Assisting the Autistic To Reduce Anxiety Caused By Their Environment

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Abstract— **Many people with Autistic Spectrum Disorder (ASD) find certain sounds so unpleasant that their lifestyle can be severely impaired by the need to avoid these noises. This paper considers several common sources of such anxiety-inducing noise in the normal home and working environments, and considers whether this problem could be addressed with mechatronic concepts. People with ASD were tested for their reactions to a range of noises, and to the same noises filtered through noise reduction devices. Analysis of the probable characteristics of the anxiety- causing noise features was made. The noises were varying in time and pitch. In addition to anecdotal and survey evidence some carefully structured tests were carried out on some participants using the devices. Based on this investigation, specific mechatronic devices are proposed, using active noise control to selectively soften the sounds, which may be suitably used by those suffering ASD. A smart home or office could deploy multiple devices, in the optimal locations to reduce any offensive noise, whilst preserving a pleasant environment that allows the user the ability to communicate. Furthermore the environment could be tuned to the needs of specific individuals, and switched when they are present.**

I. INTRODUCTION

Subjects with autism spectrum disorders (ASD) often have difficulties in interpreting what they hear and see. However, how what they sense influences their behaviour is still not generally understood. ASD patients often report characteristic symptoms, such as hypersensitivities to sound and touch [1] and parental-report studies note higher levels of sensory symptoms among those with ASD [2] compared to those without ASD. Clinical interviews have also revealed that unusual sensory reactions among more than 90% of all individuals with autism [3], and their parents rate sensory problems as one of the top two areas of difficulty for family life. Clearly improved understanding of the sensory symptoms is important, and the underlying neurobiology. Meanwhile, directly addressing the symptoms offers immediate help to the current groups of people with ASD.

The most debilitating sensory problems in autism result from environmental 'triggers', which can vary significantly between individuals. Examples of this are well described in 'The Curious Incident of the Dog in the Night-Time' [5]. In the auditory domain, causes can range from: domestic appliances (e.g. fridge freezers/vacuum cleaners); to lighting sources (particularly fluorescent tubes); or unexpected noise sources (such as dropped objects). Any combination of these, for a person with ASD, can seriously impact upon their quality of life, making even normal activities fraught with difficulty. A typical response to these problems is the wearing of ear defenders or similar sound attenuation equipment – however, the broadband attenuation produced severely limits receptive speech intelligibility, and the high visibility of the equipment introduces a further social stigma to people with ASD. Mechatronic devices have been proposed before [6], but in this paper the integration of such devices into a house are explored.

II. SOUNDS THAT DISTRESS IN AUTISM SPECTRUM DISORDER

A. Background

Certain sounds (and, by extension, sensory experiences from other modalities) are much more unpleasant in Autism Spectrum Disorder (ASD) than to the general population. Some sounds that do not elicit primarily anxiogenic responses in neurotypical participants (NTs) are able to do so in the ASD population. The social and communicative problems in ASD make it difficult to choose sounds due to the relative small number of studies on this issue, so we decided to rely on

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information from parents/participants and other anecdotal reports.

Given the paucity of data on which deconstructions of various sound frequencies are most troubling to the ASD population, it was decided that the best approach was to use naturalistic sounds rather than simpler AM or FM modulations. Hopefully in future it will be possible to isolate specific troubling frequencies but we adopted the principle that sound perception within the brain goes far beyond simple hair cell stimulation in the ear. The same goes for affective sounds and so using naturalistic, ethologically valid sounds as a starting point in our explorations of this field seems justified.

Ten sounds were selected on the assumption that they are considered by many in the ASD population, namely, Baby Crying, Electric Drill, Electric Shaver, Food Processor, Hairspray, Hand Saw, House Heater, Paper Shredder, Washing Machine, Wind Chimes. In addition, two 'distracter' sounds were selected as expected to be experienced as pleasant or neutral, namely, Ambient Spring and Lake Sound. These sounds were downloaded from online sound file depositories freesound.org [17] and soundjay.com [18]. Audacity version 2.0.2 [19] was used to edit each sound file down to 5s in duration, and resample sounds to 44.1 kHz resolution. All files were subsequently normalized to the same average volume level in the communication frequency range (0-4 kHz) [6].

B. Testing of Sounds Reported as Unpleasant by those with ASD

A noise sensitivity questionnaire was sent to 50 families associated with acute ASD asking them to identify sounds their family members liked and disliked. 12 families identified a broad range of sounds that caused the most distress, including percussive machine sounds, such as electric drills and sawing; human sounds e.g. baby crying, unexpected sounds, e.g. fire alarms; and social sounds, e.g. busy supermarkets. And all bar one respondents identified music as a positive experience, seeking it out as part of their daily routine.

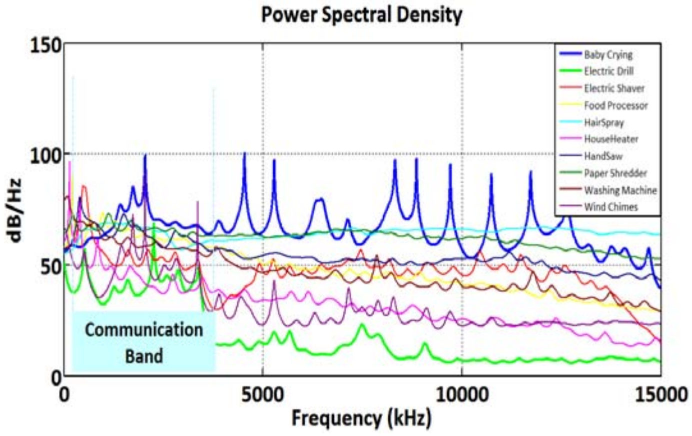


Figure 1 *Overview of Sound Battery*

Under controlled lab conditions 25 ASD volunteers listened to the normalized battery of sounds, and registered their level of pleasure/displeasure in each sound. Analysis of these revealed the most highly-rated unpleasant sounds were Baby Crying, Electric Drill and Washing Machine whilst Lake Sound and Ambient Spring were rated the least unpleasant [4].

III. CHARACTERISTICS OF ANXIOGENIC SOUNDS

Hearing perception is modified by a number of factors. For example, after a time in quietness, the hearing nerves automatically increase their sensitivity; and a sudden loud sound is then perceived more intensively. Age-, or injury-, related decay in the cochlear hair-like nerve cells reduces the hearing threshold and frequency resolution, typically more at some frequencies than at others. Age related slowing of neural responses causes decrease in temporal resolution, and sound information received in quick succession tends to blur together [9].

A loud signal at one frequency masks lower energy signals at nearby frequencies – i.e. the threshold of audibility for one sound is raised by the presence of another (masking) sound [9]. Generally the louder frequency masks the softer frequencies as indicated in Fig. 2.

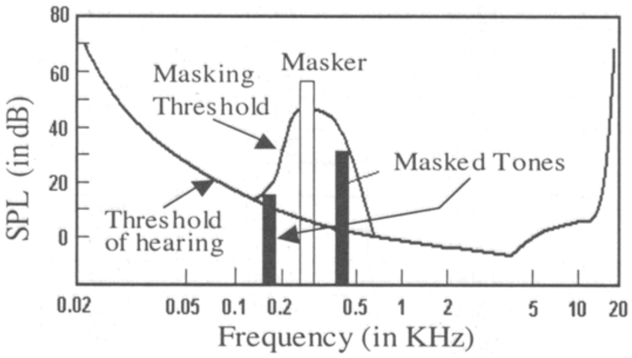


Figure 2 *Hearing masking effect [10].*

One challenge in hearing protection/enhancement design is to eliminate unwanted noise, while simultaneously preserving speech intelligibility for social interaction. Speech phonemes feature in a banana shaped cluster (Fig. 3), on a frequency and intensity audiogram.

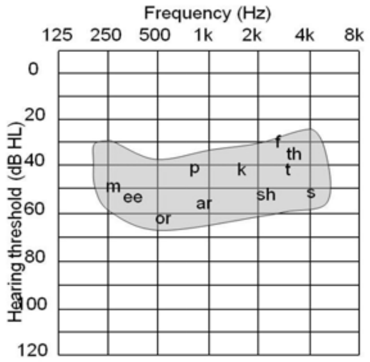


Figure 3:*'Speech banana'showing the spectrum of speech-phonemes [9].*

For the purpose of communication, there is particular interest in preserving the so-called speech banana.

While most of the power below in the speech frequency spectrum is below 1 kHz, the intelligibility of what is said depends on the formants above 1 kHz [11]. So much so that if the frequencies 800 Hz to 3 kHz are filtered out speech is unintelligible. Thus it is important that any filter or device should transmit through the bulk of the frequency range 100 Hz to 4 kHz.

It is noteworthy that many with ASD have enhanced musical perception and ability. It is evident that frequency content at lower powers is still important for intelligibility, and that sounds at lower powers can still be perceived in a generally noisy background. Music perception depends upon harmonic content, and rhythm, and many with autism show enhanced perception [12]. An awareness of this is illustrated by the play on the '*The Curious incident of a dog in the night*' (Apollo, London, from March 2013 [5]) for which the music has a large emphasis on prime numbers. These prime number harmonics are perceived as being very significant for many with autism (particularly harmonics 3, 5, 7) [3].

IV. DEVICES TO REDUCE THE NOISE PROBLEMS FACED BY THOSE WITH AUTISTIC SPECTRUM DISORDER.

To date, various anti-noise devices and apps have been produced to be used with mobile phones, and iPods. These have been of limited effect for those with ASD. Many wear ear protectors to block out environmental sound, but this increases their isolation, and may endanger their safety with the loss of key warning sounds.

A. *Static Devices*

This research group has been developing prototype static and active devices. Static devices aim to allow through the speech frequencies, but to reduce the frequency content in the 4 kHz to 12 kHz band. This will reduce significantly the harmonics that may be causing distress to those with ASD.

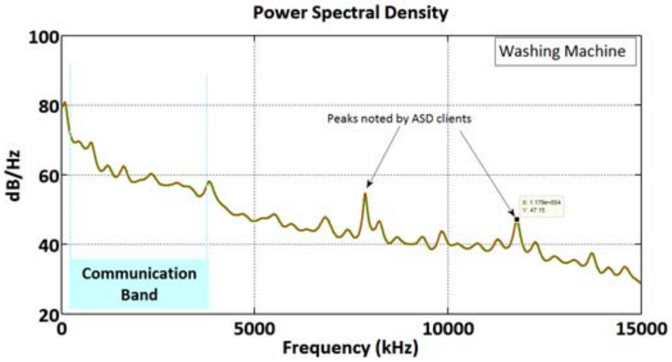


Figure 4: *High Frequency Machine Noise*

The frequencies of relevant noise peaks in machine noise in Fig.4 are in the ratio 2:3.

For use with ASD two static devices identical in appearance were developed, one effective, while the other was intended to be a placebo. Within the static device envelope it is impossible to produce a true placebo with no filtering effect.

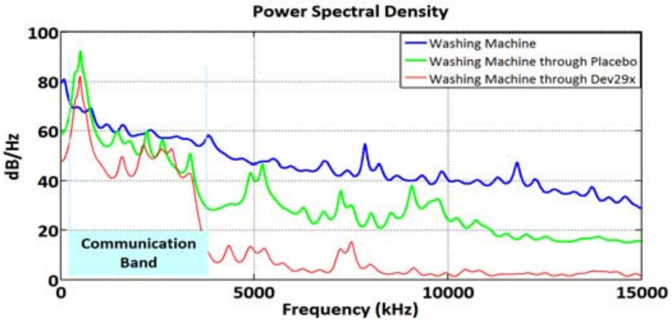


Figure 5: *Placebo device used for patients to contrast with test devices of identical appearance.*

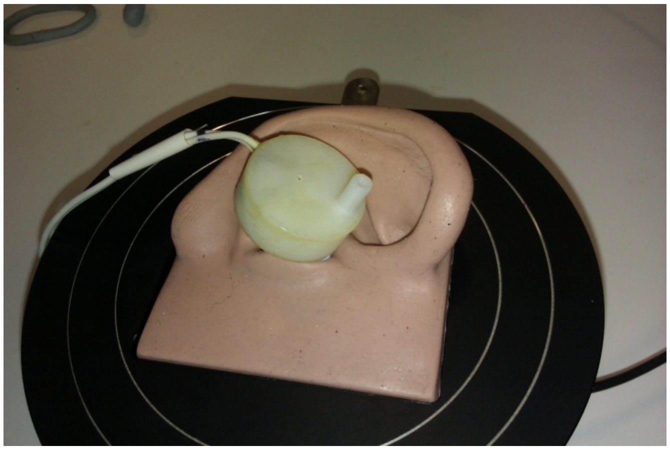


Figure 6: *Device sitting in an artificial ear for lab tests.* [3]

B. *Active Anti-Noise Devices*

Prototype active anti-noise devices have also been developed, and work on a different principle. Here any background sustained noises are sensed, and reduced to a low by out-of-phase cancelling sounds. Active devices this work well in reducing continuous background noise. This technology is common in noise reducing headphones, but requires either totally enclosed well fitting headphones or can also be effective with 'in the ear' devices. An active device has been tested in the lab and shown to be effective with steady frequency test signals and some variable signals [13][14].

Figure 7 Active Device in use.

An Active device with test signals at 3.5 kHz and 6 kHz under optimum conditions produced attenuations at these frequencies over 25 dB, but there were new signal artefacts produced as well as the original frequencies. (tests 130531).

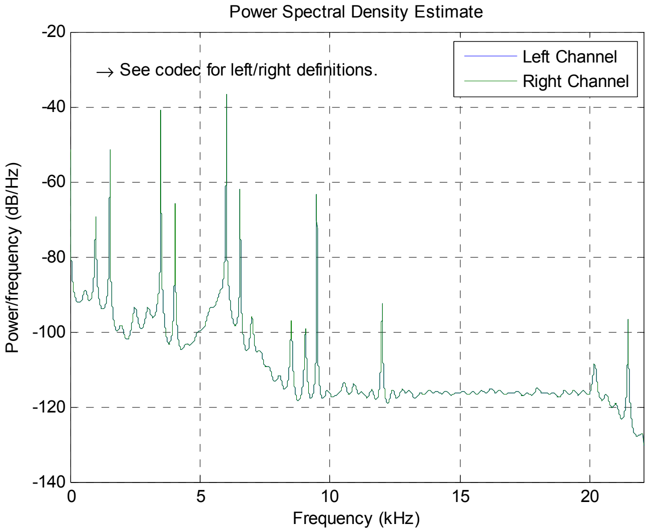


Figure 8*: Filtered signal for noises at 3.5 kHz & 6 KHz.*

V. ZONE OF QUIET

All of these devices work by producing a zone of quiet through which all sounds must pass[15]. In noise cancelling devices this is generally within the headphone, or the ear canal and are mostly only effective at eliminating frequencies below 1 kHz. The devices described all need to be effective at much higher frequencies. For sound in air

$$\lambda = \frac{c}{f} \tag{1}$$

and in air c=343 m/s, so at 10 kHz the wavelength λ=34.3 mm, and the zone of quiet should be <3.4 mm diameter to be effective. A sound reduction of more than 10 dB should then be possible.

To make the Smart Home conducive to use by ASD users it is proposed that a zone of quiet is produced between the noise source and the position of the user. This is best if it close to the source if this is practicable. In many cases putting an enclosure round the source would be impractical and expensive. Further for the rest of the household this will limit the value of the source machine too. If there is a doorway between source and where the ASD client settles this can be a good site for the ‘zone of quiet’ to be produced. Most doors can be effectively sealed around their periphery, but will still have a gap at the base of the door. Rather than sealing the door completely it is best if it opens freely, and transmits normal conversation.

Sound may also be transmitted through the walls, but this is dominantly those caused by vibration. The vibrations can cause the wall surface to transmit the sound to the air in the room. In practice if the sound sources are properly mounted little vibration should be transmitted, and the significant frequencies will only be airborne.

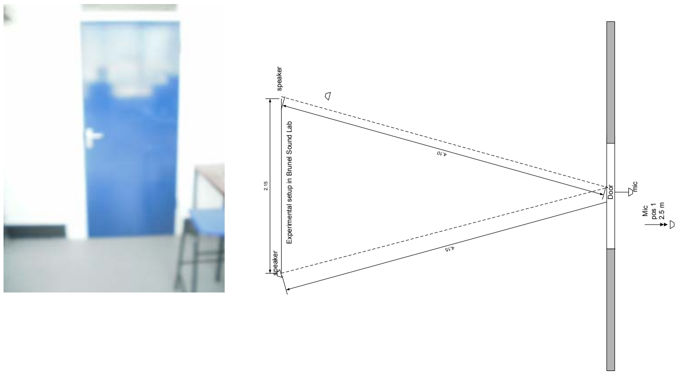


Figure 9 Test door, and layout of the speakers, and microphone relative to the door.

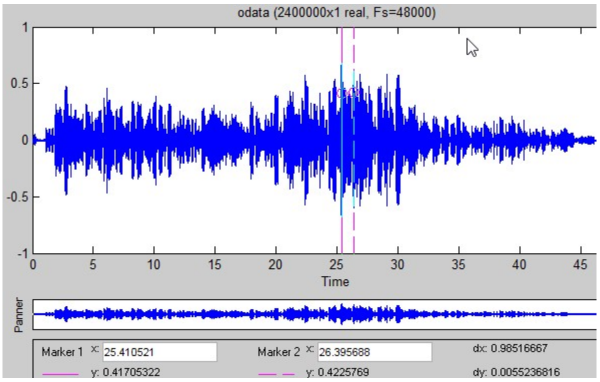
VI. TESTS ON A DOOR MOUNTED ANTI-NOISE DEVICE.

Such a device was designed, and manufactured at Brunel University. Tests were carried out between two laboratories with the device attached to the exit edge of the door. At the base of the door is a narrow channel with length the thickness (43.8 mm) of the door, and height the gap between door and the hard smooth floor (varied during tests 1 mm – 5 mm).

Gaps at the top and sides of the door were about 9 mm, and the door closed against a rebate top and sides. These gaps were small when the door was shut tight

Figure 10 Base of Door with Devices fitted along the base of the door. The artificial ear is aimed at the gap through which sound flows.

Sound recordings with a slow logarithmic swept signal from 1 kHz to 10 kHz were made without any device and an open door, followed by the door closed with the stereo speakers in phase. Then the static device was fixed along the base of the door with a range of vertical gaps from 5mm down to 1mm. Each recording lasted fifty seconds, and was saved as a .wav file.



Marker 1 X: 25.410521 y: 0.41705322
Marker 2 X: 26.395688 y: 0.4225769
dx: 0.98516667 dy: 0.0055236816

Figure 11: Response of microphone to the sweep signal.

These sound files were split to synchronize the start of each file with the start of the sweep signal.

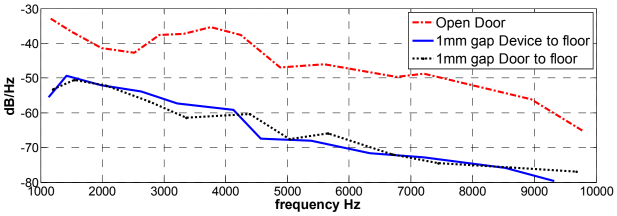


Figure 12: Effect of closed door filtering effect with 1 mm gap, and with device fitted to the door with varying gaps to the floor.

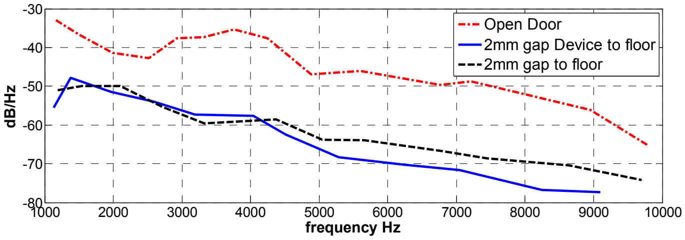


Figure 13: Responses of a door with a 2 mm gap at the base, with the device switched on and off.

Note the variation in recorded response for the open door for signals notionally equal in volume from speakers with a flat frequency response in the relevant frequency range. This is because the whole system and space is involved in the total response. Above 5200 Hz the static device improves attenuation by about 10 dB over no device. It marginally transmits more of the speech frequencies than with no device.

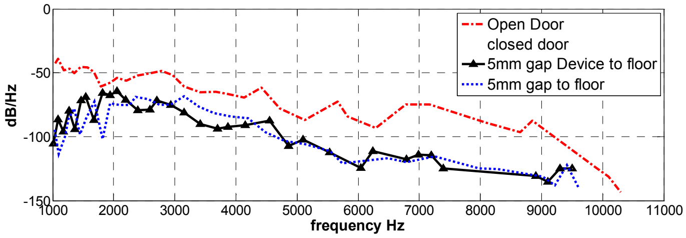


Figure14: Responses of a door with a 5 mm gap at the base, with the device switched on and off.

The static device performance showed little sensitivity to gap size for gaps of 1 mm to 2 mm but for larger gaps gives less attenuation of frequencies above 4 kHz. This accords well with the concept of a 'zone of quiet' being formed under the devices.

Thus at 5 mm gap switching the device on has little extra effect over just closing the door.

Hence one conclusion is that if closing a door improves the attenuation of offensive noises, the fitting of this device with a small gap to the floor will improve it significantly further.

These tests were conducted with the device in static mode. An early prototype active device is shown in Fig.15.

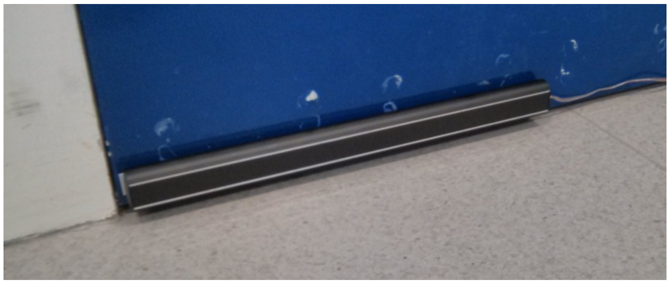


Figure 15: Prototype active device fitted to the lab door.

With the in-ear devices, described on section IV, integration of active control was possible in the same device. This could also be done with these door mounted devices. Small piezo-type speakers are ideal for incorporation into the devices.

For active devices the same attention to gap size must be made, and an improved attenuation of steady sounds should be possible.

VII. INTEGRATING THESE DEVICES INTO THE SMART HOUSE

A smart house offers the potential to customise the environment for ASD users with reference to the specific noises each finds anxiogenic. The doors between the usual room the user likes to work or rest and the source of the noise can be adapted. When an ASD user enters the house his/her presence can be sensed, and the relevant devices switched on in the appropriate manner. It would even be possible to sense which room the user and noise source were in at that time, and switch the relevant door settings accordingly. Anecdotally the families of ASD users often end in conflict because the gadgets they desire to use are the cause of disturbance and anxiety in the ASD user.

Switching on either static or active devices will improve the environment in such households, or offices.

VIII. CONCLUSIONS.

Active anti-noise devices in a mechatronic house can provide an environment for ASD users and their families that should significantly improve their lifestyles.

These devices could be installed as standalone static devices at modest cost. But if the building is being equipped for smart living the control of these devices can be integrated into the overall system to improve the sound environment. The system can be customized to individual and family needs.

Tests made on prototype devices fitted to a standard interior door between our laboratories verified that a ‘zone of quiet’ can be established in the gap between door and floor.

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