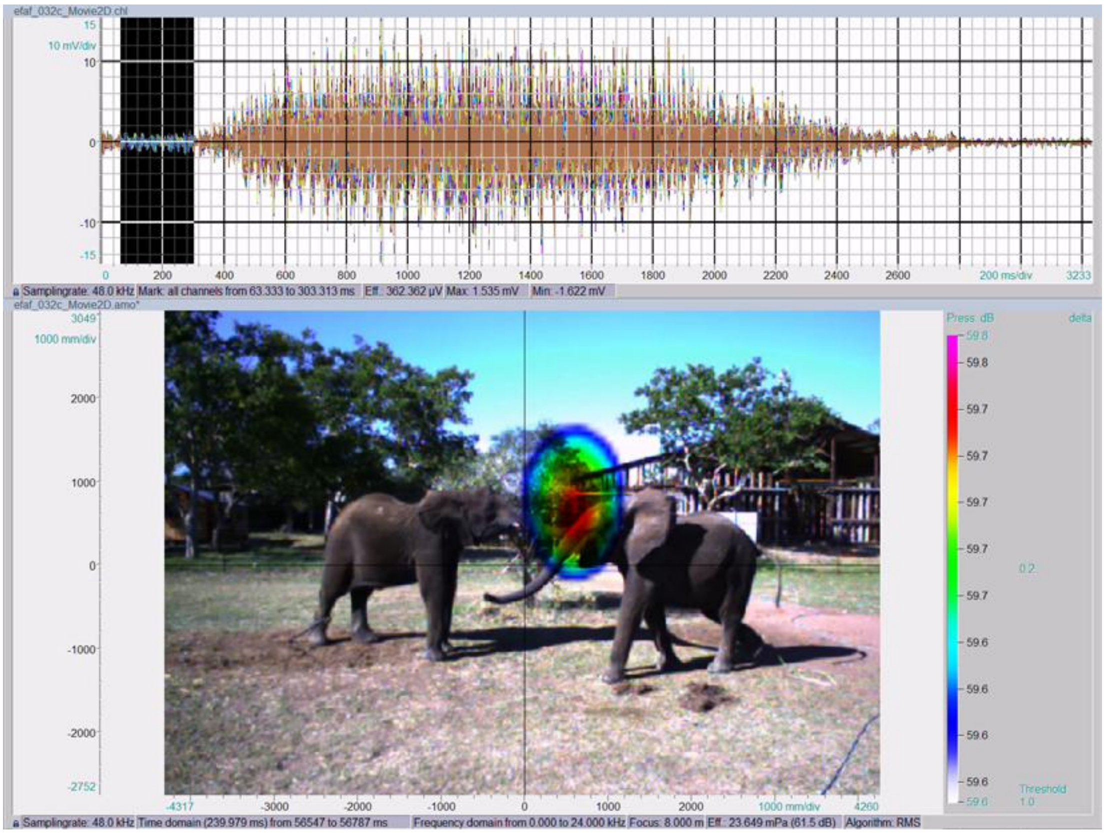
New Zealand Acoustics

Volume 28, 2015 / # 2



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New Zealand Acoustics

Volume 28, 2015 2nd Quarter

Features

Regulars

Cover Image: Snap-shot from "An audio recording with an acoustic camera" of elephant vocalisations

Source: www.ims.tuwien.ac.at/projects/elevoc

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From the President and the Editor's

President's Column

Dear Members,

I'm aware that, as an acoustician, my expertise doesn't extend to matters of temperature... but even so I'm going to pronounce that it has been blimmin' cold this week. I'm also aware that I live in Auckland, so have nothing to complain about. Nonetheless, I hope everyone is keeping warm... but if not, I invite you to pause for a minute, and prepare yourself a nice warm mug of hot chocolate before reading on. Don't make a coffee... the stuff is over-rated.

I have three topics to raise in this mid-winter column. The first is to echo Lindsay and Wyatt's comments in their Editor's column in welcoming Robbie Blakelock and Stuart McLaren to the journal team. Preparing the journal is a big task – bigger, I think, than even I can appreciate – and I'm glad we have been able to find more enthusiastic volunteers. Robbie in particular has jumped straight in the deep end, and has been on the charm offensive with our marvellous advertisers without whom this journal would cease to exist.

The first round of Continued Professional Development (CPD) submissions is just around the corner – due date is 15 July 2015. The website now contains a CPD form in MS Word format, as well as an online submission form (thanks to Neil Jepsen for his assistance in getting the form ready, and Grant Emms for sorting out the website).

Here are a few things to consider before launching into your submission:

- It is a biennial CPD scheme, so you are only required to submit this year if you were accepted as a Member under the new membership regime in 2011 or 2013
- Being biennial, submissions must only include CPD activities for the previous two years eg. for this year will only include activities from 1 July 2013 to 30 June 2015
- Those who were accepted as a Member under the new membership regime in 2012 or 2014 will be required to submit their CPD in July 2016. Not this year
- Anyone who was a member of the Society before 2011, but has not applied to be a Member under the new scheme (introduced in 2011) will now be an Affiliate, until such time as they apply to become a Member
- The CPD requirement is for Members only (not Affiliates or Fellows)
- If you are not sure what year you joined, or do not know your membership number, please contact secretary@acoustics.org.nz

I know this may all seem a bit pernickety, but this is just the start of getting the CPD scheme rolling and I'm sure that we'll all get into the swing of things before too long. If you have some doubts over whether your activities have fulfilled the requirements, I encourage you to make a submission anyway with some explanatory notes. There may be some leeway granted, this being the first time and all.

Finally, I'm pleased to announce that Sir Harold Marshall has been honoured by the Institute of Acoustics (UK) by being awarded the Rayleigh Medal. This prize is awarded annually for "outstanding contributions to acoustics", and previous recipients include Leo Beranek, Heinrich Kuttruff, Colin Hansen, Michel Bruneau, Mike Barron and John Bradley. As a New Zealand acoustician, and on behalf of the ASNZ, I'd like to say that I'm very proud of Sir Harold, and wish him all the best for the ceremony in October.

Yours faithfully,

James Whitlock

Editor's Column

Welcome to issue #2 (2015) of New Zealand Acoustics. We start with welcoming our newest team members to New Zealand Acoustics, Dr Stuart McLaren & Robbie Blakelock. Stuart is coming on-board as a new Sub-Editor while Robbie is joining the team as our new Advertising Manager.

Stuart is a Senior Lecture at the School of Public Health, Massey University. You will know Robbie from issue #1 this year where we introduced him as one of two new committee members. The appointment of Robbie brings a host of new updated and exciting ads in this issue of NZ Acoustics. We wish to take the time to thank all our advertisers who support the magazine. We welcome all new advertisers to this edition of New Zealand Acoustics and thank those who have supported New Zealand Acoustics over the years. We also wish to take a moment to also express our thanks to Fadia Sami for her service as previous advertising Manager. Fadia will maintain her duties as an ASNZ Committee Member.

In this edition we also have all the latest news updates. RMA-Net is taking a break but will be back in the next issue. We have a host of interesting papers including one visualizing sound emission of elephants & a technical review of common siren types. We also have a very interesting piece on *The Philharmonie de Paris,* which opened January this year. We recommend you take the time to read all these articles.

Lindsay & Wyatt journal@acoustics.org

Sir Harold Marshall to receive Rayleigh Medal

The Acoustical Society of New Zealand would like to congratulate Sir Harold Marshall who will in October this year receive the Rayleigh Medal from the Institute of Acoustics [IOA]. The prize is awarded for "outstanding contributions to acoustics". The prize is named after John Strutt, 3rd Baron Rayleigh.

ASNZ Continued Professional Development (CPD) scheme

A friendly reminder to all Members of the ASNZ regarding the requirement to submit their Biennial (2 yearly) record to ensure they maintain their status of Member. Key things you need to know are:

- CPD is required for Members but is not required for Affiliates and Fellows of the Society.
- CPD submissions are due on 15 July every two years from a Member's year of joining. For example, if a Member joins in 2014 or prior to 2014, their CPD submission is due on 15 July 2016, 2018, 2020 etc. If a member joins in 2015, their CPD is due on 15 July 2017, 2019, 2021 etc. Please refer to your Membership Certificate/Membership Number for date of joining. If you don't have this date it can be obtained from secretary@acoustics.org.nz.
- ASNZ will respond to individuals by 1 August only if there are issues with their submission.
- There is no additional fee for taking part.
- A total of 50 points minimum is required for each biennial (2 yearly) submission.
- The ASNZ Code of Ethics applies.
- Submissions to be submitted to ASNZ via email to: secretary@acoustics.org.nz. An online submission form is currently being developed.

All members are encouraged to ensure they make themselves aware of the requirements of the scheme by visiting the ASNZ webpage (www.acoustics.org.nz).

ISO Standards under review

The ASNZ webpage [acoustics.org.nz] now has a section pertaining to 'ISO Standards under review'. The ASNZ webpage page lists the ISO standards currently under review along with listing the New Zealand Industry Reference Group (IRG) Members. If you have comments or contributions on any of the Standards listed on the webpage contact the IRG members listed. For any other queries about New Zealand's participation in ISO committees contact should be made with Standards New Zealand via:

Isoadmin@standards.co.nz

The Acoustical Society of New Zealand

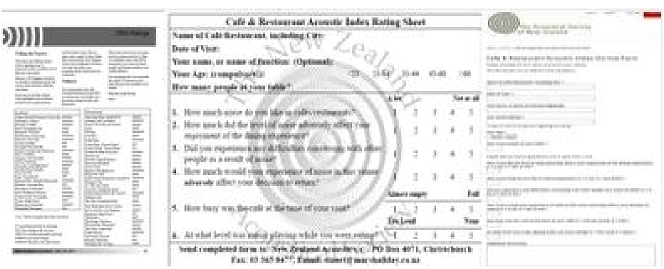
www.acoustics.org.nz

The ASNZ webpage contains a host of information including information on Membership, Journal Information and Journal Articles, Continuing Professional Development, Cafe and Restaurant Acoustic Index, Standards Committees and Standards, the Latest News and Discussion and Contact details of the Society.

Why not visit for yourself?

Cafe and Restaurant Acoustic Index (C.R.A.I.)

The Cafe and Restaurant Acoustic Index, C.R.A.I., is now completely online with all results and online forms able to be viewed and download from the acoustics.org.nz website under the C.R.A.I tab.



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Comparative study of the performance of smartphone-based sound level meter Apps

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Abstract

An increasing prevalence of sound level meter Apps may appear to be a concern to manufacturers of metering equipment but such systems are readily disregarded by professionals due to unacceptable inaccuracy, incorrect measurement methods or parameters. On a technical basis, the (typically MEMS) microphone specifications are the primary limitation to the capabilities of such devices in meeting the requirements. This considered, the attachment of a high-quality condenser microphone and pre-amplifier, as used on professional equipment, may appear to be a solution for low-cost metering that meets IEC-61672, but it is shown that many other equipment factors affect the performance of the system, and conformance to the specifications. This study investigates the premise that, while it may be argued that approximate readings, provided by smartphone metering, can at least offer an indication that further investigation may be necessary, there exists the real chance that the shortfalls in equipment properly measuring the full range of required acoustical parameters will lead to non-detection of significant workplace or environmental noise problems.

Orginally published at the 43rd International Congress on Noise Control Engineering (Inter-noise), November 2014

1. Introduction

Modern sound level meters (SLMs) have moved on significantly in recent decades from the days of analogue metering. Beyond the pre-amplifier, few functions of the device involve analogue circuitry and, once sampled by an Analogue-to-Digital Converter (ADC) the processing of the data to return the desired acoustic parameters is carried out in the digital domain by the processor. Typical smartphone hardware architecture contains some form of the necessary components and similar design elements as a SLM and thus the smartphone platform lends itself very well to carrying out the same function.

Noise monitoring by an array of low-cost, mobile; or more appropriately, moving and track-able; devices is indicated to be of high interest in the industry and is presented as a useful utility in projects requiring extensive data sourcing by Maisonneuve et. al. (2009) , wherein the pragmatic benefits of the use of a vast number of low-cost sources is very well discussed.

A plethora of new and updated sound level meter (SLM) apps is available through various online channels on a variety of mobile operating systems; predominantly Android and iOS. These range quite significantly in capability, graphical manner of the presentation of data and the particular acoustical parameters reported. Without naming any specifics, it is not uncommon to find such apps reporting parameters which are not considered standard. Also, factors such as frequency weighting are sometimes not made explicit, not possible to deactivate/change or simply not present.

1.1 The early reflections of the impulse response of an auditorium

Recent studies by Kardous and Shaw (2014) [2] have suggested that a handful of such SLM apps, when installed on certain devices and used to measure steady pink noise in a controlled test environment, are accurate enough to meet international standards for metering equipment. Similar results were reported by Nast, Speer and Le Prell (2014) [3], where devices were exposed to narrowband 250-8000 Hz noise and also by Keene et al. (2013) [4] whom again used a pink noise source. It is evident from these studies that there are many apps that can make rather accurate measurements within the constraints of the test; in the case of Kardous and Shaw, even without initial calibration, three apps were found to meet the specification marked out in the introductory passages of ANSI S1.4-1983 [5], wherein in is stated that class 2 devices must have a total error of no more than ±2.3 dB. However, such test environments are arguably not representative of the actual manner in which a smartphone-app-SLM or dedicated SLM is used for real-world measurements. Consequentially, there are of course a vast number of other acoustical tests that form the complete ANSI S1.4 and IEC-61672 standards, addressing the directional response of the SLM, distortion, linearity, tone-burst response etc. Although not made explicitly within any found study, the suggestion that a device is meeting the ANSI standard by conforming to only one aspect of the specifications is misleading.

Investigations have been carried out by Ostendorf (2011 [6], 2012 [7], 2013 [8]) that take the testing further and apply different noise sources. In complete contrast to the positive outcome of aforementioned steady-noise testing, the SLM apps were found to deviate drastically from that measured by a class 1 meter. With the same iPhone, different apps were used to measure various steady noise and single frequency tones and astounding differences of >38 dB were seen between apps for a steady 80 Hz sinusoid. Woolworth (2014) [9] reports differences of 10 dB when performing field tests, both indoors and outdoors.

1.2 MEMS microphones

One major limitation of sound level meter apps on the majority of commercial smartphones currently manufactured is the microphone. As high-definition video capture becomes highly regarded, recorded audio of high quality is also becoming a desired specification on mobile devices, but to date the main function of the audio recording system is to sample the human voice. Thus, as it is well known that speech information can be conveyed within a bandwidth much smaller than the human auditory range, mobile telecommunication devices are only strictly required to be responsive to this smaller bandwidth and by economic matters it is beneficial for them to do so. Mobile device microphones therefore have not historically had the requirement for a flat, wider frequency spectrum response that is required of measurement microphones. Until recently, it would not be uncommon to find the microphones within mobile devices to be polymer membrane electret condenser types, with a resonance of only a few kilohertz.

Matters have greatly improved with the developments of Micro-Electro-Mechanical-System (MEMS) microphones. More recent MEMS microphones have remarkably flat responses; on a par with the best ½" electret or externally-polarised condenser microphones. This is understandable, as the transduction technology employed is essentially the same as a ¼"-1" electret condenser, but with much smaller components, thus a higher resonant frequency and therefore an extended region of flat response before resonance. Where MEMS devices suffer is the noise floor, with the better devices struggling to achieve much over 60 dB (referenced to 94 dBA) signal-to-noise ratio. At the time of writing, the best-reported SNR from one particular manufacturer is 70 dB [10], although other specifications make the particular model microphone inappropriate for noise measurement (55 Hz low frequency roll-off). The absolute sound pressure upper limit of MEMS microphones is also a limitation, with 120 dBA being the general maximum.

Modern implementations of MEMS microphones commonly install the devices within the casings of the smartphone, and usually directly soldered to the circuit board. This adds to the robustness of the device but also introduces an acoustical filtering network, which can attenuate or amplify particular frequencies. MEMS devices are becoming near-equal contenders with electret condenser microphones (ECMs) by specification and applicability in noise measurement; Shelton (2014) [11] reports upon a recent project at the National Physical Laboratory, UK, wherein MEMS microphones have been seen to perform with the frequency response tolerances for type-1 working standard microphones by IEC 61094-4 [12].

Regardless, the problem will always exist for the smartphone noise meter system that the exact device chosen by a smartphone manufacturer is unknown.

1.3 Other effects within the mobile device

Beyond the microphone, the signal chain is essentially unknown. Fundamentally, smartphone designers will be targeting 'high-quality'-sounding audio rather than a perfectly flat response. Many manufacturers apply high-pass filtering to the signal from the microphone to reduce 'pop' or wind noise. As reported by Faber (2012) [13] Apple devices with iOS firmware prior to version 6 have such filters applied, and these differ between devices. Remarkably, from measurements by Faber, an iPhone 3G-S with pre-version-6 iOS has a very high-order high pass filter, with the -3 dB point over 200 Hz and a roll-off of approximately 30 dB/octave. It would be a fair hypothesis that, considering the date of the study with respect to the release date of iOS-6 (both 2012), the aforementioned result of Ostendorf with an 80 Hz tone was affected by this filter; the difference between the apps could be the result of the app designer applying correction filters with differing levels of success. From iOS version 6 onward, it is possible within software to turn off this filter but again, whether a particular app does this or not may not be made explicit.

Digital signal processing algorithms are widely implemented within the regular audio channel of a mobile device in order to reduce the signal bandwidth and bitrate. Jarivnen et al. (2010) [15] describe the relationship between the bandwidth of audio and the intelligibility of the speech, with an optimum ≈14 kHz bandwidth above which there is no improvement; furthermore, even a slight detriment with a broader, full-audible-spectrum bandwidth. The last two decades have seen significant development of the coding of voice channels in mobile communications devices in order to reduce bitrates whilst keeping the audio quality high and intelligible; methods within often use psychoacoustic effects to remove portions of the audio signal that would not be perceived and thus unnecessary to transmit. Whilst it is perfectly valid to eliminate redundant sound on perceptual grounds, it is not valid to do so regarding exposure; whether or not a listener perceives portions of the total energy reaching their hearing system is irrespective of the amount of noise exposure they receive.

2. Methodology

2.1 Hardware choice

Devices were essentially chosen by availability and then by form, software environment and age. Different sizes of device were included, from a handheld 4"-screened smartphone to 10" tablet. Android and iOS devices were selected, with a range of levels of hardware technologies and financial costs. Whilst this opened the gate wide to a lack of control over the affecting variables, and thus one may readily question the validity of conclusions arising from the resulting measurements, it is suggested that this is entirely representative of 'real-world' situations. To expand; the typical end-user is entirely unlikely to have chosen their smartphone device on the merits of its ability to accurately measure noise; more likely it has been chosen due to other marketed factors such as the screen size, processor speed, storage capacity, design aesthetics or simply the brand or colour. Additionally, any attachments such as cases fitted to the devices *were left attached*.

While blazingly obvious to the technical community that this would have an effect upon the measurement, it is entirely representative of the manner in which the untrained or poorly-informed user may download such an application to their personal mobile device.

For comparative measurements, a type-approved IEC 61672 Class 1 SLM (Cirrus Research CR:171C) was used. Calibration using a type-approved IEC 60942 Class 1 acoustic calibrator (Cirrus Research CR:515) was carried out before all measurements made with a ½" microphone.

The vast majority of smartphone devices will switch from the internal microphone when an alternative microphone is connected to the headset input. The same model of microphone and preamplifier from the SLM used for comparison measurements was used. The preamplifier was fitted with independent battery power, the gain increased by 20 dB to make it appropriate for a smartphone input and a potentiometer used to trim the output voltage such that calibrations could be carried out using the acoustic calibrator when attached to the smartphone.

2.2 Test procedures

The study implemented four different tests with a selection of devices.

2.2.1 Variance of measured sound level using different devices with the same SLM app

To demonstrate the variance in measurements made by devices which are not designed to be sound level meters, a study was devised to be typical of a workplace noise measurement, with the level measured by three different mobile devices and the Class 1 SLM. Test subjects were selected based upon their having no knowledge of the correct operation of a sound level meter. Each of the four devices were placed upon a bench and the users instructed to use each device in turn to measure the noise level experienced by an employee positioned 1 m from a small air compressor unit. The room had no acoustical treatment and results would clearly vary by the manner in which measurements were made. Additionally, the actual position of the measurement relative to the intended measured point was different, chosen by the operator.

2.2.2 Wind noise

Tests were performed in a quiet, dry, outdoor environment in the middle of a grass field, well away from any residences or roads on a gusty day, where the wind varied between near-zero and over 6 ms^{-1}. All meters/smartphone apps were set to fast time weighting. Meters/devices were held outstretched at shoulder height and the ambient noise level recorded when the wind speed was below 0.2 ms^{-1}, the speed at which the anemometer (ATP DT-618B) just began to spin and give a reading. When the wind speed reached 5 ms^{-1}, the noise levels displayed by each device were recorded. Similar measurements were made with the Class 1 meter when fitted with and without a windshield. All measurements were repeated ten times per smartphone/app combination and the averages reported in Table 1.

2.2.3 Measurement of workplace noise

Three sound sources were used; the noise from a lathe, running alone with no cutting taking place (thus only motor and gear noise), the noise from an aluminium tube being hit with an equal-height dropped hammer with a frequency of 2 Hz (timed using a metronome) and the combination of both noises simultaneously. Devices were held in the hand at a distance of 1 m from the noise sources, with the device held down and then repositioned back before taking subsequent measurements; ten in total per combination.

2.2.4 Comparative use of a type 1 microphone capsule to measure workplace noise

Various workplace noise sources were selected to give a good range of qualities; steady, impulsive, high and low crest factors, and a variety of frequency content; particularly sources with and without significant content at the extremes of the frequency range. For each noise source, the position of the microphone was kept constant. In the case of the external type 1 capsule, the sound calibrator was attached, with the trim between the pre-amplifier and smartphone device under test adjusted until the device displayed 93.7 dBA before making the measurement.

2.3 Software choice

Good agreement was found with the app selection process of Shaw and Kardous (2014) [2] and five SLM applications were selected at random from the list of ten used in their study. This presented a list of paid-for and free apps. Of the five apps chosen, only one was available for iOS and Android; the iPhone result is presented for this one app.

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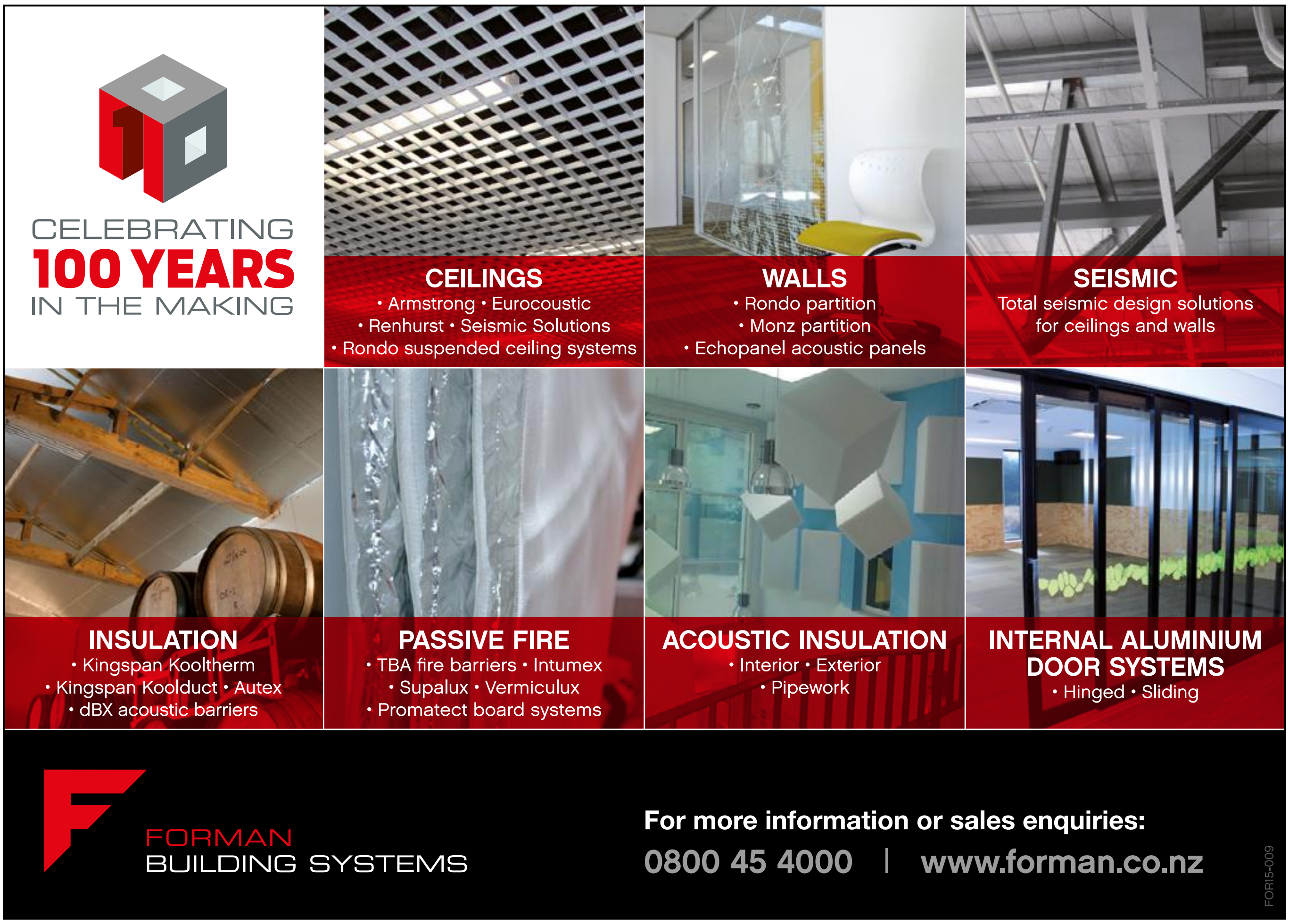
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3. Results

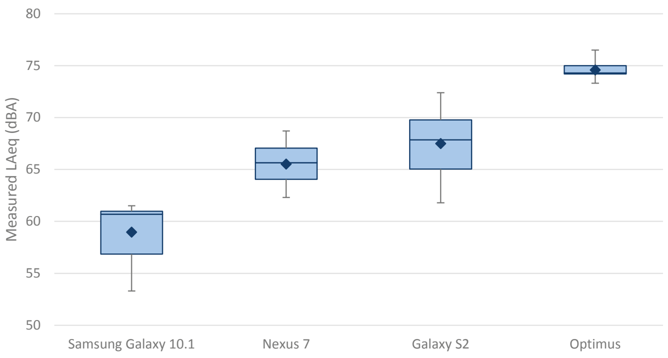

Figure 1: Box plot of the variance in measurement made by untrained users with an IEC61672 Class 1 meter and three different format mobile devices

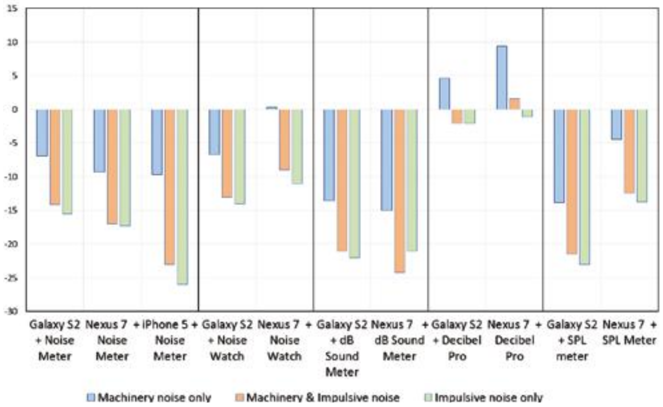

Figure 2: Comparison of same App running on similar form devices, relative to IEC61672 Class 1 SLM reading

Table 1: Wind noise measurements Optimus Class 1 meter

Device	Number of Apps tested	Average increase reading between < 0.25 ms^{-1} and 5 ms^{-1} (dBA)
Optimus Class 1 SLM with windshield	n/a	1
Optimus Class 1 SLM without windshield	n/a	8
Samsung Galaxy G2	5	12
Nexus 7	3	11
iPhone 5	3	7

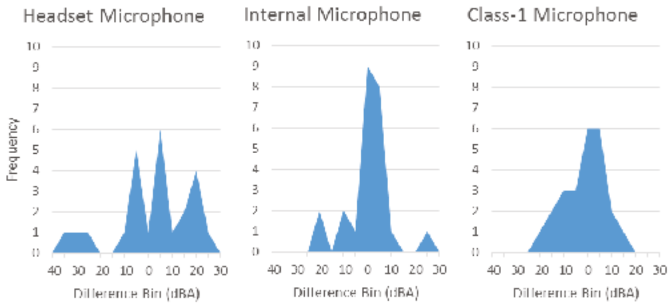

Figure 4: Histograms of differences in reported L_{Aeq}, grouped by microphone type

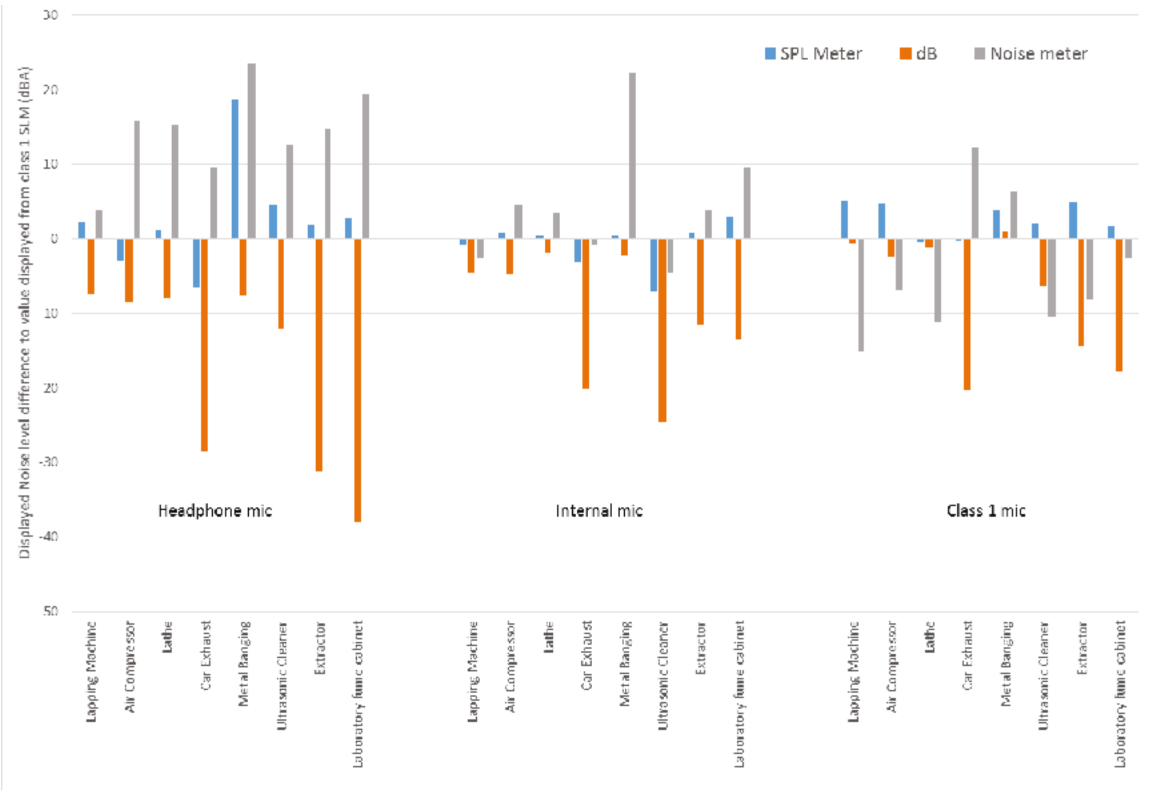

Figure 3: Difference in readings for a single iPad device, measuring different workplace noise with three different apps

4. DISCUSSION

4.1 Comparison of devices running the same SLM App

An important design factor of a sound level meter is that the form of the device is ergonomically conducive to the proper manner of making a noise measurement. By the simple action of picking up the device, the microphone is directed appropriately, placed away from the user to avert reflections and diffraction from objects (i.e. the user) near or within the direct path to the sound source. One may readily argue that the reasons for such variance are clear; the microphones are placed in non-ideal locations, disguised within the body of the device sometimes with very small apertures and often easily obscured by cases or the placement of the users' hands. Within the test, some subjects chose, without guidance, to position the devices such that the microphone pointed toward the noise source; other subjects simply held the device one-handed, screen-facing, as they would when performing a typical smartphone operation. There were two distinct occasions when the user appeared to have covered over the microphone when using the Samsung tablet, which may account for the majority of other measurements being considerably higher.

Although an increased variability is seen for two of the devices compared to the class 1 meter, there were insufficient samples in the set and additionally multiple variables simultaneously affecting the results of each test and it would be entirely inappropriate to draw any conclusions as to why a particular device had not achieved an accurate measurement. This methodology was entirely intentional however; it is this exact style environment within which a SLM app on a mobile device would be used and thus, disregarding the absolute accuracy of measurement, the methodology and results so far display an indication of the possible variability of measured L_{Aeq} due to the design of the device and the variety of manners in which the measurement could be taken.

There are numerous reasons as to why this would be; an inexhaustive list of which are:

- Devices were not calibrated,
- Hardware varies significantly, with no knowledge of the application designer in the absolute sensitivity of the microphone nor its response.
- Microphones were placed in a location on the device which was not suited for accurate acoustical measurement,
- Hardware capabilities are lacking in the ability to properly capture noise levels without refraction or reflection,
- Other software may be running on the device; apparent or not; with the possibility of interrupting background tasks,
- Performance may be compromised by the current state of the operating system; availability of free memory or storage,
- Filtering may or may not be applied to the microphone; it is often found that a high pass anti-pop filter is applied, which would detriment low-frequency measurements.

4.2 Wind noise

By design, mobile devices rarely have physical protection against wind noise; such matters are instead 'band-aided' by methods of filtering and signal processing of the microphone signal. Taking this investigation further would require an acoustic laminar wind flow chamber; clearly beyond the scope of the study, but nevertheless, the devices were definitely susceptible to wind noise, with approximately 10 dBA increase in measured level. Without any protection, measurements in anything other than still air environments would be unacceptably inaccurate.

4.3 Similar form devices running different software for workplace noise

In the results displayed in Figure 2, it would appear that there are regular trends in the measurements. Taking the results between each device using "Noise Meter", the measured levels relative to other measurements would suggest that, if some offset were applied by calibration, the smartphone apps would be reporting similar values. However, at best, this approach would produce a result similar to "Decibel Pro", which is still at best 2 dB away from the Class 1 SLM reading.

Further control of the test conditions with proper isolation of variables would be required to determine more intricate matters, although this was not the intent of the investigation. For instance, it is suggested that a calibration of the sound source could be made first, presenting a steady 1 kHz sine tone at the beginning of the recording, the volume of which could be then adjusted until the smartphone app presented the correct reading. Irrespectively, there are two matters indicated by these results:

- Non-calibration of smartphone meter apps leads to very high inaccuracies in the majority of cases,
- It would appear that there are better and worse combinations of software and hardware.

Overall, taking the difference of all results from each smartphone/app combination into account, an average difference of 11.8 dB was seen between SLM-app and the level measured by a Class 1 SLM.

4.4 iPad tests using the internal, a headset-mounted and a class 1 microphone

Consideration of the results from the headset microphone suggest the combination to be drastically poor; a difference of 57 dBA between different apps using the same hardware is difficult to believe. There are three distinct noise sources for which exceptional disagreement is seen between the app measurements; considering the qualities of the sound source in each of these three cases, all of which had high-amplitude at low-frequency content, it is clearly seen that some effect within the smartphone is rejecting low frequency content.

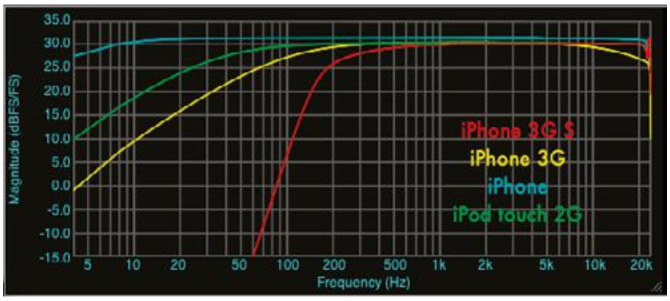

Figure 5: Input frequency response of various iPhone models, indicating high-pass filtering [16]

It would be a reasonable assumption and scope for investigation that the mobile device was performing some form of high-pass filtering, by single-tone measurements in controlled acoustic conditions. This is a known issue for older iPhone devices with firmware prior to iOS-6, as described by Faber (2009) [14], whereby very high-order filters are used by some devices (see Figure 5).

Considering the distributions of the differences in measurements from that given by the class 1 meter, seen in Figure 4, attachment of a type 1 microphone to a smartphone can result in marginal improvement over the use of the internal microphone.

Even with the additional benefit of calibration however, there are still clearly large discrepancies for noise sources of extremes of frequency content (car exhaust, extractor unit and laboratory fume cabinet in Figure 3), and issues with impulsive noise.

Upgrading the smartphone hardware system with a more appropriate/accurate measurement device clearly provides more scope for improvement, but this still does not eliminate the additional complications that are implicit in the use of a personalised, multi-function device, with various unknown additional software installed. Fundamentally, it is totally undeniable that the high-SPL-level insufficiency of the MEMS microphones fitted to the vast majority of mobile devices makes such a device unsuitable for the measurement of workplace noise.

It is proposed that, if the aforementioned considerations are incorporated and the device is stripped of all other functions and software, fitted with a few hundred pounds worth of improved front-end transducing equipment, with the software sampling and performing calculations in the proper manner, a smartphone device could very readily be transformed into an accurate acoustic measurement device, but at the end-point of such a process, the result would be drastically uneconomical, of unproven reliability and due to uncertainties of the exact hardware installed certainly not anything that could be presented for pattern approval. It is duly noted that applications are available, such as those by Faber Acoustics [13], where most of these matters are taken into account and go a long way toward producing a class-meeting SLM from a production smartphone. The breadth of testing and the documentation provided by Faber places Faber Acoustic's flagship SLM software in a performance class far above the free/low-cost SLM apps; consequentially retailing at £70 (and hence the omission of it from this study). Additionally, the smartphone itself is very high-value; with the availability of metering equipment thus well within the financial outlay of the smartphone-based approach, one would clearly ask whether there would be any benefit at all; especially when the loss of one's treasured smartphone as actually being one's smartphone is taken into account!

5. Conclusions

Additional testing would be required to draw statistically confident results; perhaps by this, more exacting reasons as to why a smartphone is particularly inaccurate could be investigated and improvements then made.

It is readily accepted, as found in previous studies, that current smartphone/app combinations can measure mid-level, steady, broadband noise sources with acceptable accuracy to meet that single aspect of international standards. However, it is argued that laboratory-based testing performed so far do not represent the methods in which a smartphone will actually be used when taken into real-world environments, especially industrial, higher-noise-level environments where workplace noise is likely to be problematic. The real-world approach taken in this study demonstrates that the use of smartphone apps in genuine noise-problematic situations is fraught with inaccuracy; it is postulated that well-trained ears would be better indicators than some of the software/hardware combinations.

If the limitation is made that a given SLM app is designed for one particular model and variant smartphone, it is considered achievable that an IEC-61672-standard noise monitoring device could be producible, but with the unrestricted variation in hardware between manufactures, their models and even period/factory of manufacture of a particular model it is highly dubious that an app can be applicable to a wide range of devices. Even then, acquiring type approval for a SLM is a lengthy process involving numerous diverse test procedures, the cost of which runs into many tens of thousands of pounds, let alone the development costs leading up to the point of testing.

Calibration is clearly a huge aspect of achieving an accurate measurement and the inability of the majority of users to be able to perform a calibration is a major factor in the accuracy of a particular device. The application of IEC-standard microphones, or at least capsules with a body that can be attached to a calibrator makes steps toward resolving this issue, but without this, the user would typically require access to a reverberation chamber or other controlled acoustic facility to perform a calibration, which is clearly not accessible to the vast majority of users.

Used appropriately, and in each individual case of measurement taking into account the limitations of the hardware/software, it is suggested that a calibrated, quality smartphone device with an app tailored to that specific hardware can be a useful tool to a qualified professional, but the development of the consensus within the general public that generic smartphone SLM apps installed on any device are an appropriate approach in which workplace noise can be monitored is a highly questionable avenue to continue upon.

Acknowledgements

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Disclaimer

It is not the intention of this study to prove or disprove any functionality of the devices, software nor combination thereof and whilst specific mention has been made to particular device brands or software, this is only made with the intention of enabling third parties making future comparisons to the results presented. Any indications of accuracy or inaccuracy are not to be considered an endorsement by the authors nor Cirrus Research plc.

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Memorandum of Understanding signed by Deaf Aotearoa and The National Foundation for the Deaf

On Saturday 9th May 2015, Deaf Aotearoa New Zealand and The National Foundation for the Deaf signed a Memorandum of Understanding (MOU). The purpose of the MOU is to establish the terms of a beneficial collaboration between Deaf Aotearoa and the Foundation so that both parties can work together, in good faith to achieve successful collaborative outcomes.

The organisations have a long history of cooperation to support and advance the interests of Deaf people and those who are hard of hearing in New Zealand. The MOU formalises the relationship and demonstrates the genuine, sincere desire of both organisations to work together on complementary projects, to communicate regularly and support each other's causes and, where appropriate to advance the collective needs of Deaf and hard of hearing people. In working together and developing the MOU, both organisations acknowledged their past history but were committed to come together with a shared vision of cooperation, respect and understanding, which is critical to the individual and collective functions of both organisations.

Both organisations have been championing the rights of Deaf people in different ways and, for the last twenty or so years, have been doing this individually. Deaf Aotearoa's Board President, Robert Hewison, and The National Foundation for the Deaf's Chairperson, Peter Thorne signed the MOU, which was drawn up after discussions by the two organisations, led by Lachlan Keating and Louise Carroll, respective Chief Executives of their organisations.

Peter Thorne on the left, Robert Hewison on the Right

Acoustic Pioneer Dr Per V. Brüel passes away

The Acoustical Society of New Zealand honours Dr Per V. Brüel who passed away on April 2nd 2015, just after his 100th birthday celebrations on March 6th 2015. Dr. Brüel in collaboration with his friend Viggo Kjaer founded the well known company, Brüel & Kjær in November 1942. Dr Brüel was known internationally not only as a pioneer but leader in acoustic instrumentation for more than 75 years. Dr Brüel had been in the forefront of acoustic measurement techniques and analysis. Through development and production of high-quality instruments for nearly all kinds of acoustic measurements, Dr Brüel has had a decisive influence on the high standard of acoustic measurements of today and on our present knowledge of acoustical phenomena. According to those who worked with Dr. Brüel and knew him well, he was a well liked charismatic person who was bright and fast thinking. Dr Brüel was described by others as a world-class engineer, although anything but a nerd. Dr Brüel passions included cars, motorcycles, airplanes (a pilot himself) and red wine. Dr. Brüel was an inspiration to engineer and inventor alike, one of his best known legacies will be his involvement with the engineering breakthroughs in the late 1930s and early 1940s with the development of the world's first acoustic analyser and the first commercial piezoelectric accelerometer known as the Type 4303.

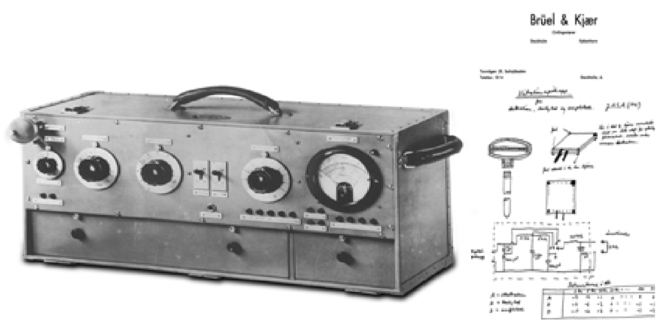

Photo: The world's first acoustic analyser the Brüel & Kjær piezoelectric accelerometer Type 4303 developed in 1943. Photos and Images source: www.bksv.com

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Visualizing sound emission of elephant vocalizations: evidence for two rumble production types

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Abstract

Recent comparative data reveal that formant frequencies are cues to body size in animals, due to a close relationship between formant frequency spacing, vocal tract length and overall body size. Accordingly, intriguing morphological adaptations to elongate the vocal tract in order to lower formants occur in several species, with the size exaggeration hypothesis being proposed to justify most of these observations. While the elephant trunk is strongly implicated to account for the low formants of elephant rumbles, it is unknown whether elephants emit these vocalizations exclusively through the trunk, or whether the mouth is also involved in rumble production. In this study we used a sound visualization method (an acoustic camera) to record rumbles of five captive African elephants during spatial separation and subsequent bonding situations. Our results showed that the female elephants in our analysis produced two distinct types of rumble vocalizations based on vocal path differences: a nasally- and an orally-emitted rumble. Interestingly, nasal rumbles predominated during contact calling, whereas oral rumbles were mainly produced in bonding situations. In addition, nasal and oral rumbles varied considerably in their acoustic structure. In particular, the values of the first two formants reflected the estimated lengths of the vocal paths, corresponding to a vocal tract length of around 2 meters for nasal, and around 0.7 meters for oral rumbles. These results suggest that African elephants may be switching vocal paths to actively vary vocal tract length (with considerable variation in formants) according to context, and call for further research investigating the function of formant modulation in elephant vocalizations. Furthermore, by confirming the use of the elephant trunk in long distance rumble production, our findings provide an explanation for the extremely low formants in these calls, and may also indicate that formant lowering functions to increase call propagation distances in this species'.

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1. Introduction

Individual and species-specific mechanisms of sound production determine the vocal characteristics accessible to receivers, and therefore, to natural and sexual selection. This evolutionary interconnection of voice production, acoustic output and function makes it necessary to understand basic sound production mechanisms when studying animal communication [1]. Mammalian vocal production at the level of the larynx is thought to follow the principles of the myoelastic-aerodynamic theory of human phonation [2]. Sound waves generated by vocal fold vibration in the larynx pass through the vocal tract, which contains air in the pharyngeal, oral, and nasal cavities, amplifying certain frequencies termed formant frequencies (or formants), before radiating into the environment. Formant frequency values are determined by the length and shape of the vocal tract, with longer vocal tracts producing lower, more closely spaced formants. Furthermore, formants are reliable cues to body size in several mammals [3-9] due to a close relationship between the frequency spacing of the formants, the caller's vocal tract length and overall body size. This, together with demonstrations of formant perception by nonhuman mammals in general [10-14] and interspecific perception [15, 16] in particular, suggests that formants may provide a universal cue to body size in vertebrates [17].

Intriguing morphological adaptations to elongate the vocal tract in order to lower formants occur in several species, with the size exaggeration hypothesis [18] being proposed to justify most of these observations (e.g. birds [19]; red deer, Cervus elaphus, [20]; big cats, Panthera sp. [21]; Goitred gazelles, Gazella subgutturosa [22]; koalas, Phascolarctos cinereus [4]; elephant seals, Mirounga

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leonina [8]). An alternative explanation, however, is that lowering formants aids long-distance call propagation [23]. Indeed, whereas formant variation in African elephant (Loxodonta africana) rumbles appears to be functionally relevant in this species' vocal communication system [24, 25], the adaptive significance of the extremely low formant frequencies of African elephant rumbles [23] is unknown i.e. it is not known whether the very low formants of elephant rumbles reflect sexual selection pressures to sound larger, or natural selection pressures to maximize call propagation distances. Furthermore, while the very low formants of elephant rumbles strongly implicate that the elephant trunk is involved in sound production [23, 26] (the un-extended trunk length of an adult female African elephant is around 1.7 to 1.8 m [27]) it is not known whether elephants emit these vocalizations exclusively through the trunk, or whether the mouth is also involved in rumble production [23, 26, 28-30].

Elephant rumbles are frequency-modulated, harmonically rich vocalizations that are known to convey information about age, individuality and arousal state [23, 29, 31-33]. Female African elephant rumbles are also thought to be used for group cohesion and coordination [31] and have been described as having a graded within-call type variation; however, no strong evidence for rumble subtypes based on structural variation has been documented [29]. Even less is known about male African elephant rumbles: the so-called "musth-rumble" is constantly produced by male elephants in musth (a condition in bull elephants characterized by increased aggressive behaviour and elevated androgen levels) and is suggested to acoustically advertise the animal's hormonal state [33]. Indeed, whereas the potential adaptive functions of African elephant rumbles have received a lot of attention, to date, the physiological mechanisms of vocal production have been largely neglected (but see: [30]).

In this study we used a novel sound visualization technique (an acoustic camera) to record five captive African elephants during spatial separation and subsequent reunions (bonding) in order to investigate whether rumbles are produced using the trunk and/or the mouth in these specific contexts. The acoustic data was then used to compare the spectral structure of rumbles given in the two contexts, and to determine whether it is possible to automatically classify these rumble variants using a smoothed spectral representation based on Linear Predictive Coding (LPC) for both rumble variants and machine learning. Our findings will improve our knowledge of African elephant rumble production, and may help to confirm the role of the elephant's trunk in producing the extremely low formants observed in these calls.

2. Methods

2.1 Data collection

2.2.1 Study subjects and housing

The subjects in this study were five African elephants (three females and two males) aged between 9 and 17

	Chichuru	Chova	Messina	Nuanedi	Shan
Sex	male	male	female	female	female
Age in years	15	17	9	10	13
N rumbles nasal (% separation context)	**26 (92%)**	**13 (77%)**	**25 (96%)**	**29 (93%)**	**22 (100%)**
Mean duration ± SD	1.9 ± 1.3	1.4 ± 0.6	2.8 ± 1.5	3.1 ± 1.8	2.8 ± 0.8
Mean F0 ± SD	16.5 ± 1.9	16.7 ± 0.6	19.5 ± 3.2	19.57 ± 2.3	20.5 ± 3.2
Mean F1 ± SD	40.1 ± 4.9	39.5 ± 9.5	45.3 ± 30.7	42.6 ± 7.4	42.0 ± 23.2
Mean F2 ± SD	117.9 ± 11.2	121.6 ± 7.4	140.5 ± 75.8	129 ± 10.1	139.1 ± 89.6
Mean SPL ± SD	52.0 ± 4.7	43.7± 8.1	51.1 ± 7.7	53.5 ± 4.8	48.7 ± 6.5
VTL (m)	*2.24*	*2.13*	*1.84*	*2.03*	*1.80*
N rumbles oral (%bonding context)	**0**	**0**	**21 (86%)**	**21 (72%)**	**10 (100%)**
Mean duration ± SD			1.66 ± 0.8	2.0 ± 1.3	1.2 ± 0.7
Mean F0 ± SD			24.7 ± 4.4	30.2 ± 2.4	22.7 ± 4.8

Table 1: Results of the acoustic analysis - The age and the sex of each recorded individual, the number of orally and nasally emitted rumbles (and the percentage of those recorded in each context, respectively), and the mean duration, mean fundamental frequency, mean formant frequency values 1 and 2, and mean sound pressure level (SPL) ± SD of rumbles per individual are presented. The estimated vocal tract length (VTL) for each individual based on the spacing in Hz between formants 1 and 2 for nasal and oral rumbles is also given.

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years (Table 1) located at Adventures with Elephants, Bela Bela, South Africa. These elephants had been captured during culling operations between 4 and 5 years ago. The elephants were fully habituated to human presence and free to roam around in an area of 300 ha.

2.2.2 Acoustic camera recordings
Recordings were captured over 4 days (22 November to 25 November 2011), with a total of 20 h of data collected during this period. The temperature during the recording sessions varied between 20 and 25°C, and recordings were only captured when wind speed was low. Two recording session were conducted at around 8 a.m and 4 p.m each day.

To visualize sound emission we used an acoustic camera star 48 array [34]. The star-shaped array has a span width of 3.4 m with 48 microphone channels (Sennheiser Electric-Capsules with MicBus microphone connectors: dynamic range 35...130 dB and 10 Hz ... 20 kHz; the microphone capsules are used in connection with a symmetrical output buffer. The buffer contains first order (-6 dB/Octave) filters for bandwidth limitation. The low cut is set to 100 Hz@ -3 dB and the high cut is set to 100 kHz @-3 dB). A video camera (Baumer TXG06C) was integrated into the array so that video and acoustic data could be captured at the same time. Additional trigger signals from the video camera allowed us to synchronize video images and acoustic data (the camera delivered the actual exposure times during recording of the video images as trigger pulses).

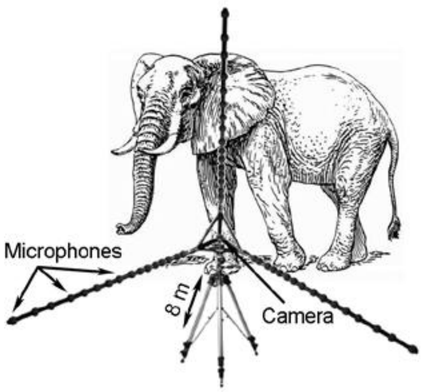

Figure 1: Experimental setup - The microphone array with 48 channels was connected to the recorder and a Laptop, and placed around 8 meters from the focal elephant.

The microphone array with 48 channels was connected to the recorder and a Laptop, and placed around 8 meters from the focal elephant.

The acoustic and video data were recorded using a mcdRec data recorder [34] at a sampling rate of 48 kHz. During recordings, the microphone array was positioned approximately 8 m (using a laser rangefinder) from the elephants (for the experimental setup, see Figure 1). Due to the data volume created by the acoustic camera, single recording sessions with this system varied between 30 and 180 s. A pre-recording trigger was set (depending on the lengths of the recordings) so that the record button could be started once the elephant(s) had started to vocalize. Thus, when the record button was pressed, everything that took place in the previous 30 s was also recorded and saved.

2.1.3 Recording contexts
Vocalizations were recorded in two distinct social contexts: spatial separation and subsequent reunions (bonding). The experimental sessions were carried out alongside the daily training routines (which typically involved chaining the elephants on one leg, a health check, and sometimes the training of particular commands). During the recording sessions elephants were chained, provided with pellets, and the keepers did not interact with them. Recordings started with the separation context. In this context the focal elephant was chained by one leg whilst the remaining elephants were walked out of sight (by the keepers) to the savannah, 500-700 m away. The focal elephant was then recorded for 5 minutes (separation context). For the bonding contexts, the other elephants were reunited with the focal elephant one by one, with the order of individuals brought back to the focal elephant alternated. Initially, keepers accompanied the incoming elephant until they had visual contact with the focal animal before allowing the incoming elephant to approach the focal animal alone. This resulted in a bonding ceremony, which usually involved the incoming elephant running towards the focal elephant and vocalising, raising the tail, spreading the ears and producing temporal gland secretions. Once reunited, the elephants remained close to each other. During this period they would entwine trunks, slightly push or back towards each other, and sometimes urinate and/or defecate [35]). Each elephant served as a subject in the experiment once a day. However, if a reunited elephant vocalized in front of the acoustic camera (within the approximate range of 8 m), those vocalizations were also captured.

2.2 Data analysis

2.2.1 Acoustic video analysis
The acoustic videos were analyzed using the software Noise Image [34]. The initial data, which were originally saved as channel files (*.chl), were reconverted into 2D acoustic movie files (amo-format, 25 f/s). This technology analyses the actual sound scene, which consists of a superposition of different sound sources, into a visual sound map. The basic principle relies on accurately calculating the specific runtime delays of acoustic sound emissions radiating from several sources to the individual microphones of the array [36]. An acoustic map of the local sound pressure distribution at a given distance is calculated using the acoustic data of all simultaneously recorded microphone

channels. The sound pressure level (SPL) is displayed by colour coding. The automatic overlay of optical image and acoustic map allows the locations of dominating sound sources to be identified.

The time function f of a point x = (x', y', z')^T on the image plane was reconstructed by delay-and-sum beamforming [37] according to equation 1. Here, t denotes time, M is the number of microphones in the array, the w_i are (optional) shading weights, the f_i are the recorded time functions of the individual microphones, and the Δ_i are the appropriate relative time delays, calculated from the absolute run times π_i as $\Delta_i = \pi_i - \min(\pi_i)$. The absolute run times are determined by $\pi_i = |\mathbf{r}_i|/v$, where v is the speed of sound in air and $|\mathbf{r}_i|$ is the geometrical distance from microphone number i to the point of interest $\mathbf{x}$.

$$\hat{f}(x,t) = \frac{1}{M}\sum_{i=1}^{M} w_i f_i(x,(t-\Delta_i)) \quad (1)$$

The effective sound pressure at point $\mathbf{x}$ (Lp dBSPL) is determined using equation 2; every individual pixel is then coloured corresponding to its effective value and a given colour table. In equation 2, n is the total number of discrete time samples taken into account in estimating the effective value, f is the reconstructed time function of equation 1 of the sound pressure at location $\mathbf{x}$, and t_k is the time value at a discrete sample index k.

$$P_{eff}(x) = \sqrt{\frac{1}{n}\sum_{k=0}^{n-1} \hat{f}^2(x,t_k)} \quad (2)$$

The acoustic movie files were visually analyzed and the vocalizations were investigated frame by frame. The location of sound emission (nasal or oral) was visually identified for each recorded vocalization by the first author and a second observer (reaching 98 % agreement). Due to the distance between the trunk tip and the mouth, it was possible to clearly distinguish between oral and nasal sound emission. The rumble was allocated as being nasally emitted when the most intensive colouring was located around the trunk tip, and orally emitted when the most intensive colouring was located around the mouth. We analyzed 179 rumble vocalizations. Peak SPL during the vocalization was quantified using the maximum value at the middle of the vocalization. Selected frames were exported from the acoustic movie to JPG-Format. For presentation, parts of the acoustic movies were exported to AVI-Format in slow motion (without sound, 5 f/s) and real time in 2D (see online supporting information Movie S1 to S4).

2.2.2 Acoustical analysis

For acoustic analysis, we exported the acoustic signal (in stereo) of each rumble video (in which we could clearly identify whether sound emission was nasal or oral) to WAV format. Acoustic analyses were performed using Praat 5.0.29 DSP package [38]. The fundamental frequency was measured over the entire utterance with the "to pitch (ac)" command (time step 0.01, window lengths 0.4 s). The settings for pitch extraction were calibrated by inspecting the accuracy of the pitch line generated by Praat on spectrograms (minimum frequency 10 Hz; maximum frequency 35 Hz in nasal and 40 Hz in oral rumbles). The minimum, the maximum, the range (max-min) and the mean ± SD fundamental frequency were extracted. In addition, minimum, maximum and mean ± SD duration of rumbles were measured from the waveform.

Because formants 3 and 4 could not be consistently measured we only considered the lower two formants in the analysis. To examine formants 1 and 2 we segmented 0.5 s of each rumble (starting from the mid-point of the vocalization). The rumble segments were then re-sampled to 6000 Hz and LPC was performed on the spectra of the annotated time units. Using a linear tube model closed at one end (partially closed at the vocal folds) and open at the other end (mouth or trunk), the formant locations (*F*) are given by equation 3 (Table 2), where n is the formant number, *c* is the speed of sound (350 m/s), and vocal tract length (VTL) in meters, using an estimated VTL of 0.75 m for the oral rumbles and 2.5 m for the nasal rumbles [26].

Table 2: Predicted formant values of oral and nasal rumbles in African elephants (after [26]) - The equation to calculate formant values based on VTL and the predicted values of formants 1 and 2 for oral and nasal rumbles in African elephants.

Formant	Predicted formant value (Hz) for nasal rumbles	Predicted formant value (Hz) for oral rumbles
Formant 1	35.0	116.7
Formant 2	105.0	350.0

$$F_n = (2n-1)\left(\frac{c}{4VTL}\right) \quad (3)$$

These estimates are derived from data on a large sample of mandibles from female African elephants (ranging in lengths from about 45 cm at age 15 to 60 cm at age 60) made by Laws and colleagues [39], taking into account that the larynx is positioned posterior to the mandible and that the lips protrude past the anterior process of the mandible, as well as considering the trunk lengths of about 1.7 meter [27]. Based on the predicted formant locations derived from equation 3, the number of peaks was set to '2 in 400 Hz' for oral rumbles, and '2 in 150 Hz' for nasal rumbles (Table 2). The VTL of each individual for nasal and oral rumbles (only nasal rumbles for males) was estimated using equation 4 [6], where *c* is the speed of sound (350m/s) and ΔF the formant spacing.

$$VTL = \frac{c}{2(\Delta F)} \quad (4)$$

2.2.3 Statistical analysis

Linear mixed-effect models (LMMs) [40] were used to investigate acoustic variation across nasal and oral rumbles in the three females Shan, Nuanedi and Messina. Separate LMMs were run in which the dependent variables were the first formant, the second formant, call duration, mean fundamental frequency and the sound pressure level. For each model, location of sound emission was entered as a fixed factor (oral versus nasal), individual identity as a random factor, and age as covariate. A scaled-identity covariance structure was used for all the LMMs, and we used a model selection criteria based on the Akaike's Information Criteria (AIC), in which the model having the lowest AIC value is chosen (sensu [41]). Age had no significant effect on the results, and the lowest AIC values were achieved when entering only location of sound emission as the fixed factor and individual identity as the random factor (omitting age). To ensure that the test compared likelihoods based on the same data, the maximum likelihood estimation method was used to test the hypotheses [42]. All statistical tests above were performed in PASW Statistics 18.0.

2.2.4 Automatic classification

For the automatic classification, we first computed a numerical representation for each nasal and oral rumble, applying a sliding window to each sound sample with a window size of 300 ms and a step size of 30 ms. For each window we computed the LPC-smoothed spectrum in the range of 0 Hz to 500 Hz (model order 8). The result was a two-dimensional (2D) LPC spectrogram that represents the smoothed spectral shape over time preserving the formant structure of the call. Note that we applied the same parameters for both types of rumbles.

Classification techniques such as Linear Discriminant Analysis (LDA) require that each sound sample is represented by a single vector. We computed the average LPC spectrum over time to obtain one representative (and time invariant) numerical vector for each sound sample. We then sub-sampled the vector to 26 components to obtain a more robust and compact representation for classification. We first employed LDA for classification. In order to evaluate the dependency of classification performance on a particular classification technique we further applied a linear Support Vector Machine (SVM) [43], and Nearest Neighbour Classification (NN).

For the evaluation of automatic classification performance, we first split the data set into a training set (1/3 of all samples) and an evaluation set (2/3 of all samples). We applied k-fold cross-validation (k=10) on the training set to evaluate stable parameters for three different classifiers and to reduce the dependency of the classifiers from the training data. All experiments were performed in MATLAB R2012a.

3. Results

3.1 Sound visualization experiments

Using the acoustic camera, we captured 179 rumble vocalizations from 5 African elephants (three females and two males). Detection of sound emission was very accurate and could be clearly allocated in 167 rumbles.

The 12 cases (~7%) in which the location of sound emission could not be clearly allocated were either due to high levels of background noise resulting in a diffuse acoustic video (10 times), or because the trunk moved towards the mouth and the location of sound emission could not be reliably discriminated (two times). Of the 167 rumbles in the analysis, 115 were uttered nasally (sound emission through the trunk) and 52 were emitted orally

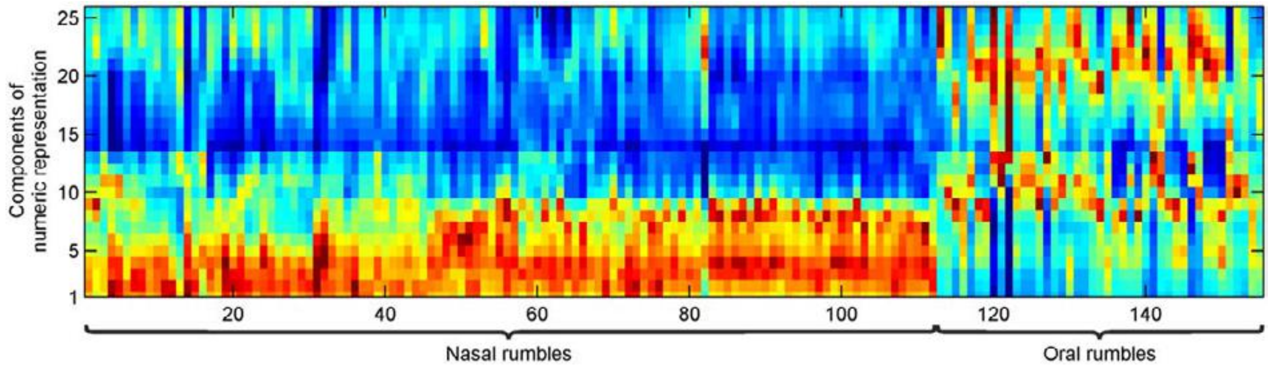

Figure 4: Automatic classification of rumbling vocalizations - Numerical descriptors (averaged LPC spectrum) for all sound samples in the experiments. Each column of the matrix represents one descriptor of a rumble. Red represents spectral peaks while blue represents low spectral components. The descriptors of the nasal and oral rumbles show significantly different characteristics.

(from the mouth). Furthermore, 92% of the rumbles were emitted nasally during the separation context and 84% of the rumbles were emitted orally during bonding situations. Orally emitted rumbles were only produced by females (Figure 2) and males mainly vocalized during the separation context, with only five nasal rumbles recorded in the bonding context.

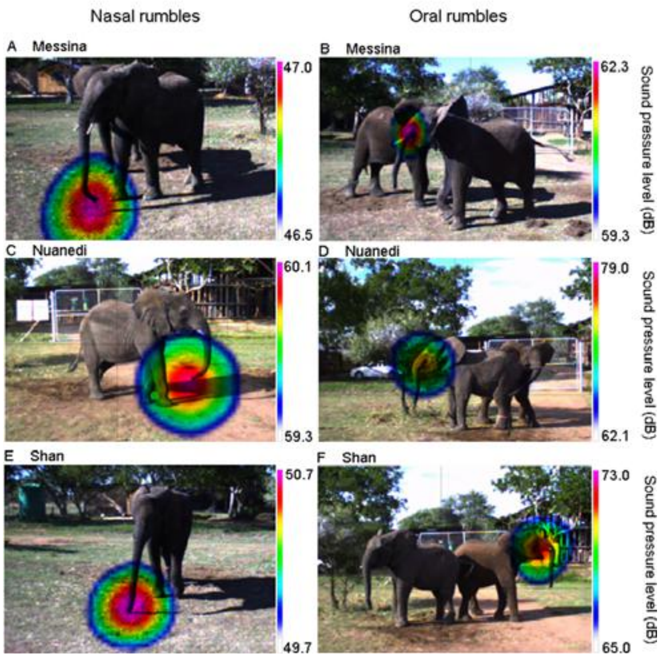

Figure 2: Sound visualization of African elephant rumbling vocalizations - Examples of nasal and oral rumbling vocalizations from three female elephants, Messina, Nuanedi and Shan. Figures A, C and E give examples of nasal rumbles, B, D and F give examples of oral rumbles.

3.2 Acoustic analysis

The values of formant 1 and formant 2 for the nasal rumbles (formant 1 ± SD = 39.79 ± 5.78 Hz and mean formant 2 ± SD = 128.76.79 ± 32.57 Hz) and oral rumbles (mean formant 1 ± SD = 169.21 ± 25.61 Hz and mean formant 2 ± SD = 415.20 ± 47.71 Hz) of the three female African elephants differed significantly (see Figure 3; LMM: formant 1: $F1, 166 = 849.006$, $p < 0.001$; formant 2: $F1, 166 = 730.004$, $p < 0.001$). These results accord well with the values predicted by a simple tube model closed at one end (closed at vocal folds) and open at the other end (mouth or trunk, Table 1), indicating that the observed spectral peak frequencies are very likely to be formants (vocal tract resonances). In addition, the duration of nasal rumbles was significantly greater than oral rumbles (mean ± SD nasal rumbles = 2.94 s ± 1.6; mean ± SD oral rumbles: 1.79 s ± 1.1; LMM: $F1, 166 = 15.786$, $p < 0.001$).

The mean fundamental frequency was significantly lower in nasal rumbles (mean ± SD = 19.7 ± 2.7 Hz) than in oral rumbles (mean ± SD = 26.9 ± 4.6 Hz; LMM: $F1, 166 = 98.373$, $p < 0.001$). Finally, the sound pressure level (Lp dBSPL @ 8 m) was significantly lower in nasal rumbles (mean SPL ± SD = 51.9 ± 6.22 dB) than it was in oral rumbles (mean SPL ± SD = 74.45 ± 7.49 dB; LMM: $F1, 166 = 229.296$, $p < 0.001$).

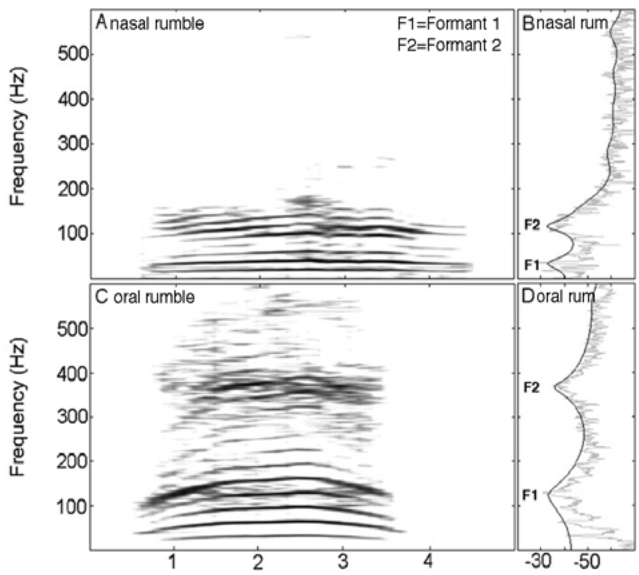

Figure 3: Spectral characteristics of nasal and oral rumbles - Spectrograms and power spectra showing an example of a nasal (A, B) and an oral (C, D) rumble, indicating formant positions (both rumbles uttered by Nuanedi, 10-year-old female).

3.3 Automatic classification

The automatic classification was performed using an LPC-based spectral representation for both types of rumbles. Figure 4 gives the representational vectors for each nasal and oral rumble in our dataset, clearly showing the different spectral characteristics of both types of rumbles. All classifiers generalized well to the underlying data (training set) with standard parameters. Next, we applied the trained classifiers on the evaluation set (which has not been used during training) and computed the accuracy of classification. We obtained a classification accuracy of 99% with LDA, meaning that only 1 vocalization was misclassified. In order to investigate the dependency of this result on the employed classification technique, we evaluated the classification accuracy of two further classifiers (Support Vector Machine and Nearest Neighbour Classifier). Both classifiers yielded accuracies above 97% similarly to LDA, demonstrating that the high classification accuracy was not dependent on a particular classification technique. Similar results were obtained when we exchanged training and evaluation sets revealing that the dependency of classification performance on the training data is low. This evaluation demonstrates that the oral and nasal rumbles could be distinguished with high accuracy by an automatic classification system without taking call specific characteristics (e.g. predefined formant frequencies) into account.

4. Discussion

Using an acoustic camera array to visualize sound emission, we have demonstrated two types of rumbles in three sub-adult female African elephants: a nasally and an orally emitted rumble. In addition, nasal and oral rumbles in our data set varied considerably in their acoustic structure. In particular, the mean frequency spacing of the first two formants predicted the estimated lengths of the two vocal paths. This corresponded to a vocal tract length of about 2 m for nasal rumbles and about 0.7 m for oral rumbles in the investigated elephants (note that all were below the age of 17 years and not yet fully-grown). Thus, by using the nasal path, an elephant lowers it's formants by around threefold. However, because the elephants in our study were all sub-adults, we must exercise extreme caution when generalising our results to all age classes. Indeed, young elephants may simply tend to produce oral rumbles more often than adults. Nevertheless, preliminary results generated from a large sample of African elephant rumbles (Stoeger et al, unpublished data) indicate that adult female elephants do produce oral rumbles (although only verified by formant structure; see Figure S1 and S2) and hence, suggest that elephants (at least females) of all age classes might produce oral rumbles in certain situations.

In addition, we have also shown that the African elephants in our study produced the two different rumble types in two distinct contexts. Nasal rumbles predominated during contact calling, whereas oral rumbles were mainly observed during the social bonding context. In human speech, formants (particularly formants 1 and 2) provide the acoustic basis for discriminating vowels and thus, are a very important means of transferring information [44, 45]. The active modulation of the lower two formants also appears to play a role in referential calling in nonhuman primates such as hamadryas baboons (*Papio hamadryas*; [46]), gelada baboons (*Theropithecus gelada*; [47]), vervet monkeys (*Ceropithecus aethiops*; [48]), and Diana monkeys (*Cercopithecus diana*; [49]). Previous elephant studies have also documented formant variation with context and/or arousal: specifically, an upward shift in the second formant seems to alert other elephants to potential danger [24], and female elephants engaged in dominance interactions produce rumbles with lower formant dispersion (spacing) compared to rumbles produced in low affect contexts [25]. However, whether this formant variation is produced by switching from nasal to oral sound production, or whether a specific formant shifting can also be achieved by modulating structures of the nasal or oral vocal tract respectively, remains to be investigated.

Interestingly, the two bulls in our dataset only produced nasal rumbles (and mainly vocalized during the separation context), which might reflect the already reported sexual dimorphism in the vocal behaviour of African elephants (bulls are less vocal and less focused on social cohesion compared to females [31]). Although this result must be treated with caution due to the small sample size and the young age of these males, if bulls do produce nasal rumbles more often than oral rumbles, they may be maximizing the impression of their size with these vocalizations. Indeed, body size and age are important correlates of reproductive success in African elephant bulls [50], and male-male competition is likely to be an important selective force acting on the acoustic structure of male rumbles. Future research, therefore, should investigate whether formants in male rumbles are predictive of the caller's body size, and document the behavioural responses of male African elephants to playbacks of rumbles with different (and maybe resynthesized) formant values. It is noteworthy that the three female African elephants mainly produced nasal rumbles in the contexts of long distance contact calling. Accordingly, because lower frequencies typically propagate over greater distances [51] another interpretation for our findings might be that lowering formants increases call propagation distances in this species'.

The oral rumbles produced by the three females recorded during bonding situations also showed an increase in fundamental frequency compared to the nasal rumbles. Increased fundamental frequency is correlated with increased arousal state in many mammalian species [52, 53] including African elephants [25, 54] and the females often showed temporal gland secretion and displayed increased locomotion during bonding, both of which indicate higher arousal levels than during contact calling. In addition, female oral rumbles were considerably louder than those emitted through the trunk. Since nasal passages in most mammals are convoluted and filled with spongy absorptive tissue, nasal sounds are typically much quieter than oral sounds [55]. Indeed, cineradiographic data indicate that loud sounds are generally produced orally in all mammals studied so far (e.g., dog barks, goat bleats, pig squeals, or monkey chatters), with some softer sounds (e.g., dog whines or pig grunts) being produced nasally [55]. These observations argue against our contention that nasal rumbles are used for long distance communication though, because vocalizations with lower amplitude will obviously not propagate as far as louder calls. Nevertheless, it is worth noting that the nasal rumbles recorded during separation contexts in our experiments were directed towards con-specifics a maximum of 600-700 meters away, and that these calls might be expected to have a higher sound intensity when directed towards elephants over greater distances. Moreover, there may be an evolutionary trade off between lower frequencies and call amplitude, if the former results in better sound transmission of relevant frequencies. In addition, it is possible that lowering formants in rumbles makes the call perceptually louder to conspecific receivers, if African elephants are particularly sensitive to very low frequencies (as may be expected given the extremely low frequencies of elephant rumbles and the hearing sensitivity observed in an Asian elephant, *Elephas maximus* [56]). Playback experiments designed to test formant perception and the frequency range of best sensitivity in African elephants are now required.

To conclude, our results show that African elephants are able to vary their vocal path and dramatically lower formants in their rumble vocalizations, and that they might do this systematically according to context or motivation. It is important to note that formants are expected to vary due to the age/size of an elephant, individual morphological variations of the vocal tract, and probably due to context, motivation, arousal state and potentially, social rank. Furthermore, it may not be excluded that elephants switch from nasal to oral sound production (or the other way around) within a vocalization. Nevertheless, by showing that rumbles can be emitted via the trunk or mouth, the findings of the current study have furthered our knowledge of elephant vocal production, and how this impacts on the acoustic characteristics of elephant vocalizations. While our small sample size and the relatively young age of the study animals means we must exercise a degree of caution when generalizing these results, our findings should stimulate new research on this species vocal communication system. In particular, we suggest that future studies determine whether the formants present in African elephant rumbles consistently vary according to the size of the vocalizing animal, and also investigate the behavioural responses of male and female conspecifics to formant variation in rumbles. Re-recording experiments could also reveal whether any size-related formant information persists over relevant distances. Finally, by introducing a sound visualization method that has not previously been used in the field of bioacoustics, we have provided a methodological advance that could be used not only to identify callers in a wide range of species (e.g. when animals call in large colonies) but also to potentially investigate whether animals use their nasal or oral vocal tract in call production, as well as confirming whether calls are produced on expiration or inhalation. Future studies incorporating this novel technique are certainly warranted.

Acknowledgments

We thank the elephant keepers from the Adventures for Elephants for their support and effort and Dr. Drasko Boko for arranging the transport of the acoustic camera.

We further thank Prof. W. Tecumseh Fitch for strongly supporting the elephant research in the Department.

Supporting information

Figures

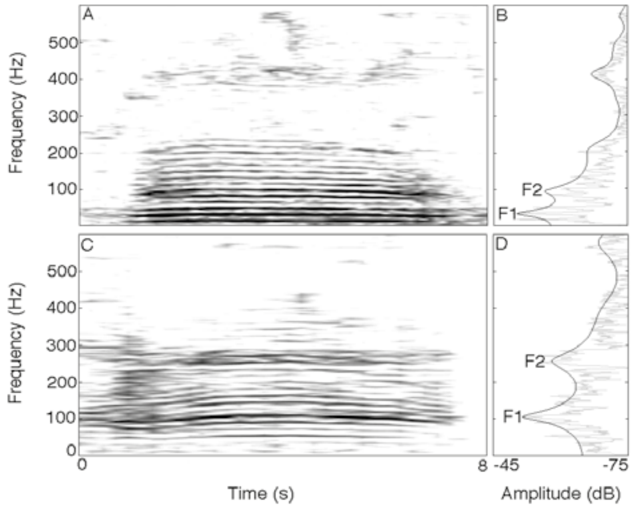

Figure S1. Spectrograms and power spectra presenting two examples of rumbling vocalizations from a 29 year old female African elephant (Drumbo) recorded at the Vienna Zoo in 2003. Recordings were captured with a condenser microphone AKG 480 B CK 62 and a DA-P1 DAT recorder. Figures A and B show a rumble recorded during spatial separation from a part of the group, and display the formant structure of a typical nasal rumble. Figures C and D show a rumble recorded during a bonding situation when the group was reunited, and resemble an orally emitted rumble based on the observed formant values.

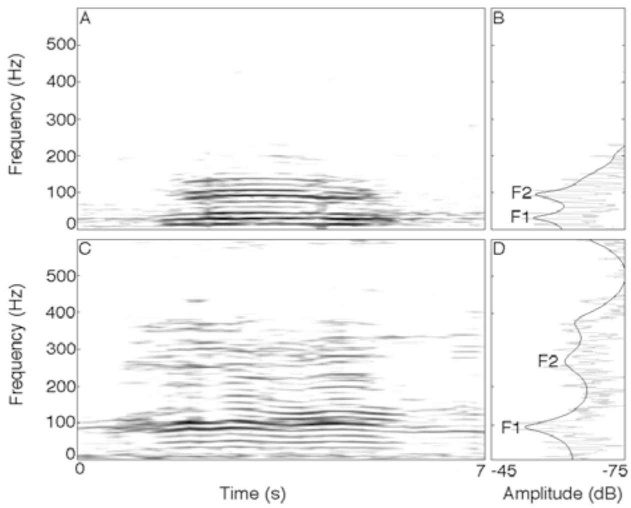

Figure S2. Spectrograms and power spectra to show examples of rumbles from a 43 year old female African elephant (Jumbo) recorded at the Vienna Zoo in 2003 (using the same equipment as described in Figure S1). Figures A and B also show a rumble recorded during spatial separation from the group, again with the formant structure of a typical nasal rumble. Figures C and D show a rumble recorded during the bonding situation when the group was reunited, again resembling an orally emitted rumble based on the formant values. Jumbo died in 2004 and her oral vocal tract was measuring at 93 cm (Weissengruber, personal communication). The formants 1 and 2 of the oral vocal tract would thus be (using equation 3) 92 Hz and 277 Hz, which corresponds very well with the formant location observed in Figures C and D.

Movie files

1. Movie S1. Nasal rumble-25fps-sound: Sound visualization of a nasal rumble. This movie shows the sound emission during a nasal rumble.
2. Movie S2. Nasal rumble-5fps-slow-mo: Sound visualization of a nasal rumble in slow motion. This movie shows the sound emission during a nasal rumble in slow motion (5 frames per second).
3. Movie S3. Oral rumble-25fps-sound: Sound visualization of an oral rumble. This movie shows the sound emission during an oral rumble.
4. Movie S4. Oral rumble-5fps-slow-mo: Sound visualization of an oral rumble in slow motion. This movie shows the sound emission during an oral rumble in slow motion (5 frames per second).

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Silent Leadership Challenge 2015

The National Foundation for the Deaf (NFD) 'Silent Leadership Challenge' is to be held on Friday 7th August. This event is a unique opportunity to show others you mean business when it comes to preventing hearing loss and improving the lives of those hard of hearing. The Silent Leadership Challenge is a hearing loss challenge for corporate and community leaders to raise awareness and funds for the vital work of The National Foundation for the Deaf in New Zealand. On Challenge Day those taking part will undertake four ten minute communication challenges while wearing MSA hearing protectors to simulate deafness. Please support the event. For further details please visit www.silentleadershipchallenge.com

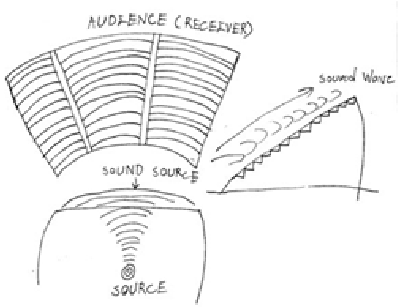
Acoustics 2015

The NSW Division of the Australian Acoustical Society (AAS) warmly invites all members of the acoustics community to attend Acoustics 2015 at the Cypress Lakes Resort in the spectacular Hunter Valley. Keynote speakers include Ulf Sandberg Senior Researcher, Swedish National Road and Transport Research Institute (VTI) James Grotberg Professor, Biomedical Engineering, University of Michigan and Richard Sandberg Professor, Fluid Mechanics and Aerodynamics, University of Southampton. Please visit: www.acoustics2015.com.au for more information.

New Zealand Acoustics grows

In this last issue (#1) we brought you the exciting news that New Zealand Acoustics was now 100% full colour. We are happy to advise that from this issue onward we are now able to print up to 10% more space, which equates to 4 more pages. We have made this change to endeavour to spread the context out and avoid back to back advertising on pages.

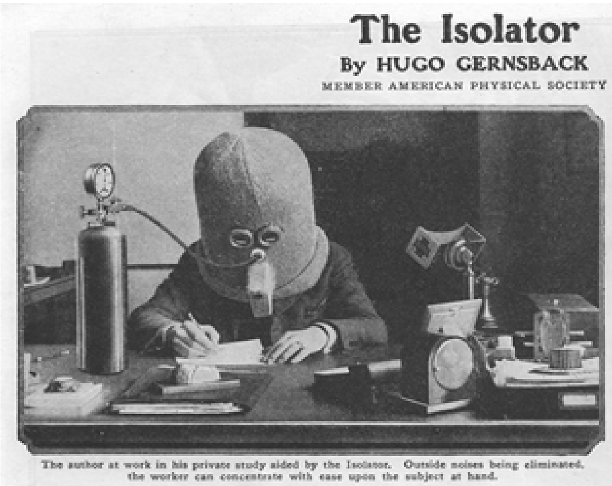
New Zealand Acoustics issue #3 - Book Competition



Keep an eye out in the next issue, #3 of 'New Zealand Acoustics' for our up and coming book competition. There will be some great prizes up for grabs.

Acoustic Isolator circa 1925

Having trouble working in the modern open plan office? The acoustic isolator is now available. The isolator is designed to help focus the mind when reading, writing and completing those difficult acoustic calculations by eliminating all outside noise allowing the user to concentrate with ease upon the subject at hand.



The Isolator

By HUGO GERNSBACK

MEMBER AMERICAN PHYSICAL SOCIETY

The author at work in his private study aided by the Isolator. Outside noises being eliminated, the worker can concentrate with ease upon the subject at hand.

Acoustic Isolator circa 1965

Having trouble working in the modern open plan office? The 'cone of silence', acoustic isolator is now available. It is favoured by agents of a certain fictional spy agency.

Acoustic Isolator circa 2015

Having trouble working in the modern open plan office? The 'cone of silence', the Silentium Comfort-Shell acoustic isolator is now available.

Silentium hopes that the Comfort-Shell will be popular at airports, train stations, coffee shops, and other potentially noisy locations, where noise-cancelling headphones are already popular. See: www.dailydot.com/technology/ces-silentium-silence

Visit to NCS Acoustics facility

On 4th March 2015, the Auckland Chapter of ASNZ held its first branch meeting of the year. We were invited by Neil Savory and Peter Bowerman of NCS Acoustics to visit their new facility in Takanini.

Formerly known as Noise Control Services, they re-branded themselves last year as NCS Acoustics to distance themselves from the public's idea that they were a company that dealt with noise control complaints. As their logo now clearly states... "they don't turn down stereos!"

Visiting their offices and factory are was an interesting prospect, particularly for those like me - who have only dabbled in mechanical services over the years. Clapping our eyes on attenuators of all shapes and sizes, and getting an insight into how they are made was very interesting indeed.

The tour started with a decent amount of food and water (carbonated and flavoured with hops of course) in their office area. Once all the cashews were dispensed with (thanks again Peter!), we commenced our guided tour of the facility.

The factory floor is a very large and - for the most part - well organised place. There are rolls of sheet metal [perforated and otherwise], absorptive materials and melanex at one end, and trucks ready to be loaded and head out the door at the other.

In the middle there's an array of heavy machinery [drills, presses, welders] and attenuators large and small in varying states of completion. Neil told us about a few large orders they're currently working on, regaled us with stories of crazy jobs he's been involved with, and invited us to climb through various bits and pieces to our heart's content.

It was neat to imagine these things – some of which are positively huge - being lifted and bolted into place, where they would sit forever more... soaking up sound and making the amenity of the outside world

...Continued on Page 42

Sirens Comparison

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Abstract

This discussion compares two common siren types. They are the diaphragm driven horn based upon an improvement to Edison's original gramophone, referred to as an electronic siren, and the rotary air-shock siren based upon an improvement to the Carter type WW2 air raid siren, referred to as a rotary siren. Differences in performance, practicality and economic viability between the two are identified, with emphasis on how a spherical atmospheric wave-front dispersal influences cost escalation for electronic sirens. The validity of a new National Standard for sirens promulgated by the New Zealand Ministry of Civil defence and Emergency Management (MCDEM) is questioned.

An Original Technical Note

1. Background

Low frequency rotary sirens are the type most widely heard and recognised, requiring very few of them to cover large areas. Cycling up and down between 200 and 600 Hz, they have an enduring reputation for penetrating structures extraordinarily well [1]. Penetrating houses in wartime England, they awakened the community, prompting Prime Minister Winston Churchill's "Siren Controversy" speech in parliament [2]. These days there is controversy where electronic sirens are replacing rotary sirens, with correspondents demanding a return to rotary sirens [3]. When electronic sirens replaced rotary sirens on New Zealand (NZ) fire appliances in the 1970's, proving to be less effective, low frequency locomotive type air horns were retro-fitted to those vehicles and are still in use today. Modern rotary sirens are being heard indoors from a substantial distance in gale force winds, over the top of television programmes, with windows closed [4].

2. Siren Function

2.1 Electronic siren function

The expansion horn on Edison's original gramophone was driven by a low density paper diaphragm excited by a vibrating needle, mechanically transferring musical vibrations to the diaphragm. Modern electronic sirens use the same mechanism, except with a high density metallic diaphragm driven by magnetostrictive force from a coil with iron core, or by Piezostrictive force from a crystal or ceramic slab. Both methods convert electrical force into mechanical force, - a form of electric motor whose power supply voltage is varied by a simple electronic timing circuit.

Due to the high density of the diaphragm, electronic sirens cannot produce non-sinusoidal waves with sharp turning points. Because the diaphragm cannot accelerate quickly enough, it produces a rounded wave.

Figure 1: Chinese Internet advertisement for a typical electronic siren

2.2. Rotary siren function

Rotary sirens are often referred to as mechanical sirens, but both rotary and electronic sirens are mechanical, each featuring a single moving component to cause air displacement but producing different atmospheric effects in the near field.

Figure 2: Solidworks image of a 150 dB New Zealand made rotary siren with 45 degree internal reflectors and impedance transformer horns

The difference between the two types is that in one siren the moving part rotates and is visible, and in the other type the moving part moves back and forth inside a housing.

The rotary siren operates on a momentary cavity with an air valve that opens and closes at high speed. Because the valve is continuously moving, there are no acceleration forces involved, so the rotary siren is able to produce atmospheric pressure pulses with very sharp turning points, thus exhibiting rich harmonics.

2.3 Using electronic sirens to mimic rotary sirens

Electronic sirens can, to a degree, mimic rotary sirens by synthesising a triangular wave by summing sinewaves that copy the Fourier transform for a triangular wave. However, it's not the same because the approximated waves will have rounded peaks and lumpy profiles, with undershoot and overshoot. Similarly, electronic sirens that attempt to mimic a triangular wave by ramping a voltage up and down, will produce a distorted version of a triangular wave with a rounded peak instead of a sharp peak, resulting in harmonic deficiency.

2.4 Sirens used as public loudspeakers (Loudhailers)

Without complex installations, outdoor loudspeakers are often unintelligible due to long reverberation times Cancellations occur at frequencies that arrive at the receiver out of phase with each other due to reflections. It can be a serious liability when a receiver's interpretation of a garbled message or its context is compromised, and the wrong action taken.

It's worse when a speaker is moving on a vehicle or aircraft, because the path lengths are varying. Helicopters are inhibited due to the presence of a doughnut shaped refractive index below the aircraft, inside which the loudspeaker is positioned, limiting reliable intelligibility to a narrow vertical field at best.

It's safer to promulgate information via broadcast radio and television and educate the community to listen to a radio broadcast whenever the sirens are heard. Libraries of pre-recorded messages are remotely selected, or changed via text to speech software to automatically over-ride radio broadcast programmes when sirens are triggered. Electronic highway billboards and community hoardings can also be networked to operate synchronously with sirens.

There has been legal action over an ineffective loudspeaker system, that has culpability implications [5]. There has also been an incident in New Zealand where people misinterpreted garbled police loudhailer instructions and fled in a wrong direction towards potential danger [6]. During the Washington navy yard shooting, witnesses described messages from police car loudhailers as "garbled," causing confusion [7]. The bedfellows of outdoor loudhailers; ambiguity and confusion, are toxic ingredients in critical situations where events are unfolding rapidly.

3. Correct coupling of sirens to the atmosphere

Sirens must be correctly impedance coupled to the atmosphere to minimise power loss by reverse reflection due to a pressure gradient at the siren mouth, analogous to a tennis ball hitting a wall and bouncing back. A coupling transformer is normally used in the form of a horn, critically shaped to convert high acoustic impedance (high pressure, small displacement) at the throat, to low impedance (low pressure, large displacement) at the mouth.

The first principles for designing acoustic radiators are similar to those for radio antennae because the distance between maxima and minima on a periodic wave, is a quarter wavelength, so the horn must be at least a quarter wavelength long at the lowest (cut-off) frequency. Practically the circumference of the horn at the mouth should be at least 1 wavelength at the lowest (cut-off) frequency.

Horns can get very large at low frequencies. Some marine fog horns are enormous and project eerie sounds over huge distances with frequencies of 200 to 400 Hz often followed by a 10 to 20 Hz grunt at the end of each duty cycle. (Turn volume up - www.sounddogs.com/previews/2742/mp3/456706_SOUNDDOGS__fo.mp3)

4. The crude nature of cheap mass-produced horns

Commercially available horns used on most electronic sirens appear to be of no particular design, perhaps profiled for consumer fashion rather than to any engineering parameter. Most electronic siren suppliers ignore horn parameters in published specifications, and seldom, mention waveforms. Some suppliers worldwide appear to be importing the Chinese siren shown in Figure 1 and replacing the brand label with their own.

The inside profile of a siren horn is critical because in addition to impedance matching, it must also be able to convert a breathing cylinder plane wave into a breathing sphere atmospheric wave. The folded horn in figure 1 is a typical example of a tendency to fold horns back inside themselves to minimise the cost of tooling dies, ostensibly proffered as a space saving measure.

The New Zealand designed rotary siren horns in Figure 2 require several stages of heat annealing during the metal spinning process over a large and complex tooling die where the metal is required to migrate across the die at compound angles without cracking. This expensive process is justified by superior horn performance. There is no need to conserve space at the top of a pole. Because world markets are saturated with cheap folded horns, their crude configuration is seldom questioned, but they are rarely seen in critical applications like low frequency marine fog horns on big ships, or serious locomotive air horns where safety is of the essence.

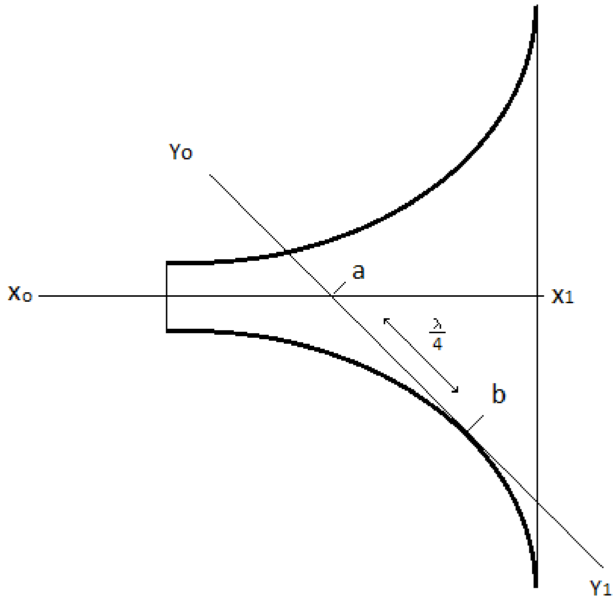

Figure 3: Visualisation of an internal folded section of horn interfere with the quarter wave dimension (a-b) along the horn profile.

Figure 3 visualises how an internal folded section of horn would interfere with the quarter wave dimension (a-b) along the horn profile. An imaginary line from X_0 to X_1 defines pressure maxima at any interval along it. If we slide a tangent (Y_0 – Y_1) along that line, the tangent will always intercept (X_0 –X_1) and the surface of the horn, at b in a correctly profiled horn. Points (a–b) being a quarter wavelength apart.

5. Unforeseen cost escalation

If you want to double the propagation distance of a siren, (an increase of 6 dB SPL) you must increase power output by 4 times because the wavefront dispersal is spherical. Numbers of installations of electronic sirens will continue to require more sirens to be added as communities complain about not hearing them, accompanied by burgeoning costs. The increase in siren numbers, batteries, and maintenance, is according to square-cube law because the acoustic wavefront dispersal is spherical. For example, consider for a moment, electronic sirens of the type shown in Figure 1, mounted on a pole. To achieve a power increase of 3 dB, you must double the number of sirens. So if you have 4 sirens on a pole and you wish to increase the power output by 3 dB, you must add another 4 sirens. To realise 9 dB gain, you must therefore have 32 sirens on the pole that originally had 4. Put simply, you need large amounts of money, increasing by square-cube law, to make a big difference at the receiver. In contrast to that, in 2012, tangential expansion horns with 45 degree centre reflectors, were fitted to a New Zealand made PSL Firemaster rotary siren and independently measured at

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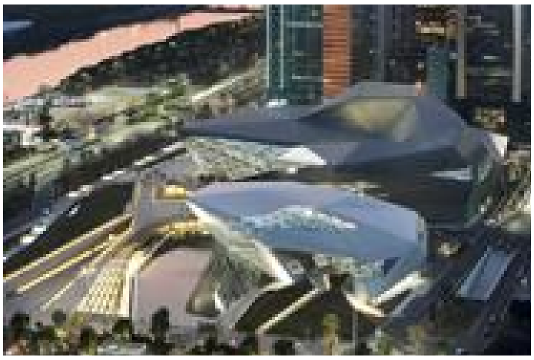
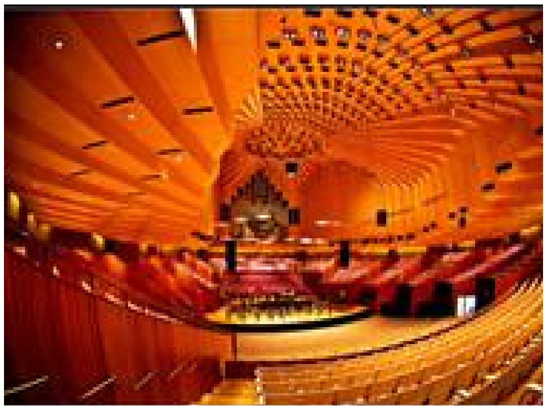
Acoustics Quiz

Name these Opera Houses:

1		
2		
3		
4		

Acoustics Quiz Answers (Vol 28, #1)

1. Divje Babe Flute
2. Balalaika
3. Hi-hat cymbals
4. Double Bass¶

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150 dB power output on axis [8]. This is a power increase of 13 dB over the published Firemaster siren specification (20 times power output), which is theoretically nearly 4.5 times the propagation distance, so the published specification of 8 km working distance for the Firemaster siren was theoretically increased to 36 km. In practice it will be less due to ground and air effects, but nevertheless a significant gain at modest cost.

6. Sound character

At a measured power output of 150 dB with a richness in odd-order harmonics, the rotary siren in Figure 4 produces around 20 times more power output than electronic sirens in current use, whilst also satisfying noise compliance when installed on a 10 metre pole. The rotary siren gets its haunting sound character from two valve sets synchronised on a common shaft typically with 10 ports in one valve, and 12 ports in the other So there are two triangular waves about 100 Hz apart with a phase offset of 6 degrees.

Because the sound character of the rotary siren is unique, it is readily recognisable over wide areas despite competition from local noise. Conversely, the electronic siren is perceived as "just another alarm we hear daily". The effectiveness of electronic sirens has been progressively eroded by the introduction of similar sounds that desensitise the community by over exposure to the sound.

There is now an emerging realisation that electronic siren potency has been diminished by desensitisation due to over-exposure [9]. Meanwhile, the potency of rotary sirens has improved because the sound character continues to escape contamination by other diurnal sounds.

7. Fire stations sirens

A similarity in sound character between fire brigade station sirens and rotary emergency sirens, is coming to an end as the New Zealand Fire service (NZFS) gradually phases brigade station sirens out in favour of telecommunications media for callout alarms. That initiative has reportedly already yielded a higher volunteer turnout to alarms [15]. The phasing out trend currently being observed, and acknowledged by NZFS, [16], is being accelerated by public pressure for fire station sirens to be silenced, making their eventual demise inevitable. A few examples can be found in [17, 18, 19, 20, 21, 22, 23, 24]. It will render rotary emergency sirens free of competition, preserving their potency for civil defence use. A vital ingredient of that potency being penetration into houses, especially in communities potentially exposed to flooding that could occur suddenly at night. To include competition from fire station sirens among main reasons for rejecting rotary sirens, as some reports have [25, 26, 27] is not entirely accurate.

8. The new National Standard for sirens in New Zealand

In August 2014, a new national standard [25, 26] for sirens was promulgated by the Ministry of Civil Defence and Emergency Management (MCDEM), featuring a sound format with a disturbing similarity to other diurnal sounds, effectively compounding public desensitisation to electronic sirens. See: www.civildefence.govt.nz/assets/Uploads/publications/Tsunami-Sirens-Standard-signal-multiple-tone-repeated-rise.wav

A supporting science document [27] for the new standard is enigmatic, one example being that it is the origin of the new sound format, but contradicts its own stated requirement that "[the signal shall be distinct from all other sounds and any other signals]" The development process for the standard was irregular, bypassing all the normal transparency protocols for the formation of standards [28, 29]. An unfortunate consequence is that although there was some academic science input to the development of the standard, it was devoid of non-selective opportunity for industry-based engineering input via the normal public draft comment process. Consultation was therefore highly selective, exposing the standard to a stigma of appearing to have been tailored towards a particular type of siren. It was unfortunately not possible to influence any moderation to that outcome, due to attempts to make submissions being unsuccessful. Rotary sirens have a proven track record that is hard to ignore. Lower Hutt city have 13 that are widely heard both indoors and out except for a couple of sites where installation adjustments are needed. Their house penetrating ability is a particularly important ingredient where there is risk of sudden flooding, especially at night. It would be an imprudent waste of resources to replace them with disproportionately large numbers of electronic sirens, solely to satisfy a questionable technical standard that is not supported by empirical evidence.

In surprise at the new sound format, a brief survey of nine randomly selected receivers [34] and one eminent recently retired acoustician [8] was conducted. The sound clip was played to them individually, and each was asked to describe the sound they heard. Without exception, the nine receivers described it as either a house burglar alarm, or a car security alarm. Two added that it might be a commercial building fire alarm. Respondents were unanimous that it was a common everyday kind of sound that would likely be ignored. The acoustician was surveyed differently. He was told before listening, that it was the newly required sound format for sirens, and was invited to comment on it. With his permission, his

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response is quoted verbatim:- "It sounds like a car alarm. For a siren that is meant to be distinctive it fails". Other independent surveys will likely yield a similar result, and that has public safety implications that cannot responsibly be ignored. On the contrary, public reaction to rotary sirens has been consistently positive because they exhibit a unique timbre that has been described by receivers as "intimidating and haunting" [30]. "Melancholy and depressing in the dead of night" [31]. Fortuitously, due to a random observer during a 2012 rotary siren test, an amateur audio/video clip (below), of the 150 dB rotary siren in Figure 4, provides a remarkable appreciation of both the sound character and the propagation distance. The wind gusts in the area averaged 42.6 kph from the west, blowing the vibrating air out to sea, so the recording site was seriously handicapped, as demonstrated by two tugboats in high wind and spray at the end of the video clip. Despite those adverse conditions, the siren excelled by being impressively loud and clear at the remarkably long distance. (Turn volume up - www.youtube.com/watch?v=DQUlENpwLNU)

9. Durability

Electronic sirens in large communities invite exceptionally high costs because large numbers of them are required to do the same job as fewer rotary sirens that are known to last for up to 70 years. Sirens need to be mains power independent because a distant knockout can effect local supply. This means small auto-start diesel generators are ideal for powering rotary sirens, but not practical for electronic sirens in such large numbers. Each electronic siren site must therefore be battery dependent involving daunting maintenance costs after the initial period of grace for new installations.

Diesel power can reduce a remote site to a super capacitor for the SCADA (Supervisory Control and Data Access) RTU (Remote Terminal Unit) with combination solar/wind replenishment, requiring no mains power and minimal battery. Diesel engine starting by compressed air is elementary. SCUBA (self-contained underwater breathing apparatus) tanks are a reliable energy storage medium and the amount of air used per engine start is small. Batteries present problems in many industries. Single batteries have a lower failure risk than batteries in banks where one sick cell can knock the whole bank out. Any type of chemical battery is the weakest component in an installation. Battery failure can be insidious and most likely to present during extreme cold or heat. It can be difficult to detect remotely because a sick battery terminal voltage can appear normal on test when the battery is incapable of delivering the required amount of energy during an alert. Remotely monitoring the terminal voltage of a battery is inconclusive.

NASA have now deemed conventional batteries an unacceptable risk for aerospace applications, and commissioned the University of Texas to develop an alternative. The result is a rotary flywheel battery that outperforms conventional batteries in all respects [32].

10. Siren testing

10.1 Electronic siren testing

Regular testing is essential, but presents daunting issues for electronic sirens because whilst battery performance might appear normal when sirens are tested at reduced power, they could fail when operated at full power in a real emergency. Proper testing of electronic sirens with battery backup should therefore only be done at full power with the mains electricity disconnected, and needs to be regular. There is then the dilemma of trading off regular testing against community desensitisation to the sound. The absence of regular testing of electronic sirens potentially exposes them to failure.

10.2 Rotary siren testing

Growl testing of rotary sirens, widely practised in the USA, only requires the siren to be rolled over a few revolutions without winding up to speed. The test and its remote measurement are automated to be performed at programmed intervals without public notification or human input. Growl testing does not generate the normal siren sound heard on alert, thereby posing no risk of community disturbance.

Some jurisdictions run their rotary sirens up to full speed for a few minutes annually to remind the community what the real thing sounds like without overexposure to the sound, and to remind them to listen to the radio when the sirens are heard.

11. Optimising installations

It is better to mount a siren on a high pole in the bottom of a valley than on a hilltop, to optimise reflections and direct the sound into the community rather than over it.. Due to their low frequencies and rich harmonics, rotary sirens will penetrate buildings and reflect readily off both hard and soft surfaces including bush covered hills.

It is better to mount a siren on a 10 metre pole than on a building because high power sirens feature a large near-field. A near-field can be visualised as a large imaginary sphere around the siren, that is populated with standing waves as opposed to travelling waves, a bit like waves on a disturbed pool of water that appear stationary when they collide with each other. The rotary siren in Figure 3 has a measured near-field of 8 metres radius, so the imaginary sphere is 16 metres in diameter. That siren should therefore be mounted on a 10 metre pole to avoid

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ground effects, rather than on or too near a building. A pole height of 10 metres also renders the 150 dB siren in Figure 3 noise compliant in New Zealand [8].

A common mistake is to locate siren installations on coastal waterfronts. It is much better to install them a suitable distance inland, where they can still be heard on the coast, thus creating a wider coverage area at no extra cost. It is a waste of power to propagate sound waves out to sea by installing sirens along beach-fronts unless there is a special need for it. Even the most directional sirens will have a cardioid polar emission profile that projects considerable sound to the rear, so this ought to be exploited rather than wasted.

12. Sirens for local source Tsunami

Sirens are not considered by Civil Defence (CD) authorities to be suitable for local source tsunami, but there are exceptions that ought to be acknowledged. For example, Wellington city, surrounded by hills for people to flee to on foot, could potentially see thousands of lives saved with a warning as short as 15 minutes. The Japan amateur video below is surprisingly unique, having been recorded well up an estuary. It shows three quarters of the period of a first wave whose full period is 36 minutes, extrapolated from an observed half-wave distance between maxima of 18 minutes. This provides an estimated warning opportunity of around 20 minutes – enough time to walk to high ground instead of standing around wondering what's happening, as this remarkable video sadly attests. The footage is a compelling illustration that some estuaries could be protected against local source tsunami. Wellington city is just one example of where a small number of high power sirens could save many lives regardless of whether a tsunami is of local, regional, or distant source. (Ignore the wildcat insert between clock 17 and 24 secs - www.youtube.com/watch?v=ldsWIf2OSYQ)

13. Cogent analogies

Traditional marine whistle buoys use a very low frequency surge powered generator basically a Helmholtz cavity that "moans" to alert mariners to a reef (turn volume up - www.youtube.com/watch?v=v5w4EHlTt_0). Additionally, on top of some buoys, is a high frequency bell that rings as the buoy sways, to provide direction for receivers (www.youtube.com/watch?v=GXIhmlR7Qss).

The bell is designed to be heard only at a short distance whilst providing good direction. If you can hear the bell, you know you are close, and you know which direction it is in because its wavelength is short, unlike the low frequency moan which gives no directional sense due to its long wavelength, but can be heard at a remarkably long distance.

Moral 1: We don't need directional information for sirens, so very high frequencies without low frequencies, are a waste of power.

13.1 Car stereo

Loud car audios remind us daily of the remarkable ability of long wavelengths at low frequencies, to penetrate houses, and propagate much better than high frequencies. Sometimes we can hear from indoors, the obnoxious thump of the bass hundreds of metres away, but more often than not, the treble music is not heard indoors at all as the vehicle passes by, rattling windows, double-glazed or not. There is no directional sense to those long wavelengths, so the bass thump sounds as if it is all around us indoors and out, rather than coming from any particular direction.

Moral 2: Receivers inside their houses could understandably wonder why electronic sirens do not work as well as car stereos, but rotary sirens do. Arguably then, it is a flawed concept to design a siren to maximise the peak frequencies of human hearing at the expense of the low frequencies if we want to successfully propagate sound waves to distant receivers and into houses.

13.2 Twin-wing helicopters

Helicopters with 2 main rotor blades, like the Bell 212 Iroquoi or Huey, propagate a main rotor beat frequency of 5.5 Hz in a forward direction. It is normally impossible for receivers to determine which direction the machine is approaching from, due to the extremely long wavelengths of the sound at 64 metres, with an impressive distance between maxima and minima along the wave, of about 16 metres. These machines can be heard 20 km away when approaching a receiver in still weather. The 5.5 Hz main rotor slap is "all around" us rather than coming from any particular direction.

Moral 3: We want sirens to sound as if they are "all around" us, so the low frequencies and their harmonics are an essential part of the sound character exhibited by a rotary siren.

14. An example of how we hear sounds differently as distance changes

Using the example of a combined whistle and bell buoy, if we sail close to the buoy in a good swell so that both bell and whistle are sounding at full power, we will perceive the bell to be the loudest, being nearer to the peak frequency of human hearing. If we then sail away until the bell loses its higher frequencies and becomes faint, we will perceive the moan of the whistle to be the loudest because its low frequency is propagated much further. Eventually, the bell will become inaudible as we sail further away, but the moan will endure for a remarkable distance. By analogy, we have compared electronic sirens (the bell) with rotary sirens (the moan), and demonstrated that electronic sirens would only be a viable option if we had many of them spaced at close intervals throughout a community.

Acknowledgements

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The Philharmonie de Paris - a new typology

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The Grande Salle of the Philharmonie de Paris opened on the 14th January 2015 amongst considerable controversy – the building was incomplete and the Architect refused to attend in protest. However, following many weeks of 24 hours a day construction, the interior of the Grande Salle was sufficiently complete for the Orchestra de Paris to perform their first official concert.

"But the €390m question is: what does the hall sound like….? In short: pretty stunning. I can't remember a new hall sounding this good or this characterful at its opening… There is a combination of dazzling clarity and generous depth in the sound that makes the whole range of orchestral possibility feel like a vivid physical presence…," says Tom Service, reporting for The Guardian. He's not alone in singing the praises of the acoustics in the striking Jean Nouvel-designed multi-level concert complex, with glowing reports in the NYT (New York Times) and Le Monde.

The project has been 8 years in the design and construction and 30 years in the planning. The City of Paris planned this new concert hall to be located on the border between central Paris and the eastern suburbs to 'bring the music to the people and bring the people to the building'. This move has been controversial as the regular concert goers from the centre of Paris now have to travel to hear the symphony rather than walk.

The original design brief from the Client was also courageous; 'The design must be a new typology – it could not be a shoebox, vineyard, fan or arena shaped hall.' The 40 page acoustic brief, prepared by Eckhard Kahle and Richard Denayrou, was probably the most comprehensive acoustic brief ever written for a concert hall. The brief required great clarity and high reverberance and specified more than 10 acoustical parameters to be achieved in the room.

In 2006 the brief was published along with a request for

La Grande Salle opening night ©BEAUCARDET

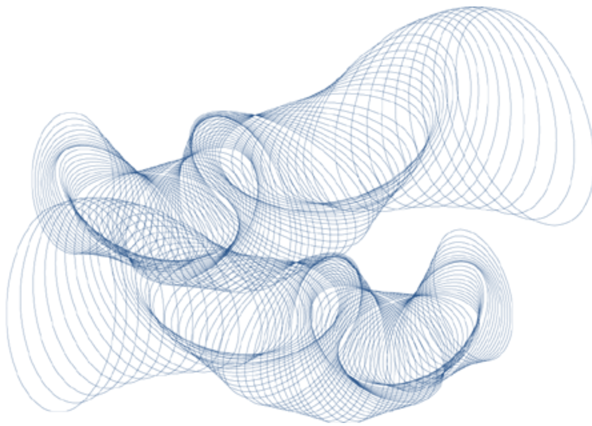
‘expressions of interest’. 98 teams submitted including Frank Gehry, Zaha Hadid and Jean Nouvel. Nouvel was recommended to contact Harold Marshall as Marshall Day Acoustics (MDA) has a reputation for responsible innovation in concert hall design. The association of AJN and MDA proved to be a winner. The team first made the short list of six and then proceeded to win the 10 week long design competition with a radical new design.

The solution to the challenging brief, is a space made up of two nested chambers – an inner floating seating area producing visual and acoustical intimacy between audience and performer and an outer space with its own architectural and acoustical presence. This original design required innovations in architecture, structural engineering, stage design and acoustical engineering. Jean Nouvel and lead acoustician, Sir Harold Marshall conceived the room during a synergetic design workshop with the Architect, Acoustician and Theatre Consultant working in a highly collaborative environment. This ‘meeting of minds’ (a MDA specialty) achieved a result that is not possible with an autocratic or formulaic approach to design.

The photo shows the floating inner seating planes and the clouds (or nuage) that weave their way through the upper space to provide lateral reflections to all the upper seating. Supplementary reflections are provided by ribbons at the rear of some seating areas and by side walls around the stalls. Though a large-capacity hall (2400 seats), the Philharmonie auditorium feels remarkably intimate. This is due to the significant lateral sound energy and the physical proximity – the distance from conductor to the farthest listener is only 32 metres.

The overall result at this early stage, appears to be an outstanding acoustical success for both listeners and the musicians. The conductor of the Orchestre de Paris, Paavo Jarvi, stated in an interview after the first concert; “For me the most important thing is the acoustics, it’s the sound of the hall. Let me be the first to report to you, it is a huge success” and later, on facebook, “The acoustics are fantastic!”

The Philharmonie de Paris is a new paradigm in acoustical design. It is 70% larger in volume than a typical concert hall for 2,400 and achieves remarkable clarity and intimacy in a warm reverberant environment.



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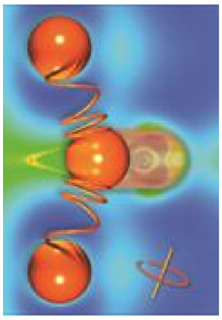
just that much nicer.

On behalf of the Auckland branch of ASNZ, and all those who attended the visit… I'd like to thank Neil, Peter and Ray for the guided tour and the insight they gave into what it's like working at the coal face of mechanical noise control. Prepared by James Whitlock.

Experiment reveals new mysterious properties of sound waves



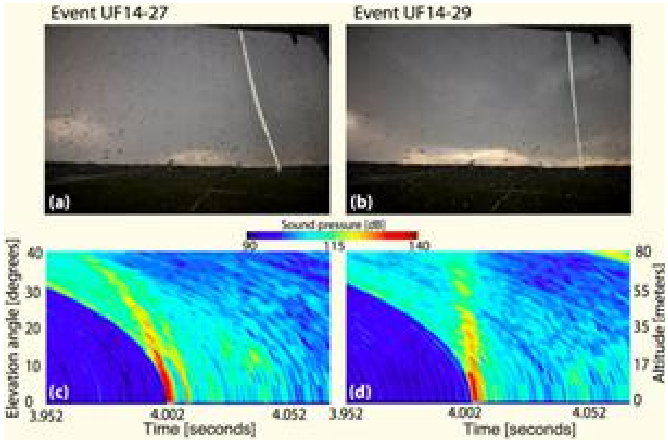
The Nature Materials Journal (March 23rd 2015 issue) describes how researchers at the Ohio State University have discovered how to control heat with a magnetic field. The article describes how an experiment conducted by the Ohio State University research team proved that the phonon – the elementary particle that carries heat and sound– has magnetic properties.

This artist's rendering (graphic shown above) based on computer simulations, depicts a phonon heating solid material. Atoms of the material, shown in orange, are joined with flexible atomic bonds, shown as springs.

The phonon imparts heat by colliding with the centre atom, creating a vibration in the springs. The trail of the passing phonon is marked with increased magnetic field intensity, shown in green. The figure in the lower right shows the direction of the applied magnetic field. The researchers found that a sufficiently strong magnetic field can cause phonons to collide with each other and be deflected off-course, which slows the flow of heat through the material. (Image Source: *Renee Ripley, courtesy of The Ohio State University*).

First 'Images' of thunder captured

For the first time, scientists have imaged thunder, visually capturing the sound waves created by artificially triggered lightning. Researchers from Southwest Research Institute (SwRI) presented in May the first images at a joint meeting of American and Canadian geophysical societies in Montreal, Canada. (Image Source: *Courtesy of University of Florida, Florida Institute of Technology, and Southwest Research Institute*).



Asona Product finalist in Interior Design Awards 2015

Asona, a specialist New Zealand manufacturer, distributor and installer of acoustic products has created bespoke ceiling lanterns made from glass mat composite paper for a recent project in collaboration with Architect Michael Fisher. Fisher entered this element of the project into the 'Craftsmanship' section of the New Zealand Interior Design Awards 2015 where it was selected as a finalist.

New fire extinguisher: Bass hum booms flames out

Two engineering students developed a fire extinguisher that works with sound waves.

See: http://edition.cnn.com/2015/03/27/us/sound-fire-extinguisher for full article. (Images Source by Evan Cantwell George Mason University)

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2015

Inter-Noise 2015. San Francisco, USA. 9th to 12th August 2015.
www.internoise2015.com

12th Wespac 2015. Singapore. 6th to 10th December 2015.
www.wespac2015singapore.com

22nd International Congress on Sound and Vibration [ICSV22]. Florence, Italy. 12th to 16th July 2015. www.icsv22.org

7th International Conference on Vibration Engineering [ICVE2015]. Shanghai, China. 18th to 20th September 2015.
www.csve.net.cn

Australian Acoustical Society Annual Conference. Pokolbin, Australia. 15th to 18th November 2015. www.acoustics2015.com.au

2016

Inter-Noise 2016. Hamburg, Germany. 21st to 24th August 2016.
www.internoise2016.org

International Congress of Theoretical and Applied Mechanics [ICTAM]. Montreal, Canada. 21st to 26th August 2016.
www.ictam2016.org

22nd International Congress on Acoustics [ICA 2016]. 5th to 9th September 2016. Buenos Aires, Argentina.
www.ica2016.org.ar

International Workshop on Rail Noise [IWRN]. Terrigal, NSW, Australia. 12th to 16th September 2016.
www.iwrn12.acoustics.asn.au

2017

Acoustics 2017 Joint meeting of the Acoustical Society of America and the European Acoustics Association. Boston, USA. 25th to 29th June 2017. www.acousticalsociety.org

2018

175th Meeting of the Acoustical Society of America. Minneapolis, USA. 7th to 11th May 2018. www.acousticalsociety.org

2019

23rd International Congress on Acoustics [ICA 2019]. Aachen, Germany. 8th to 13th September 2019. http://icaci.org/icc2019

Dates and information may change, for more information please see:
www.icacommission.org/calendar.html

Phoenix sues FAA over 'extreme discomfort' from airplane noise

How bad is the airplane noise over Phoenix? Bad enough that some residents can't hear each other talk. Bad enough that many can't sleep and bad enough that the city is now suing the Federal Aviation Administration (FAA).

For a full article see: http://edition.cnn.com/2015/06/02/travel/phoenix-sues-faa-airplane-noise

Publication Dates and Deadlines

New Zealand Acoustics is published quarterly in March, June, September, and December.

The Deadline for material for inclusion in the journal is 1st of each publication month, although long articles should ideally be received at least 4 weeks prior to this.

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Associate Membership of the Acoustical Society of New Zealand is open to anybody interested in acoustics. Members receive benefits including;

- Direct notification of upcoming local events
- Regular mailing of Noise News International
- Reduced charges for local and national Society events
- Priority space allocation for trade stands at society events
- Discounted rates on selected acoustic products

To join the society, visit www.acoustics.ac.nz or contact the Secretary; secretary@acoustics.org.nz