of the length of the papilla two rows of haircells have bundle orientation opposite from the other two rows as illustrated in figure 5. From the SEM images there appears to be no tectorial membrane or other overlying structure in this region. This is consistent with other descriptions of lizard ears [11]. However we should note that preparation artifacts (especially dehydration) can shrink or distort delicate tectorial tissue.

Along the dorsal segment of the organ, the length of the longest stereocilia changes significantly as shown in figure 6. At the extreme dorsal tip of the tapering papilla, the (largest) stereocilia are less than 5 µm. It is not clear whether the very small haircell bundles at the extreme tip of the papilla are mature haircells or new cells being generated. It is possible that this is an area of regeneration of the sensory epithelium. In the ventral direction stereocilia length progressively increases, and we note (fig 6) long 20-30 µm stereocilia at the end of this region. The progression in stereocilia length along the papilla is not strictly linear; there appear to be sectional changes. For the haircells with long stereocilia we can often see a longer thinner kinocilium. At the ventral boundary edge of this region of long stereocilia we see smaller haircells; as with the dorsal tip of the papilla these might be newly generated haircells.

At the ventral end of the basilar papilla is an almost separate sensory epithelium in which the haircells are not in four orderly rows, and have relatively short stereocilia (5-10 µm). As shown on figs. 3 and 7 we note a tectorial plate structure that overlies some of the haircells. We suggest that this whole area is normally covered with a tectorial membrane but only this plate or sallet remains in this SEM specimen.

In figure 8 we illustrate this dorsal region in another specimen where the tectorial plate or sallet has been removed, showing the (somewhat disrupted) haircell bundles beneath. In this image we can note that some of the haircells have lost some of all of their stereocilia. This results from the close attachment of the hair bundle to the tectorial plate that, when removed, takes with it some of the stereocilia. Wever [11] has used a lizard family classification system based on the tectorial membrane characteristics of the basilar papilla, and has defined the Lacertidae as having a “combined tectorial and sallet system of ciliary restraint”. This is consistent with our observations here in *Anolis carolinenis.*

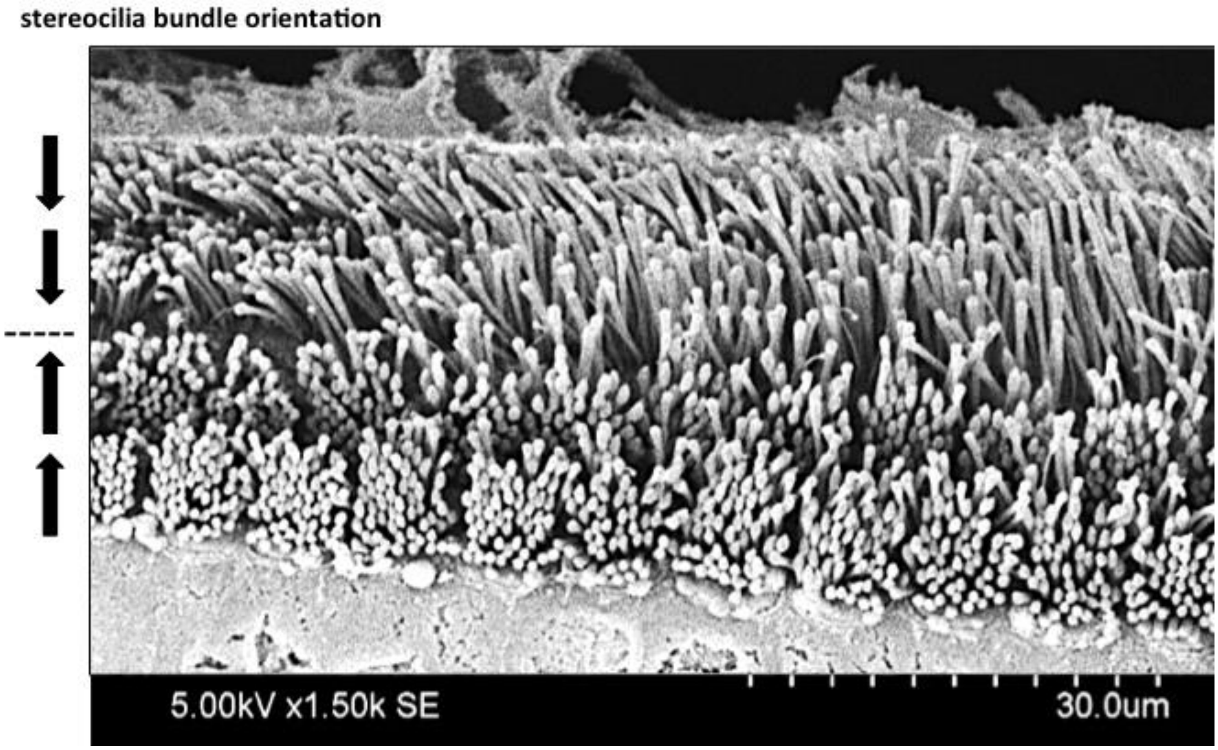

Figure 5: Stereocilia orientation of four rows of haircells along the dorsal length of the basilar papilla.

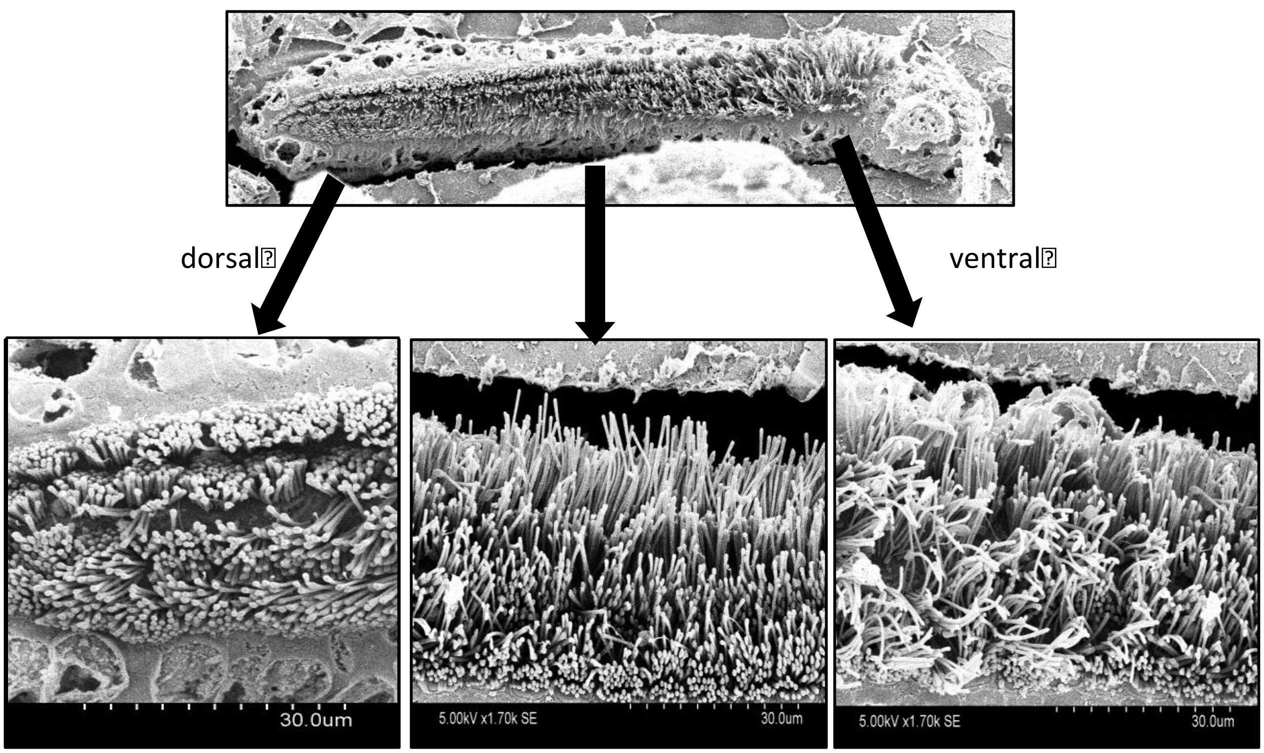

Figure 6: Changes in haircell stereocilia length according to position along the basilar papilla.

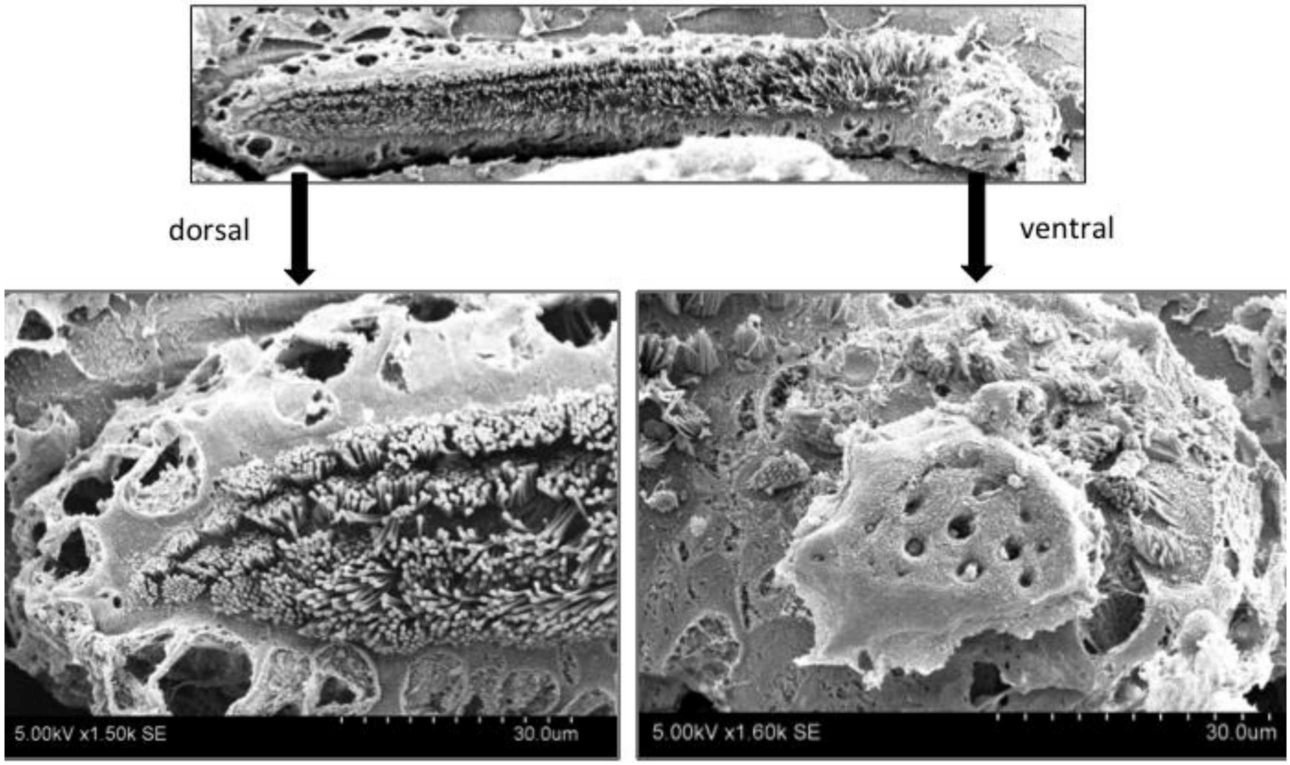

Figure 7: Haircells with short stereocilia at both extremes of the basilar papilla. At the dorsal tip (left image) small rudimentary haircells appear to be regenerating. At the ventral end (right image) remnants of a tectorial plate or sallet partially covers the short stereocilia haircells.

4 Conclusion

We have provided here a complete description of methods to prepare inner ear specimens from the lizard species *Anolis carolinensis* for scanning electron microscopy. We have made a detailed description of the auditory end-organ, the basilar papilla, as revealed using SEM.

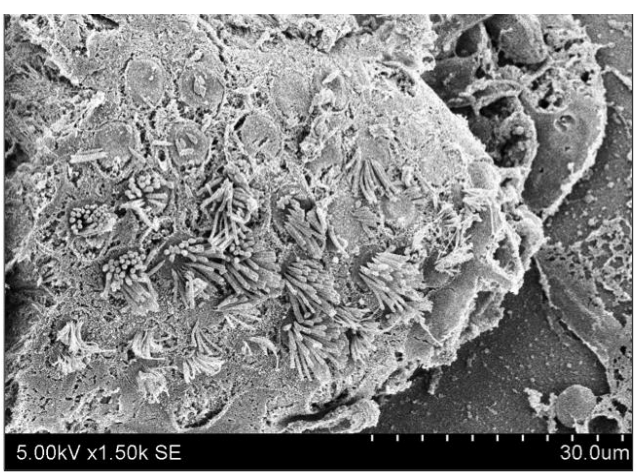

Figure 8: The ventral region of the basilar papilla showing short stereocilia haircells after removal of an overlying tectorial plate or sallet.

Acknowledgements

Support for this study has come from the Harry Barberian Scholarship Fund, Department of Otolaryngology – Head & Neck Surgery, University of Toronto.

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Impact Of Traffic-Related Environmental Noise On School Children And Teachers In a Brazilian City

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Résumé

Les bruits environnementaux dans les zones urbaines sont connus pour provoquer des anomalies fonctionnelles, reflétées dans le comportement et la santé humaine. Dans les pays en développement tels que le Brésil, les écoles publiques sont exposées à des niveaux de bruit élevés à cause des mauvaises infrastructures, en particulier dans le domaine de la protection contre le bruit. Dans les écoles exposées à des niveaux de bruit au-dessus des limites fixées par les normes et directives internationales, les étudiants et les enseignants sont à risque plus élevé de problèmes de santé et leur performance peut être compromise. Dans la présente recherche, nous avons évalué l'impact du bruit environnemental sur les enfants et les enseignants de trois écoles publiques (une école maternelle, une école primaire et une école secondaire) d'une métropole du nord-est du Brésil, en mettant l'accent sur le bruit généré par le transport routier, le métro et le transport aérien qui sont d'importants générateurs de bruits dans les centres urbains. Des cartes de bruit environnemental ont été générées et les enseignants ont reçu des questionnaires centrés sur l'impact de la pollution sonore sur la santé et les résultats des élèves. Cette recherche visait à soutenir les efforts de la planification urbaine et de politique publique, à travers une mesure réel des niveaux de bruit et de leurs effets possibles. Les résultats démontrent la nécessité d'adopter des mesures de traitement acoustique dans les milieux scolaires et d'appliquer plus fermement les réglementations à propos des émissions sonores dans les transports publics.

Mots clés: pollution sonore, cartographie acoustique, évaluation du bruit, limites du bruit, bruit dans les écoles.

Abstract

Environmental noise in urban areas is known to cause functional abnormalities reflected in human health and behavior. In developing countries such as Brazil, public schools are exposed to high levels of noise due in part to poor infrastructure, especially with regard to noise attenuation. In schools exposed to noise levels above the limits specified by regulations and international guidelines, students and teachers are at greater risk of health problems, and performance may be compromised. In this study we evaluated the impact of environmental noise on children and teachers at three public schools (a kindergarten, an elementary school, and a high school) in a Northeast Brazilian metropolis, with emphasis on noise generated by street, above ground rail and air traffic. Environmental noise maps were generated and teachers were administered questionnaires focusing on the impact of noise pollution on health and performance. The study was intended to subsidize efforts at urban planning and public policy making by measuring actual noise levels and probing their possible effects. As shown by our results, public schools are in urgent need of noise attenuation measures, and enforcement of noise emission regulations for public transportation needs to be more emphatic.

Key words: Noise pollution. Noise mapping. Noise assessment. Noise limits. Noise in schools.

1 Introduction

Public schools in developing countries such as Brazil are often strongly impacted by environmental noise associated with heavy traffic and the absence of proper noise attenuation due to insufficient investments in infrastructure. In this study we looked at the impact of environmental noise on school children and teachers in Fortaleza, a state capital in Northeastern Brazil. To do so, we assessed the acoustic characteristics of three public schools exposed to environmental noise generated primarily by street, above ground rail and air traffic.

According to WHO guidelines [1], noise is the second-most important source of pollution worldwide, and noise levels over 70 dB(A) can cause illness. While noise is generally defined as an undesirable sound, perception varies from one individual to another, depending on interest: a

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sound perceived as attractive by one individual may be intolerable to others [2].

Environmental noise is known to cause functional abnormalities reflected in physical and behavioral health. Powaska et al. [3] have shown that high noise levels cause the organism to release adrenaline into the blood stream, associated with changes in heart rate and blood pressure. Lee et al. [4], using data of male workers of a metal manufacturing factory, from a period of 9 years, established that “chronic noise exposure increases SBP (systolic blood pressure) independently”. In a broader sense, considering the general population, it is usually recognized the need of more evidences of these effects [5–7] . However, Basner et al. [8] state that "Evidence of the non-auditory effects of environmental noise exposure on public health is growing".

The WHO [1] has concluded that noise pollution can affect the health and academic performance of children and adolescents. In fact, school children constitute a particularly vulnerable group. Noise levels over 80 dB(A) are believed to increase aggressiveness and withdrawal in children. According to the same report, exposure to undesired sounds increase listening and reading difficulties, attentional dispersion and irritability among students, compromising communication. Average noise levels in classrooms should not exceed 35-40 dB(A). Levels between 50 and 65 dB(A), though acceptable, can induce mild stress which may develop into loudness discomfort, hypervigilance and anxiety over time [9]. Asuquo et al. [10] cautions about the potential for noise-induced hearing loss due to exposure to loud noise. They state also that “Noise is a disturbance to the human environment that is escalating at such a high rate that it will become a major threat to the quality of human lives if nothing is done to reduce it”.

High noise levels can also lead to the development of occupational voice disorders and is one of the main causes work-related diseases [11]. As shown by Oliveira [12], noise in the work environment is an important source of health problems among school teachers. The negative effects of noise pollution include cognitive fatigue, memory loss, loss of ability to perform complex tasks, irritation, tension, headache and occupational dissatisfaction. Fiorini and Matos [13] compared health complaints and discomfort reported by teachers from two public schools, one located in a relatively quiet neighborhood where noise was mostly produced by the students, and one located downtown where noise was primarily external to the school. The teachers of both schools reported working in a noisy environment, but voice disorders were less frequent in the first school (44.4%) than in the second (50%).

To reduce the negative effects of noise pollution on the well-being of the population and on public spending, the problem must be clearly defined based on information collected in real-life scenarios. The purpose of the present study was to evaluate the impact of primarily traffic-related environmental noise on school children at different ages.

2 Noise from urban traffic

Calixto [14], Gilbert [15], Griffiths and Langdon [16] and Langdon [17], among many others, have identified traffic as the main source of noise pollution in the urban setting. The pollution results from a blend of multiple sounds generated by cars, trucks, motorcycles, buses, trains and airplanes at different speeds and rates of acceleration. Toronto Public Health [18] points out some evidences relating the prevalence of heart diseases among people disturbed by road or air traffic noise.

Land vehicles (especially cars and buses) are the most common form of commuting in cities, resulting in an intensive traffic flow and an increasingly congested street network. Some large cities also have a rail service running underground or at ground level. In the latter case, it constitutes a major source of noise pollution.

Many Brazilian cities have grown in disorderly fashion, with almost no urban planning, generating an array of environmental problems, including noise pollution. A study conducted by the Civil Aviation Institute [19] in Rio de Janeiro proposed cut-off values predictive of complaints from communities exposed to different noise levels (Table 1).

Table 1: Noise levels and expected reactions.

IPR* Level (dB(A))	**Reaction**
≤ 53	No reaction expected
53-60	Moderately noisy environment. Many complaints expected.
> 60	Extremely noisy environment. Complaints expected from nearly all residents. Community action expected.

* IPR – *Índice Ponderado de Ruído (Portuguese for weighted noise index), similar to L_{dn} (day night level).* Source: IAC [19]

Relster (apud Öhrström [20]) concluded that seeking psychological care, using tranquilizers and receiving treatment at psychiatric facilities were significantly more likely among residents of noisy neighborhoods than residents of quiet areas in Copenhagen. Formal complaints also become more numerous as noise levels rise. Fyhri and Aasvang [21] models produced results that lead to similar conclusions for the city of Oslo.

In a study on teacher-student communication, Oliveira Nunes and Sattler [22] evaluated the interruptive effect of periodical flyovers. All the interviewed teachers reported being seriously annoyed by the noise and having to raise their voice in the classroom. Likewise, 79% of the students reported having to raise their voice during flyovers, and 72% experienced difficulties understanding the teacher. The teachers agreed the noise had a negative influence on student performance.

Based on 149 measurements, Alves Filho [23] found Brazilian vehicles to emit louder sounds than British vehicles, as measured by Cromptom and Gilbert [24]. The deleterious effects of environmental noise on the health and behavior of urban populations are conceivably more relevant in Brazil than in Europe and the US, highlighting the importance of the present study.

3 Methods

Three public schools (a kindergarten, an elementary school and a high school) were selected for a case study, covering children and adolescents between 3 and 18 years of age. The facilities were located in areas with different environmental noise profiles.

The international airport of Fortaleza (Pinto Martins) is located in the geometrical centre of the metropolis, with the runway oriented along an east-west axis. The adjacent areas are subject to special municipal by-laws of occupation and noise protection, but this is not always complied with. In addition, most of the rail track (which runs north-south) is at ground level or elevated, producing a considerable acoustic impact on the immediate surroundings.

Figure 1 shows the location of the three schools, the rail tracks and the airport approach/departure corridor. The streets in the vicinity of the schools were classified as local, collector, arterial or highway, in accordance with the terminology employed by the law instituting the city's master plan [25].

- School #1 is for children aged 3-9 years. It is located in a quiet residential neighborhood, surrounded by local streets with low traffic flow (Figure 2).
- School #2 is attended by students aged 11-15 years. It is located in an area strongly impacted by street, above ground rail and air traffic, along an airport approach corridor (flyovers at 200 m altitude). The building abuts on an arterial with medium traffic flow. The external wall behind the building is a few meters away from the above ground rail track (Figures 3 to 6).
- School #3, the largest of the three schools, is attended by adolescents aged 11-18 years. It is located on an urban highway with intense traffic flow, along the airport departure corridor, though a little further removed from the airport than School #2 (Figures 7 to 9).

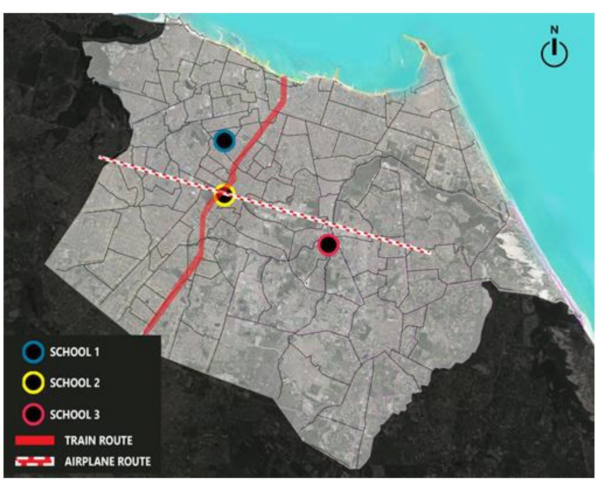

Figure 1: Map of Fortaleza showing the location of the three schools, the rail track and the airport approach/departure corridor .

Figure 2: External view of School #1.

Figure 3: External front view of School #2.

Figure 4: External back view of School #2. Note the proximity to the above ground rail tracks.

Figure 5: View from school #2

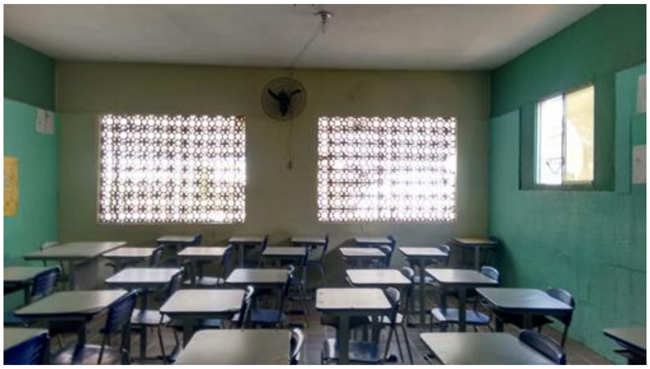

Figure 6: Classroom in School #2. Note the windows/vents.

Figure 7: External front view of School #3.

Figure 8: Another external view of School #3, left of the highway.

Figure 9: Noise measurement equipment deployed in a classroom in School #3.

Urban legislation

The WHO [1] recommends an external noise limit of 55 dB(A) for playgrounds and schools, but according to Maschke [26], a limit of 65 dB(A) is more realistic in densely urbanized areas. Canadian environmental noise guidelines [27] establish a limit of 50 dB(A) for Class 1 areas (urban centers with mostly street traffic-related environmental noise) between 7 am and 11 pm, and 55 dB(A) for outdoor living areas with greater exposure to external noise.

In Fortaleza, Law #8097 [28] specifies a limit of 55 dB(A) (daytime) or 50 dB(A) (nighttime) for noise emitted by machines, engines, compressors and stationary generators. For other types of noise (e.g., loudspeakers), 70 dB(A) (daytime) or 60 dB(A) (nighttime) is permitted. Vehicle noise emissions are regulated by federal law. Brazilian noise level regulations [29] are based on zoning criteria. Thus, School #1 is located in a zone classified as "mixed but predominantly residential", while Schools #2 and #3 are located in "mixed areas (residential and commercial) with commercial and administrative vocation" (Table 2).

Noise maps

The noise level was modeled and predicted using noise maps, as described by Garavelli et al. [30], Costa *et al.* [31], Guedes [32] and Souza Filho *et al.* [33], among others. Noise maps were produced with the software package Computer-Aided Noise Abatement (CadnaA) [34] displaying sound levels at 5 dB intervals, with color coding according to international standards [22]. They were subsequently validated by on-site measurements. The maps allowed to conduct individual and multiple analyses of the impacts of each noise source (street traffic, above ground rail traffic, industry and other linear and punctual emissions).

Basemap and landscape

Each of the selected schools was localized within a 400 m x 400 m block on the 2010 basemap of Fortaleza, and information on the immediate surroundings was gathered, including the height of buildings and major noise sources. The landscape was subsequently corrected and updated based on Google street views (2016). Perforated/porous surfaces (e.g., vents, windows, perforated bricks) were considered void (classrooms in public schools have permanently open vents or windows due to high temperatures and lack of air conditioning).

Table 2: Criteria for maximum acceptable noise levels in external environments, according to NBR 10151/2000.

Environment	Daytime dB(A)	Night dB(A)	School
Country houses and farms	40	35	
Strictly urban areas, hospitals, schools	50	45	
Mixed, predominantly residential	55	50	#1
Mixed, commercial and administrative vocation	60	55	#2 #3
Mixed, recreative vocation	65	55	
Predominantly industrial	70	60	

Street traffic flow

To collect information on street traffic flow we adopted the methodology used by the authors of the Acoustic Map of Fortaleza [35]. Traffic flow was quantified on weekdays between 9 and 10:30 am and between 2 and 4 pm, coinciding with school hours, during the first term of 2017, by measuring the flow of motorcycles, cars, trucks and buses for 15 minutes. Hourly traffic flow was then estimated by multiplying the number of observed vehicles by 4. The vehicles were classified according to weight: light (motorcycles, cars, pick-ups, minivans) and heavy (trucks and buses). The street classification was updated according to the observed traffic flow (Table 3).

Air traffic flow

Information on the number of commercial airliners flying over School #2 during the study period (Table 4) was retrieved from the database of the government agency operating the airport [36]. At Schools #2 and #3, air traffic-related noise was recorded according to frequency range and expressed in LAeq (mean frequency for the sampling period) using a sound meter (DEC 5030 Class 2). The temperature was 30-31ºC and the air velocity was ~2 m/s.

Rail traffic flow

Information on the flow of the north-south rail line (most of which is at or above ground level) was retrieved from reports provided by the government agency running the service (Metrofor). The 80-m long trains run at 21-min intervals each way between 6:34 am and 8 pm, at up to 70 km/h. Rail traffic-related noise frequency ranges were recorded at School #3.

Data management and software

The collected data was stored in a database generated with the software CadnaA [34]. Several factors interfering with sound propagation were considered, including vegetation, absorption in the atmosphere, reflection and diffraction, in order to quantify attenuation caused by barriers and reflection from opposite surfaces, as recommended by Quartieri et al. [37].

The model RLS90 was used in the analysis of hourly vehicle flow. The streets were processed as linear sources divided into segments processed by the program as punctual sources with noise levels in accordance with the characteristics of the traffic and the physical environment. Inputs included street name, width, pavement type, flow direction, and hourly daytime flow of vehicles (volume, composition and speed).

The SRM II model was used in the analysis of rail traffic flow by entering noise levels for frequency ranges between 31.5 and 8000 Hz (Table 5). Inputs included train type (with noise levels predetermined by the program), maximum speed at the study location, hourly flow, wheelset, track structure, and the presence of expansion joints.

Table 3: Street traffic flow outside the three schools.

Vehicles flow in 15 min			
	Motorcycles	Cars	Trucks
School #1	17	41	1
School #2	163	308	53
School #3	505	1656	115
Number of vehicles in the period			
	Type of street	light vehicles	heavy vehicles
School #1	Collector	231	2.32%
School #2	Arterial	1871	12.3%
School #3	Highway	8604	5.82%

Table 4: Average number of flights at the international airport of Fortaleza (Pinto Martins)

Period	**n**
6 am to 9 am	5
9 am to 12 am	20.6
12 am to 3 pm	36
3 pm to 6 pm	9.8
6 pm to 9 pm	13.4
9 pm to 12 pm	25
12 pm to 6 am	9

Source: INFRAERO [36]

Questionnaire and interview

Seven teachers from each school filled out standardized questionnaires containing nine questions focusing on the impact of noise pollution on occupational health and student performance. Subsequently, a short interview was conducted to give the teachers the opportunity to make additional observations relevant to the problem. The interviewees represented 88%, 58% and 55% of the teaching staff at Schools #1, #2 and #3, respectively.

4 Results and discussion

The results of the study are presented in two sections: analysis of on-site measurements and noise maps, and analysis of the teachers' responses to the questionnaire and interview.

Table 5: Distribution of traffic-related noise measured at Schools #2 and #3 according to frequency range.

			Octave Spectrum (dB)									
School	Traffic	Time	31.5Hz	63Hz	125Hz	250Hz	500Hz	1kHz	2kHz	4kHz	8kHz	L
#2	street	fast	13.9	30.8	39.0	38.0	40.0	43.5	43.1	42.5	30.4	64.5
#2	street + air	fast	22.5	36.7	54.7	62.5	65.5	67.3	67.8	63.9	54.3	81.6
#2	street + rail	fast	28.0	47.6	62.7	68.0	65.7	58.7	52.5	45.5	33.5	87.2
#3	street	fast	23.4	39.3	49.6	55.1	52.7	58.1	56.3	50.7	40.4	75.8
#3	street + air	fast	21.3	40.5	48.2	54.4	57.6	59.9	57.8	49.9	39.1	75.8

4.1 On-site measurements and noise map analysis

The results of the noise maps were validated by on-site measurements (Table 6). At each sampling point, 10 measurements were taken at 30-s intervals. The LAeq values were calculated using Equation 1 [38]:

$$LAeq = 0.01(L90 - L10)^2 + 0.5(L90 + L10) \quad (1)$$

Table 6: Comparison between noise levels modeled with the software CadnaA and on-site measurements, values in dB(A).

Traffic		School #1	School #2 Front	School #2 Back	School #3
Street	External	62.6	67.8	59.1	67.2
	CadnaA	64.0	68.0	59.0	70.0
Rail	External		71.3	73.1	
	CadnaA		71.0	71.0	
Air	External		67.2	69.3	
	CadnaA		70.0	74.0	

The Brazilian legislation provides no guidelines for this type of measurement. We therefore adopted the criterion of the Portuguese Environmental Agency, according to which a difference of up to +/- 2 dB between simulated and measured values is acceptable [39]. Silva [40] points out that more flexible criteria (up to +/- 4 dB) may be used in urban settings. The points on the noise map selected for validation were those providing technically adequate measurement conditions. The data obtained on calibration confirmed the values obtained with the noise map modeling.

The street noise map for School #1 (Figure 10) indicates low traffic flow and quiet surroundings, especially inside the blocks. Noise levels were 60-64 dB(A) on local streets and up to 73.7 dB(A) on the nearest collector. According to Brazilian regulations, the average noise level of "mixed, predominantly residential areas" should not exceed 55 dB(A). The façade of the building was exposed to noise at 64 dB(A), but behind the building, on the same side as the patio, the level of external noise was only 43 dB(A). Figure 11 presents the results for this school of a three-dimensional modeling (3D) of the noise levels at the building facade and patio.

Figure 12A is a street noise map for School #2, showing a noise level of 75 dB(A) in front of the building (facing an arterial) and 62 dB(A) behind the building (facing a local street, and closer to the elevated rail tracks). Figure 12B shows the combined effect of street and rail traffic-related noise (front=76 dB(A), back=71 dB(A)). Figure 12C combines all three sources of traffic-related noise (front=79.8 dB(A), back=74 dB(A)). The frequency of train runs (interval=21 min, each way) and commercial flights (interval=12 min) was confirmed by on-site observation.

A broader view of School #2 area and the noise impacts of street traffic are presented in Figure 13. These effects only are well above the legal limits. During flyovers and trains going past the above ground rail system, noise levels in the most exposed classrooms peaked at 76.4 dB(A) and 80 dB(A), respectively, on the side facing the arterial, and 78.9 dB(A) and 83.1 dB(A), respectively, on the side facing the tracks. These levels are well above the ideal (≤ 45 dB(A)) and acceptable (≤ 65 dB(A)) levels recommended by Thiery and Meyer [41] for classrooms. The 3D modeling of the noise impacts on School #2 facade and patios is shown in Figure 14.

On the highway outside School #3, noise levels reached 83.5 dB(A). Due to the absence of acoustic barriers, the school façade was impacted at 70 dB(A). Inside the building, on the side facing the highway, the level was 67.8 dB(A), the highest value observed in the study when considering street traffic alone (Figure 15). Both School #2 and #3 are located in zones classified as "mixed areas with commercial and administrative vocation", for which regulations specify an external noise limit of 60 dB(A). The WHO has concluded that undesirable sounds, such as noise generated by passing trains and airplanes, compromise the intelligibility of oral communication, with negative impacts on concentration, attention and well-being.

4.2 Analysis of questionnaires and interviews

School #2 was the oldest in the sample. Not surprisingly, the average time of employment of the teachers at this school (6.1 years) was longer than at School #1 (4.2 years) or School #3 (1.9 years) (Figure 16). Most teachers considered the work environment very or extremely noisy, with no significant difference between the schools (Figure 17).

The responses to Question #3 (Figure 18) revealed that the impact of external noise was much smaller at School #1 than at School #2 or School #3. Since all three schools were exposed to high noise levels, it follows that the noise perceived by the teachers at School #1 was from internal, non-traffic-related sources. School #1 is for children aged 3-9 years, and space is very limited. In fact, all teachers at School #1 observed a very significant difference in student behavior between classrooms facing the patio (higher noise level) and classrooms facing the street (lower noise level). The internal noise was generated by student activities during breaks.

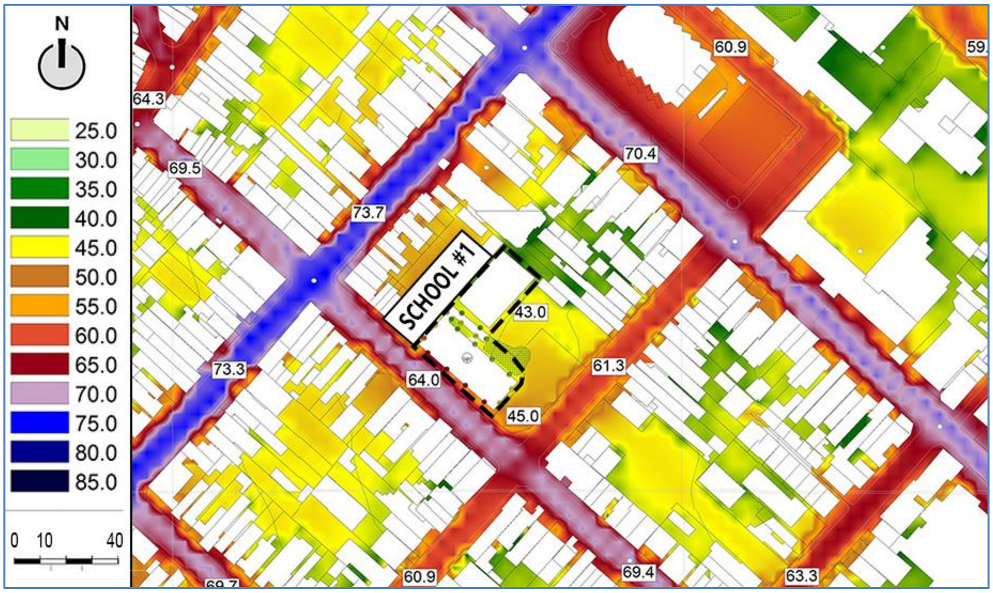

Figure 10: Street noise map of area surrounding School #1.

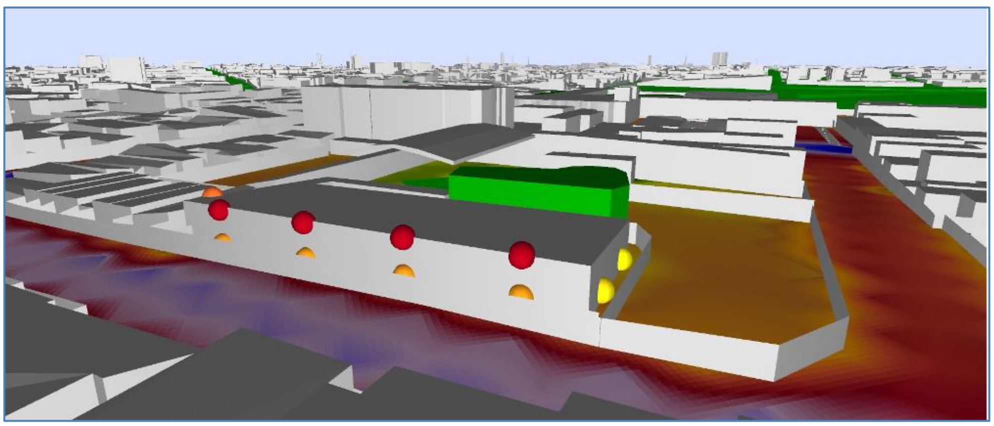

Figure 11: 3D modeling of street traffic noise for School #1

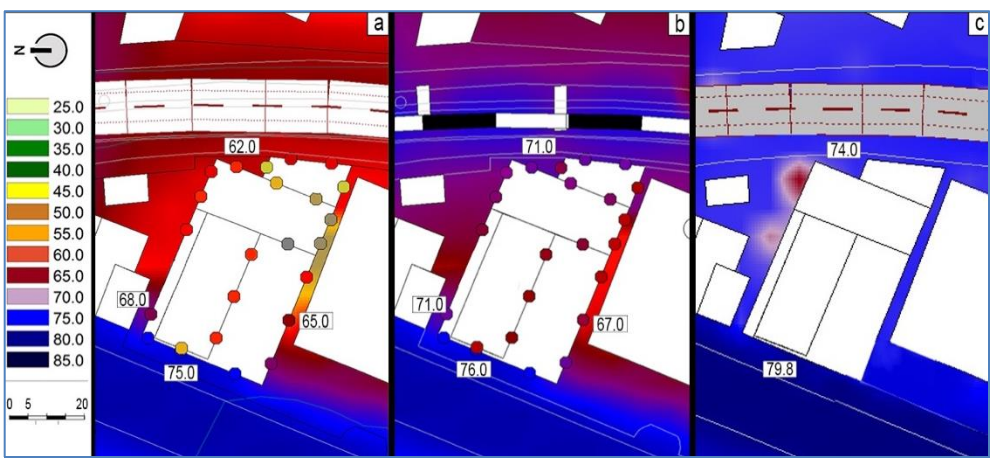

Figure 12: Interference of traffic-related noise at School #2. A: street traffic, B: street + rail traffic, C: street + rail + air traffic.

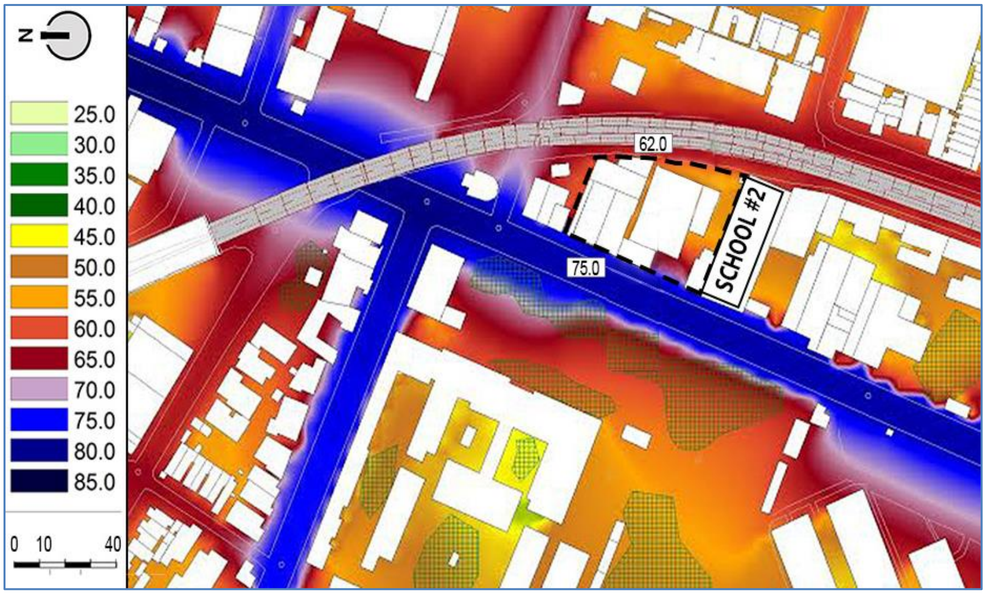

Figure 13: Street noise map of area surrounding School #2.

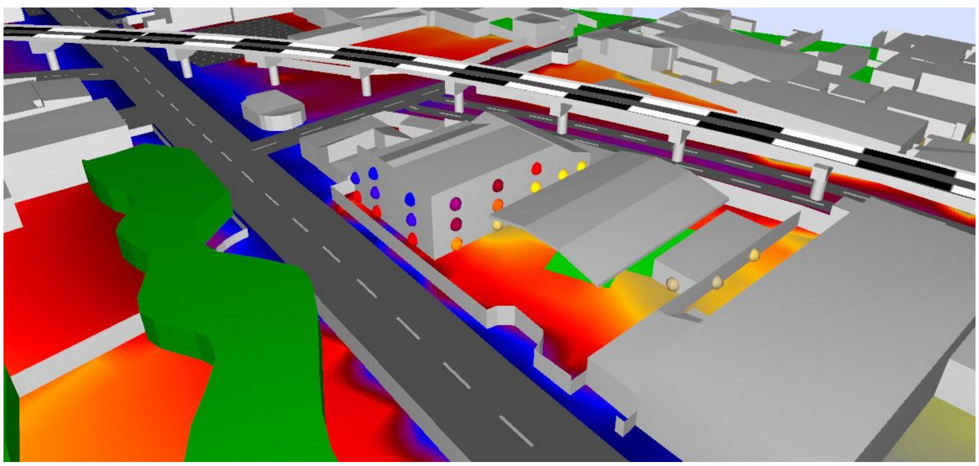

Figure 14: 3D modeling of street traffic noise for School #2

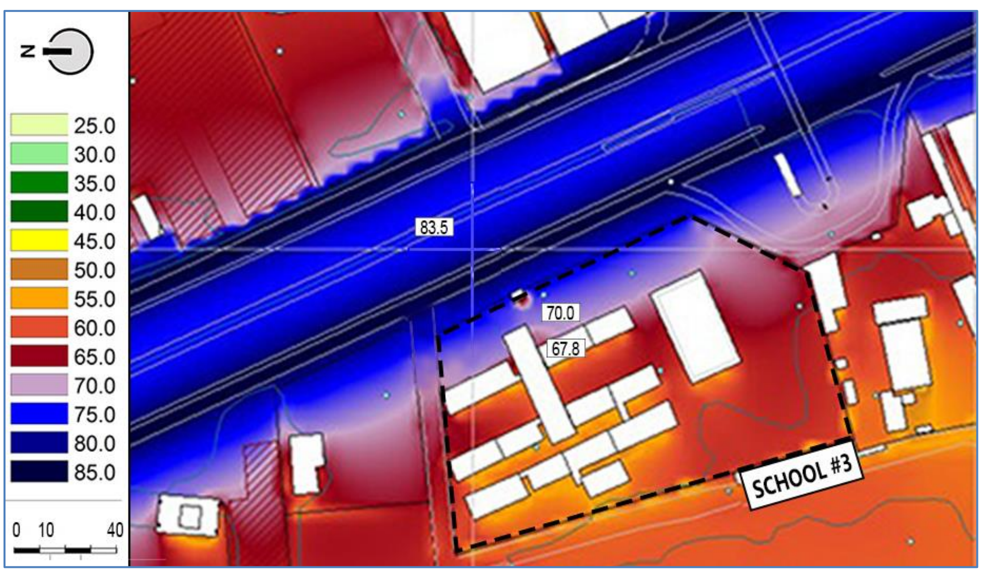

Figure 15: Street noise map of area surrounding School #3.

The teachers reported frequent problems with distraction, agitation and loss of concentration during classes, making it necessary to raise the voice.

School #2 was impacted by all three forms of traffic. Over half the teachers considered the noise from street and above ground rail traffic very or extremely annoying, but only 20% were annoyed by noise from airplanes. This is supported by the finding that peak noise values were higher for rail traffic than for air traffic.

In School #3, over 80% of the teachers attributed high or extreme relevance to noise from buses, cars, trucks and, above all, motorcycles. Our measurements did not show high levels of air traffic noise, but some of the teachers reported being annoyed by it (Figure 19).

Over half the teachers at School #2 had not observed relevant differences in student behavior between classrooms with high and low noise levels (Figures 19 and 20). According to some, differences in behavior were primarily associated with socioeconomic background and immaturity. In contrast, at School #3, where students are over 15 years old (thus more mature), over half the teachers reported a big or extreme difference in behavior between classrooms with high and low noise levels.

In addition to loss of concentration associated with traffic noise, the students also suffered from visual distraction (Figures 21 and 23): the street was visible through the open window/vent, which served as a source of light and ventilation due to high daytime temperatures and the prohibitive cost of air conditioning. Unsurprisingly,

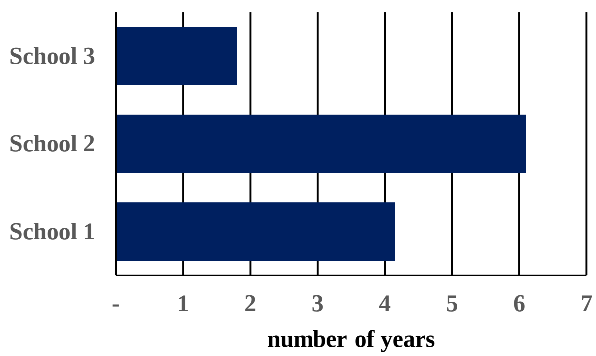

Figure 16: How long have you worked at this school?

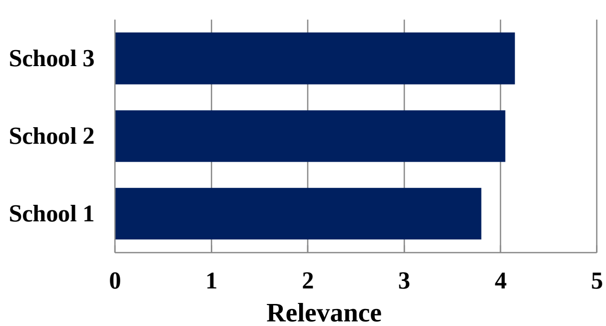

Figure 17: How relevant is noise in the workplace?

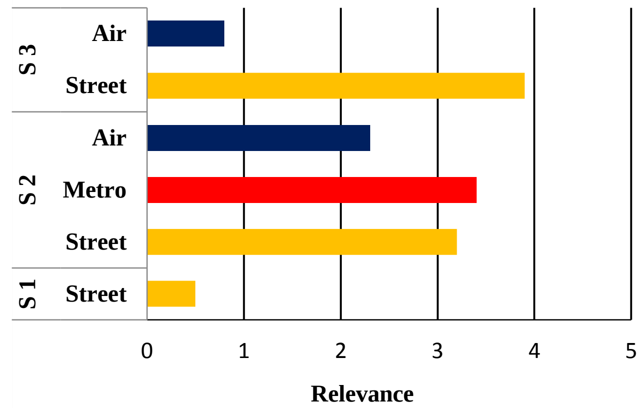

Figure 18: How relevant is external, traffic-related noise?

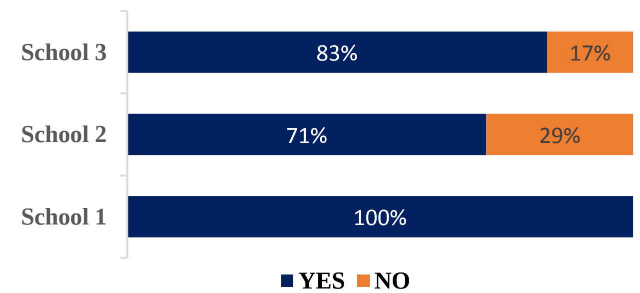

Figure 19: Do you perceive any difference in student behavior between classrooms with high and low noise levels?

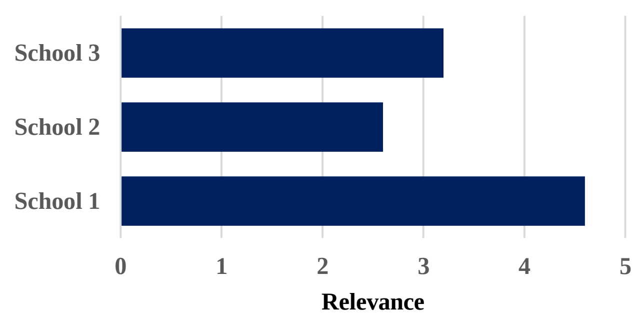

Figure 20: What is the relevance of this difference?

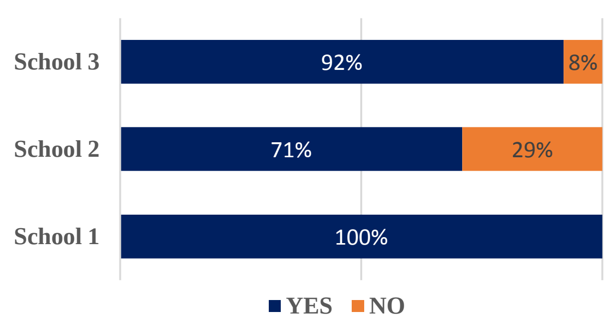

Figure 21: Is teaching more difficult in noisy classrooms?

the students furthest removed from the blackboard had greater difficulties understanding the teacher. To mitigate this difficulty and prevent vocal fold injury, some teachers resorted to using microphones during class.

The questionnaire included items about health problems associated with high noise levels in the work environment (Figures 12 and 24). Problems such as hoarseness, sore throat, stress and hearing loss were reported by all teachers at School #1, and by some of the teachers at the other two schools. Two teachers at School #1 were receiving treatment for vocal fold injury.

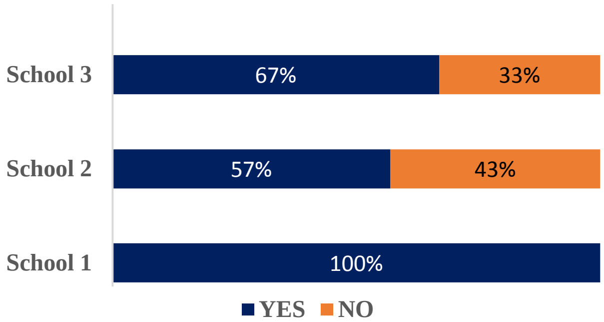

Figure 22: How you observed any health problems associated with noise in the workplace?

5 Conclusion

In this study we found three public schools in Fortaleza to be highly impacted by traffic-related noise pollution. The observed noise levels were above the maximum limits allowed by national and international legislation, as shown by the noise maps produced.

The limits were exceeded even at School #1, which is located in a relatively quiet neighborhood. In this case, the noise was from internal rather than external sources, due to questions of architecture and grade (age). The most severe impacts were observed at School #2, which was exposed to intense noise pollution from street, above ground rail and air traffic. School #3 was mostly affected by noise from street traffic, but noise levels were higher than at the other schools due to the intense highway flow and the absence of acoustic barriers.

The teachers' responses to the questionnaire revealed the existence of health problems, such as hoarseness, stress and vocal fold injury, attributable to noise pollution in the work place. The students displayed noise-related behavior changes, including agitation, learning difficulties, loss of concentration and visual distraction during classes, potentially compromising academic performance.

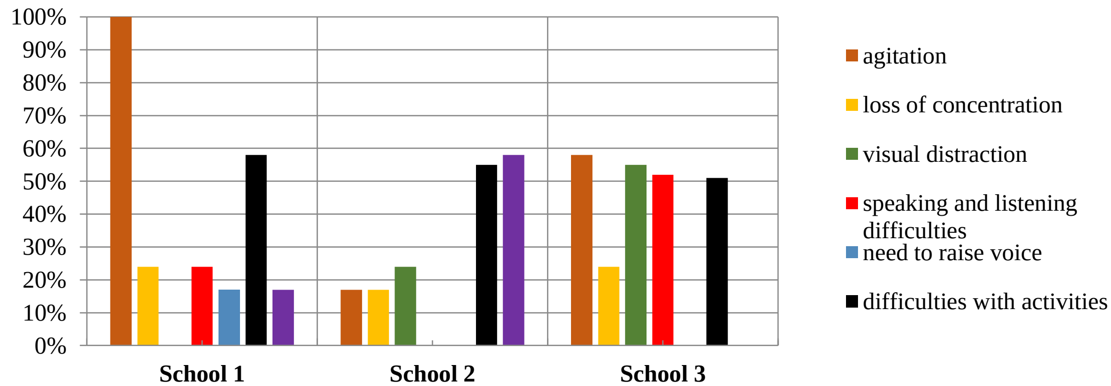

Figure 23: What are the teaching difficulties?

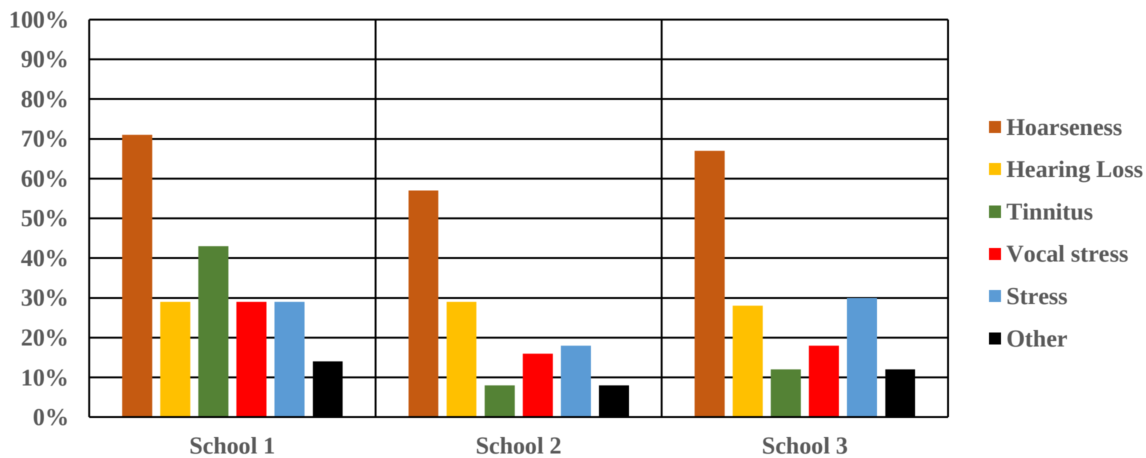

Figure 24: What noise-related health problems have you observed?

Our results highlight the importance of implementing stricter public policies for protecting school children against environmental noise pollution. To do so efficiently, urban development plans and regulations should be carefully revised, and more funds should be allocated to endow urban infrastructure and public schools with acoustic protection. The problems identified in this study may also be mitigated by stronger enforcement of noise emission regulations for public transportation, a major source of environmental noise pollution.

It is hoped our findings will serve as subsidy for urban planners, encourage greater allocation of public funds to noise protection measures (especially in schools) and highlight the need for controlling noise emissions by vehicles and monitoring health deficits associated with noise pollution.

Public schools play a crucial role in emerging economies like Brazil. However, many schools lack adequate physical infrastructure and protection. The children and adolescents attending such schools are highly vulnerable, biologically and psychologically, to the noise-related health problems observed in this study.

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ACOUSTIC SHIELDS - A STUDY OF FIELD ATTENUATION

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Résumé

Ci-joint est une étude sur l'atténuation du son par l'entremise d'absorbants acoustiques utilisés pour protéger l'ouïe des musiciens d'un orchestre symphonique. Les absorbants acoustiques furent placés derrière les oreilles des musiciens étant exposés aux niveaux sonores les plus élevés dans la fosse de l'auditorium du « Four Seasons Centre for Performing Arts » à Toronto. Pour mesurer l'atténuation des absorbants acoustiques, des dosimètres furent posés à l'avant et l'arrière des écrans. L'atténuation de chaque absorbant fut déterminé en calculant la différence de Leq des deux dosimètres. Deux types d'absorbants, Wenger et Manhasset, furent mesurés. Le résultat final d'atténuation fut de -0.48 dBA.

Mots clefs: son, musicien, absorbant acoustique, atténuation sonore

Abstract

Here is a study of the sound attenuation of acoustic shields used in a symphonic orchestra to protect musicians' hearing. The shields were placed right behind the ears of players who had the highest exposure to the sound of instruments in the pit of the auditorium in the "Four Seasons Centre for Performing Arts" in Toronto. In order to measure the attenuation of the shield, noise dosimeters were located in front and behind the shields. The attenuation of each shield was calculated as the difference between the Leq measured on both dosimeters. Two types of shields, Wenger and Manhasset, were measured. The overall attenuation was found to be -0.48 dBA.

Keywords: noise, musician, acoustic shield, noise attenuation

1 Introduction

Symphonic music is characterized by having wide frequency content and variable sound levels including high peak levels. In many occasions, the sound levels exceed 85 dBA (8-hour exposure), the limit provided by the American Conference of Governmental Industrial Hygenists (ACGIH) for the noise to be "safe". As per ISO 1999:1990, 50% of a male population exposed to 85 dBA for 40 years will experience 2 dB hearing loss average at 1, 2 and 4 KHz. The 85 dBA limit is by now accepted by legislation and safety standards across the world.

Several attempts are made for the reduction of musicians' noise exposure, the most common of which are the use of hearing protectors and acoustic shields [1]. Also, new technologies have been introduced using active noise control, however, this was not effective for musicians [2]. The latter are in most cases made of plastic plates in varying shapes and sizes that are mounted on a stand or the chair of the person whose hearing is intended to be protected. As such, they act as a sound barrier, reducing the sound level at the hearing zone of the shielded musician. However, their effectiveness is limited by flanking transmission and by reflections on nearby surfaces.

The present study was to measure sound attenuation by shields in the orchestra pit of the Four Seasons Centre for Performing Arts in Toronto during 11 performances of the ballet *Le Petit Prince* with music by Kevin Lau. The orchestra was considered large, consisting of 65 musicians, which for the size of the theatre, meant that the density was relatively high. The shields measured were made by Wenger and by Manhasset.

1.1 Risk of hearing loss and noise controls for orchestra players

Many studies have been conducted by measuring noise exposure of classical orchestra players [3-5]. Each study found many points toward a potential risk of hearing loss and the need of some form of noise control to reduce the noise exposure of musicians. The earplugs recommended to musicians were of the passive type – linear with frequency. They are passive because no electronics are involved. They are linear since their attenuation is almost flat with frequency, which is something highly desired by musicians to ensure that the perceived sound feels "natural", without change in the spectrum shape.

Acoustic shields are used in many symphonic orchestras. They consist of a pole with a plastic (polycarbonate) sheet of varying dimensions. Shields are located behind the head of the person to be protected. In

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most situations, shields are found in front of the brass section. In some models, the shield is covered with sound absorbing material, and as a result, is not transparent. Anecdotal evidence is that this is resisted by musicians due to the need for an unobstructed view of the conductor. The height of the pole can be extended up to 1.5 m above ground. Many of the designs allow for changing the angle of the shield. Nearly all of the commercially available acoustic shields are meant for individual use.

Acoustically, shields act as noise barriers. In theory, an infinite noise barrier can achieve a maximum attenuation of 22 dB from a point source [6]. Among others, the attenuation is a function of the distances between the barrier and the source and also between the barrier and the receiver. The relative height of the barrier with respect to the receiver and the source also plays an important role. In practice, the attenuation of an outdoor highway noise barrier rarely exceeds 15 dB for receivers located close to the barrier. Indoor noise barriers are much less effective, due to edge diffraction and reflections from the ceiling and nearby hard surfaces.

1.2 Previous Research

Williams and Presbury [7] surveyed orchestras in Australia and found that while some orchestras did protect musicians with noise barriers (ranging from personal perspex shields to wood risers with soundproof materials), they did so without having done any testing to determine their effectiveness. One orchestra that conducted tests of polycarbonate barriers achieved a reduction of 4 dB over an 8-hour period. Research done by the National Acoustic Laboratory and the school of Industrial Design at the University of Technology, Sydney, developed a shield that showed attenuation of 8 to 10 dBA in laboratory conditions with the sound source directly behind and 3 to 5 dBA in a field test with an orchestra. The latter result was attributed to the fact that sounds produced by an orchestra disperse and are not coming from one location. Shields may be most effective in reducing sound levels from a single source.

Martinez et al. [8] studied a prototype shield consisting of a reflecting portion made of acrylic glass and an absorbent portion made of an unnamed acoustically absorbent material. In orchestral situations, where the only sound source was coming from directly behind the shield, 9 dB attenuation was observed. However, this was a rare instance where only an instrument directly behind the shield was playing and therefore not applicable to the scenario in the present study. Most instruments to the front and sides of the shields were playing throughout and there was no difference in sound level due to the shield.

O'Brien et al. [9] conducted tests on a purpose-built acoustic screen made of wood and Perspex (a type of acrylic) panels. Different configurations were tested with shields of different lengths and combinations of wood and Perspex. Attenuation of 3.4 to 4.3 dB was observed for the short screen and 4.1 to 5.8 dB for the long screen. No increase in sound level was observed to the sides of the shield showing that adjacent musicians would not be adversely affected. Distance from the sound source and the user was a significant factor in the reduction of sound levels despite the use of a shield. Teglas [10] conducted tests on both a Wenger Acoustic Shield and a Manhasset Acoustic Shield and had mixed results. Sound levels/doses for individuals were reduced in environments that allowed for sufficient space between the shield-protected musician and sound sources. Musicians seated close to each other in small rehearsal venues were exposed to higher sound level/doses with regard to the usage of shields (the shields reflected more sound to the user).

Libera [11] tested the Wenger and Manhasset shields in an orchestra pit and showed an average reduction of 1.28 dB in sound level when the sound source was directly behind the shield-protected musician. However, when using a sound source at the side, an increase in sound level was measured.

Williams and Stewart [12] performed a series of tests on the Goodear acoustic shield (made of an opaque sound absorbent material to prevent sound reflection) and a transparent plastic shield in a large anechoic test room with sound isolation from external noise. They observed shield attenuation of 7 and 9 dB when the sound was directly behind the shield-protected user. However, measurements obtained at the side of the plastic shield, where a fellow musician would sit adjacent to the user, showed an increase of 3 dB in sound level. There was no difference in sound level at the adjacent position of the Goodear shield. While these lab studies successfully demonstrated shield attenuation, the authors were interested to evaluate two commonly used models in real working conditions

2 Method

2.1 Participants

The participants from this study were 16 musicians from the National Ballet of Canada Orchestra who are seated in areas of highest sound levels based on results from previous sound mapping [13].

2.2 Instrument and setup

The dosimeters used in this study were Bruel & Kjaer personal noise dosemeters types 4445 and 4448. Each measurement consisted of a pair of readings from dosimeters located in front, where the protected musician is seated, and behind the shield, where the sound is coming from. As shown in Figure 1, one dosimeter was set up on the shoulder of the musician seated in front of the shield to measure the musician's actual noise exposure. The second dosimeter was set on the shield stand, positioned at ear height, 10 cm away from the shield, representing the noise exposure behind the shield.

Figure 1: Photo of the dosimeter setup. The arrows in the photo point out the locations of the personal and area dosimeter.

2.3 Measurement

All dosimeters started recording at approximately 1/2 hour before the start of each performance. They were not paused during intermissions and continued running. All dosimeters were shut off roughly 30 minutes after the end of each performance. Musicians were advised not to generate any artifact noises by yelling at, breathing heavily towards, or accidentally touching the dosimeter's microphone.

2.4 Data retrieval and processing

There were a total of 27 paired measurements in this study. Each pair consisted of measurements of the sound exposure both in front of and behind each shield attenuation. The attenuation of each shield was calculated as the difference of the sound exposures in dB(A) measured by dosimeters located on both side of the shields.

Noise exposure data were retrieved using PC software Protector 7825 (version 5.2) made by Bruel & Kjaer in March, 2016. To give an accurate representation of the musicians' noise exposure, each measurement was cropped to include only 15 minutes of practice time prior to the start of each performance plus the entire 2 ½ hour-performance, including intermission.

2.5 Environment

The 11 performances took place at the *Four Seasons Centre for the Performing Arts*, a 2,071 seat theatre with an orchestra pit beneath the stage, shown in Figure 2. All measurements were conducted inside the pit which measures 15.5 meters in width, 6.4 meters in depth (the stage protruded 3.3 meters over the pit, while 3 meters was unobstructed from above), and the stage was 2.4 meters above the floor of the pit.

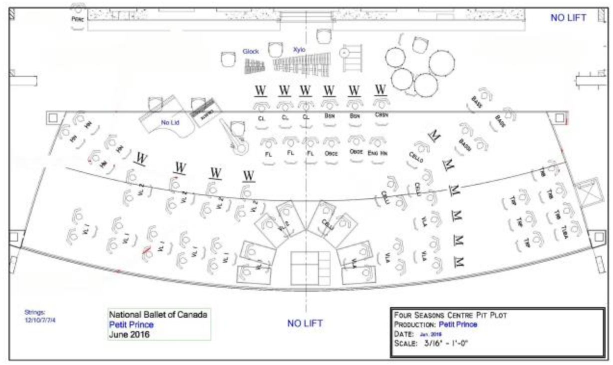

Figure 2: Floor plan of the orchestra pit of the *Four Seasons Centre for the Performing Arts*. Location of shields are shown as: W-Wenger, and M-Manhasset.

Figure 3: Photo of the Wenger acoustic shield.

2.6 Measurement

Two types of acoustic shields are used by the orchestra: Wenger acoustic shield (Figure 3) & Manhasset acoustic shield model 2000 (Figure 4). The Wenger shields are made of clear polycarbonate with dimensions of 0.57 m by 0.43 m. The Manhasset shields have larger dimensions of 0.65 m by 0.55 m, and they are made of Lexan polycarbonate. The thickness of both types of shields is of 6 mm. Since the density of the material is 1,200 kg/m^3, the surface density is 7.2 kg/m^2. The transmission loss, according to the mass low will be around 22 dB at 500 Hz.

Figure 4: Photo of the Manhasset acoustic shield.

3 Results

3.1 Attenuation of both types of shields

Tables 1A and 1B shows all 27 individual attenuations calculated as the difference between the sound levels measured on both sides of the shields. They are divided into results from the Wenger and from the Manhasset.

There are 27 paired measurements. Each row represents the attenuation calculated from a single pair of data. At the bottom of the table are the calculated Standard Deviations, Standard Errors and the Mean values for each shield. The Student's T-test, at the bottom of table 1B, measures the statistical significance between the attenuation differences. It shows that the existing difference is statistically significant.

It should be observed that there are a number of negative attenuations that are equivalent to a real amplification of the sound. In the case of the Wenger shields, it is as large as 6.1 dBA in one instance. Individual results are also represented in figure 5.

Figure 5: Individual attenuations. The attenuations of the Wenger shields (in blue) ranged from -6.1 dBA to 1.4 dBA, whereas the attenuation of the Manhasset shields (in red) ranged from 0.8 to 5.1 dBA.

It must, however, be kept in mind that all measurements were performed in a real work situation, meaning that the influence of the location of the shield and the instruments in the perimeter of the player were not taken into consideration. All shields remained at the same location throughout the course of this study. Therefore, it cannot be definitely stated that one type of shield is better than the other because there is the possibility that both types may perform identically when located at the same spot.

Table 1A: Individual attenuation of Wenger shields.

Instrument In Front	Instrument Behind	Individual Attenuations (dB)
Clarinet	Percussion	-4.9
Clarinet	Percussion	-3.5
Bass Clarinet	Percussion	-2.2
Bassoon	Percussion	-2.5
Bassoon	Percussion	0.4
Contra Bassoon	Percussion	-1.3
Violin	Piccolo	1.4
Violin	Piccolo / Piano	-1.3
Violin	Piano / Horn	-2.8
Violin	Piano / Horn	-0.3
REPEATS	***REPEATS***	
Clarinet	Percussion	-6.1
Clarinet	Percussion	-3.7
Bassoon	Percussion	-3.0
Bassoon	Percussion	-3.6
Bassoon	Percussion	-2.4
Contra Bassoon	Percussion	-1.5
Contra Bassoon	Percussion	-1.1
Violin	Piccolo	-1.1
Standard Deviation		1.85
Standard Error		0.45
Average		-2.14

Table 1B: Individual attenuation of Manhasset shields.

Instrument In Front	Instrument Behind	Individual Attenuations (dB)
Viola	Trumpet	3.7
Viola	Trumpet	4.1
Viola	Trumpet	4.3
Cello	Trumpet	2.3
Cello	Trumpet / Trombone	0.8
Cello	Timpani	5.1
Repeats	***Repeats***	
Viola	Trumpet	3.5
Cello	Trumpet	3.9
Cello	Timpani	1.1
Standard Deviation		2.09
Standard Error		0.70
Average		2.67
Student's T-Test		<0.00

3.2 Repeatability

The authors were interested in the variation of attenuation for a given shield (and same setting) during different performances. For that reason, the attenuation of some shields was repeated twice and the shields selected for repeated measurements was selected at random. Results appear in Table 2.

Previous study has shown that the variations are within the range of the accuracy of a field noise measurement, and therefore are not considered significant [14].

Table 2: Repeatability of the results.

Shield Type	No of Repeats	Variation (dBA)
Manhasset	2	1.6
Manhasset	2	4
Wenger	2	2.5
Wenger	2	2.8
Wenger	3	1.1
Wenger	3	0.4
Wenger	3	2.4
Wenger	2	1.3
	Average	**2.0**
	Max/Min	**0.4 – 4.0**

3.3 Total attenuation

Table 3 shows the statistical data of all shields pooled together. As expected from Table 1, the average attenuation is negative. The standard deviation is quite large, showing a large variation among attenuations.

Analysis of variation (ANOVA) was used to test the difference in sound level by the type of shield and/or arrangement of instruments. P values less than 0.05 were considered statistically significant. Arrangement of the instruments was categorized based on whether the two instruments in front of and behind the shields were similar or different with one another (table 3B). A-linear regression model was used to estimate the effect of sound level at the front adjusted for shield and arrangement of instruments.

The results of this analysis show that the attenuation obtained by the use of the two types of shield is negligible (P=0.125 > 0.05). It is well within the limits of the measurement error in a field test [14]. In total, sound levels were analyzed at 16 stations, of which 10 were shielded with Wenger (W= 0.57m x 0.43m =0.2451m^2) and 6 were shielded with Manhasset (M= 0.65m x 0.55m = 0.3575m^2). In terms of arrangement of the instruments, the 16 stations had different instruments in the front and behind the shield (e.g. clarinet-percussion, viola-trumpet,—violin-piccolo, cello-trumpet). The overall mean sound-level in front of the shield was 87.34dB (95% CI; 86.66-88.03); and average sound level behind the shield was 86.75dB (95%CI; 85.94-87.55). In general, there was no significant difference between the means of Leq in front of and behind the shield. Regression analysis did not reveal any significant statistical association between Leq in front of and behind the shield, and also Leq in the back and the arrangement of instruments; while association of shield type and Leq behind the shields was significant (p<0.01). Significant difference was found in the mean Leq measured behind the shields by shield type (p<0.01) without considering the pairings of the instruments (eg. Viola-Trumpet, Clarinet-Percussion).

Table 3A: Statistical analysis for the shield type.

Shield type	Wenger		Manhasset	
Measurements location	In front	Behind	In front	Behind
Mean SL (SD)	88.6 (2.2)	86.2 (0.6)	85.7 (1.2)	86.7 (1.8)
P value	0.005 <0.05 *		0.18 > 0.05	

* P values less than 0.05 are considered statistically significant.

Table 3B: Statistical analysis for the instrument arrangement.

Instrument arrangement	Different instruments (e.g. clarinet-percussion, viola-trumpet)	
Measurements location	In front	Behind
Mean SL (SD)	89 (2)	86.3 (0.6)
P value	0.045 <0.05 *	

*P values less than 0.05 are considered statistically significant.

4 Discussion and Conclusion

The high number of uncontrolled variables, which is generally unavoidable in a study of this kind, made it difficult to come to general conclusions. The size of the shield's surface area was too small compared to the distances from the source to the shield and from the shield to the receiver. The relatively small surface of the shield allows for edge diffraction around all four edges of the device. Therefore, the flow of acoustical energy around the shield becomes as significant as the flow through the shield.

Then, the distance between the shield and the head of the musician located in front of the shield is relatively long compared to the size of the shield, reducing the effectiveness of the shields. This distance and the location of the head should vary during a music session due to the fact that musicians move around in their chairs during performance, resulting in an ever larger edge diffraction

There is another factor, related to musicians located on the sides of the protected colleague. The shield not only offers no protection to these musicians, but may even increase their sound exposure due to sound reflected from the shields. In those circumstances, the sound of the instrument behind the musician is not as important as the lateral contributions, thus reducing the benefit of the shield. Sound reflection is a significant factor contributing to musicians' elevated noise exposure, and this is especially true for those musicians seated close to the walls of the pit and also because the shields are made from polycarbonate, which is a reflective material. On top of the sound coming from reflections and other musicians, there is also sound generated by the protected musician, that contributes to his exposure. (This may explain some or all the negative attenuation results obtained in the present study.) In summary, musicians are exposed to the sound coming from their own instruments, sounds coming from other instruments, and sounds reflected by the walls, the floor, and the shields. This may explain the results seen in tables 3A and 3B, where the mean sound levels are generally higher in front of the shields than behind the shields.

Results in Table 1A and Fig 1B show a significant difference between the attenuations from both types of shields. This could be caused by the difference in the size of the Plexiglas boards. The Manhasset's surface is almost 50% larger than the Wenger's, and this is something that may explain the difference in attenuation.

Finally , for our population, the attenuation was not significantly affected between different sessions. This appears to indicate that players do not move much between performances. This was already studied by Qian et al [15], who arrived at the same conclusion that the variations are not significant.

5 Recommendation for future studies

During our data collection, we found that the majority of musicians prefer to have shields, especially those musicians who are seated close to areas with the highest noise exposure. Therefore, the important question that remains is, why do musicians like shields and feel protected when they are in place despite our data showing that they are not effective? Further studies should investigate whether or not the shields are effective during those short bursts of high noise intervals.

As explained above, the present study was based on 2.5-hour noise exposures measured on both sides of the shields. They represent the energy averages over the entire measuring period. Therefore, results include not only the results of the "through the shield" energy flow, but also effects from the playing of instruments surrounding the shield.

A characteristic of orchestral music is the wide range of sound levels generated by the musicians. For most of a performance, the noise level does not exceed the accepted 85dB threshold. However, there are times during a typical 2.5-hour performance when the musicians produce sound levels well in excess of 85dB, and those passages generally involve the brass and percussion sections. Those occasions are intense and potentially hazardous to the players in front of them, and the players in front often rely on shields for some level of protection during the loudest passages. It will be desirable to examine the attenuation provided precisely from this scenario, which may explain the preference mentioned above.

We hope that future studies will be able to answer this question.

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PREVALENCE OF HEARING LOSS AMONG UNIVERSITY MUSIC STUDENTS

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Résumé

Cette étude a examiné la sensibilité auditive d'étudiants musiciens (N = 53) et non musiciens (N = 54) âgés entre 17 et 31 ans. Les deux groupes ont été comparés pour les différences de seuil auditif, les incidences de la perte auditive décrite par la moyenne des sons purs, et les incidences d'encoches neurosensorielles à 3, 4 ou 6 kHz. Les données ont également été utilisées pour explorer les relations entre la sensibilité auditive et l'âge, le sexe, l'âge du début des cours de musique, les instruments de musique joués, le nombre d'années jouant cet instrument, le type d'instrument, l'utilisation de protection auditive et le temps d'écoute d'appareils de musique personnelle. Aucune différence significative dans les niveaux de seuil auditif entre les deux groupes n'a été trouvée. La prévalence globale d'encoches neurosensorielles était de 1,9% pour les musiciens contre 9,3% pour les non-musiciens utilisant l'algorithme Niskar (2001), et de 20,8% pour les musiciens contre 31,5% pour les non musiciens utilisant l'algorithme de Coles (2000). Les deux algorithmes ont identifié plus de non musiciens avec des encoches, bien que la différence entre les deux groupes ne soit pas significative. Les musiciens qui utilisent la protection auditive ont beaucoup plus d'encoches neurosensorielles, et il y a eu une faible corrélation entre la sensibilité auditive et l'âge. Les autres paramètres étudiés ont montré très peu ou pas de relation avec la sensibilité auditive. Les résultats ne montrent aucune augmentation de l'incidence de la perte d'audition chez les étudiants universitaires en musique par rapport à un groupe témoin. Cependant, cela ne signifie pas que les étudiants en musique ne sont pas à risque de subir une perte auditive. Il est possible que les outils de mesure que nous avons utilisés ne soient pas suffisamment sensibles pour détecter les premiers stades de la perte auditive ou que l'effet de l'exposition au jeu d'instruments de musique se manifestera quelques années plus tard.

Mots clefs : Musiciens et perte auditive, seuil auditif, bruit causant une perte auditive, étudiants en musique

Abstract

This study examined the hearing sensitivity of university music students (N = 53) and a control group (N = 54) between the ages of 17 and 31. The two groups were compared for differences in hearing threshold levels, incidence of hearing loss described by pure-tone average levels, and incidences of notches at 3, 4 or 6 kHz. Survey data were also used to explore relationships between hearing sensitivity and gender, age, music lesson starting age, musical instruments played, number of years playing that instrument, instrument type, use of hearing protection and personal music device listening time. No significant differences in hearing threshold levels between the two groups was found. Overall prevalence of notches was 1.9% for music students versus 9.3% for the control group using the Niskar (2001) algorithm, or 20.8% for music students versus 31.5% for controls using the Coles (2000) algorithm. Both algorithms identified more controls with notches, although the difference between the two groups was not significant. Music students who use hearing protection had significantly more incidences of notches, and there was a weak correlation found between hearing sensitivity and age. The other survey parameters studied showed very little or no relationship with hearing sensitivity. The results do not show any increased incidence of hearing loss among university music students as compared to a control group. However this does not imply that music students are not at risk of hearing loss. It is possible that the measurement tools were not sufficiently sensitive to detect early stages of hearing loss or that the effect of the exposure to music instrument playing will manifest itself a few years later.

Keywords: musicians hearing loss, hearing threshold levels, noise induce hearing loss, music students

1 Introduction

Professional musicians are often dependent on having and maintaining good hearing health to be successful in their line of work. As such, hearing loss can threaten a musician's ability to perform well and can have a detrimental effect on their career. Hearing loss worries many musicians; when members from five major classical orchestras in Finland were surveyed, 94% expressed concerned for their hearing [1]. We are seeing a growing concern about hearing impairment due to music exposure among musicians, but also among music students and music teachers [2, 3].

It is quite possible that the very act of working as a musician causes irreparable damage to hearing because of

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repetitive exposure to high sound level. Noise-induced hearing loss (NIHL) is usually caused by repeated exposure to high intensity sounds over a period of time and it can affect individuals of all age including young adults [4, 5].

It is generally accepted that 80 dB(A) is the criterion for the maximum sound level that workers can be exposed to without increasing their risk of hearing loss; exposure to sound above this level over an extended period can cause permanent damage [6]. The American National Institute for Occupational Safety and Health [7] and the Canadian Centre for Occupational Health and Safety [8] recommend no more than eight-hours' exposure at 85dB(A) and they suggest that for every increase of three dB, the time limit for exposure be reduced by half [9]. Sound exposure measurements in musicians have confirmed levels over 85 dBA, either in the sound level produced by specific musical instruments or by the orchestra [10-16]. These studies have concluded that musicians are at risk for hearing loss due to the potentially noxious levels of sound exposure present in their working environment. However, according to Schmidt and colleagues [6], it may not be appropriate to apply industrial norms to a musician's environment. A factory worker is exposed to a constant high level of sound over many consecutive hours while musicians are only exposed to high level of sound for short peak periods with quieter moment in between. In addition, contrary to factory workers, musicians are exposed to sound spectra where lower frequencies dominate and these frequencies are less damaging to the ear. One should be cautious about drawing conclusions with respect to hearing loss from these studies, as they do not directly measure hearing threshold levels or incidence of hearing loss. Moreover, when measuring sound levels in a musician's environment, factors such as frequency and duration of rehearsals, type of acoustics in the rehearsal hall or practice studio, number of players in ensembles, number of performances, and type or genre of repertoire should be taken into consideration. These factors vary greatly from day to day and do not comply easily with consistent measurements. For example, musicians do not always practise or rehearse music that produces high levels of noise exposure; Westmore and Eversdeen [17] state there is no risk of hearing loss when playing a Mozart symphony while there may be some risk attached to playing a Bruckner symphony. We agree with Schmidt and colleagues [18] that the intermittent and fluctuating nature of musicians' exposure to various sound levels may be less harmful than continuous noise exposure of a factory or an industry non-fluctuating sound exposure. Thus there will always be uncertainty about whether sound level measurements are representative of what musicians are actually exposed to on a regular basis.

Another approach to determine musicians' risk of hearing loss is to perform hearing tests to determine hearing threshold levels and incidence of hearing loss. Noise-induced hearing loss (NIHL) or hearing loss from long-term noise exposure is often identified by a specific audiometric configuration or 'notch' in the 3 to 6 kHz region [5, 19]. Axelsson and Lindgren [20] conducted one of the early studies on NIHL in musicians and concluded that exposure to classical music in an orchestra on stage or in an orchestra pit can cause auditory trauma. Of the 139 musicians tested, 43% were found to have pure-tone thresholds outside the normal range for their age as determined by Spoor [21] who investigated the effect of aging (presbycusis values) in relation to noise-induced hearing loss. The authors attributed the hearing loss to musical exposure since they could not explain it by other factors from participant histories, including hereditary hearing loss, military service, ear disease or aging hearing loss. Other studies [4, 17, 22, 23] investigating hearing loss in musicians reached similar conclusions, indicating that performing as a professional musician may increase the risk of individual hearing loss. This situation is not limited to classical musicians. Kähäri and colleagues [24] assessed 136 rock and jazz musicians and, according to the study's definition of hearing loss and hearing disorders, found that 49% had hearing loss and 74% had self-reported hearing-related symptoms. Halevi-Katz and colleagues [25] studied professional pop, rock and jazz musicians and also found a positive correlation between the extent of the exposure to amplified music and hearing thresholds of 3-6 kHz; the more exposure musicians had, the poorer their hearing thresholds.

However, methodological limitations in these studies raise questions about the validity of their conclusions. One common limitation is the absence of a control group [22]. Some studies address this issue by comparing their results with pre-existing data sets from other studies [4, 20, 23]. Often, the group of musicians is compared with the data from the International Organisation for Standardization (ISO) that reports the mean numbers for a population of ontologically normal individuals, with age- and sex-corrected hearing thresholds. Some researchers [18, 24] have raised the possibility that the ISO corrections still have some confounding effect for age and could influence the results when musicians are compared to this data. Others suggest that the hearing of the general population, especially for men, has improved since the last update of ISO7029 [26]. In many cases, it is difficult to make definitive conclusions among the different studies due to inconsistencies in how hearing loss is defined (see Appendix A), and/or potentially varying testing conditions and equipment. Another common methodological problem relates to demographic characteristics of the musicians being studied. Quite often, little homogeneity exists within the sample group with regards to age (see Appendix A), number of years of playing, type of music played or musical instrument played. The variance between groups for these demographic characteristics makes it difficult to attribute noise-induced hearing loss solely to music exposure. This is particularly problematic for age differences as presbycusis can deteriorate hearing acuity independent of noise exposure.

To further add to the ambiguity of hearing-loss risk level, several studies provide conflicting evidence to the research presented above, concluding that hearing loss in musicians cannot be attributed solely to the profession. In fact, an early study by Arnold and Miskolczy-Fodor [27] reported that a group of 30 professional pianists was found to have unusually good hearing as compared to the general population. Studies with orchestral musicians have made similar conclusions. Karlsson, Lundquist, and Olaussen [28] demonstrated in a study with 417 orchestra members that performing in a symphonic orchestra does not involve an increased risk of hearing damage. Kähäri, Axelsson, Hellström and Zachau [29] evaluated 140 classical orchestral musicians and found no significant hearing losses that could be attributed to exposure to musical noise. This was further corroborated by the same authors in a follow-up study [30].They examined the hearing threshold of 56 musicians 16 years later and found that there was no sign of any progressive hearing loss except the expected loss related to age. Similar findings were observed in a follow-up study of 123 classical musicians in which no increased hearing damage was observed over a 6-year period [28]. Schmidt and colleagues [18] also reported that the hearing loss of musicians was smaller than the noise-induced permanent threshold shift of the general population. In fact, most of the 394 orchestra musicians that they tested had better hearing at 3, 4 and 6 kHz than expected. Several other studies [28, 31-34, 35] concur that musicians have no increased risk of hearing loss. This situation is not limited to classical musicians, as a review of previous studies reporting on rock and jazz musicians has also found that these musicians had nearly unaffected hearing in a large number of cases in spite of long exposure times to high sound levels [36]. In a study with college students in a jazz-band program, Gopal and colleagues [37] found that all but one experimental subject had normal hearing. While they did find a temporary threshold shift at 4000 Hz after exposure to jazz ensemble-based activity, the mean pure-tone thresholds for right and left ears at 4 kHz were better for the musician group compared to the control group. While these studies arrive at different conclusions than the ones presented earlier, they share similar methodological limitations: the majority have no control group to support their conclusions and sample populations show little homogeneity (see Appendix A).

Hearing acuity is of utmost importance to musicians who depend on their hearing for their profession; therefore, it is vital to understand the risk of hearing loss caused by the music they create and understand the extent to which it is a problem requiring serious consideration. The summary in Appendix A shows that the reported percentage of noise-induced hearing losses in which there was no known cause other than music ranged from 16 to 52.5%; at the same time, a number of studies found no indication of hearing loss due to music exposure. The age of participants ranged between 11 and 70 years and many studies failed to account for the effect of age on hearing loss. Neither the definition of hearing loss nor the criteria used for a noise-induced hearing loss were the same for all studies so the approaches and the results are not consistent. These conflicting results combined with the limitations present in the current literature on hearing loss in musicians justifies the need for further study examining the prevalence of noise-induced hearing loss in musicians when compared to a control group. Therefore, this study will address the following questions:

1. Is there a difference between music and non-music university students in:
   a. hearing threshold levels
   b. incidence of hearing loss
   c. incidence of noise-induced hearing loss (referred to as a notch)?
2. Is there a relationship between hearing sensitivity and the following factors in student musicians: gender, age, starting age for music lessons, musical instruments played, number of years playing that instrument, use of hearing protection and personal music device listening time?

An examination of current literature shows that young musicians have been neglected as a population, with young adult musicians rarely participating in research studies [5, 6]. Little is known about the hearing of university music students and on the damage that their music studies might cause. It has been established that most musicians only start using hearing protection devices once symptoms appear, and tend to neglect them during individual rehearsals [1]. This would indicate that if musicians are indeed at risk, they might not be conscious enough about their hearing health until damage has occurred. The absence of studies focusing on young adult musicians provided the impetus to choose university students as the sample population when comparing hearing loss between musicians and controls.

2 Methodology

2.1 Participants

For the music group, only individuals who had played more than 7 years in the classical tradition were selected. All music students considered for this study had practised seriously over a number of years, enough to be successful in the university audition and show that they had reach the minimum performance level to be admitted into a university music program. All participants in the music group had completed or were in the process of completing an undergraduate music program. The number of hours of actual practice and rehearsal time at the time of the testing was not retained as a selection criterion. We believe that this information is less reliable than the number of years a participant had been playing their instrument and the level they had attained to be admitted into a university music program. For example, at the time of the testing, some graduate students were no longer in a performance program but were engaged in thesis research. Their amount of daily practice had diminished, but all of them had initially been admitted into an undergraduate music performance program and had met the audition requirements and a minimum of seven years of practice on their instrument. Hearing sensitivity is not something that improves once you stop being exposed to certain noise levels (i.e. stop practicing your instrument); the damage done is permanent, so it was more important to consider the number of years of practice and the performance level reached, than the amount of practice at the time of the testing.

While we recognize that singers, like other instrumentalists, may be at risk of hearing loss [38], vocalists were not retained for this study because of the many differences between singers and instrumentalists. Singers usually start their training late; many university students in voice had been training for less than 5 years, therefore were not comparable with our instrumental participants. Additional concerns were with respect to practice time (most vocal instructors in our institution recommend 2 hours or less of daily practice to protect their voice, while most instrumental instructors recommend more than 3 to 5 hours of daily practice), and the inherent difference in the way the sound is produced (internal versus external instrument).

The control group was made up of university students of the same age group who are not involved in a university music program. Any individual who had played a musical instrument for 5 years or more was not retained for this study.

Participants were recruited by advertising free audiology evaluations offered by the "Clinique universitaire interprofessionnelle en soins de santé primaires" [Interprofessional University Clinic in Primary Health Care] from the Faculty of Health Sciences at the University of Ottawa. These advertisements were posted within the University of Ottawa School of Music, Faculty of Social Sciences and Faculty of Engineering. Participants who registered for hearing evaluations were asked if they would be willing to participate in a research project and agree to have the Clinic provide us with their test results anonymously. Interested participants signed consent forms and then completed the demographic questionnaire, which asked questions about gender, age, current academic program and use of hearing protection and personal music device listening time. Participants also had to complete a questionnaire on their music background. Students for the control group were asked if they had learned a music instrument in the past and for how long. Music students had to provide information regarding the age at which they started music lessons, musical instruments played, number of years playing that instrument, practice and rehearsal time and use of hearing protection.

In order to have groups of participants that were similar in age, only individuals between the age of 17 and 31 were considered for participation in this study—this range reflects the typical age of university undergraduate and graduate students.

Table 1 shows the number of participants recruited and the number of participants retained for this study.

Table 1: Recruitment statistics, including potential participants who were removed because they did not meet the experiment group criteria.

Participant recruitment	**Control**	**Music Students**	**Total**
Total recruited	81	72	153
Removed (Age > 31)	1	7	8
Removed (Vocalist)		6	6
Removed (Played instrument < 7 years)		6	6
Removed (Played instrument ≥ 5 years)	26		26
Total used in analysis	**54**	**53**	**107**

The 53 music students consisted of 30 females and 23 males. Their mean age was 22.5 years (range: 17 to 31, *SD* = 3.1). All were trained in classical music and were registered in the following programs: Bachelor of Music (*n* = 23), Master of Music (*n* = 17), Master of Arts in Music (*n* = 9), Honours bachelors with specialization in music (*n* = 3), recently completed an undergrad music program and now working as a musician (*n*=1). The primary instruments were as follows: 19 pianists, 10 string players, 15 brass and wind players, 7 guitarists, 1 percussionist and 1 harpist. The mean number of years practicing their instrument was 14.6 (range: 7 to 26, *SD* = 4.7). Seven participants also indicated that they were exposed to other type of musical sources and identify those as 'loud sound': a military band, a band, a rock group, a music group and gigs (various unspecified venues). This was taken into consideration in the analysis and is discussed in the results section.

The 54 participants in the control group were made up primarily of engineering and psychology students (because of where the project was promoted). There were 36 females and 18 males, with mean age of 23.0 years (range: 18 to 30, *SD* = 2.5). Among this group of non-music students 22 had played an instrument in the past. The mean number of years playing an instrument was 2.1 (range: 0 to 4, *SD* = 1.0).

2.2 Procedure

Participants underwent an otoscopic and audiometric evaluation. Otoscopy ensured the ear canal was clear of debris or wax that might interfere with testing, and audiometry (Kamplex AD-25; Madsen Midimate 602; Midimate 603; Madsen AC40) involved measuring hearing thresholds between 250 to 8000 Hz.

2.3 Data analysis

A statistical analysis (Statistical Package for Social Sciences) and Microsoft Excel were used for the data analysis. All *p*-values are two-tailed and considered significant below the 0.05 level. The data analysis was completed as follows:

Hearing loss

a. Hearing threshold levels: the difference in median hearing threshold levels was compared for the two groups using the Mann-Whitney U test. To check for asymmetrical hearing loss, hearing thresholds levels between each ear were compared using the Wilcoxon signed-rank test. Non-parametric tests were used for these analyses because the hearing threshold levels were distributed non-normally.
b. Incidence of hearing loss: the differences in incidence of hearing losses, based on pure-tone average (PTA) threshold levels were compared. As shown in Table 2, each participant was categorized according to degree of hearing loss as described by Clark [39]. Fisher's exact test was used to compare the number of participants in each group for each hearing loss level.

Table 2: Classification of degree of hearing loss calculated from the pure-tone average (PTA) thresholds

	PTA threshold range (dB)
None	≤15
Slight	16 to 25
Mild	26 to 40
Moderate to profound	≥41

c. Incidence of noise-induced hearing loss: the audiometric notch was used as an indication of noise-induced hearing loss since according to Feuerstein and Chasin [19], in contrast to acoustic trauma, hearing loss from long-term noise or music exposure is typically in the 3 to 6 kHz region. There is very little agreement about a standard definition of a notched audiogram [40], therefore notches were identified using two algorithms commonly adopted to be sure that the results were not merely a factor of the notch definition used. The first definition used was outlined in Niskar and colleagues [41] in which the audiogram must meet all of the following three criteria for at least one ear: (1) threshold values at .5 and 1 kHz were ≤ 15 dB, (2) the maximum threshold value at 3, 4, or 6 kHz was at least 15 dB higher than the highest threshold value for .5 and 1 kHz and (3) the threshold value at 8 kHz had to be at least 10 dB lower than the maximum threshold for 3, 4, or 6 kHz. The second algorithm used is from Coles, Lutman, and Buffin [42] in which the threshold at 3, 4 or 6 kHz is at least 10 dB greater than that at 1 or 2 kHz and at 6 or 8 kHz. After identifying notches using the above definitions, Fisher's exact test was used to compare the number of participants in each group with an audiometric notch. Finally, notches were categorized according to their frequencies, and in which ear they occur.

Factors possibly affecting music students' hearing sensitivity

The relationship between music students' hearing sensitivity and gender, age, music lesson starting age, number of years playing, musical instruments played, use of hearing protection and personal music device listening time were analyzed. For these analyses, the high frequency pure-tone averages (HFPTA) and/or incidences of notches were used as they are indicative of noise-induced hearing loss [19].

3 Results

3.1 Hearing loss

Hearing threshold levels

The Mann-Whitney U test was used to compare hearing threshold levels between music students and control. Figures 1 and 2 show the median threshold levels at each frequency tested for the left and right ears. There were no significant differences between the two groups at any frequency level, although a slight trend favouring the control group is evident. Of the 16 comparisons (8 frequency levels for each ear), music students' median thresholds were slightly higher for five measurement frequencies, while the non-music students' median threshold was higher at just one frequency level (8kHz in the right ear). The median thresholds were equal for the remaining ten measured frequencies.

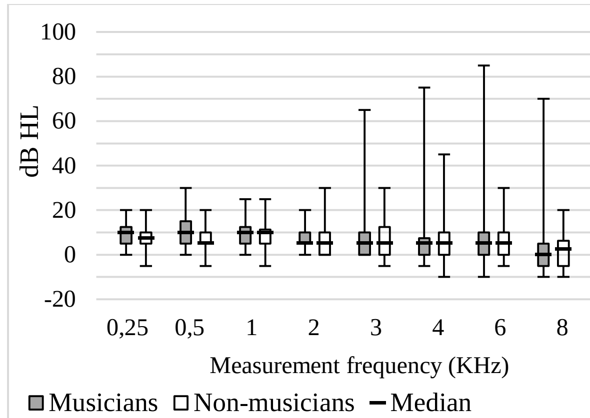

Figure 1: Comparison of hearing threshold levels (dB) for each measurement frequency in right ear. Boxes represent the range from 1st to 3rd quartile and the lines represent range from minimum to maximum. No significant differences were found between music students and control.

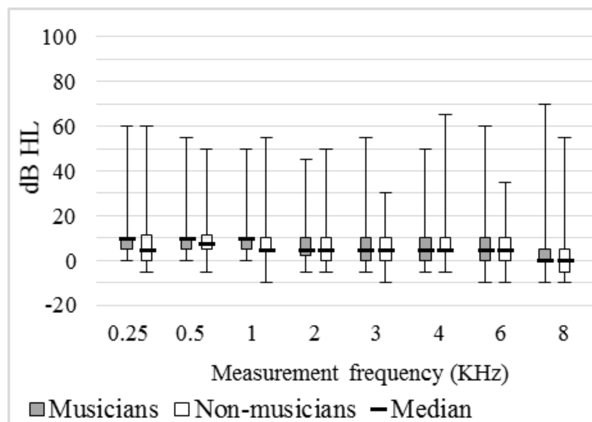

Figure 2: Comparison of hearing threshold levels (dB) for each measurement frequency in right ear. Boxes represent the range from 1st to 3rd quartile and the lines represent range from minimum to maximum. No significant differences were found between music students and control.

For both groups, hearing threshold asymmetry was investigated. The Wilcoxon signed-rank test showed no significant differences in hearing threshold levels between the right and left ears.

Incidence of hearing loss

Incidence of hearing loss using pure-tone average thresholds were analyzed for differences between music students and control Pure-tone average thresholds were calculated for each ear at the following frequencies: 500, 1000, and 2000 Hz, the frequencies usually considered for this purpose [19].

Each participant was then classified by his/her degree of hearing loss. Fisher's exact test was used to compare incidence of hearing loss for each hearing loss level. Table 3 shows that six music students and three controls exhibited signs of hearing loss; however, no significant differences were found in the prevalence of hearing loss between music students and controls.

Table 3: Incidence of hearing loss using the pure-tone average thresholds for three frequencies: 500, 1000, and 2000 Hz. Number and percentage (in parenthesis) of participants are shown.

Degree of Hearing Loss	**Music Students**	**Control**	***p*-values**
No hearing loss (0-15 dB)	47 (88.7%)	51 (94.4%)	.32
Slight hearing loss (16-25 dB)	4 (7.5%)	2 (3.7%)	.44
Mild hearing loss (26-40 dB)	1 (1.9%)	0 (0.0%)	.50
Moderate or severe hearing loss (> 40 dB)	1 (1.9%)	1 (1.9%)	1.00
Total with hearing loss (> 15 dB)	6 (11.3%)	3 (5.6%)	.32

A second similar test compared high frequency pure-tone averages (HFPTA) for 3000, 4000 and 6000 Hz between music students and control. This was included to give an indication of noise-induced hearing loss, which more commonly appears at higher frequency levels. Table 4 shows that three music students and five of the non-music students had some degree of hearing loss. Again, no significant differences were found for incidence of hearing loss between music students and control at any hearing loss level.

Table 4: Incidence of hearing loss using the pure-tone average thresholds for three frequencies: 3000, 4000, and 6000 Hz. Number and proportion (in parenthesis) of participants are shown.

Degree of Hearing Loss	**Music Students**	**Control**	***p*-values**
No hearing loss (0-15 dB)	50 (94.3%)	49 (90.7%)	.72
Slight hearing loss (16-25 dB)	1 (1.9%)	3 (5.6%)	.62
Mild hearing loss (26-40 dB)	0 (0.0%)	1 (1.9%)	1.00
Moderate or severe hearing loss (> 40 dB)	2 (3.8%)	1 (1.9%)	.62
Total with hearing loss (> 15 dB)	3 (5.7%)	5 (9.3%)	.72

Incidence of noise-induced hearing loss (notches)

The incidences of notches were analyzed to compare for differences between music students and control. Two algorithms were used to determine the presence of a notch, as described above. Using the first algorithm from Niskar and colleagues [41], only one of the 53 music students had a notch, while five of the 54 non-music students had a notch in one or both ears. Fisher's exact test was used to evaluate for differences between incidences of notches between music students and control. While there is a noticeable higher incidences of notches among the control participants, no significant differences were found, $\chi2$ (1, n = 107) = 2.747, p = .10. The second algorithm from Coles and colleagues [42] identified more notches, again with more among the control participants (17 participants with notches in one or both ears, compared to 11 music students) but no significant difference between the two groups: $\chi2$ (1, n = 107) = 1.593, p = .21.

The notches were also tabulated according to the frequency at which they occur. Table 5a and 5b show the distribution of notches found using each algorithm. Notches were found at each of the three frequencies, although they are slightly more prevalent at 3000 Hz.

Table 5a: Incidences of Notches According to Frequency using Algorithm 1

	Notch location (Hz)		
	3000	4000	6000
Music students			
Unilateral (right ear)			
Unilateral (left ear)			1
Bilateral			
Musician total			**1**
Control			
Unilateral (right ear)	1	1	1
Unilateral (left ear)			1
Bilateral	2		
Control total	**3**	**1**	**2**

Table 5b: Incidences of Notches According to Frequency using Algorithm 2

	Notch location (Hz)		
	3000	4000	6000
Music students			
Unilateral (right ear)	1	1	3
Unilateral (left ear)	2	1	1
Bilateral	2	2	
Music student total	**5**	**4**	**4**
Control			
Unilateral (right ear)	3	1	2
Unilateral (left ear)	1	4	1
Bilateral	5	1	4
Control total	**9**	**6**	**7**

3.2 Factors possibly affecting hearing sensitivity

Gender

Among music students, there were 30 females and 23 males, and among controls, there were 36 females and 18 males. The median HFPTA was compared for males and females within each group using the Mann-Whitney U test. Pure-tone average for the higher frequencies (3 to 6 kHz) was used for this analysis (and the others that follow) as this is indicative of noise-induced hearing loss [19]. There was no significant difference in hearing sensitivity between males and females for either group. For music students: *Md* (females) = 6.67, *Md* (males) = 6.67, U = 344, z = -0.027, *p* = .98. For controls: *Md* (females) = 7.50, *Md* (males) = 5.0, *U* = 290, *z* = -.64, *p* = .52.

Age

The correlation between age and the hearing threshold level for each group was investigated using HFPTA. The age distribution for each group was similar: the mean age for music students was 22.5 years (range: 17 to 31, *SD* = 3.1), and the mean age for controls was 23.0 years (range: 18 to 30, *SD* = 2.5). For both groups there was a weak correlation between the two parameters, with hearing thresholds worsening slightly with increased age; however the results were non-significant for both groups. For music students, *r* = .26, *n* = 53, *p* = .06. For controls, *r* = .16, *n* = 54, *p* = .26.

Music lesson starting age

Within the musician group only, the effect of music lesson starting age was explored. The music students' age at the start of music lessons ranged from 3 to 14 years (*M* = 8.7). No correlation was found between HFPTA and starting age (*r* = 0, *n* = 52, *p* = *.99*).

Year of playing

The number of years that the musician participants have been playing their instrument ranged from 7 to 26 (M = 14.6). A partial correlation (controlling for participant age) showed no relation between years of playing and HFPTA threshold: *r* = 0, *n* = 51, *p* = *.96*. Furthermore, those with more years of playing had fewer incidences of notches (using the Coles [42] algorithm): only two of the eleven notches were identified for participants with 15 to 26 years of playing experience.

Musical instrument

The impact of instrument type on hearing sensitivity was examined by grouping the instruments into the following categories: brass (*n* = 6), guitar (*n* = 7), piano (*n* = 19), strings (*n* = 10), wind (*n* = 9) and other (*n* = 2). A Kruskal-Wallis test revealed no significant differences in HFPTA threshold levels and instrument played: χ2 (5, *n* = 54) = 1.02, *p* = .91.

Difference in hearing between left and right ear was investigated for those instruments that have been shown to potentially cause asymmetrical hearing loss [6]. The mean HFPTA between the right and left ears, and the incidences of notches for each ear were compared. The notches used for this analysis were only those identified by the Coles and colleagues [42] algorithm, as there was only one notch for musician participants identified using the other method. The results in Table 6 show only a small difference in threshold levels between the ears, although one unilateral notch was found for each instrument of interest. While conclusions are not possible due to the small numbers of participants for each of those instruments, it can be observed that the unilateral notch appears in the ear that would be expected: right ear for flute and French horn [20], and left ear for violin [23, 43]. The number of participants for each instrument is not sufficient for a statistical analysis to confirm the significance of these results.

Table 6: Comparison of right and left ear pure-tone average threshold levels and incidences of notches using the Coles et al. (2000) Notch definition.

		Mean HFPTA (dB)		Participants with Notches		
	#	RE	LE	RE	LE	Bilateral
Flute	4	7.5	5.0	1		1
French Horn	2	0.0	4.2	1		
Violin	8	6.0	7.7		1	
Other	39	6.8	6.2	3	3	1

Use of hearing protection

A majority (42 out of 53) of musician participants did not use hearing protection. Ten responded that they either use hearing protection, or sometimes do, and one participant did not answer the survey question. The ten participants who use hearing protection play the following instruments: flute (*n* = 3), guitar (*n* = 3), violin (*n* = 2), percussion (*n* = 1) and trumpet (*n* = 1).

To compare the hearing of the participants who use hearing protection and those who do not, the difference in hearing threshold levels and incidences of notches as identified by the Coles and colleagues [42] algorithm were investigated. The Mann-Whitney U test showed no difference in HFPTA between those who use hearing protection (*Md* = 8.3, *n* = 10) and those who do not (*Md* = 5.0, *n* = 42), *U* = 176, *z* = -0.81, *p* = *.42*. However, Fisher's Exact test indicated a significant difference in incidences of notches among participants who use hearing protection (5 out of 10, or 50%) compared to those who do not (6 out of 42, or 14%), χ2 (1, *n* = 52) = 6.12, *p* = 0.01. This finding was not confounded by age or years of playing; the mean of these parameters for those who use hearing protection and have notches was very close to the mean values of those with no notches.

Personal music device listening time

The participants indicated the amount of time per day spent listening to personal music devices with headphones. Listening time for both groups ranged from 0 to 5 hours; however, the Mann-Whitney U test showed controls' listening time (*Md* = 1.5, *n* = 49) to be significantly higher than that of music students (*Md* = 1.0, *n* = 53), *U* = 839, *z* = -3.11, *p* = *.002*.

The effect of music device listening time on HFPTA was explored using a Pearson product-moment correlation coefficient. A weak positive correlation was found for the music students (*r* = .22, *n* = 51, *p* = .08), and no correlation was found for controls (*r* = -.06, *n* = 46, *p* = .75).

The effect of music device listening time on incidences of notches was explored by comparing listening time of those with notches compared with listening time of those without. For both music students and controls, the Mann-

Whitney U test showed no relation between these two parameters (music students with notch: *Md* = 1.0, *n* = 11, no notch: *Md* = 1.0, *n* = 42, *U* = 221, *z* = -.22, *p* = .82, and controls with notch: *Md* = 1.5, *n* = 15, no notch: *Md* = 1.5, *n* = 34, *U* = 355, *z* = -.45, *p* = .65).

Exposure to loud noise

Participants were asked "Are you regularly exposed to loud sound?" and if so, to explain. 43% of the music students (23 out of 53) responded that they are exposed to loud noise. In most cases, the loud noise they referred to was that of their instrument and/or exposure to other instruments while performing in a group. Seven of the responses referred to noise other than that of the practice or performance of classical music. Those seven cases included other types of music performance (e.g. rock music, military band rehearsal) and other noise such as bars and audio production. Eight of the 54 controls (15%) responded that they are exposed to loud noise, referring to bars, clubs, crying children and machine operation.

The effect of the reported exposure to loud noise (not including that of classical music practice/performance) on hearing sensitivity was examined using incidences of notches and HFPTA levels. There was no effect of exposure to loud sound on incidences of notches for both music students and controls (just two of the 11 notches in music students and one of the 17 notches in controls were found in those exposed to loud noise). The Mann-Whitney U test showed no effect on the HFPTA for the controls exposed to loud sound (those exposed to loud sound (*Md* = 7.50, *n* = 8) compared with those not exposed (*Md* = 9.06, *n* = 46), *U* = 183, *z* = -.04, *p* = .97). For music students there was an effect on HFPTA where those exposed to loud sound not related to the practice and/or performance of classical music (*Md* = 10, *n* = 7) had higher a HFPTA compared to those not exposed (*Md* = 5, *n* = 46), *U* = 66, *z* = -2.53, *p* = .01).

4 Discussion

The objective of the present study was to assess the risk of hearing loss for music students by comparing the hearing sensitivity of young adult music students (ages 17 to 31) with a similar group of controls. This was accomplished by comparing hearing threshold levels, incidence of hearing loss as determined by pure-tone threshold levels, and incidence of noise-induced hearing loss as determined by presence of audiometric notches. The results demonstrate no significant differences between music students and controls for all of these hearing sensitivity metrics. These findings are consistent with several other studies that found that musicians do not have increased risk of hearing damage [5, 6, 15, 17, 28-31, 34, 44].

Kähäri and colleagues [24] reviewed different reasons that could explain why musicians, with a long history of sound exposure, do not necessarily show hearing losses. It could be that musical sound exposure has a positive effect that stimulates and activates the stapedial muscle and this could contribute to a toughening effect [45-47]. It could also be that, due to genetic factors, musicians have different susceptibilities to noise-induced hearing disorders [48]. Schmidt and colleagues [18] have also considered the possibility that musicians are less susceptible to noise-induced hearing loss than the general population; they have better hearing and their hearing may degenerate at a slower speed than what would be expected with normal aging.

Nevertheless, a number of other studies found that exposure to classical music in an orchestra can cause auditory trauma [4, 20, 22, 23, 43]. Two common limitations were observed in these studies: the absence of a control group in most studies and little homogeneity within the sample groups. To compensate for these shortcomings, the current study was constructed to measure the hearing acuity difference between music students and controls with similar demographic characteristics. To account for the effect of age on hearing loss, the age ranges in each group were small. Homogeneity within the musician group was ensured in terms of number of years of playing (more than 7 years) and type of music played (trained in the Western classical music tradition). However, a lack of homogeneity in instrument type was unavoidable; inclusion criterion was that a participant should be studying any musical instrument in the classical music tradition. For that reason, we included orchestral musicians, pianists and guitarists.

Regarding the incidences of notches, the findings unexpectedly reveal a noticeable higher incidences of notches among controls; however, no significant differences were found. Schmidt, Verschuure, and Brocaar [6] used a similar notch definition as algorithm 2 in this study, and found a similar proportion of musicians with notches (16% compared to 19% in this study). They also found no differences between musicians and a non-musician control group. However, other studies found much higher proportions of musicians with notches. Using a notch algorithm similar to algorithm 1 in this study, Jansen, Helleman, Dreschler, and de Laat [4] found a 20% notch rate compared with the current study's result of 2%. Using an algorithm similar to algorithm 2 in this study, Royster, Royster, and Killion [43] found a 52.5% notch rate. Both of these studies included older participants (up to ages 64 and 70 respectively), so it is not surprising to see higher incidences of notches. Phillips, Henrich, and Mace [5] studied younger musicians (ages 18 to 32) and found an alarmingly high notch rate of 45%. However, the notch algorithm appears to be modified significantly from the Niskar and colleagues [41] definition, and it is not therefore possible to directly compare the results. Other studies that report incidences of notches do not provide a clear methodology used to identify notches [17, 23]; with no standardized method to identify audiometric notches, it is not possible to directly compare results with these studies.

It should be emphasised that the notches found in the current investigation were distributed almost evenly between frequencies of 3, 4 and 6 kHz. This is in contrast to other studies that found notches among musicians to be more prevalent at 6 kHz. Both Jansen and colleagues [4] and Kähäri and colleagues [29] found notches in the median audiograms at 6 kHz. Phillips and colleagues [5] found that 78% of the notches occurred at 6 kHz. This can be compared with industrial workers who typically have notches at 4 kHz [5]. This suggests the possibility that, in comparison to other studies, a smaller proportion of the notches identified in this study can be attributed to practicing or performing music, and thus some of the noise-induced hearing loss that was identified was likely due to other factors.

A comparison of hearing sensitivity between left and right ears revealed no signs of asymmetrical hearing loss among either group. These results are consistent with studies such as Schmidt and colleagues [6], which found no asymmetrical hearing losses. However, other studies have shown that asymmetrical hearing loss is common, usually with more loss in the left ear [14, 49, 50]. Many studies with musicians have found a link between this asymmetry and the instrument played: larger hearing loss in the left ear were found with violinists [23, 42-44, 51, 52], while larger hearing loss of the right ear was found among flautists [20, 44], French horn players [20] and piccolo players [51]. The current study found that a horn player, violinist and flautist each had an audiometric notch in the expected ear as mentioned above, however the number of participants from each instrument group was not sufficient to draw conclusions from these results.

Unexpectedly, a higher proportion of notches were found among music students who use hearing protection compared to those who do not. It is possible that music students who have noticed some signs of hearing loss would make an effort to protect their hearing, whereas those who think their hearing levels are normal may not feel the need to use hearing protection. This speculation is supported by Laitinen [1] who found that hearing protection was more often used among musicians who have symptoms of hearing loss. Some other studies have reported on usage rate of hearing protection, but none reported audiological evaluation results using hearing protection usages as an independent variable.

Personal music devices can submit users to harmful exposure levels. A recent study by Twardella and colleagues [53] found that in one quarter of those who use such devices, exposure levels exceeded 85 dB(A), the occupational limit in many jurisdictions [7, 8]. Daniel [54] also reported that temporary and permanent hearing problems are more common now that children and teenagers have increased exposure to portable music players. In the current study, there was a weak positive correlation between listening time and HFPTA among music students, but the same trend was not observed in the control group. No relation was found between listening time and incidences of notches for either group. Other studies had similar results. Twardella and colleagues [53] found that high exposure to music from personal devices in adolescents could be considered as a risk factor for developing noise-induced hearing loss; however, prevalence of audiometric notches was not found to be significantly associated with higher personal music device exposure. It is interesting to note that the controls listen to personal music devices more than music students do. It may be surmised that music students, due to the importance of audition to their vocation, are more aware of potential causes of hearing loss, and therefore do not use headphones as much as the general population. Alternatively, there may be other reasons they seek silence when they are away from their instruments. Another study [22] found that more than 50% of musicians avoided noisy environments and sought silence in their leisure time.

Another indication that music students may be more sensitive and aware of sound or noise exposure is their response to the survey question, “Are you regularly exposed to loud sound?” Twenty-three (43%) of the music students responded yes. In comparison, only 8 (15%) of the controls responded yes. Furthermore, most of the controls reported examples of loud sounds were indeed high noise-exposure sources (e.g., bars, machine operation and construction work), whereas many of the musician’s reported examples that would not likely yield such high exposure levels (e.g. piano teaching). This indicates that the music students had a different perception of what could be considered a loud sound.

Gender had no effect on hearing sensitivity. This result was as expected; the International Organization for Standardization 7029 [55] statistical distribution of hearing thresholds as a function of age shows that noticeable differences between males and females do not appear until beyond the age of 30. Phillips and colleagues [5], who also studied younger musicians, found no gender effect.

In our study, several parameters relating specifically to the music students’ music experience were investigated for effects on hearing sensitivity. These included: music lesson starting age years of playing, and musical instrument. No effect on hearing sensitivity was found for these variables. With respect to the impact of instrument type, results found in the literature are inconsistent. Some studies, all of which included older orchestral players, found some differences in hearing, depending on instrument or instrument group (worse hearing in brass players [20, 35], double bass and flute players [28], better hearing in lower string players [4], piano, harp and low string players [43]), but others, including Phillips and colleagues [5] with a young musician population, found that instruments were not significant factors [17, 23, 29, 31]. Schmidt and colleagues [18] report that instrument groups are poor predictors of the hearing thresholds. Effects on hearing for the other parameters we tested for were not reported on in the literature.

5 Limitations and future direction

When interpreting the results of this study, it is important to consider several methodological limitations. Firstly, the students were invited to participate through advertisements; as such, the recruitment process was not random. There exists the possibility that the sample population was not representative of the general population, as it could be biased towards those who had some reason to believe their hearing might be compromised and wanted it tested. Conversely, it could have attracted those who are concerned about hearing loss, but have very good hearing due to their awareness and cautiousness about noise exposure.

Of utmost importance are the audiogram's limits in terms of what it allows us to measure. Although the audiogram is a very important clinical tool, one has to keep in mind that the picture it yields of an individual's hearing is limited in several aspects. First of all, the traditional audiogram measures hearing from 250 Hz to 8 kHz. However, considering human hearing can detect sounds up to 20 kHz, measuring thresholds for higher frequencies (9-20 kHz) provides a more complete picture of one's hearing status. Extended high-frequency audiometry (EHFA) has been shown to be useful in diagnosing hearing loss related to several conditions, among which is noise-related hearing loss [56]. Hence, such a measure would have been relevant for this study. Additionally, off-frequency listening, a phenomenon in which a tone of a particular frequency is detected via inner hair cells (IHCs) and neurons with characteristic frequencies different from that of the tone prevent dead cochlear regions from being revealed through routine audiological evaluations [57]. Consequently, such regions might have been present in some participants, but not have been detected through the traditional audiogram. Similarly, cochlear synapthopathy, which is characterized by dysfunctional IHC/type I auditory-nerve fiber synapses, has been shown to result from noise exposure. Because this dysfunction cannot be detected using traditional audiometry, cochlear synaptopathy is often referred to as noise-induced hidden hearing loss (NIHHL) and might have been existent for some participants [58]. Finally, the audiogram only measures one of the characteristics of sensorineural hearing loss: reduced sensitivity. However, sensorineural hearing loss also leads to reduced frequency selectivity, reduced temporal resolution and abnormal growth of loudness [59]. Another limitation of this study was that otoacoustic emissions (OAEs) were not measured. Given that OAEs are thought to reflect activity of the outer hair cells (OHCs) [60] and that OHCs are generally the first affected in case of sensorineural hearing loss, this measure might have provided valuable additional information.

Pure-tone audiometry might not be a sufficiently sensitive test to detect early stages of hearing loss and it might be preferable to do a full assessment of hearing [24, 29, 61], including the evaluation of hearing disorders other than hearing loss. Kähäri and colleagues [24] suggest that frequent hearing problems are tinnitus, hyperacusis, distortion and/or diplacusis, speech in noise, and uncomfortable loudness level of pure tones. Laitinen and Poulsen [61] state that aspects other than hearing loss must be considered, since the most frequent hearing disorders that affect musicians are tinnitus and hyperacusis.

The experiment design would not be able to show a causal relationship between music performance and hearing loss. Some studies [10-17, 34, 35] use dosimetric measurement to attempt to address this, however we felt that this would not provide reliable data due to the variability in practice and performance environments, especially for student musicians. Furthermore, even if a hearing impaired musician's exposure was found to be high, the hearing loss could be due to other causes. Thus, the nature of this type of experiment is such that it is not possible to conclusively claim that any given musician's hearing loss is due to the practice or performance of their instrument. Nevertheless, in retrospect additional information about the performance environment including sound level data would have been of interest, and future researchers may well find it valuable to use dosimetry in following this line of research.

While we strived to select homogenous experiment groups, there was still some variability that was unavoidable. The exposure of the musician group varied in terms of practice time, years of study, and group performances; these parameters were taken into consideration, however they were not objectively measured. Additionally, we cannot assume that participants were not exposed to other noise unrelated to their instrument, even if they did not mention this in the questionnaire. Finally, we did not have sufficient sample sizes within each instrument type to draw conclusions on an individual instrument basis. Furthermore, in grouping the various instrumentalists together as a musician group there was potential to hide the effect of noise exposure, given the presence of quiet instruments such as flute or guitar. That said, we are confident this was not an issue, as we did not find lower threshold levels for those participants playing quiet instruments. With respect to the control group, participants ideally would have no music experience at all, however we had to allow for some music experience in order to recruit sufficient sample size.

6 Conclusion

Based on current findings, it would seem that young adult musicians do not exhibit a higher incidence of hearing loss than a control group, at least not with the conducted measures. However, it is important to remember that this might be because music students have not yet been affected with a permanent hearing loss. Gopal and colleagues [37], when measuring college students after a 50-minute jazz and band classroom activity, found a significant temporary threshold shift bilaterally at 4000 Hz. This shift in threshold is thought to be temporary in nature, since follow-up testing did not demonstrate the shift, but it may be that temporary auditory changes seen in these music students could put them at risk for hearing loss in the years to come. It would be important, as a follow-up studies, to conduct a larger experiment with more participants from each instrument group to determine the effect of instrument type on hearing sensitivity, and to test musicians in the next age group (30-40 years old) to find out if these musicians are starting to show sign of hearing loss. A longitudinal study would help find out whether the percentage of noise-induced hearing losses increases with time for these young musicians.

If university music students do not show apparent damage, it might be a good time to educate them about the importance of being careful with exposure to loud noise and teach them how to protect their hearing system. While musicians can protect themselves with hearing protection, they are not always ready to consider earplugs; they may consider that they are uncomfortable and can affect their hearing during performance, particularly with regard to timbre and dynamics [25]. The time to discuss these topics might be while these young musicians are in university.

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Appendix A: Previous Study Parameters and Results

	Authors	Definition of hearing loss or hearing loss criteria	Comparison group	Age	Result	Musician type
Found increase risk of hearing loss	Axelsson and Lindgren, 1981	Threshold level greater than 20 dB on one ear and one frequency	Other study (Spoor, 1967)	20 to 70	43% of musicians showed worse pure-tone thresholds than would be expected with regard to age.	Classical
	Emmerich, Rudel, & Richter, 2008	Permanent threshold shifts larger than 15 dB SPL	None	30 to 69 & 11 to 19	More than 50% of the musicians had a hearing loss of 15dB(A) and more.	Classical
	Jansen, Helleman, Dreschler, & de Laat, 2009	Threshold level > 15 dB at any of the measured frequencies. Notches categorized as moderate or profound	ISO 7029 (2000)	23 to 64	Most musicians could be categorized as normal hearing, but their audiograms show notches at 6 kHz. (11% had moderate notches, 9% had profound notches).	Classical
	Ostri, Eller, Dahlin, & Skylv, 1989	Threshold level ≥ 20 dB at any threshold in one or both ears	ISO 7029 (1984)	22 to 64	58% of the musicians had a hearing impairment. 50% of males and 13% of females showed typical audiogram with notched curve.	Classical
	Kähäri, Zachau, Eklöf, Sandsjö & Möller, 2003	2 or more frequencies at ≥ 25 dB or 1 frequency at ≥ 30 dB in ≥ 1 ear	None	26 to 51	49% of participants with hearing loss	Pop, rock, jazz
	Halevi-Katz, Yaakobi, Putter-Katz, 2015	Threshold shift at 3 to kHz	None	20 to 64	More music exposure was positively linked to higher hearing thresholds in the frequency range of 3-6 kHz	Pop, jazz, rock
Found no increased risk of hearing loss	Karlsson, Lundquist, & Olaussen, 1983	Not indicated	Other study (Spoor, 1967)	20 to 69	Thresholds measured did not differ from the reference values from Spoor (1967)	Classical
	Kähäri, Axelsson, Hellström, & Zachau, 2001a	Not indicated	ISO 7029	23 to 64	HFPTA values in most ears distributed around the ISO 7029 median.	Classical
	Kähäri, Axelsson, Hellström, & Zachau, 2001b	Not indicated	ISO 7029	35 to 64	Most HFPTA values were distributed between the ISO median and within the 90th percentile.	Classical
	Johnson, Sherman, Aldridge, & Lorraine, 1985	Not indicated	Past study (Spoor, 1967)	24 to 64	Musicians did not appear to have hearing remarkably different from normal expectations.	Classical
	Schmidt, Verschuure, & Brocaar, 1994	Presence of dip (hearing loss in one or both ears ≥ 20 dB for 3,4 or 6 dB with the loss at the two nearest frequencies on both sides of the dip amounting to at least 5 dB less), high-frequency and extended high-frequency sensorineural hearing loss, or conductive hearing loss	Study control group (medical students)	21 to 40	Musicians: 16% with noise dips, 20% with high-frequency losses: 72% with extended high-frequency losses. Similar results found in control group.	Classical (*n*=39), light music (*n*=26), pop music (*n*=5), ethnic music (*n*=2), not provided (*n*=7)

	Authors	Definition of hearing loss or hearing loss criteria	Comparison group	Age	Result	Musician type
Found no increased risk of hearing loss	Toppila, Koskinen, & Pyykkö, 2011	Not indicated	ISO 1999	43 to 50	The hearing of classical musicians corresponds to that of the non-noise exposed population according to ISO-1999:1990.	Classical
	Gopal, Chesky, Beschoner, Nelson, Stewart, 2013	Not indicated	Non-musician control group	19 to 33	The musician group showed a significant temporary threshold shift bilaterally at 4000 Hz after exposure, however, musician's mean threshold levels pre-exposure were better than that of the control group.	Jazz
	Russo, Behar, Chasin, & Mosher, 2013	Not indicated	ISO 1999	NA	Measured hearing losses for all instrument groups did not approach clinically significant levels, although instrument groups experiencing the highest levels of exposure also had the highest pure-tone thresholds.	Classical
Does not definitively conclude if there is an increased risk of hearing loss	Westmore & Eversden, 1981	Not indicated	None	29 to 60	23 out of 68 ears showed changes consistent with noise-induced hearing loss, but most of those had only slight or early changes. 4 musicians had a hearing loss of more than 20 dB at 4KHz.	Classical
	J. D. Royster, L. H. Royster, & Killion, 1991	Presence of a dip or notch (threshold at 3, 4 and/or 6 kHz being 10 dB or worse than adjacent lower and high frequencies or a dip of 10 dB or more superimposed on a sloping high-frequency-emphasis loss.	ISO 7029 (1984)	30 to 70	Mean hearing threshold levels were only slightly worse than the ISO 7029 median, however 52.5% of musicians showed notched audiograms.	Classical
	Phillips, Heinrich, & Mace, 2010	Presence of a notch 15 dB in depth at 4000 or 6000 Hz relative to the best preceding threshold	None	18 to 32	45% of participants had a notch in at least one ear, however susceptibility to noise-induced hearing loss cannot be ascribed solely to the instrument played and other exposures.	Classical

A METHOD TO PRECISELY MEASURE WIND TURBINE PRESSURE DISTURBANCES, INCLUDING NOISE

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Résumé

Les sources de bruits complexes ne sont pas faciles à mesurer lorsque les conditions changent constamment. Les éoliennes sont un exemple de ces sources difficiles. Certains disent que c'est comme de la magie; maintenant vous les entendez et maintenant vous ne les entendez plus. Le son va et vient et change avec la distance, la température, l'humidité, la vitesse du vent, la direction du vent, le cisaillement du vent, l'inversion thermique, l'absorption acoustique, etc. Son bruit et sa détectabilité peuvent également être masqués par divers bruits de fond intermittents. Il y a également un bruit indésirable inhérent au système de mesure lui-même, tel que le bruit de l'écran du vent qui doit être séparé des sources d'intérêt. Celles-ci doivent être identifiées de manière à ce que seuls les enregistrements non nettoyés qui ne contiennent pas d'artefacts soient choisis et que les sources d'intérêt soient analysées. En tant que variables, beaucoup peuvent, parfois, avoir un effet cumulatif sur les sources, augmentant leur présence. Différents récepteurs (humains et animaux) réagissent différemment avec différents types de bruit. Les récepteurs qui vivent dans ces conditions ont tendance à éprouver de la gêne.

Mots clefs : bruit de turbine éolienne, infrason de turbine de vent, tonalité éolienne, modulation d'amplitude de turbine de vent, bruit de turbine éolienne

Abstract

Complex noises sources are not easily measured when the conditions constantly change. Wind turbines are an example of these challenging sources. Some say it's like magic; now you hear them and now you don't. Sound comes and goes and changes with distance, temperature, humidity, wind speed, wind direction, wind shear, thermal inversion, sound absorption, etc. Its annoyance and detectability may also be masked by various forms of intermittent background noise. There is also unwanted noise inherent with the measurement system itself, such as wind screen noise that needs to be separated from the sources of interest. These need to be identified such that only clean records where artifacts are not present are chosen and the sources of interest are analyzed. Being variables, many may, at times, have a cumulative effect on the sources, increasing their presence. Different receptors (humans and animals) react differently with different types of noise. Receptors that live under these conditions tend to experience annoyance.

Keywords: wind turbine noise, wind turbine infrasound, wind turbine tonality, wind turbine amplitude modulation, wind turbine noise

1 Introduction

So how does one measure and record fluctuating sound pressure levels according to standards and monitor the following parameters all at the same time?

- Sound Level Meter parameters including time-variant LAeq, LCeq, LAmax, LAmin, L10, L90, L50, L95, LCeqs (Far Field) etc., Instantaneous and averaged
- SLM parameters time histories
- The fluctuation strength of the modulation (whooshing)
- Time-variant Loudness
- Weather parameters such as wind speed, wind direction, temperature, humidity, light intensity, barometric pressure, etc.
- Infrasound BPFs (Blade-Pass Frequencies, 0.5-20Hz)
- Low frequency noise. (20-200 Hz)
- Audible noise (20-20,000 Hz)
- Spectral distribution of 7. 8. & 9, using Narrowband FFT analysis
- Synchronous audio and video to identify conditions
- Raw time record for playback and listening validating measurement recording
- Tonality according to Octave and Narrowband standards such as in ISO1996-2 Annex C

2 Challenges

Experientially, if one of these parameters is missed at any point in time measurement overall uncertainty can result.

Multiple turbines present the challenge of measuring all these parameters simultaneously and in different locations inside and outside receptor areas. Where there are turbines in multiple directions we expect one source to become dominant but alternating with another, for instance, if wind direction changes. However, the total pressure of all the

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turbines will always be measured at the microphone location using standard outdoor measurement microphones. Type I measurement microphones are preferred due to reliability during harsh Canadian weather. Also, higher frequencies will be absorbed more with distance than lower frequencies. Environmental noise guidelines such as MOECC NPC-350 are used to simplify this complex situation to regulate audible noise levels using A-weighting. Other techniques can be explored as listed above(1-12).

Outdoor weather conditions can deteriorate leading to instrumentation errors and failures.

3 System and setup

The SINUS Soundbook system chosen is PTB approved for the highest world standards for acoustic instrumentation. Type I GRAS 40AZ infrasound measurement microphones also measure full spectrum audible noise such that relationships between audible (20-20,000Hz), low frequency (20Hz-200Hz) and infrasound(.5-20Hz) are measured simultaneously (Fig. 2). New measurement microphones such as the GRAS 146AE are durable in the harshest conditions and can also be deployed in wet and subzero temperatures.

The following typical setup example (Fig. 1) measures all relevant parameters. It was developed as a result of years of experience successfully measuring wind turbine noise. In this case, the 6-hour LAeq is below night time NPC-350 guidelines (35dB) yet there are BPFs (infrasound) present outside. There is low BPF penetration inside a home even though levels vary in different locations within.

4 Guidelines

It is not the intent of this short review to discuss details under which the diverse conditions exist. Ontario has guidelines for audible noise. However, guidelines for C-weighted criteria, amplitude modulation, and low frequency including infrasound have not been established. The system in Fig. 2 meets and exceeds current NPC-350, NPC-300 and other guidelines and is expandable for future changes to these guidelines.

5 Measurements

Tonality measurements can be made in two standard methods, Octave and Narrowband FFT. An example of an intermittent tonal condition is given in Fig. 4. In this case the Tone assessment is made according to ISO 1996-2 Annex C using the Soundbook SAMURAI software.

Theoretically predictable infrasound generated by wind turbines is present as Blade-Pass-Frequencies and harmonics. The example in Fig. 5 demonstrates that pressures are higher at low frequencies inside the home relative to outside the home. Identical GRAS 40AZ Type I measurement microphones were used and can be compared with less expensive micro barometers. The measurement microphones have the added capability to measure audible noise due to a .5-20,000 Hz bandwidth in the same measurement and are traceable to IEC 61094 WS3F.

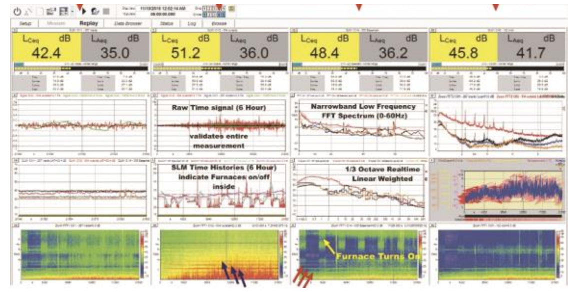

Figure 1: a) Sound level meter (SLM) - Over 100 parameters simultaneously recorded at various locations inside & outside a dwelling. b) Narrowband infrasound FFT spectrum (0-10hz) indicates blade pass frequencies inside & outside a dwelling. c) Weather station parameters. d) Inside basement BPFs are the lowest in this case. e) Inside living room indicates furnace is not interfering with BPFs. f) Outside. g) Inside kitchen BPFs are low in this case. h) SLM time histories short time records. i) Raw time signal (20 second) validates measurement.

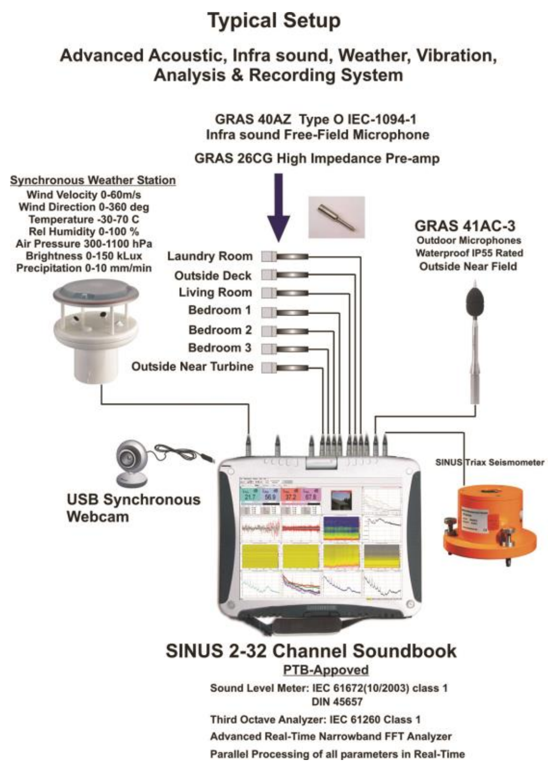

Figure 2: Advanced system setup

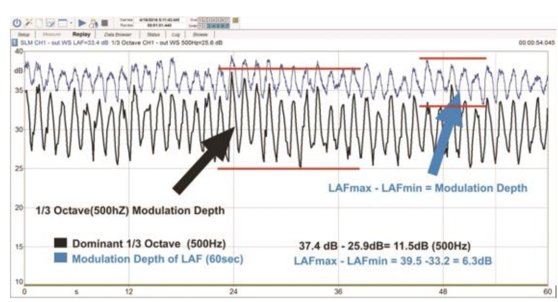

Figure 3: Modulation depth: an example of amplitude modulation or fluctuation of the LAF.

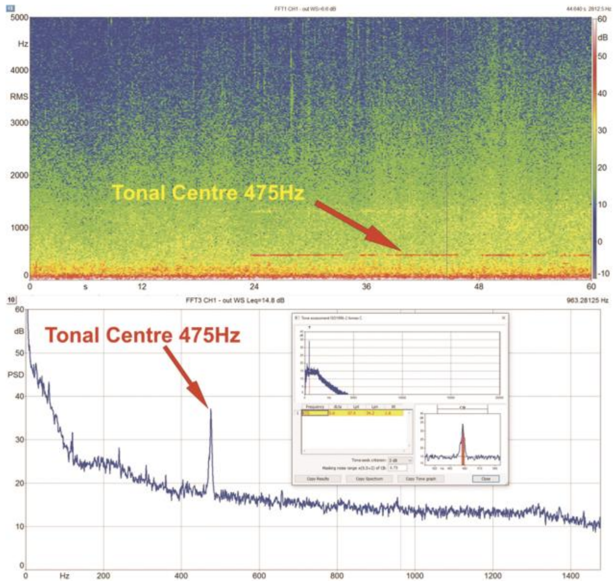

Figure 4: Tonality.

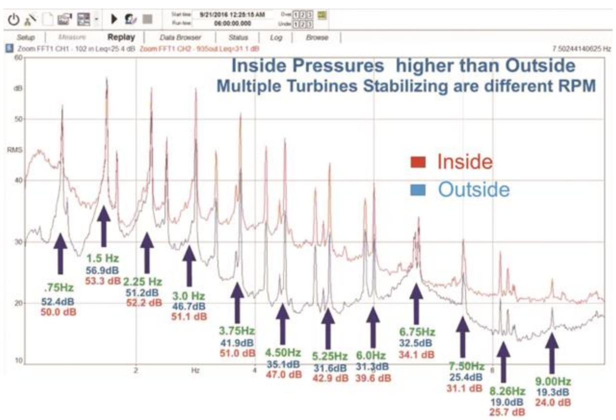

Figure 5: Wind Turbine BPFs (infrasound) Measured simultaneously Inside and Outside a Home.

Wind speed is a primary factor for both power generation and turbine RPM stability. The graph in Fig. 6a and 6b indicate the turbines stabilize at constant 14.4 RPM at wind speeds above 3.5m/s. Colourized arrows in Fig. 6a indicate wind direction. Measurements of temperature, relative humidity, light intensity and barometric pressure are also recorded. Both the sonogram in Fig. 6b and the windspeed in Fig. 6a indicate varying BPF RPMs at 4320 seconds in the 6-Hour LAeq. After 12,000 seconds, the BPFs become stable at 15RPM.

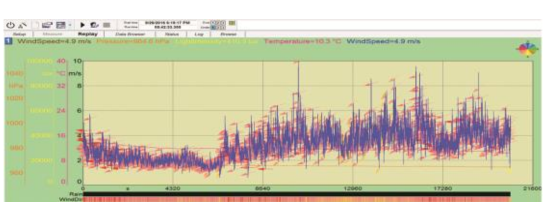

Figure 6a: BPFs Changing with Wind Speed and Wind Direction.

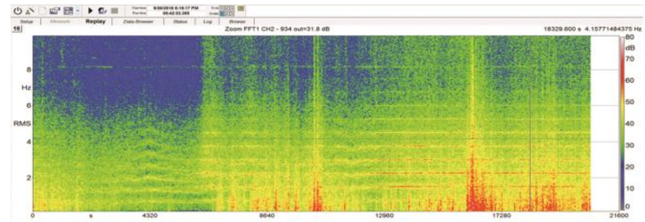

Figure 6b: 3D Sonogram of Wind Turbine Speed Transition by measuring Sub-Audible Pressures (BPFs).

Conclusion

Complex dynamic sources such as multiple wind turbines require advanced measurement solutions and concepts to eliminate measurement uncertainty.

Constant speed wind turbines have stationary and very stable signatures allowing them to be easily measured and separated from random, naturally occurring infrasound using Advanced Narrowband FFT analysis and multi-processing with validation techniques for eliminating measurement uncertainty.

Real-time Analysis is a superior method to produce valid recordings vs. record collection and post-processing off-site. This significantly streamlines the entire measurement process and allows for validation through the constant review of multiple measurement results. This method requires no data editing by third parties if implemented properly and minimizes human error with multiple file handling. The real-time analysis method used also identifies instrumentation setup problems that may occur during long term monitoring as well as other interfering noise sources.

FFT sonograms show fingerprints of turbine BPF's that appear simultaneously at many locations inside and outside homes. These require proper validation before any further calculations are applied.

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[2] Acoustic Interaction a Primary Cause of Infrasonic Spinning Mode Generation and Propagation from Wind Turbines, 166th Meeting ASA San Francisco Dec 2013 Kevin A. Dooley and Andy Metelka

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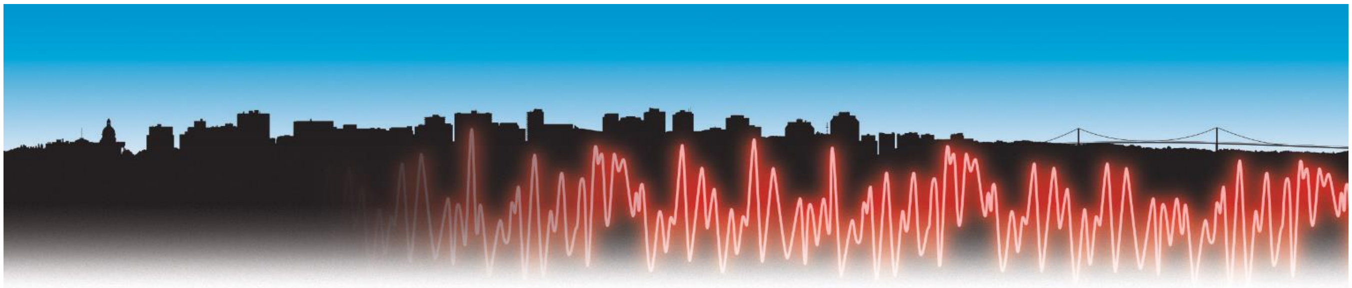

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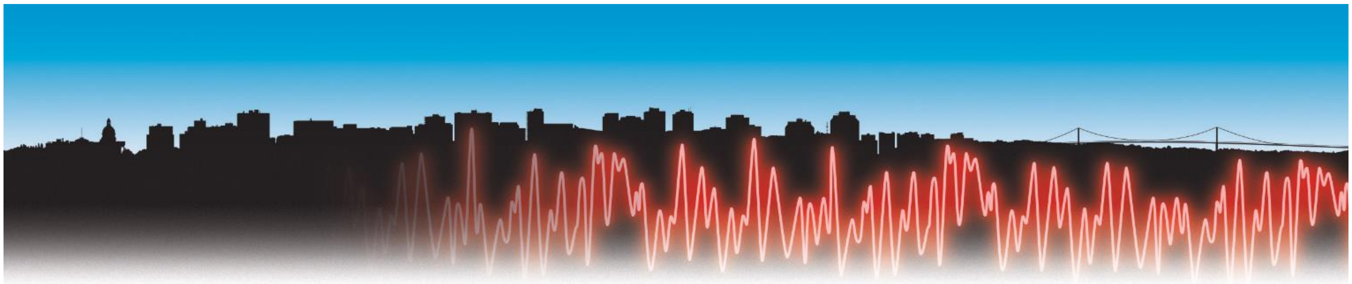

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Suite au succès des numéros spéciaux régionaux de l'Acoustique canadienne, en juin 2015 pour Montréal, en juin 2016 pour Toronto, et en juin 2017 pour Halifax, un prochain numéro est planifié pour juin 2018 et inclura des articles provenant uniquement des régions de Vancouver et de Victoria, en Colombie-Britannique.

Comment en faire partie?

Pour contribuer à un de ces numéros « régionaux », les auteurs sont invités à soumettre un article (de 2 pages maximum), sous la rubrique « Numéro spécial » dans notre système en ligne au http://jcaa.caa-aca.ca **avant le 31 mars 2018**. Il est possible de soumettre un même article dans les deux langues officielles.

Chaque article sera révisé par le comité éditorial de l'Acoustique canadienne qui veillera à ce que les politiques de publications de la revue soient respectées (contenu original, contenu non commercial, etc. – voir les politiques de la revue pour de plus amples détails) tout en accueillant les articles qui font la promotion de l'expertise des auteurs, des services offerts par les compagnies, les réussites de consultants et autres sujets du même ordre.

Un vrai « répertoire régional » dans lequel vous voulez paraître!

Chacun de ces numéros spéciaux régionaux peut être considéré comme un véritable répertoire des noms et services locaux liés à l'acoustique. Ils sont publiés en format papier et envoyés à tous les membres nationaux et internationaux de l'ACA. Une version électronique est aussi disponible en ligne sur le site internet de la revue. Le contenu de ces numéros est indexé, donc facilement trouvable au moyen de moteurs de recherche classiques, tels Google, Bing, etc. Les auteurs sont invités à bien choisir les mots clefs pour maximiser la visibilité de leur article. Des opportunités de publicité ad hoc sont également offertes pour jumeler chaque article avec une page complète de publicité.

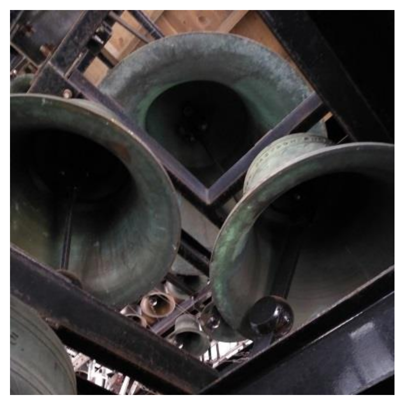
Pour toutes questions, vous pouvez communiquer avec Sasha Brown (sasha.brown@worksafebc.com), Dr. Maureen Connelly (Maureen_Connelly@bcit.ca) ou Dr. Roberto Racca (secretary@caa-aca.ca). Pour réserver un espace de publicité dans un de ces numéros spéciaux, veuillez communiquer avec Bernard Feder (advertisement@caa-aca.ca).

Une telle opportunité ne se reproduira pas avant 7 à 9 ans, assurez-vous d'en profiter maintenant!

ACOUSTICS WEEK IN CANADA 2017

More than 185 people converged to learn, share and socialize at Acoustics Week in Canada 2017. The event was hosted October 11-13, 2017 at the Delta Hotel and Conference Centre in Guelph, Ontario. The conference featured 3 keynote speakers, technical presentations and a large exhibition of acoustical products and services.

The conference brought together thinkers and doers in Canadian Acoustics to discuss current developments in the field. Wednesday started with a keynote address by Elliot Berger titled Bang! Damage from Impulse Noise and the Effectiveness of Hearing Protection, which was followed by a day packed with technical presentations. The first feature of Thursday was John Bradley's keynote titled A Rationale for a National Classroom Acoustics Standard. The technical presentations which followed also featured an extensive workshop on Tools and Guidelines for the Calculation of ASTC by Christoph Hoeller and Jeffrey Mahn of the National Research Council.
The final morning of technical presentations was started with a keynote by Samir Ziada titled Flow-Excited Acoustic Resonances in Shallow Cavities. All in all, the papers and presentations illustrated the diverse subjects covered within the association. However no subject area was better represented than architectural acoustics, with one third of the papers in this subject area. The presentations sparked many discussions – during breaks, meals and social events.



The social events began with a choice of two tours on Wednesday afternoon. The first was to the 36-bell carillon and historic pipe organ at St. George's Church, which were both capably demonstrated by Gerald Manning. The second tour was to RWDI's newly-constructed testing facilities, where some of cutting-edge science and testing were on display.

An Oktoberfest-themed reception followed the tours on Wednesday evening, in keeping with the Bavarian Oktoberfest festival running at the same time in nearby Kitchener-Waterloo. Characteristic foods like roulade, schnitzel, sauerkraut and pretzels were enjoyed with local craft beers. Traditional German music and a performance by a dance troupe from the Schwaben Club rounded out the Bavarian theme.

Products and services relevant to the field of acoustics were showcased in a well-attended exhibition which began on Wednesday evening and continued during the breaks and lunch on Thursday. There was a large assortment of things to see, try and discuss. Many people took the opportunity to make or renew connections with the 30+ exhibitors who were present.

The distinctive atrium of the University of Guelph's Summerlee Science Complex was the site of our banquet and annual awards ceremony. Details of the awards are reported elsewhere in the journal. The evening concluded with a diverse musical concert by the Artelli String Ensemble, made up of Guelph Symphony Orchestra members.

The successes of this conference are due to the efforts of many people. Thank you to all who attended and shared of their knowledge and experience. Special thanks to the generous sponsors who made it possible to add special features, enhance the meals for your enjoyment. And finally, to my fellow organizers: Christian Giguere, Kyle Hellewell, Dalila Giusti and Bernard Feder – we owe many thanks for the successful execution of this conference. Thank You! It has been my pleasure to serve you as conference chair.

Peter VanDelden

SEMAINE CANADIENNE D'ACOUSTIQUE 2017

Plus de 185 personnes ont convergé vers Guelph pour apprendre, partager leurs connaissances et socialiser lors de la Semaine canadienne d'acoustique 2017. L'événement a eu lieu du 11 au 13 octobre 2017 au Delta Hotel et Conference Centre de Guelph, en Ontario. Trois conférenciers invités, des présentations techniques et une exposition de produits et de services en acoustique figuraient au palmarès du congrès.

Le congrès a rassemblé des chefs de file et les acteurs principaux de l'acoustique au Canada pour discuter des développements récents dans le domaine. Le mercredi a débuté par une conférence plénière par Elliot Berger intitulé « Bang! Les dommages causés par le bruit impulsif et l'efficacité de la protection auditive », qui a été suivie d'une journée remplie de présentations techniques. Le premier événement du jeudi fut le discours de John Bradley intitulé « Justification pour une norme nationale en acoustique pour les salles de classe ». Les présentations techniques qui ont suivi ont constitué un vaste atelier sur les outils et les lignes directrices pour le calcul de l'ITSA par Christoph Hoeller et Jeffrey Mahn du Conseil national de recherches du Canada. La dernière matinée de présentations techniques a débuté par un discours de Samir Ziada intitulé « Résonances acoustiques excitées par écoulement dans les cavités peu profondes ». Au total, les différentes communications et présentations au congrès ont couvert les divers sujets abordés au sein de l'Association. Cependant, avec un tiers des présentations au congrès, aucun domaine n'a été mieux représenté que l'acoustique architecturale. Les présentations ont suscité de nombreuses discussions durant les pauses, les repas et les événements sociaux.

Les événements sociaux comprenaient un choix de deux visites le mercredi après-midi. La première portait sur le carillon de 36 cloches et l'orgue historique de l'église St. George, qui ont tous deux été habilement démontrés par Gerald Manning. La deuxième visite a porté sur les installations d'essai nouvellement construites chez RWDI, où certains bancs d'essai et tests de pointe ont été présentés.

Une réception sur le thème de l'Oktoberfest a suivi les visites le mercredi soir, en lien avec le festival bavarois de l'Oktoberfest se déroulant en même temps à Kitchener-Waterloo. Des aliments typiques comme la roulade, le schnitzel, la choucroute et les bretzels ont été dégustés avec des bières artisanales locales. La musique traditionnelle allemande et une représentation d'une troupe de danse du Schwaben Club ont complété le thème bavarois.

L'exposition des produits et services liés au domaine de l'acoustique, qui a débuté le mercredi soir et s'est poursuivi durant les pauses et le lunch du jeudi, a suscité un vif intérêt. Il y avait un grand assortiment de nouveautés à découvrir et à essayer. Beaucoup de personnes ont profité de l'occasion pour établir ou renouveler des liens avec plus des 30 exposants présents.

L'atrium bien distinctif du Complexe scientifique Summerlee de l'Université de Guelph a été le lieu de notre banquet annuel et de la cérémonie de remise des prix. Un rapport détaillé des prix et des récipiendaires est rapporté ailleurs dans ce numéro. La soirée s'est terminée par un concert musical de la troupe « Artelli String Ensemble », composée de membres de l'Orchestre symphonique de Guelph.

Le grand succès du congrès de cette année a été rendu possible grâce aux efforts de nombreuses personnes. Merci à tous ceux et celles qui ont participé et partagé leurs connaissances et leur expérience. Un merci spécial aux généreux commanditaires qui ont permis de personnaliser le congrès, d'améliorer les repas et de rendre possibles de petits à-côtés pour votre agrément. Et enfin, à mes collègues organisateurs: Christian Giguère, Kyle Hellewell, Dalila Giusti et Bernard Feder - nous devons beaucoup de mercis pour cette réussite. Je vous remercie! J'ai eu le plaisir de vous servir comme président du congrès.

Peter VanDelden

AWC2018

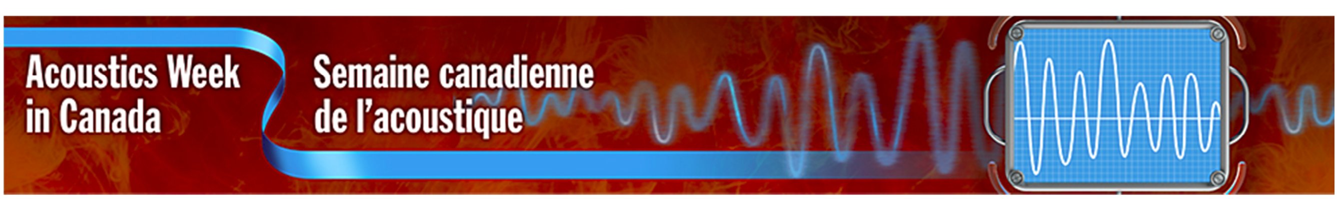
Joint AWC2018 and ASA 176th Meeting, Victoria, BC, 5-9 November 2018

The 176th Meeting of the Acoustical Society of America (ASA) will be held jointly with the Acoustics Week in Canada 2018 of the Canadian Acoustical Association (CAA) in Victoria, BC, Canada, on 5-9 November 2018.

The conference will be organized by the Acoustical Society of America using their guidelines and procedures, while the Canadian Acoustical Association will organize some special sessions and handle its regular business and core activities, such as standards committee, student awards, etc.

For more information, visit http://acousticalsociety.org/meetings

To contact Dr. Roberto Racca, AWC2018 conference coordinator, please send an email to: conference@caa-aca.ca



AWC2018

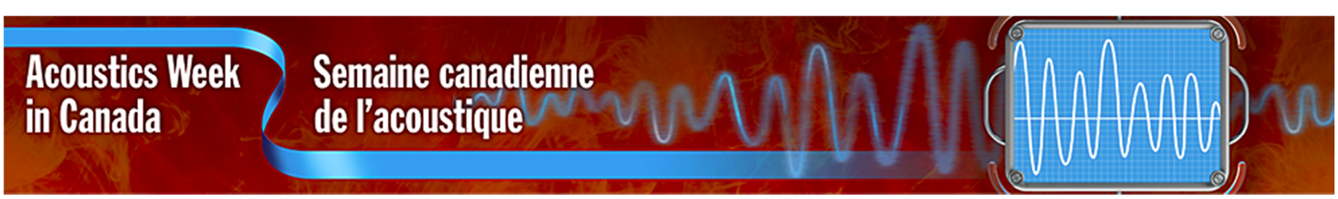
Congrès commun entre AWC2018 et la 176e rencontre de l'ASA,
Victoria, C.-B., 5-9 novembre 2018

La 176e rencontre de l'Acoustical Society of America (ASA) se tiendra conjointement avec la Semaine canadienne d'acoustique 2018 de l'Association canadienne d'acoustique à Victoria, C.-B., du 5 au 9 novembre 2018.

La conférence sera organisée par l'Acoustical Society of America selon leurs méthodes et procédures, tandis que l'Association canadienne d'acoustique y organisera des sessions spéciales et tiendra ses rencontres régulières ainsi que ses activités propres, telles la rencontre des comités de normalisation, le programme de prix pour les étudiants, etc.

Pour plus d'information, visiter http://acousticalsociety.org/meetings

Pour contacter Dr Roberto Racca, le coordinateur du congrès AWC2018, merci d'écrire un courriel à : conference@caa-aca.ca



Special issues on thematic topics related to acoustics

Acoustics is a broad subject matter, as you know, that currently employs hundreds of us across Canada in fields as different as teaching, research, consulting and others. To reflect such diversity the Canadian Acoustics journal published a series of special "regional" journal issues to highlight acoustics professionals, groups and companies located within the greater-areas of major cities in Canada.

After the success of these special "regional" journal issues, the Canadian Acoustics journal decided to program a series of special "thematic" journal issues to highlight the diversity of the many application areas related to acoustics. To reflect such diversity, the Canadian Acoustics journal is currently inviting submissions for the next special "thematic" issue, tentatively programmed for March 2019, **which will mainly focus on audiology and neuroscience**.

How to be part of it?

To contribute to these special "thematic" journal issues, authors are invited to submit their manuscript under the "Special Issue" section through the online system at http://jcaa.caa-aca.ca **before November 15th 2018.**

Each manuscript will be reviewed by the Canadian Acoustics Editorial Board that will enforce the journal publication policies (original content, non-commercialism, etc., refer to the Journal Policies section online for further details) while welcoming promotion of authors' expertise, companies' services, and consultants' success stories and the like.

A true "professional directory" you want to appear in!

Each of these "thematic" special issues of the journal can be considered as a true directory for professionals and services specialized in related fields of acoustics. They will be published in hardcopies and sent to all CAA national and international members, while electronic copies will be made available in open-access on the journal website. The content of these issues will be entirely searchable and comprehensively indexed by scholar engines as well as by major internet search engines (Google, Bing, etc.). Authors are invited to carefully select their keywords to maximize the visibility of their articles, while ad-hoc advertisement opportunities will be given to pair each article with a one-page full advertisement.

If you have any questions, please contact Dr. Olivier Valentin (olivier.valentin@etsmtl.ca). To secure an advertisement for this special issue, please contact Mr. Bernard Feder (advertisement@caa-aca.ca).

Such an offer will only appear every 7 or 9 years, so make sure to take advantage!

Numéros spéciaux portant sur des sujets connexes à l'acoustique

Comme vous le savez, l'acoustique est un vaste domaine qui offre des centaines d'emplois à travers le Canada, et ce, dans différents secteurs tels que l'éducation, la recherche, la consultation professionnelle etc... Afin de bien refléter cette diversité, l'Acoustique Canadienne a publié plusieurs numéros spéciaux « régionaux » afin de faire connaitre davantage les professionnels de l'acoustique d'une même grande région urbaine du Canada. Suite au succès de ces numéros « régionaux », l'Acoustique Canadienne a décidé de mettre en avant la diversité des nombreux domaines d'application connexes à l'acoustique en programmant plusieurs numéros spéciaux « thématiques ». L'Acoustique Canadienne fait donc un appel à soumettre une série d'articles pour le prochain numéro spécial planifié pour mars 2019 **dont la thématique sera principalement consacrée à l'audiologie et aux neurosciences**.

Comment en faire partie?

Pour contribuer à un de ces numéros « thématiques », les auteurs sont invités à soumettre un article, sous la rubrique « Numéro spécial » dans notre système en ligne au http://jcaa.caa-aca.ca **avant le 15 novembre 2018**. Il est possible de soumettre un même article dans les deux langues officielles.

Chaque article sera révisé par le comité éditorial de l'Acoustique canadienne qui veillera à ce que les politiques de publications de la revue soient respectées (contenu original, contenu non commercial, etc. – voir les politiques de la revue pour de plus amples détails) tout en accueillant les articles qui font la promotion de l'expertise des auteurs, des services offerts par les compagnies, les réussites de consultants et autres sujets du même ordre.

Un vrai « répertoire professionnel » dans lequel vous voulez paraître!

Chacun de ces numéros spéciaux «thématiques» peut être considéré comme un véritable répertoire des professionnels et des services spécialisés dans les domaines connexes de l'acoustique. Ils sont publiés en format papier et envoyés à tous les membres nationaux et internationaux de l'ACA. Une version électronique est aussi disponible en ligne sur le site internet de la revue. Le contenu de ces numéros est indexé, donc facilement trouvable au moyen de moteurs de recherche classiques, tels que Google, Bing, etc… Les auteurs sont invités à bien choisir les mots clefs pour maximiser la visibilité de leur article. Des opportunités de publicité ad hoc sont également offertes pour jumeler chaque article avec une page complète de publicité.

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CANADIAN ACOUSTICS ANNOUNCEMENTS - ANNONCES TÉLÉGRAPHIQUES DE L'ACOUSTIQUE CANADIENNE

Looking for a job in Acoustics?

There are many job offers listed on the website of the Canadian Acoustical Association!

You can see them online, under http://www.caa-aca.ca/jobs/

August 5th 2015

ICSV26 to be held in Montreal, July 2019

The 26th International Congress on Sound and Vibration (ICSV26) will held in Montreal, Canada, from 07 - 11 July 2019 at Hotel Bonaventure.

The local organizing committee and scientific committees are currently being formed. Please contact us if you are interested to be part of the adventure! :-) - - You can also check out our website at www.icsv26.org - - Jeremie Voix (conference-chair@icsv26.org) - Franck Sgard (technical-chair@icsv26.org) -

October 12th 2017

AWC18 in Victoria, BC

The 176th Meeting of the Acoustical Society of America (ASA) will be held jointly with the Acoustics Week in Canada 2018 of the Canadian Acoustical Association (CAA) in Victoria, BC, Canada, on 5-9 November 2018.

The conference will be organized by the Acoustical Society of America using their guidelines and procedures, while the Canadian Acoustical Association will organize some special sessions and handle its regular business and core activities, such as standards committee, student awards, etc. - - For more information, visit http://acousticalsociety.org/meetings - - To contact Dr. Roberto Racca, AWC2018 conference coordinator, please send an email to: conference@caa-aca.ca

November 24th 2017

PER BRUEL GOLD MEDAL FOR NOISE CONTROL AND ACOUSTICS AWARDED TO MALCOLM J. CROCKER

The Per Bruel Gold Medal for Noise Control and Acoustics was established in 1987 in honor of D. Per Bruel, who pioneered the development of sophisticated noise and vibration measuring and processing equipment. The medal recognizes eminent achievement and extraordinary merit in the field.

Malcolm Crocker, PhD, distinguished university professor emeritus at Auburn University in Alabama, is recognized for promoting international collaboration, education and the dissemination of knowledge in noise control and acoustics through the formation of professional organizations, the establishment of journals and congress series, and the creation of reference volumes for practitioners. - - Dr. Crocker joined Auburn in 1983 as head of mechanical engineering department. He was promoted to distinguished university professor in 1990 and has been an emeritus professor since 2011. Dr. Crocker has made significant contributions in acoustical fields including finite element analysis, muffler design, statistical energy analysis, transmission loss of partitions and sound intensity measurements.

February 2nd 2018

Abstracts INTER-NOISE 2018 - Due March 12th!

INTER-NOISE 2018, 26-29 august - Chicago, Illinois - Only a few days left for submitting an abstract. -

INTER-NOISE 2018, the 47th International Congress and Exposition on Noise Control Engineering will be held in Chicago, Illinois, USA on 26-29 August 2018. The Congress theme is Impact of Noise Control Engineering. The

Congress is organized by the Institute of Noise Control Engineering of the USA (INCE-USA on behalf of the International Institute of Noise Control Engineering (I-INCE). - MARCH 12, 2018 is the deadline for submitting Abstracts for INTER-NOISE 2018. - Visit our website http://www.internoise2018.org/ -

March 1st 2018

À la recherche d'un emploi en acoustique ?

De nombreuses offre d'emploi sont affichées sur le site de l'Association canadienne d'acoustique !

Vous pouvez les consulter en ligne à l'adresse http://www.caa-aca.ca/jobs/

August 5th 2015

AWC18 à Victoria, B.-C.

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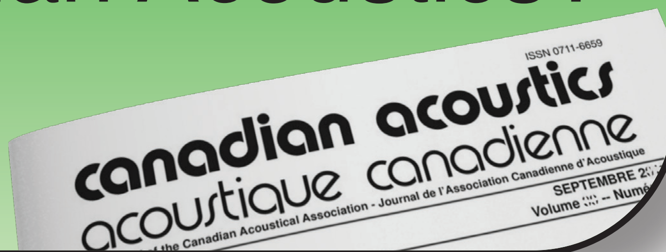
November 24th 2017

Why publish in Canadian Acoustics?



Because, it is...

- A respected scientific journal with a 40-year history uniquely dedicated to acoustics in Canada
- A quarterly publication in both electronic and hard-copy format, reaching a large community of experts worldwide
- An Open Access journal, with content freely available to all, 12 months from time of publication
- A better solution for fast and professional review providing authors with an efficient, fair, and constructive peer review process.

Pourquoi publier dans Acoustique canadienne ?

Parce que, c'est...

- Une revue respectée, forte de 40 années de publications uniquement dédiée à l'acoustique au Canada
- Une publication trimestrielle en format papier et électronique, rejoignant une large communauté d'experts à travers le monde
- Une publication "accès libre" dont le contenu est disponible à tous, 12 mois après publication
- Une alternative intéressante pour une évaluation par les pairs, fournissant aux auteurs des commentaires pertinents, objectifs et constructifs

Application for Membership

CAA membership is open to all individuals who have an interest in acoustics. Annual dues total $110.00 for individual members and $50.00 for student members. This includes a subscription to ***Canadian Acoustics***, the journal of the Association, which is published 4 times/year, and voting privileges at the Annual General Meeting.

Subscriptions to *Canadian Acoustics* *or* Sustaining Subscriptions

Subscriptions to ***Canadian Acoustics*** are available to companies and institutions at a cost of $110.00 per year. Many organizations choose to become benefactors of the CAA by contributing as Sustaining Subscribers, paying $475.00 per year (no voting privileges at AGM). The list of Sustaining Subscribers is published in each issue of ***Canadian Acoustics*** and on the CAA website.

Please note that online payments will be accepted at http://jcaa.caa-aca.ca

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Areas of Interest: (Please mark 3 maximum)

1. Architectural Acoustics
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5. Psychological / Physiological Acoustic
6. Shock and Vibration
7. Hearing Sciences
8. Speech Sciences
9. Underwater Acoustics
10. Signal Processing / Numerical Methods
11. Other

For student membership, please also provide:

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(University) *(Faculty Member)* *(Signature of Faculty Member)* *(Date)*

I have enclosed the indicated payment for:
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For individuals or organizations wishing to pay by check, please register online at *http://jcaa.caa-aca.ca* and then mail your check to:

Executive Secretary, Canadian Acoustical:
Dr. Roberto Racca
c/o JASCO Applied Sciences
2305–4464 Markham Street
Victoria, BC V8Z 7X8 Canada

Formulaire d'adhésion

L'adhésion à l'ACA est ouverte à tous ceux qui s'intéressent à l'acoustique. La cotisation annuelle est de 105.00$ pour les membres individuels, et de 50.00$ pour les étudiants. Tous les membres reçoivent ***l'Acoustique Canadienne***, la revue de l'association.

Abonnement pour la revue *Acoustique Canadienne* et abonnement de soutien

Les abonnements pour la revue ***Acoustique Canadienne*** sont disponibles pour les compagnies et autres établissements au coût annuel de 105.00$. Des compagnies et établissements préfèrent souvent la cotisation de membre bienfaiteur, de 475.00$ par année, pour assister financièrement l'ACA. La liste des membres bienfaiteurs est publiée dans chaque issue de la revue ***Acoustique Canadienne***..

Notez que tous les paiements électroniques sont acceptés en ligne http://jcaa.caa-aca.ca

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Cocher vos champs d'intérêt: (maximum 3)

1. Acoustique architecturale
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11. Autre

Prière de remplir pour les étudiants et étudiantes:

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Dr. Roberto Racca
c/o JASCO Applied Sciences
2305–4464 Markham Street
Victoria, BC V8Z 7X8 Canada

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Association canadienne d'acoustique

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