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Auraltypical acoustics? A critical review of acoustical foundations, standards and practices

Prof. John Drever[1]
Goldsmiths, University of London
New Cross, London

Mattia Cobianchi[2]
Goldsmiths, University of London
New Cross, London

Carmen Rosas Pérez[3]
Heriot-Watt University
Edinburgh

ABSTRACT

The evolving concept of aural diversity was born out of awareness that there is a deeply embedded and intertwined, singular model of hearing at the core of the preponderance of acoustic standards and guidance, and hence practice. This is exemplified with the prescription of the 'otologically normal' hearer derived equal loudness contours (ISO 226:2003), giving form to ubiquitous A-weighted decibel – the 'otologically normal' characterising the hearing of healthy 18 to 25-year-olds. The consequence is the design and support of less favourable, even hostile acoustic environments for those that fall outside of this group, which can result in discomfort, distress, negative impact on health and well-being and societal exclusion. In order to understand the different aspects that underpin this 'auraltypical' situation, this paper critically reviews the prevailing set of acoustic standards and scientific methodology with reference to a case study on ultra-rapid hand dryers.

1. INTRODUCTION

The new and evolving concept of aural diversity was born out of awareness that there is a deeply embedded and intertwined, singular model of hearing at the core of the preponderance of acoustic standards and guidance, and hence practice (1) (2). This is exemplified with the prescription of the 'otologically normal' hearer derived equal loudness contours (3) giving form to ubiquitous A-weighted decibel – the 'otologically normal' characterising the hearing of healthy 18 to 25-year-olds. The consequence is the design and support of less favourable, even hostile acoustic environments for those that fall outside of this small subset of society, which can result in discomfort, distress, negative impact on health and well-being and societal exclusion (4). In order to begin to understand the

[1] J.drever@gold.ac.uk
[2] m.cobianchi@gold.ac.uk
[3] mcrosasp@gmail.com

different aspects that underpin this prevailing 'auraltypical' (5) situation, this paper highlights four interrelated areas:

- Standards and Guidance: predicated exclusively on the 'otologically normal', hence not representative of aurally diverse hearing – with specific reference to the case study that initiated the concept of aural diversity, on high-speed hand dryers in public and workplace toilets (6).

- Pedagogy: reviewing aural typical models of hearing in teaching and training, and exploring how there is a tendency to compartmentalise aurally divergent hearing when it is included.

- Scientific methods and practice: in addition to a reliance on WEIRD samples, auditory science and acoustics research have a tendency to base their practice on 'auraltypical' hearing, with regard to the representation of hearing types in their samples and more generally in the mindset of the practice.

- Audiometry: normal hearing for tones is not always normal hearing for speech, with specific reference to autistic people.

A study that was initially prompted by the distress of the researcher's infant, Drever's environmental noise study of ultra-rapid hand dryers in in-street and off-street public convenience provisions (7), found a wide range of people were finding the sound of hand dryers challenging and in extremes, intolerable, within an already complex and challenging space for many, yet essential for all:

- pregnancy, fetuses, infants, children and older people
- people with particular diseases or medical problems (e.g. high blood pressure)
- people dealing with complex cognitive tasks
- visually impaired people and those who rely on effective speech intelligibility
- hearing impaired people (conductive, sensorineural & mixed hearing loss)
- hearing aid users and cochlear implant users
- hyperacusis, misophonia, phonophobia, tinnitus, recruitment sufferers
- people with post-traumatic stress disorder (PTSD)
- people with Tourette's syndrome
- people with cerebral palsy
- autistic people with hyperacute hearing
- people with dementia
- people with acoustically related social phobias (i.e. parcopresis, paruresis) (8)

This list mirrors and adds to the WHO's vulnerable groups referenced in the Guidelines for Community Noise 1999 (9). Considering the extent that which society at large is represented in this list begs the questions, notwithstanding the UK's advanced set of acoustic regulations and guidance, why has this situation happened, and why have we let it happen. Acoustics is tending to design and support less favourable, even hostile acoustic environments for some of these people, which can result in discomfort, distress, negative impact on health and well-being and societal exclusion and exclusion from the workplace. The reason for this, this paper postulates, is that these people are not deemed 'normal' and hence diverge from the model of hearing that much of acoustics is predicated, a singular model of hearing that is the deeply embedded and intertwined, at the core of the preponderance of acoustic standards and guidance, and hence practice. This is exemplified with the prescription of the 'otologically normal' hearer derived equal loudness contours (10), giving form to ubiquitous A-weighted decibel – the 'otologically normal' characterising the hearing of healthy 18 to 25-year-olds. Developing this notion to a wider scale, this paper proposes that we live in an auraltypcial world:

> Auraltypical people tend to impose their understanding of normal hearing on everyone else as correct and natural (11)

This is in contrast to a more desirable society based on aural diversity:

> On embracing aural diversity, the default normative metrics of auditory acuity (or the need for recourse to metrics at all) that are customarily implemented as natural and universal, such as the thresholds of audibility and pain are problematized, and, as we acknowledge other variants on aural experience that human life— from foetus to old age— has to offer, hearing inevitably becomes an unstable subject. (12)

2. PEDAGOGY & TEXTBOOKS

Acoustics teaching and training are habitually woven in with standards and guidance, as the rudimentary role of the professional acoustician is to practice in accordance with the standards, guidance and related legislation.

From a review of current online course materials in acoustics, the following facts and figures on hearing are often reproduced and presented to students as universal scientific facts:

- The threshold of hearing is 0 dB
- The threshold of pain is 140 dB
- Frequency perceptions range from 20 Hz to 20 kHz
- The ratio of the quietest sound perceived to the loudest (without damaging your hearing i.e. 120 dB) is 1 000 000 000 000: 1.
- The ear canal is a 2.7cm tube which boosts frequencies around 3.5kHz
- Humans have binaural hearing and can localize sounds in space around them, with angular resolution down to 1^{o}

Equal loudness contours are tacitly used as a benchmark for loudness perception, along with concomitant metrics such as A-weighted decibels, phons and sones, etc. and again, are often treated as scientific fact – e.g. "Using these curves, the loudness level of any pure tone can be determined from its frequency and its sound pressure level" (13).

The term 'normal hearing' is commonly used in textbooks – e.g. "Thus if we have normal hearing our threshold should be about 0 dB" (14). 'Normal' is used to stand in for 'otologically normal' which represents a specific criteria set out in BS ISO 226:2003

> person in a normal state of health who is free from all signs or symptoms of ear disease and from obstructing wax in the ear canals, and who has no history of undue exposure to noise, exposure to potentially ototoxic drugs or familial hearing loss[…]within the age limits from 18 years to 25 years inclusive (15).

Without knowledge of this standard, it is reasonable to assume that 'normal' referred to a form of statistical representation of society.

Many textbooks present the graph of the equal-loudness contours from the standard and similar versions of a diagram of hearing thresholds, mapping frequency and sound pressure in dB, including speech and pain (16).

With their concerted focus on the "listener", with detailed and elaborate acoustic criteria, the classic tomes on concert hall design of Barron and Beranek (17) presume a unified and idealized hearer and are more concerned with a cultured, discerning listener rather than an audiological one.

3. REVIEW OF STANDARDS AND GUIDANCE

Using a case study to help exemplify an auraltypical predicament, this section will refer to standards and guidance related to high-speed hand dryers in public and workplace toilets at the time of the study (18).

BS 6465 (19)
On providing toilets, you must also provide hand drying facilities according to BS 6465. This is why we find hand dryers installed in awkward and inaccessible places, even blocking access to the toilet for some.

BB 93: Acoustic Design of Schools (20)
This offers the most acoustical detail on toilet provision in schools. Toilets are included in the Activity noise and noise tolerance for room type guidance.

- Activity Noise (source room): Average
- Noise Tolerance (receiving room): High
- Ambient noise levels (dB L_{Aeq}(30mins): 50
- Impact Sound Pressure level limit (dB L'nT(tmf,max),w): 65
- Reverberation time (Tmf(s)): 1.5

BS 8233: 1999 (Residential, Industrial, Offices) (21)

The standard covers sound insulation and noise reduction for buildings. It provides internal noise criteria for washrooms, 45 – 55 dB L_{Aeq}. The lower value is considered a good standard and the upper figure is considered a reasonable standard. (p.19) The range is used to aid with privacy between spaces or between rooms. It also recommends desirable reverberation times, without specifying a figure. It also "recommended that any partition separating a WC from a noise-sensitive room should have a weighted standardized level difference (DnT,w) of at least 38 dB." (P.19)

British Toilet Association (22)

The Summary of Best Practice In 'Away From Home' Toilet Provision (2010) by the British Toilet Association, recommends: Alternative methods of hand drying are desirable to ensure continuity of supply and provide for customer choice, e.g. electrical hand dryers and paper towels. http://britloos.co.uk/about/ There is no direct reference to sound levels.

Good Loo Design Guide (23)

The Good Loo Design Guide published with the Centre for Accessible Environments and RIBA is an inclusive guide to the provision of WCs to suit a wide range of users, and gives guidance on various WC layouts, in line with Part M of the Building Regulations and BS 8300:2001. There is guidance on good design for visually impaired people, but this is totally focused on visual aspects.

Standard Specifications, Layouts and Dimensions (SSLD) 3: Toilets in Schools (24)

Department for Education and Skills has provided guidance notes produced to inform the Building Schools for the Future programme in 2007. Regarding hand drying, they recommend recycled paper towels and if electric hand dryers are used, they should be the high-efficiency, high-velocity air sheet hand dryer type. This guidance stresses the importance of aural privacy. In order to achieve this, they propose to increase the background noise within the toilet facility to a level of 55dB (A). It is not clear how this will be achieved as they also recommend that any noise from the mechanical ventilation should not exceed 45dB (A). The guidance recommends a lower reverberation time than BB93, below the upper limit of 1.5s. Ideally, they are looking for a reverberation time of one second (provided the room is less than 8m x 5m in size with a plain plasterboard suspended ceiling).

For acoustic separation between adjacent rooms thy recommend the guidance in Approved Document E:2003, Resistance to the passage of sound and BB 93. For sound separation between the male and female toilets of at least Rw 45dB is asked for. They also encourage a weighted sound reduction of 40dB between the accessible toilet and the hand washing area. It is not explained why this is necessary.

Lifetime Homes, Lifetime Neighbourhoods: A national strategy for housing an ageing society (CLG 2008) (25)

Recommends adequate public toilets to allow older people to retain their independence for as long as possible, which includes the installation of loop systems.

Equality Act 2010 (26)

It is arguable that the recent Equality Act could relate to hand dryer noise, as a form of Indirect disability discrimination:

> Service providers are required to make changes, where needed, to improve service for disabled customers or potential customers. There is a legal requirement to make reasonable changes to the way things are done (such as changing a policy), to the built environment (such as making changes to the structure of a building to improve access) and to provide auxiliary aids and services (such as providing information in an accessible format, an

induction loop for customers with hearing aids, special computer software or additional staff support when using a service). (27)

Living in the Community: Housing Design for Adults with Autism by Andew Brand (2010) (28)

This guidance has many suggestions related to lowering sound levels in interior design with regard to hyperacusis and could be extended with regard to publicly accessible toilet provision.

The Accessible Toilet Resource (2008) (29)

As part of VivaCity 2020, this project is a large university-based research consortium that is developing tools and resources to support the design of socially inclusive cities. This is the only guidance that spells out the hazards of hand dryers to a range of vulnerable groups:

> A hot air dryer should not be the only method of hand drying available in the accessible cubicle. Some users find the noise from the hot air dryer distressing. Caregivers of people who have had a stroke report that hot air dryers can startle and distress the person being cared for. Parents report that hot air dryers often frighten children, and it has been suggested that such fixtures may also distress some children with disabilities. (30)

Summary of guidance

There are standards on unoccupied background sound levels of toilets, and the guidance on school provision is particularly strong with regards to privacy, however, there appears to be a gap regarding the levels of a sound source (individual and multiples) such as a hand dryer *in situ*. Only VivaCity 2020 has referenced hand dryer sound levels as an issue but this is only guidance on good practice. The Control of Noise at Work Regulations 2005, which is concerned with hearing loss due to exposure, would only be relevant for a toilet attendant or cleaner who spent much of the working day in a toilet with continual hand dryer use. The list of vulnerable groups above is not necessarily concerned with hearing damage from prolonged exposure, however. It is also worth repeating that such regulations are predicated on A-weighted decibels, for example, employee exposure is based on L_{Aeq}.

4. SCIENTIFIC PRACTICE ON AUDITORY SCIENCE AND ACOUSTICS PRACTICE EXCLUSIVELY BASED ON "NORMAL HEARING"

The first class of "geographical" sampling biases that impact on acoustics and soundscape research is the reliance on WEIRD samples. Most psychology and environmental psychology articles have an intrinsic bias in relation to researchers and participants: they are mostly from the Western, Educated, Industrialized, Rich, and Democratic societies. In 2010, in a review of comparative databases from across the behavioural sciences, Henrich concluded that `WEIRD subjects are particularly unusual compared with the rest of the species – frequent outliers` (31). Subsequent studies by Rad et. al in 2018 (32) and Tam and Milfont in 2020 (33) found only marginal improvements. The relevance of these results in this context is due to the prominent role that psychology plays in the knowledge-base and methodologies that we use to study sound and noise perception.

Then there is a second class of "local" sampling biases. A first sampling bias issue is the wilful discrimination of "non-normal" hearers, since most acoustics and soundscape studies use a selection criterion for the participant's “normal hearing”, whether measured with audiometry or self-reported. The second type of sampling bias issue results when the participants are only apparently selected randomly. Often participants recruiting strategies and data gathering methodologies are chosen because of convenience for the researchers and tend to sample college students or existing users of public space with verbal or textual engagement. The problem is that the student population for example can be already severely biased in terms of minority representation (gender, age, ethnicity, socio-economic status, sensorial and neuraldiversity etc.).

These issues have already been highlighted in the WHO document on the *Guidelines for Community Noise* more than 20 years ago, in 1999:

> Protective standards are essentially derived from observations on the health effects of noise on “normal” or “average” populations. The participants of these investigations are selected from the general population and are usually adults. Sometimes, samples of participants are selected because of their easy availability. However, vulnerable groups of people are typically underrepresented. (34)

Our duty of care toward vulnerable groups and minorities should push the researchers to go beyond what would be an accurate “statistical representation” of a group and weight their needs as more important than the “normal” or “typical”. Including multiple perspectives and different needs will result in a better space for everyone, the ‘typical’ population included.

5. “NORMAL HEARING” FOR TONES IS NOT ALWAYS “NORMAL HEARING” FOR SPEECH

The use of tonal audiometry, i.e. where pure sine tones of various frequencies (typically in the 250 to 8000 Hz range) are used (such as equal loudness contours), may classify a participant as a ‘normal hearer’, but would miss any processing diversity, like in the case of autistic participants who may have different neural processing of speech, especially in presence of other competing sounds or noise.

Jones et al. found indeed that in terms of capacity for discrimination of frequency, intensity and duration differences in pair of sounds, 72 autistic adolescents did not differ on average from 57 IQ - and age-matched control participants (35). But when other competing sounds are present, the differences in perception and speech intelligibility capacity are significant.

In 2004, Alcantara et al. tested the speech-in-noise perception abilities of 11 autistic adults and adolescents with normal-hearing against an age-matched control group of 9 neurotypical participants, and reported that the autistic participants “required a higher SNR, whenever there were temporal dips in the background sound, to perform at the same level as the controls” (36). A 2009 study on children found that “that children with ASD process speech in quiet only as well as TD children do in background noise” (37).

These processing differences have also been documented through functional MRI. Samson et al. in 2010 compared 15 autistic and 13 non-autistic participants presented with auditory stimuli varied in spectral and temporal complexity and stated “While we observed similar hierarchical functional organization for auditory processing in both groups, autistics exhibited diminished activity in non-primary auditory cortex and increased activity in primary auditory cortex in response to the presentation of temporally, but not of spectrally complex sounds” (38). In 2020 Hernandez et al. investigated the differences in the areas of the brain that are recruited when noise is present and found that “ASD youth showed significantly greater activity in left-hemisphere speech-processing cortex (i.e., angular gyrus) while listening to conversation-in-noise (vs. conversation or noise alone)" (39).

5. CONCLUSIONS

This paper begins to explore key areas related to acoustics: pedagogy, scientific method and standards. It is the beginning of a much larger study exploring the auraltypical preconditions of acoustic and noise control research and practice which will help show how we can make changes towards a much-needed aural diverse one. Acousticians should be designing and supporting positive listening experiences for the whole society and the need to be able to reliably communicate the needs of all hearers and sound makers with other engineering disciplines is essential.

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