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BOOK OF ABSTRACTS

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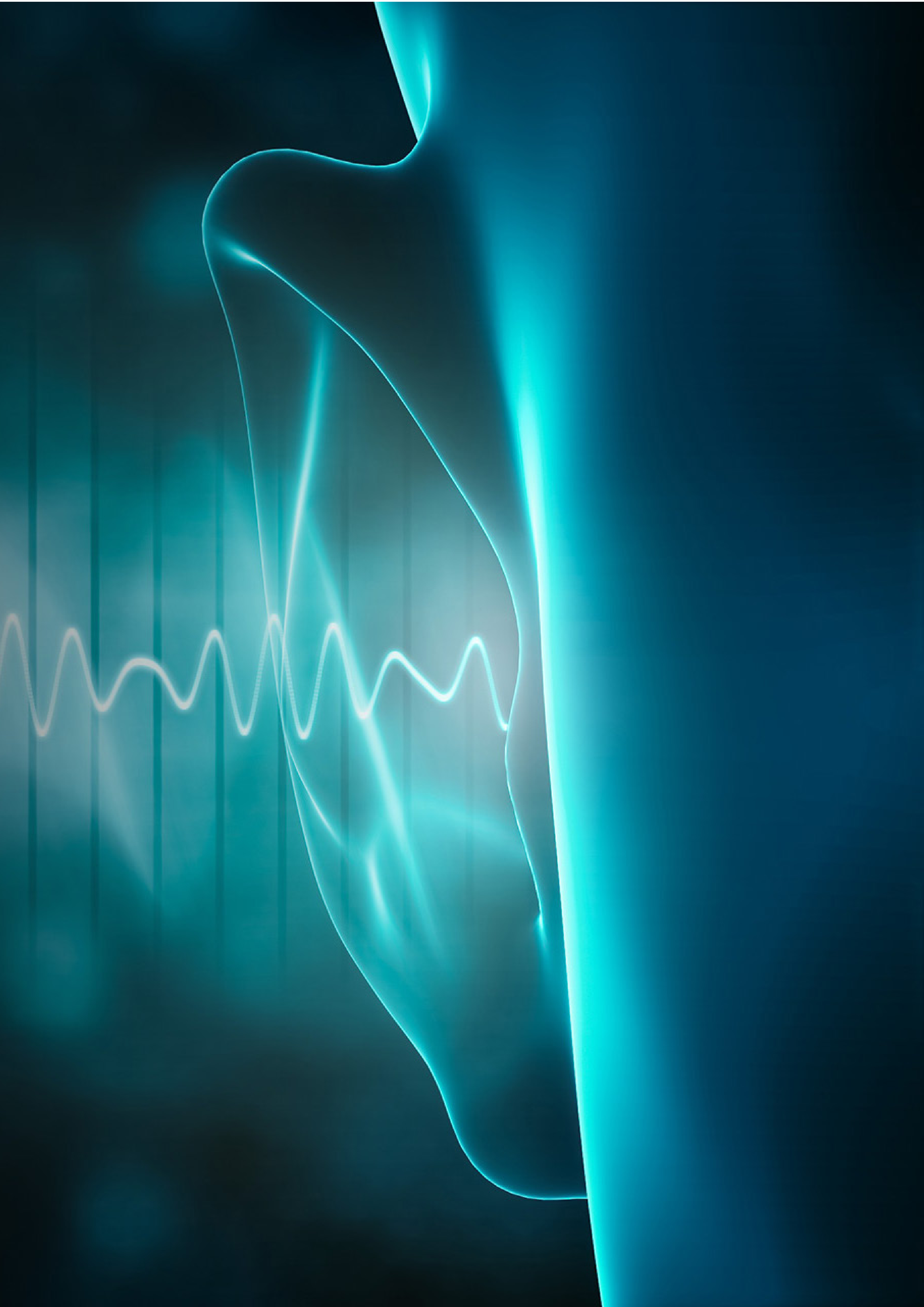

Diagnosis and Quantification of Noise-Induced Hearing Loss

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Exposure to intense noise for a sufficient time can lead to noise-induced hearing loss (NIHL). The diagnosis of NIHL is important for people claiming compensation for such loss incurred during their employment. Early diagnosis may also be used to identify especially susceptible individuals and to remove them from the noisy situation so as to prevent further damage. The audiometric pattern produced by noise exposure depends on the type of noise. Noise types producing different effects include: steady broadband noise, as occurs in some factories; more impulsive factory sounds, such as hammering; noise exposure during military service, which can involve very high peak sound levels; exposure to very intense tones; and exposure to low-frequency noise and vibration. It is argued that existing diagnostic methods, which were primarily developed to deal with NIHL produced by steady broadband noise, are not adequate for the diagnosis of NIHL produced by different types of exposures. Diagnostic methods for some of the types of noise exposure are described, focusing on noise exposure during military service. The highest diagnostic accuracy in this case has been obtained using a deep neural network, employing as input the age-expected hearing loss values and the audiometric thresholds for each ear. It is recommended that quantification of NIHL for all types of exposures is based on comparison of the measured hearing threshold levels with the age-associated hearing levels (AAHLs) for a non-noise exposed population, as specified in ISO 7029 (2017), usually using the 50th percentile, but using another percentile if there are good reasons for doing so. It is recommended that the overall NIHL for each ear be quantified as the average NIHL across the frequencies 1, 2, and 4 kHz.

Noise annoyance assessment in the soundscape approach

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The annoyance of a noise source can be assessed in two ways. The first way is to assess the annoyance of the noise source occurring in isolation. This is called the environmental noise management approach The second way is to assess the annoyance of a part of the sound scene in which the noise source occurs. This is called the soundscape approach. Using the two experiments as examples, I will discuss the advantages and disadvantages of each of these approaches with the particular focus on the noise annoyance generated by wind turbines.

Real-life benefits of hearing-preservation cochlear implantation in children

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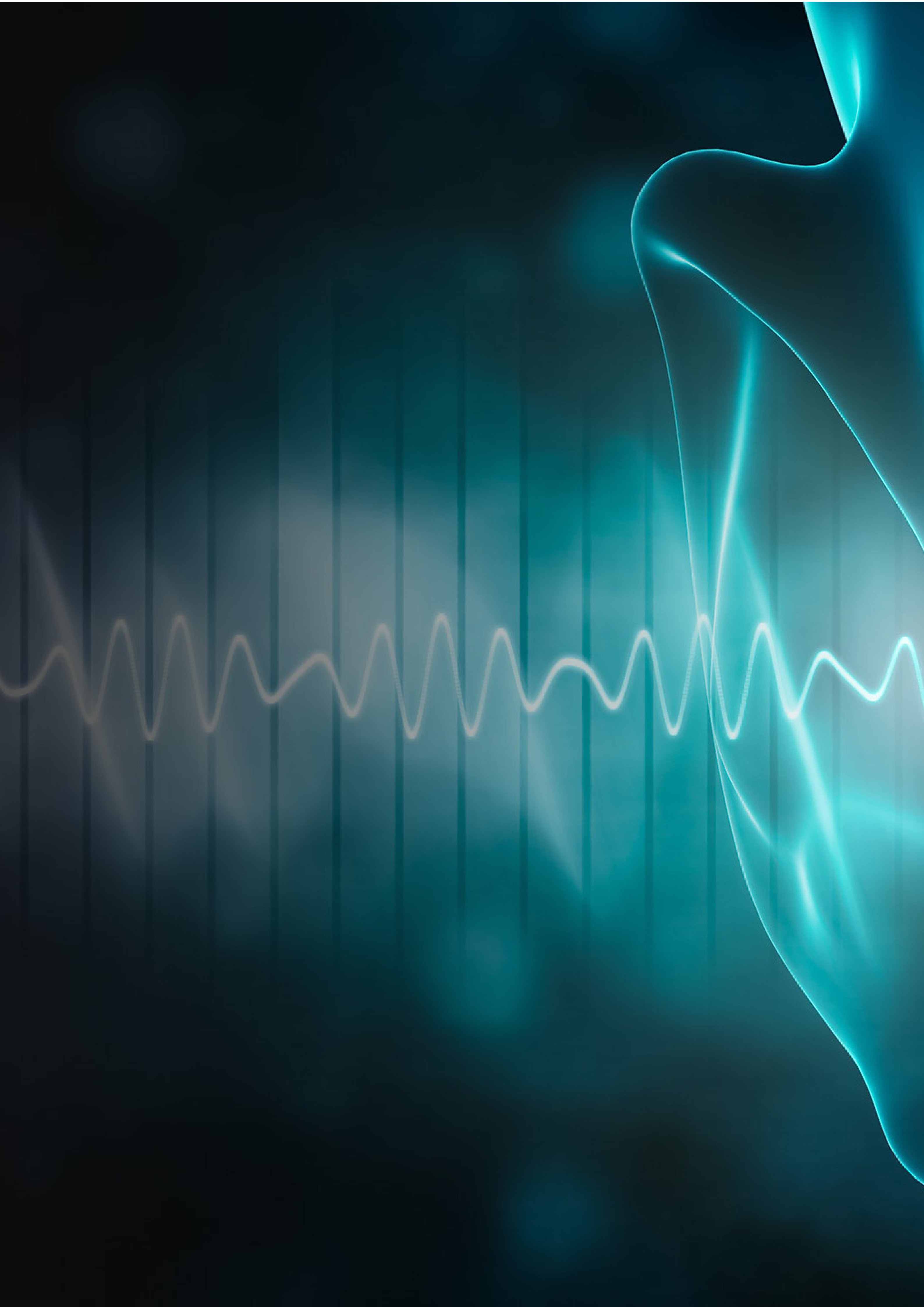
Despite the recent advances in cochlear implant (CI) systems, the amount of speech information available for children with a cochlear implant compared to their normal hearing peers or hearing-aid wearing peers, is limited. These differences become particularly apparent in challenging situations, such as noisy environments when several speakers are present. Some features of speech that are essential for communication, such as stress, intonation and emphasis can be significantly impaired in paediatric CI users. In addition, music perception is poor in this group, which can have consequences for development and social interaction. Combination of electrical hearing with preserved acoustic hearing has the potential to address these issues and enable children with a CI to more closely follow a normal course of auditory development. To date, the clinical evaluation of benefit following hearing preservation CI has focused on laboratory tests like pure-tone audiometry and speech perception, which fail to capture real-life benefits.

Initial data from two prospective studies with CI paediatric participants will be discussed. In study one, participants with hearing preservation cochlear implantation (HPCI) were tested with and without access to their electro-acoustic or electro-natural hearing preservation. 19 participants were tested so far on spatial release from masking, complex pitch ranking, melodic error detection, perception of prosodic features in speech. Mean age =11.5 years (SD: 0.57, range: 9-16 yrs). The mean low-frequency (125, 250, 500 Hz) pure-tone audiometry average was 51.20 dBHL (SD: 20.81, range: 16.67-87.5 dBHL). There was a trend towards greater spatial release from masking, pitch discrimination, melody detection in HPCI condition compared to all other conditions tested. In study two, the outcomes for bimodal users i.e., CI in one ear and a hearing aid in the contralateral ear, were compared with bilateral hearing aid and bilateral cochlear implants users (15 participants; 6 bimodal, 3 hearing aid and 6 CI users). Mean age =11.9 years (range: 7-16 yrs). All groups demonstrated spatial release masking. Bimodal users trended towards better melodic detection, CI user performed best in pitch perception, followed by bimodal then hearing aid user.

Our results suggest that the addition of acoustic hearing alongside CI provides some benefit in real-life outcomes. HPCI gives greater access to spatial cues with improvement in speech recognition in noise, whereas addition of a hearing aid improves melodic perception.

Acknowledgments: These studies are funded by Cochlear Research and Development Limited (IIR-2184 and IIR 2185) and supported by the NIHR Manchester Biomedical Research Centre (CPMS ID 51724). Wong is additionally funded by Dr Isabel Clifton Cookson Scholarship (dual-award PhD programme between The University of Manchester and The University of Melbourne).



PRESENTATIONS

Hidden hearing loss: A paradigm shift in hearing care

Stéphane F. Maison

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Sensorineural hearing loss results from the loss of, or damage to, the sensory cells. Recent studies from animal models and human temporal bones show that hair cell loss can be preceded by the loss of synaptic connections between the inner hair cells and the spiral ganglion neurons. The silencing of these neurons degrades auditory processing and likely translates into a variety of perceptual abnormalities including speech discrimination difficulties, particularly in noisy environments, and tinnitus via an induction of central gain adjustment secondary to loss of afferent input to the central nervous system. This presentation will review 1) the scientific background that led to the discovery of cochlear synaptopathy, 2) how, at this stage of our research, we may uncover this neural deficit in humans and 3) how such discovery currently impacts the field of otology and audiology.

Research supported by a grant from the NIDCD (P50 DC015857) and generous contributions from the Tom and Helene Lauer Fund.

Perceptual Effects of Recreational Noise Exposure for Young People with Normal Audiograms

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There is much concern regarding the impact of recreational noise exposure on hearing health. The World Health Organisation estimates that over 1 billion young people could be at risk of hearing damage, through attendance at loud music events and use of personal listening devices in particular. However, the evidence for an association between typical recreational exposure and hearing loss is actually rather weak. Previous research has often been based on pure tone audiometry (PTA), but PTA is relatively insensitive to hair cell loss, and has very little sensitivity to the neural damage that is associated with noise exposure in animal models. Hence, it is possible that people with normal PTA have suprathreshold perceptual deficits due to their listening habits. Across several studies, our group at Manchester has examined the effects of recreational noise exposure on performance for a wide range of behavioural tasks, from basic sound discriminations to speech-in-noise and musical tasks, in hundreds of young people with normal PTA. Overall, we have found little evidence for performance deficits related to self-reported noise exposure in this cohort, but tinnitus and hyperacusis were associated with higher exposure. It is possible that substantial perceptual deficits occur only when the noise-induced damage is sufficient to cause PTA threshold elevation.

The Search for Noise-induced Effects of Synaptopathy in Individuals with Normal Audiograms

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It was discovered about 14 years ago that exposing animals to noise can lead to partial loss of the ribbon synapses between inner hair cells in the cochlea and primary auditory neurons [1,2], without affecting the thresholds for detecting sounds. Loss of ribbons synapses is called synaptopathy and deficits in auditory processing together with normal audiograms have been called "hidden hearing loss" [3] or "hidden hearing disorder" (HHD) [4]. However, HHD can occur as a result of factors other than synaptopathy.

Many studies have been conducted to try to assess whether noise-induced synaptopathy occurs in humans, and, if so, what its perceptual consequences are. It has been assumed that greater noise exposure produces, on average, greater synaptopathy, and that greater synaptopathy leads to greater deficits in auditory processing. Hence, greater noise exposure should be associated with greater auditory deficits. However, it may be the case that the degree of synaptopathy needs to be substantial before measurable perceptual effects occur [5,6]. Studies seeking to find effects of synaptopathy have involved a wide range of measures and have given very mixed results; some studies have shown that greater noise exposure is associated with deficits in auditory processing, including the ability to understand speech in the presence of background sounds [7,8], while others have shown no such deficits [9,10].

The discrepancies across studies probably reflect a variety of factors. One factor is connected with the difficulty of the tasks used. It seems likely that synaptopathy has its largest effect for difficult tasks, such as understanding speech in background sounds at low speech-to-background ratios. The tasks used in some studies may have been too easy to reveal the effects of synaptopathy. A second factor is connected with the definition of a "normal" audiogram. In some studies, the noise-exposed group had slightly higher audiometric thresholds than the non-exposed group, even though thresholds for both groups were ≤ 20 dB HL. Even small threshold elevations can affect auditory processing, impairing the ability to understand speech in noise [11] but improving the ability to detect amplitude modulation at low sensation levels [12,13]. A third factor is connected with the age range of the participants. Synaptopathy tends to increase with increasing age, although with considerable individual variability [14]. In studies using participants with a wide range of ages, the effects of noise-induced synaptopathy would have been confounded with the effects of age-related synaptopathy. A fourth factor is connected with variability in general listening skills, which can affect performance on a wide range of auditory tasks. Some occupations, such as being a professional musician or a recording engineer, are associated with good listening skills but greater noise exposure. Hence, the deleterious effects of noise exposure may be offset by greater listening skills.

Two recent studies both involved very homogeneous groups of participants, namely students at Indian universities [15,8]. All participants were young (the study of Jain et al. involved older participants also, but the results for these are not considered here) to minimize the effects of age-related synaptopathy. The noise-exposed groups listened to personal music players (PMP) at high volumes for two or more hours per day, whereas the non-exposed groups did not regularly listen to PMPs. None of the participants had significant exposure from other noise sources. In both studies, the noise-exposed group and the control group had very similar audiometric thresholds over the conventional frequency range (up to 8 kHz), but the exposed group had higher audiometric thresholds above 8 kHz.

The first study [15] showed that the ability to understand speech in quiet did not differ for the noise-exposed and control groups, but the noise-exposed group had slightly but significantly higher performance for understanding speech in noise, even though the speech stimuli did not contain audible energy above 8 kHz. Stream segregation was assessed using a rapid sequence of vowel stimuli differing in fundamental frequency (F_0). Larger differences in F_0 were required for stream segregation for the noise-exposed group. The authors argued that impaired hearing for frequencies above 8 kHz is associated with impaired auditory function at lower frequencies, perhaps linked to synaptopathy, despite normal audiometric thresholds at those frequencies.

The second study [8] also showed that the ability to understand speech in quiet did not differ for the two groups, but the noise-exposed group had slightly but significantly higher performance for understanding speech in noise. The participants were also assessed for their ability to detect amplitude modulation of a 4000-Hz sinusoidal carrier presented in threshold-equalizing noise [16] at 30, 60 and 90 dB SPL using modulation frequencies of 8, 16, 32, and 64 Hz. At 90 dB SPL but not at the lower levels, the thresholds were significantly higher (worse) for the exposed than for the control group, especially for low modulation frequencies. The fact that AM detection only differed across groups at the highest level is consistent with the existence of synaptopathy in the noise-exposed group, since synaptopathy is thought to selectively affect neurons with high thresholds [17].

Overall, the results are consistent with the idea that noise-induced synaptopathy does occur in humans, but its effects on the perception of speech in noise are small, at least for relatively young participants with moderate noise exposure, and are only revealed when the exposed and control groups are similar in age and other factors. Also, it cannot be ruled out that noise-exposure has effects on the auditory system other than synaptopathy.

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Predicting prevalence of noise annoyance using the CTL method

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Dose-response functions that attempt to relate the prevalence of a consequential degree of transportation noise-induced annoyance to long term cumulative noise exposure levels have typically been derived by descriptive statistical methods. These methods are not based on understanding of the effects of noise on people, but only on the correlation between predictor and predicted variables. They have no explanatory value to aid understanding of the relationship between exposure and annoyance and offer little guidance for research intended to improve the accuracy and precision of predictions. In this paper a first-principles alternative to descriptive analysis is described which requires fewer assumptions than regression analysis, suggests further research that can lead to genuine understanding of community-level effects of transportation noise, and yields average dosage-response relationships that agree closely with modern, source-specific curve fits.

The Influence of Wind Turbine Infrasound on Human Cognitive Performance

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Infrasound (IS) and low frequency noise (LFN) are commonplace in modern environments, emanating from sources such as traffic, ventilation systems, wind farms, and industrial machinery. However, research concerning their health impacts is often ambiguous due to other audible components during exposure. Despite these indications, direct investigation of infrasound's effects on human health in a randomized, controlled manner is scarce. One study demonstrated that long-term exposure (1 month) to infrasound doesn't affect human behavior, including health and cognitive functions [1]. However, it was associated with a decrease in gray matter in the brain, impacting somatomotor and cognitive functions like memory and speech processing. Another study noted changes in the primary auditory cortex and superior temporal gyrus, areas responsible for higher order auditory processing, upon infrasound exposure. Wind turbines, a particular type of noise source, have distinct acoustic characteristics, contributing to higher perceived annoyance. A Finnish survey [2] found that people living near wind turbines reported symptoms such as ear problems, cardiac issues, headaches, dizziness, and fatigue. A portion attributed these symptoms to the turbines' infrasound, with symptomatic respondents living closer to the wind farm and more often suffering from chronic diseases and annoyance.

The primary goal of the current study is to investigate if the IS and LFN from wind turbines in Poland impact human well-being, particularly determining whether modulated IS and LFN negatively affect mental performance compared to signals without modulation.

The study used preliminary recordings and sound pressure measurements from the Kościuszko ventilation shaft of the Wieliczka salt mine near Krakow, Poland to confirm the recording equipment's suitability for infrasound and low-frequency noise measurements. Subsequent in-situ recordings were conducted on two wind farms at varying distances from the turbines. Due to stable weather conditions, recordings from one farm were used in the experiment. The recorded wind turbine noise was filtered to obtain only infrasound, using a finite impulse response low pass filter.

The study was conducted in a large, well-equipped audio engineering warehouse in Krakow, employing industry standard subwoofers for generating high levels of low frequencies. The warehouse's light construction avoided profound and uncontrolled standing waves. Sound recording used a DPA 4006 microphone, a ZOOM F8n field recorder, and an in-situ calibrated SVAN 959 sound analyzer. The target stimuli levels were based on measurements from wind farm. The stimuli were amplified to achieve the closest possible levels to target frequencies. Despite subwoofers' limitations in very low frequencies, an acceptable compromise was reached between the target and achieved sound source levels.

Three noise exposure conditions were used: recorded wind turbine noise, background noise, and synthesized low-frequency noise. The SPLs were measured continuously throughout the experiment. The exposure area featured random application of stimuli, reference signal, or none. The background noise was a result of external urban sounds, discussions, and audio signals generated during class work.

Participants included 129 audio engineering students aged 21–24 years, who volunteered for the study. The group sizes varied from 8 to 12, and all participants reported normal hearing. A cognitive test evaluating attention was conducted after approximately 70-80 minutes of exposure to the audio conditions. Ethical approvals were obtained from relevant committees. Of the subjects, 64 were exposed to recorded wind turbine noise, 43 to no stimulus, and 22 to the reference signal.

A Work under Stress Simulator test was used to examine the impact of infrasound and low-frequency noise on cognitive functions, particularly attention. The test requires participants to complete a task under stress-inducing stimuli within three minutes. In this experiment, the stressors were different exposure conditions. Before the test, participants filled an initial questionnaire to evaluate their pre-class well-being, including questions about their sleep and health status. Post-exposure, they answered another questionnaire about symptoms related to acoustic conditions, such as unusual sensations, hearing additional sounds, pressure in ears or head, feeling vibrations, or any discomfort. These questionnaires helped assess the effects of different sound exposures on participants.

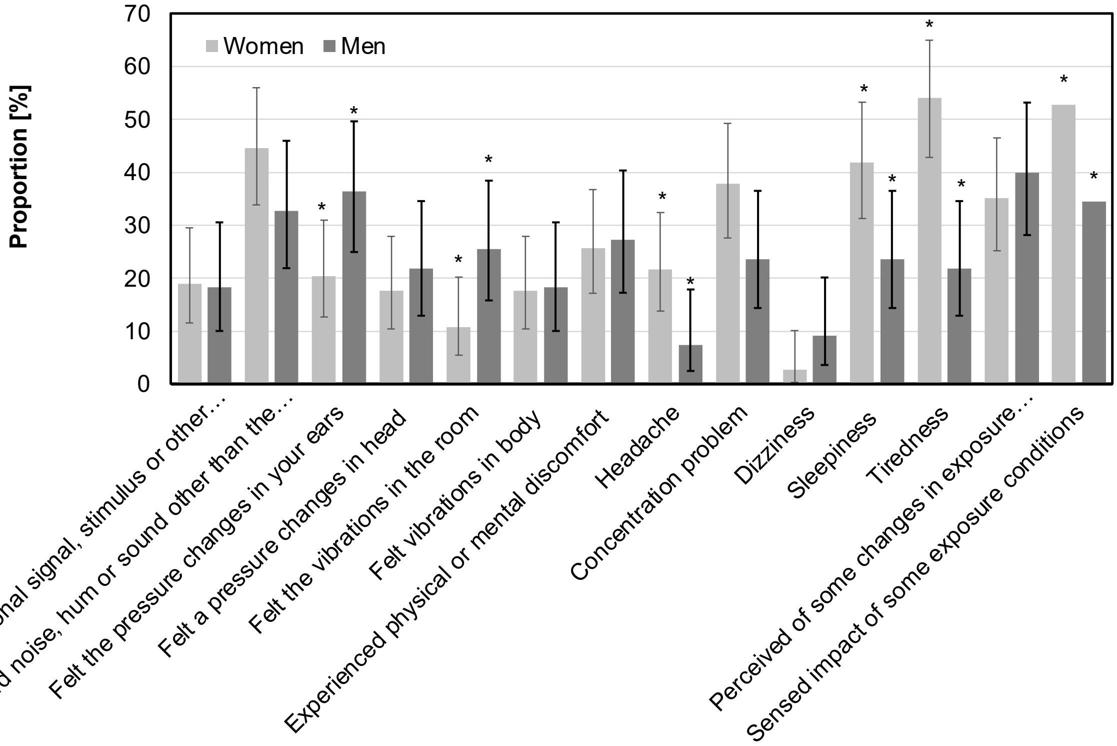

Figure 1: Answers to the post-exposure questionnaire in study subjects divided into gender subgroups that were exposed to stimuli

The study concluded that while there were no significant differences in response rates between subjects exposed to WT originated infrasound and steady infrasound, minor differences were noted between those exposed to WT infrasound and those unexposed. Generally, unexposed individuals reported fewer instances of head pressure changes, discomfort, and perceived changes in exposure conditions.

Significant gender differences were noted (Figure 1). Males more frequently perceived changes due to exposure conditions, while females more often reported feeling worse after classes. However, gender had no significant impact on responses to the post-exposure questionnaire or on subjects' self-assessment of well-being before classes. Furthermore, no significant associations were found between psychometric test performance and pre-class self-assessment of well-being. However, subjects well-rested before classes reported feeling better afterward. No significant differences in performance levels under various exposure conditions were found in males and females. Similar results were observed when analyzing the total number of feelings and ailments subjectively related to exposure conditions. The study concludes that the perceived influence of WT infrasound on well-being is more likely due to unintentional perception of stimuli, the presence of infrasound background below 5 Hz, or females' propensity to report negative well-being after classes if they were tired beforehand.

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Detection of wind turbine noise combined with other modulated noise

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Wind turbine noise is commonly reported as the most annoying source of noise. One of the possible reasons for this is the amplitude modulation observed in the signals generated by wind turbines. However, it is still not clear how much this phenomenon influences the overall perception of wind turbine noise. In order to better understand this, we conducted an experiment in which people (out of a pair) were asked to point out the sound of a wind turbine. We used recordings made in the field and six broadband sounds that were also modulated at the same depth and modulation frequency as the turbine recordings. The results showed that people did not always correctly identify wind turbine sounds, especially when the sound level was low (and the distance from a turbine was high). The most difficult pair consisted of wind turbine noise and modulated highway noise.

Proposals of evaluation criteria for infrasound in the general environment

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Community noise is recognized as an environmental stressor that causes annoyance, reduced well-being, and possibly non-auditory adverse health effects. Wind turbines are a specific type of noise source that affects large areas. The noise emitted by wind turbines does not resemble ordinary industrial noise. It has unique acoustic characteristics, such as amplitude modulation (AM) and tonality, as well as low frequency noise (LFN) and infrasound (IS) [1,2]. In addition, it has been suggested that IS and LFN may be responsible for adverse health effects in people living near wind farms. The aim of this study was therefore to propose assessment criteria for infrasound in the general environment that are specific to wind turbines.

According to the results of previous studies, human tolerance to infrasound is defined by the hearing threshold [3,4]. Infrasound that cannot be heard (or felt) is not annoying and is not thought to have any other adverse or health effects. However, at levels just above the hearing threshold, IS can be annoying and its annoyance increases very rapidly with increasing sound pressure level (SPL) [5]. Recent research largely confirms the earlier findings that there is no evidence that infrasound well below the hearing threshold can have any effect on humans [6,7]

To assess infrasound, the international standard ISO 7196:1995 recommends the use of the G-weighting filter, which have the same slope between 1 and 20 Hz (close to 12 dB per octave) as the hearing threshold curves, equal loudness curves and equal annoyance curves. It is therefore not surprising that there is a close relationship between the G-weighted SPL and the annoyance perception [5].

Meanwhile, only a few countries (e.g., Danish, Australian and Japanese), have set infrasound limits. These limits are usually not higher than 85–90 dBG and none of them are specific to wind turbines. Furthermore, there are currently no widely accepted international health-based limits for LFN derived specifically for wind turbines. Outdoor LFN limits have been introduced by some states or provinces in Australia and Canada and by Japan, but these also do not apply directly to wind turbines. A number of them assume that the difference (dBC−dBA) >20 dB indicates the presence of LFN, and they set the upper limits of the C-weighted equivalent-continuous sound pressure level (L_{Ceq}) at 65 and 60 dBC during the day and night, respectively. On the other hand, several European countries, including Denmark, Germany, Sweden, the Netherlands, Finland, Poland and the United Kingdom, as well as Australia, Canada and Japan, have exposure criteria in use or proposed for the assessment of LFN in dwellings. However, Denmark is one of the few countries with regulations specifying acceptable LFN levels in dwellings, specifically for wind turbine noise [6].

Over the years, a number of low frequency hearing threshold studies have been carried out to determine the lowest levels that are audible to an average person, often a young person, with normal hearing. Although hearing thresholds at 20 Hz and above have been standardised by International Organisation for Standardisation [7-9], those below 20 Hz have yet to be determined. The most recent HTs (below 20 Hz) have been proposed by Watanabe & Møller [10], Møller & Pedersen [11] and Kurakata & Mizunami [12] (Table 1 and Fig. 1). As can be seen from Figure 1, 10% of the young people would be able to perceive 10 Hz at about 90 dB. It also found that the difference between the median hearing thresholds of young adults around 20 years of age and older adults over 60 years of age was about 10 dB, irrespective of frequency. This shows that older people (up to about 60 years of age) retain good hearing in the low frequency range, in contrast to the often significantly reduced sensitivity at higher frequencies [13].

In terms of the assessment criteria for infrasound, the average hearing threshold corresponds to tones with a G-weighted SPL of approximately 96 dBG. In turn, infrasound at the $L_{p,G}$ levels below 85–90 dB is usually inaudible. It is therefore reasonable to assume that the individual hearing threshold should be 10–15 dB lower than the average threshold, so the recommended limits for environmental infrasound could be 85 or 80 dBG.

However, since the hearing threshold defines the human tolerance to infrasound, its evaluation seems to be based on the frequency analysis. It is worth noting that the G86 curve has been recognised as the threshold of auditory perception of infrasound reached by 90–95% of the population [14]. Therefore, the G86 and G80 curves can be used as a criterion curves for the infrasound from wind turbines.

In summary, two assessment methods and corresponding exposure limit values have been proposed for wind turbine infrasound, i.e. Method I - based on the G-weighted SPL measurements and Method II - based on frequency analysis in 1/3-octave bands in the frequency range 4-20 Hz. Separate limit values have been set for outdoor living areas in the open countryside (Area A) and for areas with noise-sensitive land (Area B). In the case of Method I, as recommended, IS limits of 86 dBG (for areas A) and 80 dBG (for areas B) were proposed, while in the case of Method II - the G86 and G80 criterion curves were chosen (for arears A and B, respectively).

Table 1. Hearing thresholds of infrasound determined in young otologically normal subjects aged 18-25 years [10,11].

Frequency [Hz]	Hearing threshold [dB]	
	Watanabe & Moller [10]	Moller & Pedersen [11]
1.6	–	124
2	–	122
2.5	–	119
3.15	–	117
4	107	114
5	–	110
6.3	–	106
8	100	102
10	97	98
12,5	92	92.7
16	88	97.7
20	79	83.5

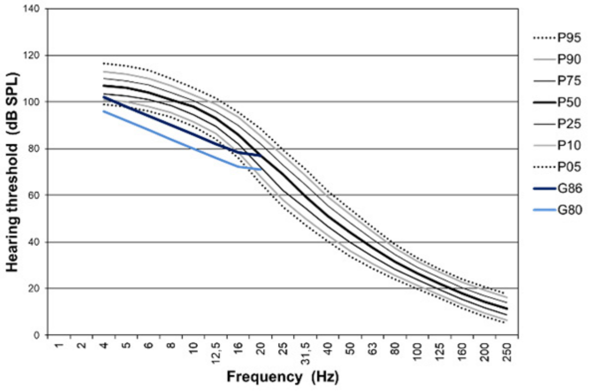

Figure 1: Distribution of hearing thresholds in the frequency range 4-250 Hz in young otologically normal people togetherwith the G86 and G80 curves [12].

Acknowledgment

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Preliminary study of wind turbine visual annoyance reduction with source masking in virtual reality

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Numerous studies have shown that wind turbines are recognized as acoustically annoying or highly annoying at significantly lower generated levels than other typical noise sources (e.g. road-traffic noise, industrial noise) located near dwellings. Simultaneously, a number of studies shows that annoyance related to wind turbine noise may have other, non-auditory, causes such as socio-economic factors or visual disturbance caused by wind turbines presence in the landscape. Numerous attempts are being made to reduce the noise of wind turbines and reduce the annoyance caused by the noise generated by them. The study aims to determine the conditions of visual masking of wind turbines and to examine how visual factors affect the overall evaluation of wind turbines. Experiments were conducted in a VR environment. The subjects were presented with visual samples of a wind turbine at different distances, which they viewed as if from inside a dwelling to minimize the acoustical influence of noise on annoyance assessment. Static and dynamic objects were used as maskers: buildings, a busy road, tree branches with and without leaves. Those were presented to cover (completely or partially) the view of the wind turbine or shadow flicker. Laboratory results are to be verified with real-life cases of visual masking of wind turbines. Based on these, it will be determined whether visual masking is a factor that can improve the overall annoyance rating of wind turbines.

Keywords: wind turbine noise, masking, audiovisual annoyance, virtual reality

Sound Spectra-temporal Structure Impact on the Perception of Speech and Music – Phd progress report

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Currently, the main emphasis in auditory perception research is on the multi-track and neural multi-domain processing of auditory information, and less work is done on specific, measurable physical parameters of sound responsible for specific effects of its interpretation - for example, what physical properties of sound determine whether singing or speech is recognized in a given auditory stimulus.

In the research included in this dissertation, an attempt was made to identify the physical parameters of sound relevant to the aforementioned aspects of auditory perception, their magnitudes and interrelationships. In light of recent research, the spectral-temporal shape of acoustic stimuli seems to be particularly important for auditory perception.

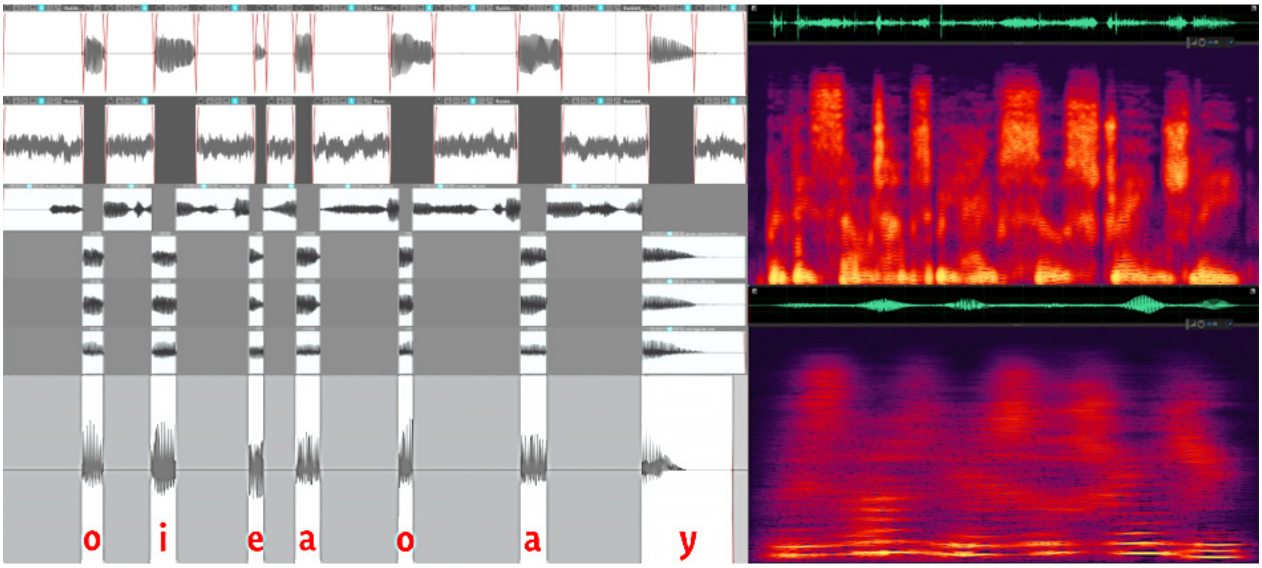

Figure 1: phrase “Sometimes behave so strangely” by D.Deutsch analyzed and transformed, checking persistence of melody in speech to song illusion. No the left various modification using synthesized phrases and pitch tuning. On the right, transformation using P.Albouy[1] filters – right up: . spectral blur demonstrated , that melody disappeared, but words remain clear; right down: temporal blur showed, that melody remains but words are not understable any more

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The Use of fNIRS Technology to Assist Candidate Selection and Post-Implant Programming of Infants with Cochlear Implants

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With the advent of newborn hearing screening, deafness can be identified very early, making it possible to provide hearing aids soon after birth with the goal of maximising the infant's potential for oral language development. However, when an infant needs a cochlear implant (CI), there are many blocking points that can prolong the time it takes to reach the point at which the infant has a CI that is accurately programmed [1]. Many of the decision points required to reach that goal rely on behavioural information that can be unreliable and require the infant to have reached a certain developmental level.

- Are we sure that the infant's hearing level estimate (from electrophysiology measures) is accurate? Many clinics wait till the infant can perform behavioural hearing assessment, which can take more than 9 months, particularly if there are additional development issues.
- Is a CI going to be a better option than a hearing aid? For adults, this question is usually addressed by testing speech understanding with the hearing aid. However, there is currently no objective test of speech understanding that can be used for this purpose, leading to delays in cochlear implantation to assess language development behaviourally.
- How do you program a CI for a young infant? There is currently no objective electrophysiology method that is accurate or reliable or clinically feasible. Again, delays to wait for development to be sufficient for behavioural testing can mean delaying implantation for over 9 months and more in cases of developmental delay. Even then, these infants with poor exposure to auditory information can be very difficult to test behaviourally until much older.
- How accurate or appropriate is the infant's CI program? Again, clinics must rely on behavioural information, which can be very difficult to obtain.

The first two bullet points represent particularly severe problems for infants with auditory neuropathy, in whom electrophysiology measures are unreliable, and hearing sensitivity is not correlated with speech understanding.

Functional near-infrared spectroscopy (fNIRS) is a developing technology that uses near-infrared light to image brain activity in surface layers of the cortex. It measures changes in oxy- and deoxy-haemooglobin (HbO and HbR) in response to stimuli. Its features make it suitable for objective assessment to complement or replace information obtained using electrophysiology. It is not affected by sleep (so suitable for very young infants), is not susceptible to electrical artifacts, and its interpretation is not affected by neural dis-synchrony (as is electrophysiology in auditory neuropathy). fNIRS does come with challenges of its own: the current standard statistical analyses rely on an assumption (common to many imaging methods) that the stimulus response has a predictable morphology and it does not vary between different stimulus epochs. We have shown that these assumptions do not hold in sleeping infants, and so alternative analysis methods are necessary.

Our laboratory has developed fNIRS test and analysis methods to assess detection of, and discrimination between, different speech sounds in individual sleeping infants. During this development process, we discovered that the fNIRS responses to stimuli are made up of two independent responses: an auditory response, and a brain arousal response [2] that are overlapping in time and have opposite signed effects. The arousal response is modulated both by habituation and by the salience of the stimulus, whereas the auditory response morphology (duration and peak latency) also depends on the salience of the stimulus. Our novel analysis technique can take these changes across infants, and epochs into account.

In brief, a modelling technique uses a stochastic process to capture the unique statistical properties of neural responses, illustrating neighborhood covariance relative to stimulus onset across a series of post-stimulus responses spanning the expected response lengths. The modelling technique derives a generalized neural response by capturing salient, contiguous overlapping data points in the response signals whilst suppressing non-overlapping, non-correlated regions. Statistical significance is established by comparing the derived neural stochastic process against arbitrary baseline signals. The detection phase of the experiment extracts baseline signals from the silence period, whereas the discrimination phase of the experiment extracts baseline signals from the non-silence baseline in which a repeated standard sound is presented. A stimulus-derived response significantly different from the baseline determines a significant detection or discrimination response. In the data set presented here, a detection or discrimination response was considered to be present if the statistical comparison of difference between baseline and stimulus-derived responses was significant with a = 0.01 and reached a consistency with additional trials. An automatic stopping algorithm was implemented that finishes the test session once responses are considered to be present or after 10 trials (or blocks) if the responses were not detected. For each infant a second analysis was undertaken whereby randomly-selected sets of baseline epochs were compared to each other using the same modelling process. This analysis estimates the probability that the infant data might produce a false positive result (i.e. detecting a response when there was no response). If the results of the response detection algorithm using the control baseline epochs exceeds a high confidence threshold (in this data set a = 0.01), we deemed the results of the response detection algorithm using the real stimulus epochs to be potentially inaccurate due to the baseline epochs being too variable.

The following tables indicate the sensitivity and specificity of the two tests (detection and discrimination) obtained for 30 normal-hearing infants with speech sounds presented at 65 dB SPL. Two of the infants were tested on two separate occasions several months apart, hence there are 32 possible tests). Separate analyses were performed in 4 different regions of interest (ROIs), which were left and right temporal regions and left and right prefrontal regions. A comparison of ROIs did not show significant differences in regions for identifying a significant response. In both detection and discrimination tests, the majority of infants showed significant responses in 3 or 4 of the 4 ROIs. In no individual test or ROI, did the assessment of potential false positive responses produce a probability greater than 0.01 (specificity estimate of close to 100%). The overall sensitivity estimates depend to some extent on how the 4 different ROI tests in the same infant are combined, which is a focus of current research. If we accept a single significant result, then the sensitivity estimate for detection (at 65 dB SPL) is 100%, and for discrimination between 100% and 92% depending on the contrast tested. If we require at last 2 ROIs to show a significant response, the sensitivity for the detection test is 97% and for the discrimination test is between 94% and 78% depending on the contrast tested.

Table 1. Number of individual tests showing significant detection responses in different multiples of ROIs.

	All 4 ROIs	3/4 ROIs	2/4 ROIs	1/4 ROIs	0/4 ROIs
# individuals	21/32	9/32	1/32	1/32	0/32

Table 2. Number of individual tests showing significant discrimination responses in different multiples of ROIs.

# individuals	All 4 ROIs	3/4 ROIs	2/4 ROIs	1/4 ROI	0/4 ROIs
Ba/Tea	8/16	5/16	2/16	1/16	0/16
Ba/Bee	15/26	5/26	3/26	1/26	2/26
Ba/Ga	9/18	3/18	2/18	3/18	1/18

Since there is no gold standard objective test for speech discrimination in infants, the development of the test and analysis methods needed to be undertaken in the normal hearing cohort, under the assumption that all those infants can both detect and discriminate between the speech sounds used. Thus, the sensitivity estimates are "worst case scenarios" for discrimination where we have no certain way of knowing whether an individual infant could discriminate the sounds. In my presentation, I will present a series of case studies of individual infants with hearing impairment to illustrate the clinical value of the fNIRS tests for answering key questions relevant to the infants' hearing management.

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Auditory and Speech Context Effects Under Cochlear Implantation: Implications for Signal Processing

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Much of our perception is relative, with current sensory input being interpreted based on previous experience, recent history, and other simultaneously occurring input from the same and different senses. Context effects in auditory and speech perception can have multiple sources, from the ear itself (via adaptation and efferent effects) to higher-level (cortical) networks. Cochlear implants (CIs) provide an important window into context effects and their origins, because the CI bypasses the ear and directly stimulates the auditory nerve, meaning that any context effects relying on peripheral or efferent effects should be absent in CI users. In addition, degraded spectral resolution provided by the CI means that any context effects relying on spectral resolution of the normally functioning ear should also be affected. If context effects are found to be absent or altered in CI users, then these findings could potentially be used to reintroduce such effects via signal processing in the CI itself. This talk will review a number of context effects that have been studied in our lab over the past decade in CI users. These effects range from the peripheral, psychoacoustic effects, such as auditory enhancement, through speech context effects, in which the identity of vowels can be influenced by the preceding context, to more linguistic effects, where listeners can take advantage of the semantic context of a sentence to predict ambiguous words within the sentence. The results paint a complex picture, where some effects are reduced or absent, others remain intact, and yet others are enhanced, relative to the effects observed in listeners with normal acoustic hearing. The insights provided by the results provide new directions to understand auditory and speech perception and improve processing for CI users.

Sound and Education. Transformational aspects of Listening

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The aim of my short introduction to the issue of the meaning of sound perception in education is to outline (1) a broader picture of education, sound(s), and listening. I claim that education is happening in an audio-sphere (audio-time/space) and this conditions the need for listening to different kinds of sounds and their movements, relationships, structures, and meanings. We need to study listening and recognize the different forms it takes in educative (experiential) situations.

I would also like to speak briefly about (2) ancient *mousike* (the highest form of practicing music, its essence partially preserved in Plato's idea of philosophy). It was the educative and cultural practice of the celebration of movement and sound, and their abilities to create deeper meanings in human experience. The history of humanity can be described as a history of disconnection between philosophy and music (both as scientific endeavors). However, this separation directs us to the primary disruption of the unity of song (sounds), dance (an ordered movement), and words (the expressive participation of occurring meanings) in human experience.

Nowadays the interest in sound perception is increasing, opening a new area of possibilities for reconnecting sounds and education. We can ask ourselves if contemporary research gives us a chance to welcome, once again, the unity of science and music as disciplines that not only co-exist but are also interwoven with one another. Perhaps, it gives us a chance to turn our attention to the experience of listening and discover its powerful, transformational aspects in the understanding of human's relationships with the world.

Non-invasive brain stimulation – characteristics and applications

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Non-invasive brain stimulation (NIBS) techniques, such as transcranial magnetic stimulation (TMS) and transcranial electrical stimulation (tES), are valuable tools in the fields of human systems and cognitive neuroscience. They play a crucial role by providing insights into the significance of specific brain structures or patterns of neuronal activity for brain functions.

Depending on the protocol, NIBS applied “online” allows (i) the *quantification* of local network characteristics by delivering stimuli that are sufficiently powerful to elicit direct neural output, (ii) *interference* with ongoing neuronal processing, or (iii) *modulation* of the level or timing of spontaneous or task-related neuronal activity. The so-called “offline” NIBS applications can lead to long-lasting effects of (i) *facilitation* or (ii) *inhibition* of a response of a certain brain region.

The broad functionality of NIBS techniques has the potential to be widely utilized in translational and clinical applications.

Auditory Stimulation to Modulate Slow Waves During Sleep and Its Effects on Cardiovascular Dynamics

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Non-rapid eye movement (NREM) sleep is considered an important period of recovery for the brain and body. Large amplitude, low-frequency slow waves, the hallmark electrophysiological oscillations of this period, are likely involved in promoting such beneficial effects. To explore their functional role in various brain and body processes, non-invasive brain stimulation has become of high interest. Over the last decade, especially auditory stimulation has emerged as a promising non-invasive approach to selectively enhance slow waves during deep NREM sleep.

We recently explored the parameter space of different auditory stimulation approaches and characterized their brain oscillatory and cardiovascular responses [1]"ISSN":"0161-8105","abstract":"Slow waves, the hallmark feature of deep nonrapid eye movement sleep, do potentially drive restorative effects of sleep on brain and body functions. Sleep modulation techniques to elucidate the functional role of slow waves thus have gained large interest. Auditory slow wave stimulation is a promising tool; however, directly comparing auditory stimulation approaches within a night and analyzing induced dynamic brain and cardiovascular effects are yet missing. Here, we tested various auditory stimulation approaches in a windowed, 10 s ON (stimulations. We demonstrated a robust enhancement of slow waves independent of the slow wave target phase of auditory stimulation and that sound volume can be used to modulate slow wave dynamics. Moreover, we showed cardiovascular activation during times of stimulation, indicating subcortico-cortical synchronization processes likely being involved. Thereby, auditory slow wave stimulation may contribute to cardiovascular stability during sleep.

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Binaural beats brain stimulation and its unpredictable effects

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Binaural beats brain stimulation is a popular strategy for supporting cognitive tasks, e.g., home or school learning. However, its effectiveness is questionable and may be related to a placebo-like effect. In two experiments, we tested over 1,000 individuals at their homes or in a lab simulating a school as they performed a two-part fluid intelligence test. Some took the second part listening to binaural beats (i.e., during-task/online stimulation), while others did so in silence or listening to other sounds. We divided the binaural beats group into three subgroups. The first one we informed that they would listen to sounds that improve the brain's work inducing the placebo effect, the second that neutral sounds, and the third that some sounds the nature of which was not defined. One extra group listened to binaural beats during a break (as if before lessons, i.e., offline stimulation), and the nature of sounds was also not expressed to these participants. In brief, we found that listening to binaural beats dramatically deteriorated the score if used during a task / online. Use during a break / offline had no effect, similar to silence or other sounds. Thus, our results show that binaural beats brain stimulation brings unpredictable effects. Exposing to these unpleasant sounds does not help cognitively or may weaken the effectiveness of mental activities instead of supporting them. As such, we recommend a restraint and more studies in binaural beats brain stimulation application to improve everyday cognitive activity.

Experiencing crisis as an adaptive phenomenon by hearing impaired children and their families

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Hearing loss as a multifaceted phenomenon has not only an individual dimension, but also a social one. When it concerns a child, it also affects the entire family system. Hearing disorders are treated as a special type of disability and I draw particular attention to the causes and consequences of such an approach. I present it as a crisis situation, but at the same time I point to its adaptability. It is not only the child diagnosed with hearing impairment that experiences the crisis, the whole family experiences it. Yet, at the same time, everyone confronts this situation and adapts to it.

The process of development is the same for all children, they undergo a series of changes - physical, mental, emotional and social – these are dynamic changes. It is no different in the case of hearing-impaired children. They experience the same stages of development, but the difference is that there is a hearing disorder in the background of their functioning. Their lives are often determined by ENT procedures, hearing rehabilitation, speech therapy and learning to communicate with the environment. These difficult situations are primarily faced by the child, but their parents and guardians also face similar challenges.

A family is a system that is "a complex, integrated entirety characterized by organized patterns of interaction that take a circular rather than linear form" [1]. Urie Bronfenbrenner points to family primary context, which supports the development processes of its members through mutual, direct and long-term interactions based on close emotional ties [1]. In a crisis situation faced by a hearing-impaired child and their family, this support becomes of particular importance and becomes the basis for adaptation.

A hearing-impaired child requires special attention from parents, whose activities should be focused on development and comprehensive support. This applies not only to the rehabilitation process but, most importantly, to their attitudes towards the child. The development of children is also determined by the environment in which they live. Children and the environment influence each other. During contact with the environment, the process of socialization of the individual takes place. This phenomenon is even more unique in the process of raising a hearing-impaired child as they grow up in a specific environment, as well as in a specific cultural circle that affects their development.

In this paper, I will refer to Bronfenbrenner's concept of the ecological environmental model, in which the author presents the development of a child in the environment and the interdependencies between them, creating a theory of ecological systems. According to this theory, development is a process of mutual and progressive accommodation of human and the social environment. The environment is created by various systems closer (microsystem) and further (mesosystem, exosystem and macrosystem) together with all the connections that exist between them and that may affect the development of the individual [2].

In this sense, I will analyze the crisis and its adaptive possibilities. Because the crisis of disability, which is connected to hearing impairment, can and should become an adaptive phenomenon. Perceiving the existential crisis in the context of constructively dealing with it is fundamental for understanding the possibility for growth and development through the crisis and positive adaptive changes. In the family system, and in the context of the ecological environmental model, one can look at hearing disorders as a subjective and adaptive phenomenon for the child and its caregivers.

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A child with autism spectrum disorders with hearing impairment – diagnostic difficulties, supporting the development of communication

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Autism spectrum disorder (ASD) is a neurodevelopment disorder with symptoms often observed early in a child's development in two areas: 1) abnormalities in social interaction and communication and 2) restricted and repetitive patterns of behavior and interest. According to a CDC report published in the Morbidity and Mortality Weekly Report (MMWR) Surveillance Summary in 2020, an estimated 1 in 34-44 (20.6 per 1,000) school-age children have been identified with an autism spectrum disorder. These data were consistent with data from 2018 [1]. The causes of the disorder are sought in abnormalities of development and brain functioning, which may be genetically determined, but environmental factors that act prenatally or in the early postnatal period are also taken into account [2, 3].

Difficulties with hearing are not included in the symptoms of ASD, but often the first difficulties that parents observe relate to the lack of reaction to speech, less often to sounds from the environment. Hearing is typical in most situations. However, it happens that children with ASD are diagnosed with simultaneous hearing loss. The diagnostic process of a child with ASD and concurrent hearing impairment is complicated, mainly due to the limitations resulting from ASD. The situation is also problematic if the child is initially diagnosed with a hearing impairment and, in the following months/years, the child is diagnosed with ASD simultaneously. Primary hearing loss often obscures the symptoms of ASD. It happens that the signs of hearing loss come to the fore, and other difficulties in development are explained by hearing impairment.

During the speech, the symptoms of a child with ASD will be presented, and a case study of a deaf child with ASD will be given.

In addition, the difficulties that arise in supporting the development of communication skills in a child with ASD with simultaneous hearing impairment will be indicated.

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The Influence of TTS on The Perception of Spectrum Changes by People with Presbyacusis

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The paper presents the results of a study on the perception of spectra changes by people with presbyacusis and compares them to the results obtained for otologically healthy subjects. For both groups the Temporary Threshold Shift (TTS) was induced by an hour-long exposure of loud music played at the equivalent level of 92.6 dB (max 101.6 dB). The experiment involved 20 people, divided into two groups of 10 each. The first group consisted of people between the ages of 50 and 60 who feature the typical symptoms of presbyacusis – they had an increase in hearing threshold of 35 to 45 dB for high frequencies. These people had experience in stage and studio work. The second group consisted of 20-25 years old, with normal good hearing. All participants were audiometrically tested, with pure-tone audiometry. The test stimuli used in the experiment contained the musical material with introduced changes in sound spectrum up to +/- 6dB in low (125 Hz), middle (1000 Hz) and high frequency (8000 Hz) octave bands. Samples were presented in pairs where the 1st one contained the original (non-equalized signal) and the 2nd – the processed signal. The subjects' task was to answer if these samples sounded the same, or not.

The sensitivity to spectral changes has been expressed as the percentage of the correct answer number obtained before and after the loud music exposure within 1 hour. It should be noted that the listeners did not exhibit the additional mental fatigue.

The results of the experiment indicate that the degree of detectability of signal spectrum changes from hearing impairment varies: for the group with presbyacusis, in the higher frequency range (8 kHz octave band) a decrease in detectability of small spectrum changes (± 1.5 dB) was noted, while for significant changes (±6 dB) these changes are more noticeable, which may be related to the narrowing of the auditory area resulting from presbyacusis [1]. Comparing the results of the experiment in review with the results of a study on the discrimination of sound color change under listeners' fatigue caused by a temporary increase in the hearing threshold (TTS) [2], it can be noted that the results of detection of spectral changes for frequencies with a value of ±6 dB obtained for a group of listeners with hearing loss are similar to those obtained for healthy listeners after 60 min of exposure to loud music. Thus, it can be said that in the high-frequency range, the impressions of listeners with hearing loss correspond to those of persons with normal hearing but fatigued by long-term exposure to noisy music. It should also be noted that a slight changes in timbre in the middle and low frequency ranges are similarly noticeable for both groups under the hearing fatigue following 60 minutes of listening, resulting in an increase in the hearing threshold of 5 - 7 dB, depending on frequency, which is consistent with literature reports [3,4].

The results of the experiments allow us to conclude that the listeners with age-related deafness have similar perceptual properties in the high-frequency range in terms of detecting changes in the sound spectrum as persons with normal hearing, in whom a temporary threshold shift by about 5-7 dB occurred. Although the permanent threshold shift for this frequency range in these subjects ranged from 30 to 45 dB, it should be noted that these listeners did not exhibit the mental fatigue to which healthy listeners were affected [2]. The explanation of presented results may be also supported by the semantic content of sound: listeners with presbyacusis rated the stimuli as less sharp, or with a high degree of uncertainty, while the first signal in pair was treated similarly than the sample in the second interval. This situation is similar to that of perception of the sharpness impression of speech signals [5]. Thus, it can be predicted that fatigue in the group of elderly listeners may cause an additional degradation in the detection of spectral changes of various signals.

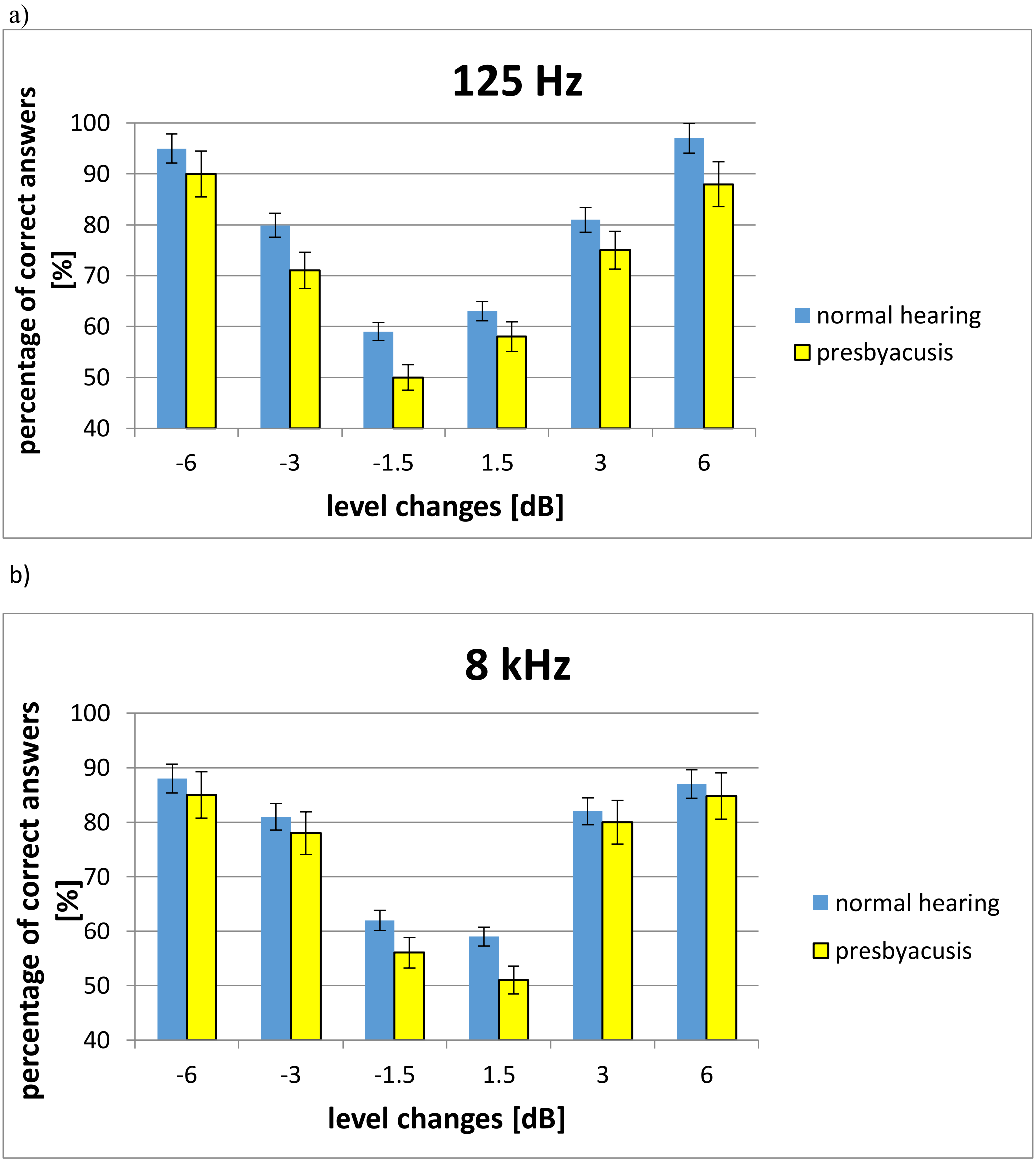

Figure 1: Percentages of correct spectral change detection responses for frequency of a) 125 Hz, and b) 8 kHz, for people with normal hearing and with presbyacusis, after 1-hour exposure to the loud music.

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Psychoacoustic Study of the Rock Art Sites of Cuevas de la Araña (Bicorp, Spain)

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Rock art sites are places of archaeological interest where human-made markings can be found on natural surfaces. Aggregation sites are a particular type of site where hunter-gatherers and agricultural and pastoral groups gathered periodically to conduct many types of transactions in a context where social and ritual activities were of key importance. One of their characteristics is that they are surrounded by other sites that can be denominated as "satellites", archaeologically characterized by a smaller size and less material. The Cuevas de la Araña rock art site, located in Bicorp (Spain), has been identified as one of such aggregation sites. In July 2021, an acoustic study was conducted on this site, its satellites (with a lesser amount and diversity of rock art), and some mountain shelters without rock art (Santos da Rosa et al., 2022). The acoustic analysis showed that Cuevas de la Araña had optimal acoustics to intensify the sensory effect and emotional impact of the ceremonies likely performed with musical accompaniment, due to its longer reverberation. The present study aims to investigate, via a listening test, the extent to which the acoustics of Cuevas de la Araña can interfere in modern-day listeners' perception of sound.

The listening test was conducted in the Aalto Acoustics Lab (Aalto University, Finland) in Autumn 2022. Ten individuals took part on it. Six impulse responses were studied in this test: three measured in sites with rock art (including Cuevas de la Araña and two satellites, from now on, *art+*) and three measured in nearby mountain shelters of similar geological characteristics, but without remains of rock art (from now on, *art-*), all of them captured in 3rd order Ambisonics format. The test consisted of a paired comparison of different versions of a series of five 20-seconds musical excerpts, including singing and drums. The test had 45 trials, and on each one, two versions of the same musical excerpt were presented: one convolved with an *art+* impulse response, and one convolved with an *art-* impulse response. Using an electronic tablet, participants reproduced the sounds in loop. They were asked to write, on a separate paper sheet, at least one and up to four differences that they perceived between the two sounds. Participants wrote a total of 1852 words and short expressions describing the sounds. These were classified using a natural language processing technique and k-means clustering methodology, obtaining ten clusters. The analysis was conducted using the R package *tm*, a framework for text mining applications (Fienerer & Horner, 2023).

Of the ten resulting clusters, the first seven contained words and expressions referring to, respectively, their perception of the size of the room, how "wide" the room was, the prominence of low frequencies, how "narrow" the room was, the directivity of sound, the distance from the sound source, and the reverberation. The clusters eight and nine were not taken into account because of the small number of words and expressions that contained (8 and 9, respectively). Cluster number ten contained a mixture of terms that did not fit in any other category. Since clusters two and four both referred to the width of the perceived space, these were considered as one single semantic category in further analyses. Also, although the cluster of terms referring to distance (cluster number six) only contained the word "far" and its variations, the words "close" and "closer" appeared 182 times in cluster number ten. In further analyses, these words were included in the same semantic category as the words from cluster number six. The words and expressions of each semantic category were classified into the opposite endpoints of a bipolar scale. Thus, words from the semantic category of *room size* were classified into those that expressed that the sound was perceived in a *bigger* or *larger* space and those that expressed that the sound was perceived in a *smaller* space. Table 1 summarizes the classification of words and expressions into semantic categories.

Table 1: Classification of words and expressions into semantic categories, based on the classification by the method of natural language processing and k-means clustering.

Semantic category	Clusters	Words and expressions	Classified into opposite endpoints
Room size	Cluster 1	“smaller”, “large room”, etc.	Containing synonyms of “small” vs. “big”
Width	Cluster 2, Cluster 4	“narrow”, “wider room”, etc.	Containing the string “narrow” vs. “wide”
Low frequencies	Cluster 3	“more lows”, “less low”, etc.	Containing the word “less” vs. “more”
Sound directivity	Cluster 5	“more direct”, “less direct”, etc.	Containing the word “less” vs. “more”
Distance	Cluster 6, words “close” and “closer” in Cluster 10	“farther away”, “closer”, etc.	Containing the string “close” vs. “far”
Reverb	Cluster 7	“more reverb”, “less reverb”, etc.	Containing the word “less” vs. “more”

A Chi-square test was performed on each contingency table containing the amount of words on the two opposite endpoints assigned to *art+* and *art-* sounds, of each semantic category. The results show that *art+* sounds were significantly more often perceived in a *bigger* and *wider* space, *further* and with more *reverb* than *art-* sounds, while *art-* sounds were significantly more often categorized as more *direct* than *art+* sounds (figure 1).

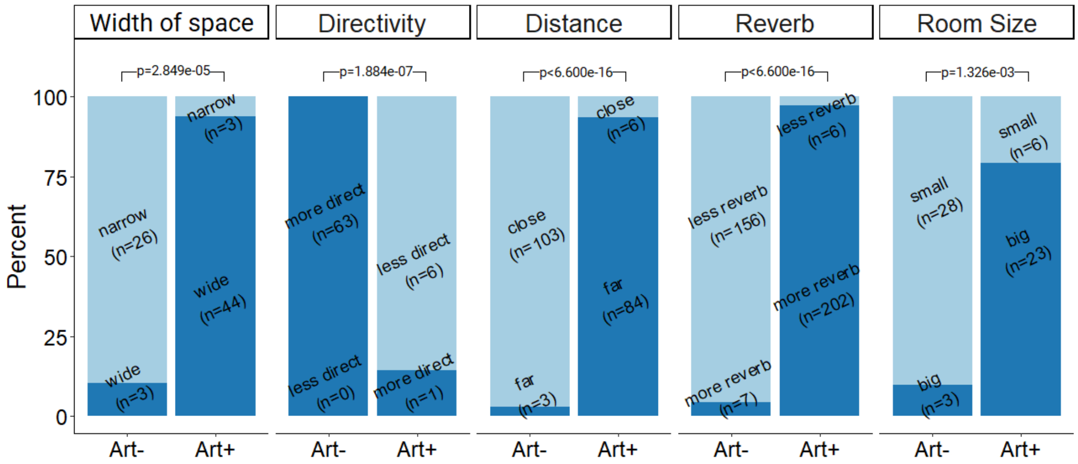

Figure 1: Proportion of *positive* and *negative* words of each semantic category attributed to *art+* and *art-* sounds.

The results from the analysis of the contingency tables determine that there are audible differences between *art+* and *art-* sounds. These differences in perception can be attributed to the differences in terms of reverberation revealed in the previously conducted analysis of the impulse responses. Longer reverberation can induce the perception of a space as larger and wider (Cabrera et al., 2005). In comparison to a dry space, a reverberant acoustic environment can also create the effect of the sound source being further from the receiver (Bronkhorst & Houtgast, 1999; Kolarik et al., 2015). In a reverberant space, by definition, sounds are perceived as less direct because the direct sound from the source is blended with the reflections from the surfaces. In the present study, a difference was found between the acoustic perception of those sites of the studied area of Cuevas de la Araña that are marked with paintings, and of those that are not marked. Furthermore, a corpus of vocabulary for the description of a particular type of outdoor acoustic space –mountain shelters- has been identified, and sets up a basis for further research about the psychoacoustics of rock art sites.

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Localisation of a Sound Source in Stereophonic Recordings And Binaural Presentations. Comparison of 11 Stereophonic Microphone Techniques

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The popularity of portable devices for listening to music has resulted in a significant proportion of recordings being listened to in stereo headphones. Computer gamers also use headphones more often than traditional speaker systems. The global earphones and headphones market size was valued at USD 58,25 million in 2022 and is expected to grow at a compound annual growth rate of 12,6% from 2023 to 2030 [1]. The correct placement of sound sources in the stereo space is important for high quality recordings. It is widely believed that for stereo loudspeakers, the best sound source localisation is achieved using coincidence microphone techniques [2,3].

In this experiment, we tested which stereo recording techniques allow for correct sound source localisation in a recording played through stereo headphones. The most common stereo microphone techniques considered were: AB, ORFT, XY, M-S and the so-called ‘artificial head’ (Neumann KU100). Six variants of NOS/DIN type systems were also tested: two different microphone capsule characteristics, each with three different capsule distances. As a reference, this part of the test also analysed the direct ability to locate the sound source using a loudspeaker system. The same signals and presentation angles were used in this test.

The results show significant differences in the ability to localise the sound source depending on the recording configuration used.

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How physiologically arousing are baby crying and dog barking sounds? A comparative study

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Exposure to environmental sounds may lead to emotional and physiological changes. Notably, noises perceived as annoying may elevate stress responses. Recent reports, seem to point to a more detrimental effect caused by exposure to particular sounds, namely the sounds of babies crying [1,2,3]. Exposure to these sounds might be more distracting than exposure to other sounds. It has been argued that humans might be particularly attuned to such signals, which might lead to either greater arousal levels.

In the study we report, we compared the physiological responses to the sound of a baby crying and to two sounds of dogs barking and to white noise of equivalent level. The physiological measures taken were heart rate and galvanic skin response. Twenty participants were tested on a reaction times task, a spatial working memory task, and in a mathematical processing task. It was found that the effects of exposure to dog barking noises did not differ statistically from exposure to baby crying noises. Both types of sounds led significantly different results from white noise.

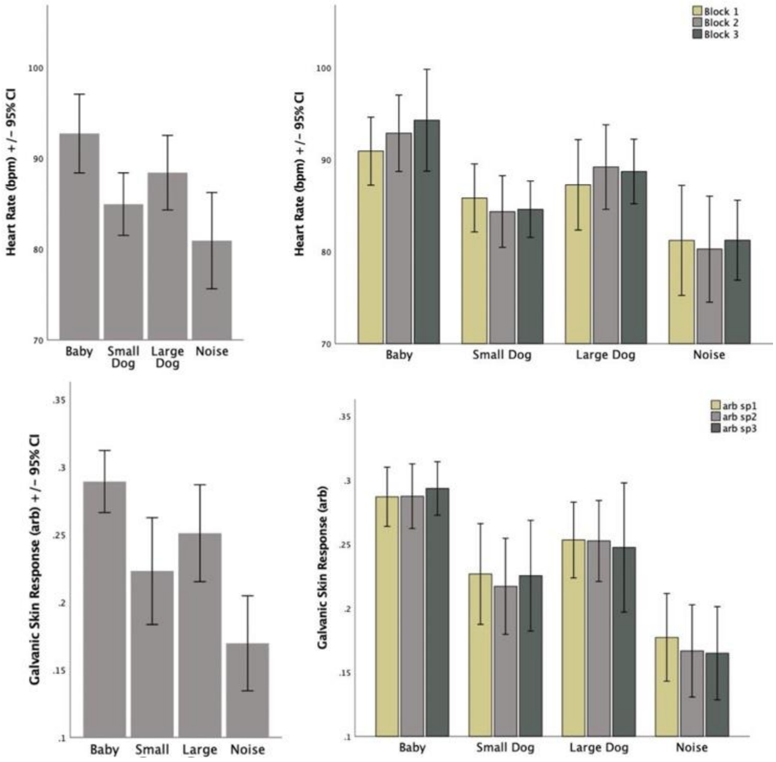

Figure 1: Heart Rates (top) and Galvanic Skin Responses (bottom) in Task 1.

Figure 1 shows the heart rates and galvanic skin responses obtained during a simple reaction times task.While the sound of the baby crying yielded the highest physiological activation levels, it did not differ significantly from the reactions to the large dog barking. The control noise of equivalent level led to significantly lower activation levels than the remaining sounds.

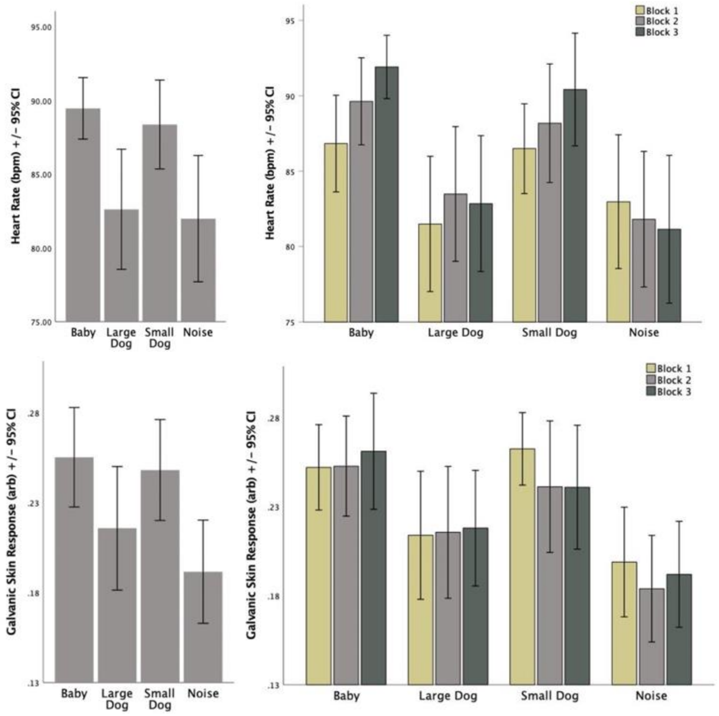

Figure 2: Heart Rates and Galvanic Skin Responses in Task 2.

Figure 2 shows the physiological responses during a memory task. Baby crying and small dog led to the highest activation levels, whereas noise led to the lowest activation levels.

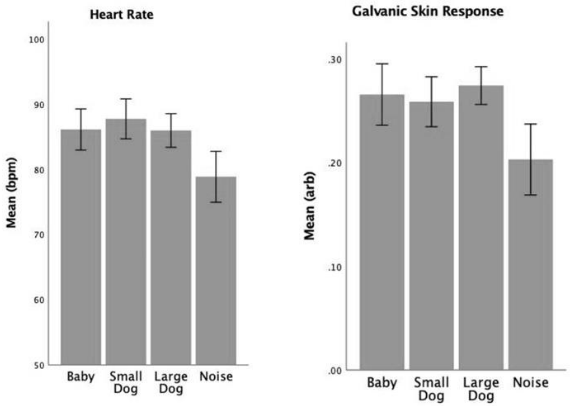

Figure 3: Heart Rates and Galvanic Skin Responses in Task 3.

Figure 3 shows physiological responses while performing a mathematical task. Both the crying sound and the barking sounds led to significantly higher activation levels that the control noise sound.

It is concluded that, while different tasks lead to different effect magnitudes, in general the baby crying noise always leads to significantly greated physiological activation and the dog barking sounds always have the potential to lead to similar responses.

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The effect of exposure to baby crying and dog barking sounds on reaction times, working memory and mathematical processing

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It has long been established that exposure to environmental sounds may cause changes to cognitive performance. Recent reports, however, seem to point to a more detrimental effect caused by exposure to particular sounds, namely the sounds of babies crying [1,2,3]. It has been argued that humans might be particularly attuned to such signals, which might lead to either greater arousal levels or greater attentional capture and load.

In the study we report, we were interested in evaluating the impact of exposure to the sound of a baby crying against comparable sounds of dogs barking and to white noise of equivalent level on the ability to perform specific cognitive tasks. Twenty participants were tested on a simple reaction times task, a spatial working memory task, and in a mathematical processing task.

In the Reaction Times task, it was observed that reaction times were significantly lowered when participants were exposed to baby crying and dog barking sounds, as opposed to equivalent level white noise (Figure 1). This effect did not change throughout time.

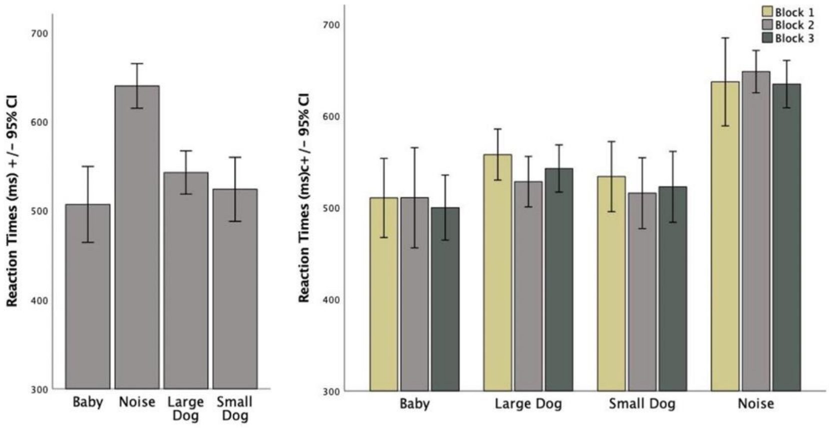

Figure 1: Reaction Times.

In the Spatial Memory Task, it was observed that the memory span was lower in the noise condition, however these differences did not reach statistical difference. Throughout time, memory span improved in most conditions (Figure 2).

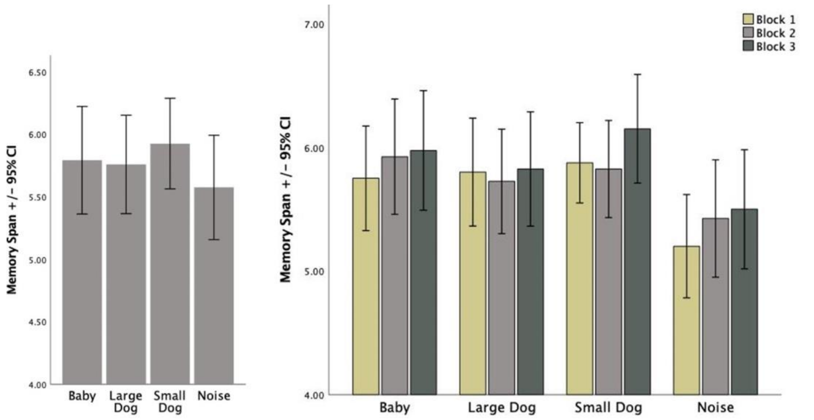

Figure 2: Memory spans.

In the mathematical task, there were significantly more correct responses in the noise condition, as compared to the baby and small dog conditions. (Figure 3) Responses were significantly quicker in the noise condition, as opposed to both dog conditions and the baby condition (Figure 3).

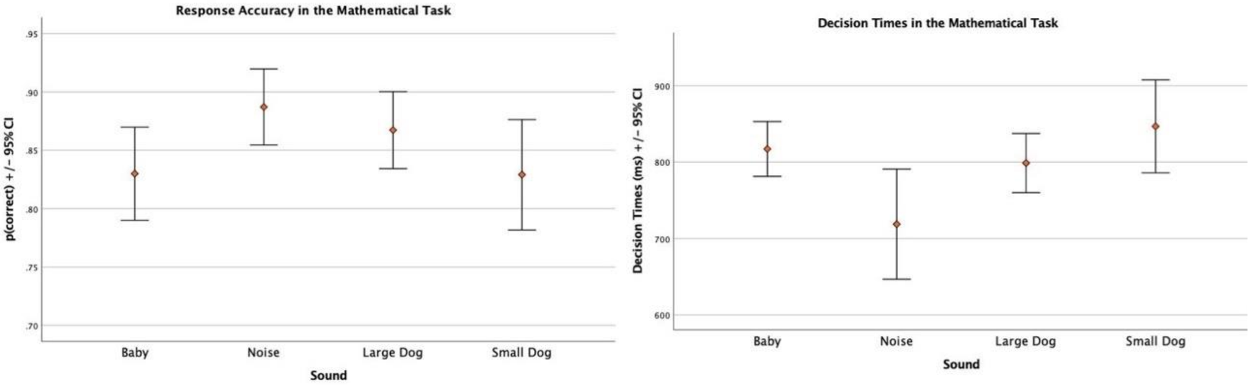

Figure 3: Proportion of correct responses and response time in the Mathematical Task.

We conclude that there is some support to assume that some biological distress sounds can interfere differently than other sounds with some basic cognitive processes.

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Comparison of the effectiveness of Polish speech masking with PSTS, ISTS signals and babble noise

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The aim of the research was to check the effectiveness of Polish speech masking with speech-like signals PSTS (Polish Speech Test Signal), ISTS (International Speech Test Signal) and babble noise. The first two maskers were informational maskers and the babble noise was an energetical masker. The ISTS signal reflects a female speaker for six different mother tongues (American English, Arabic, Chinese, French, German, and Spanish) reading “The north wind and the sun”. The PSTS signal was constructed in the same manner as ISTS but the language material was taken from Polish textbooks and contemporary literature. It was assumed that PSTS and babble noise would mask Polish speech better than ISTS, because they contain Polish language phonemes (which are not present in ISTS). The experiment consisted of presenting the listeners with one-syllable words from the Polish Word Test in the presence of ISTS, PSTS and babble noise. Signal to noise ratios at which the listener correctly repeated 50% of the verbal material were determined. On the basis of this information, the effectiveness of masking of Polish speech by PSTS, ISTS and babble noise was compared. Since the research hypothesis has not been confirmed, possible causes and further directions of research will be presented.

Harmonicity Influences the Prediction Error Responses to Unexpected Sounds

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The auditory system evolved to infer information about the environment from acoustical waves. Audition is a fundamental sense for humans, as it enables verbal communication and helps with orientation in the world. Although data provided by the hearing apparatus is relatively sparse, the brain is able to infer surprising amounts of information from this data [1]. Many recent studies suggest that this inference is possible because the brain forms top-down predictions about the incoming auditory stimuli and their causes. These predictions are formed using an internal, generative model that is constantly updated by statistical regularities in the incoming sensory data. A 'surprise' response (or prediction error) is generated when predictions do not fit the sensory data and is used to update the contents of the internal model [2-3]. These 'surprise' responses in the auditory system are seen as primary sources of mismatch negativity (MMN) recorded with electroencephalography (EEG) [4]. Crucially, these responses (as well as generative model updating in general) are thought to be moderated by the reliability (or precision) of the incoming stimuli, lending the most weight to stimuli that are most reliable [2].

Many sounds in the environment are harmonic complex tones comprised of a fundamental frequency (f_0) and a set of frequencies that are integer multiples (harmonics) of that fundamental (Figure 1a and 1b). Conversely, inharmonic sounds have various deviations from the harmonic series (Figure 1c and 1d). Previous studies have shown that highly harmonic signals tend to produce a more salient pitch sensation, pitch comparisons are easier for harmonic sounds and violations of harmonicity impair the intelligibility of speech [5-6].

In this study we aimed to test the hypothesis that violations of predictions for harmonic sounds would elicit a stronger electrophysiological response (as measured with MMN) than inharmonic sounds, due to higher precision-weighting of prediction errors in harmonic sounds. We conducted an experiment in which subjects (N = 36) listened to a series of artificially generated complex tones. These were either harmonic, inharmonic (with random jittering of harmonic frequencies), or inharmonic-changing (with jittering patterns changing for each consecutive sound). The tones were presented in a roving oddball paradigm (on average 20% chance of deviant) with varying fundamental frequencies (500 Hz - 800 Hz in 50 Hz intervals).

We used a linear mixed models analysis to null models with ones that use harmonicity to predict MMN amplitude and latency. Our preliminary results revealed a significant difference in mean MMN peak amplitude ($\text{Chi}^2(2) = 20.856$; $p < 0.001$) but not MMN peak latency ($\text{Chi}^2(2) = 2.850$; $p > 0.05$). Consistent with our hypothesis, MMN was stronger in the harmonic condition in comparison to the inharmonic-changing condition ($p < 0.001$). Surprisingly, no significant differences were found between the harmonic and inharmonic conditions ($p > 0.05$) (Figure 2). These results contribute to the ongoing discussion of precision-weighting of prediction errors in context of predictive coding. They also highlight the importance of harmonicity in early brain processing of sound.

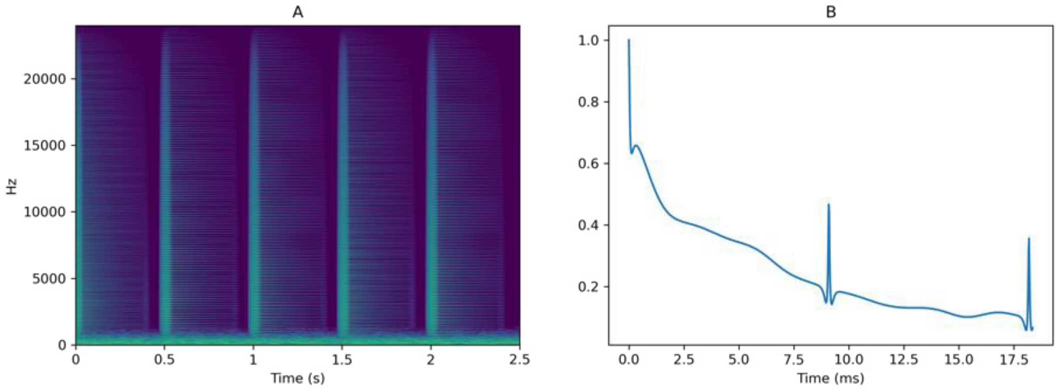

Figure 1a and 1b: An illustration of inharmonicity. Panel A shows a spectrogram of five harmonic sounds. Note the perfectly aligned harmonic overtones at integer multiples of fundamental frequencies. Panel B shows a autocorrelation plot for the first harmonic sound, with notable peaks at around 9 and 18 ms.

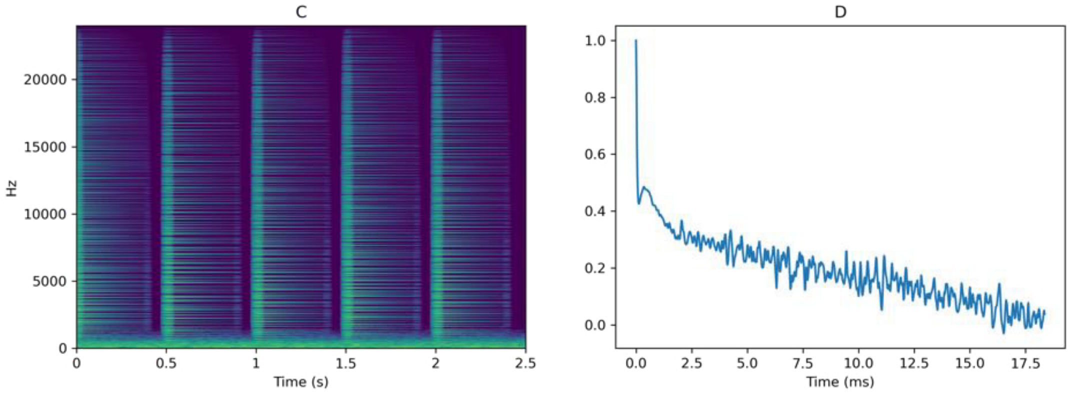

Figure 1c and 1d: An illustration of inharmonicity. Panel C shows a spectrogram for inharmonic sounds (of the same F0 as in panel A). Jitters in different places of the frequency spectrum can be clearly seen. Panel D shows an autocorrelation for an inharmonic sound, with no clear periodicity.

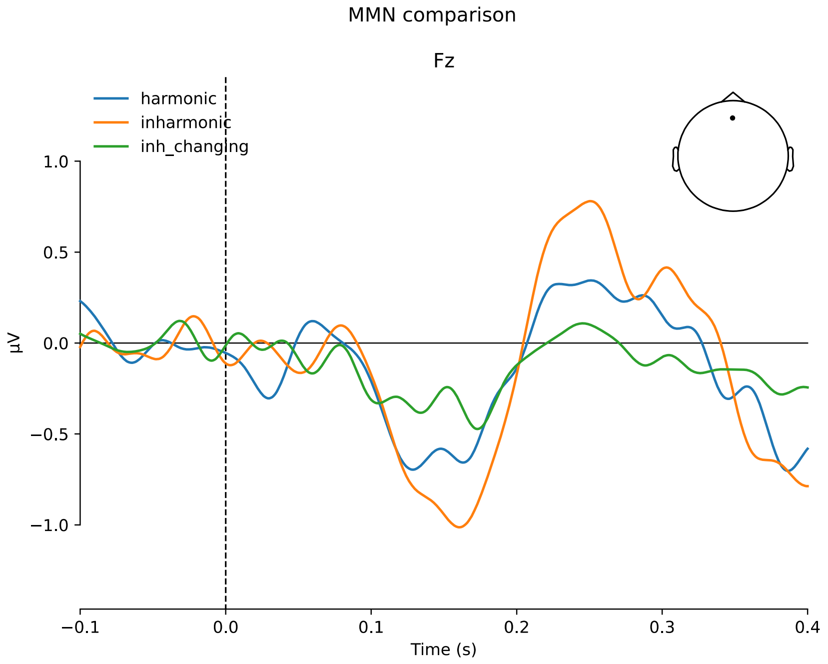

Figure 2: Difference waves resulting from subtracting the standard from the deviant responses in three experimental conditions. Time axis represents the time form stimulus onset. MMN peaks were evaluated in the time window 70-250 ms from stimulus onset. Evoked responses from 36 individuals, electrode *Fz.*

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Subjective Localisation of a Sound Source in Immersive Sound System and Stereophonic Loudspeakers System

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Immersive sound systems (ISS) are increasingly being installed in multi-purpose concert halls. As the manufacturers of the systems advertise, ISS allow for the exact location and separation of sound sources and performer movement. It is well known that, on the contrary, using a traditional stereo system, only the central part of the audience placed at the ‘best point’ benefits from stereo sound. This study compared the ability to locate the sound source using stereo and immersive systems installed in the same space. Two immersive systems from different manufacturers were analysed. Fifty listeners took part in the study and were asked to locate the source. The results show significant differences in the assessment of sound source localisation depending on the system used.

Minimum Audible Angle in 3rd Order Ambisonics in Horizontal Plane for Energy-Preserving Ambisonic Decoder (EPAD)

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Ambisonic technology, like other immersive audio systems, is gaining recognition and finding a wider range of applications. In addition to providing an accurate mathematical representation of the sound field, decoding algorithms take into account psychoacoustic phenomena to create more realistic listening experiences. This study focuses on examining the localization in the horizontal plane in 3rd Order Ambisonics by determining the Minimum Audible Angle (MAA) values.

Experiments were executed in AGH UST Laboratory of Auralisation. Sound signal (here Gaussian noise burst) was rendered with the Energy-Preserving Ambisonic Decoder (EPAD), which is the most accurate for the frequency range above 200 Hz.

A listening test was conducted employing a modified adaptive method (2 up 1 down, 7 reversals procedure). The obtained results are compared with the distribution of with reference values from literature based on experiments using physical sound sources (Mills, 1958). Additionally, subjective outcomes are analysed in the context of calculated (Politis, 2016) sound distribution (Fig. 1).

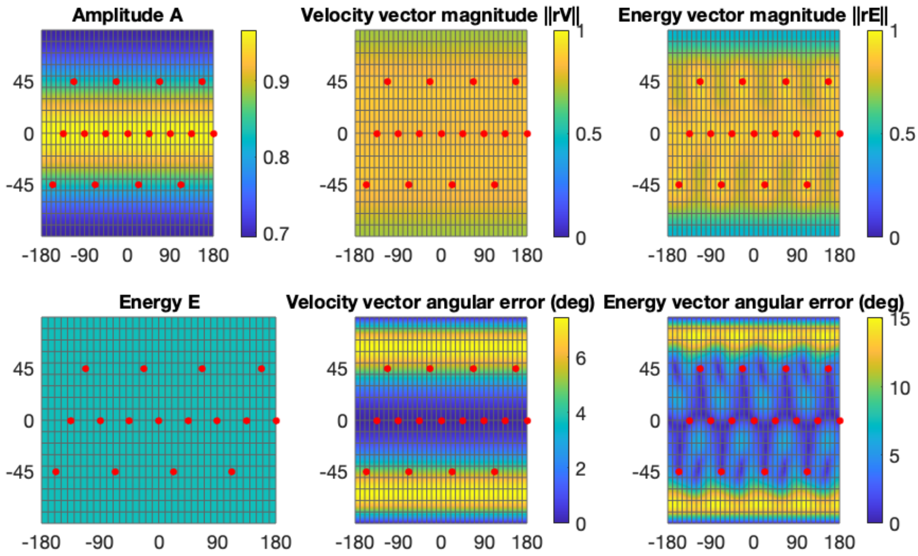

Figure 1: Amplitude, velocity and energy distribution calculated for EPAD.

The analysis of the results reveals differences in localization among listeners. Values of the MAA achieved in experiment are coherent with the result reported by Boerger (Boerger, 1965) with MMA value 1.24°(for 0°). Although the average MAA value for angles other than 0° are still higher, up to over 20° (for 90°). These differences for might be caused by order of ambisonics, speakers' layout along with decoding method and their mutual dependencies. At the same time it is important to notice that the calculated sound distribution does not indicate the source of this phenomenon.

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POSTER
SESSION

Speech in noise recognition in musicians and non-musicians

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Speech-in-noise (SiN) perception is the ability to identify spoken words when background noise is present - it is important for successful communication. Speech shares traits with music such as rhythm, melody, hierarchy [1]. Multiple studies show different results to how musicians perform compared to non-musicians in recognizing speech in noise [2]. In this study, musicians' and non-musicians' performances are compared in recognizing Polish speech in noise using *Polish sentence tests for measuring the intelligibility of speech in interfering noise* [3]. The study included 24 Polish native speakers with an age range of 22 to 31 years (M = 24.71, SD = 2.629). Twelve of the participants were musicians (had 8+ years of musical experience) and 12 were nonmusicians. The musicians group had between 8 and 18 years of musical experience (M = 14.25, SD = 2.96).

A linear mixed model was used to analyze the data, with test results (SRT – speech reception threshold at 2, 3 and 4 turnpoints) as the outcome variable, group (musician/nonmusician) as the fixed effect, and the participant as random effect.

The results showed no significant effect between the group variable and SRT_2/3/4 (speech reception threshold at 2, 3 and 4 turnpoints). There was an increase in SRT_2 result for those in nonmusician group, compared to musician group (Est. = 0.47, SE = 0.31, p = 0.143), an increase in SRT_3 result for those in nonmusician group, compared to musician group (Est. = 0.53, SE = 0.31, p = 0.106) and an increase in SRT_4 result for those in nonmusician group, compared to musician group (Est. = 0.48, SE = 0.27, p = 0.087). These results suggest that there are no significant differences between musicians and nonmusicians in recognizing speech-in-noise. This could be due to the small sample size or the variable choice. As shown in Figure 1, the musicians group has less variability that nonmusicians group, which suggests that the possible differences could be explained by a different variable than speech reception threshold.

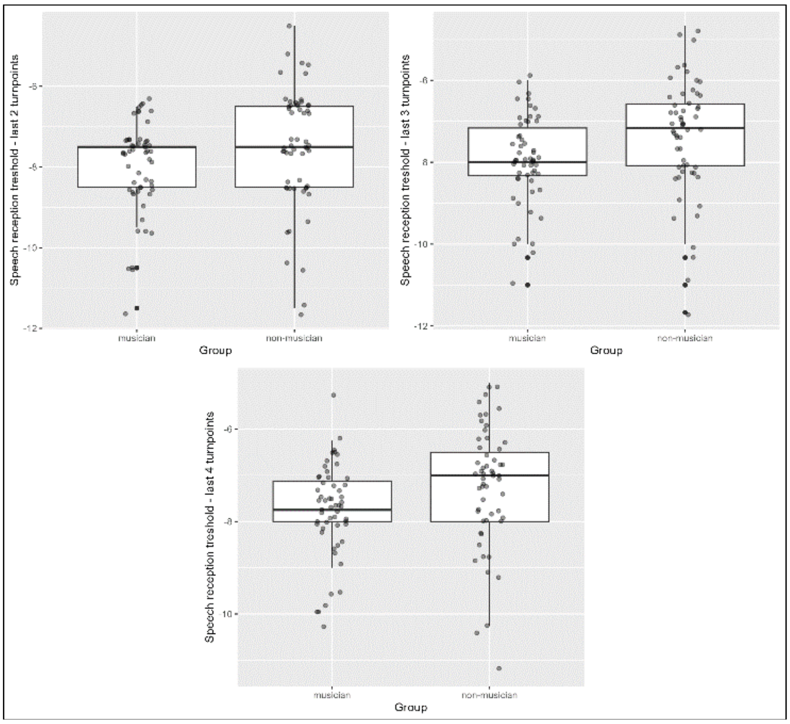

Figure 1. Comparison of speech recognition threshold results (SRT_2, SRT_3, SRT_4) with two groups – musician and nonmusician.

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Pitch Perception in Context of Tonality and Harmonicity

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Pitch perception is a complex and nonlinear phenomenon influenced by many factors. Vital part of pitch recognition is the harmonic series [1], [2]. Its structure can be changed and it may affect the property of the sound which is harmonicity. Changing distances between the individual component tones creates inharmonic sounds [3]. In the theory of Predictive Coding their entropy is high, so that it could be difficult to perceive their pitch [4]. The sounds analyzed by the nervous system usually occur in a musical context. The Western European music is based on a tonal system and certain pitches exist in hierarchical relationships with each other. Each of them have a specific musical function, which gives the music meaning. Eventually two main factors may have an influence on perception of pitch: tonal context in which it is located and their physical structure [5]. Taking these two factors into account, I investigated the extent to which tonal context and harmonicity affect pitch hearing. I designed an experiment in which I asked people to compare the similarity of pairs of harmonic and non-harmonic sounds in 3 keys. Each pair began with the 1st, 1st# or 3rd degree of the scale and consisted of a perfect quarter, perfect fifth or an octave. The time of answering was measured. I tested 26 non-musicians. I asked them to estimate similarity of two pitches from 0 (the least similar) to 100 (the most similar). Before each pair there was a cadency as tonal context. On the evaluation of similarity few main factors have an influence: intervals, their position on the scale, harmonicity and tonal context. Results shows, that people perceive pitches of perfect quarter as more similar, than pitches of perfect fifth (Figure 1). The least similar were octave equivalents (Figure 1). Also pairs starting from first degree of scale from tonal context were judged as more simiar (Figure 2). Inharmonic pairs in minor key context were judged as more similar, than harmonic pairs (Figure 3).The evaluation time of harmonic and non-harmonic pairs does not differ enough to conclude that the perception of pitch of non-harmonic sounds is more difficult for the nervous system than for harmonic sounds. Results somehow overlap with those from C. L. Kromhansl's *Probe tone ratings.*

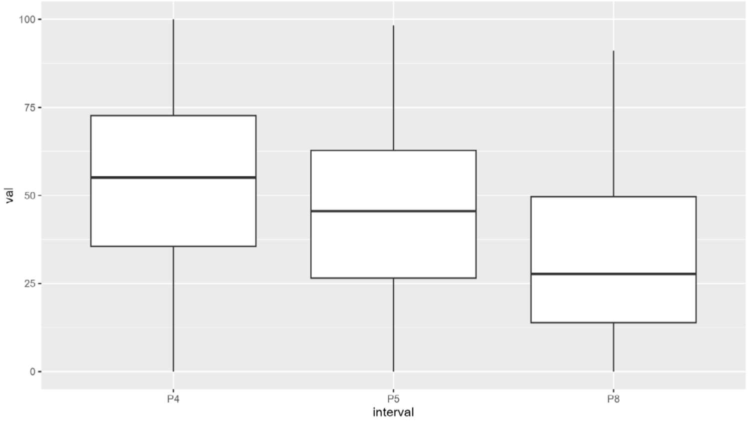

Figure 1: Ratings of pitches in different intervals (P4 – perfect quarter, P5 – perfect fifth, P8 – perfect octave).

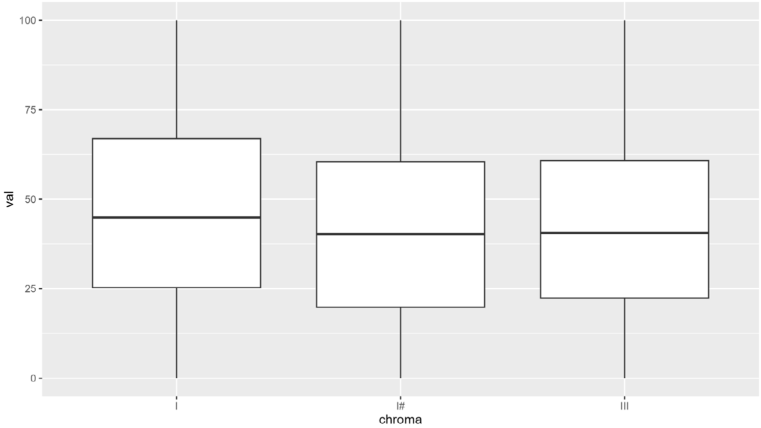

Figure 2: Ratings for scale degree (I – first, III – third, I# - first altered).

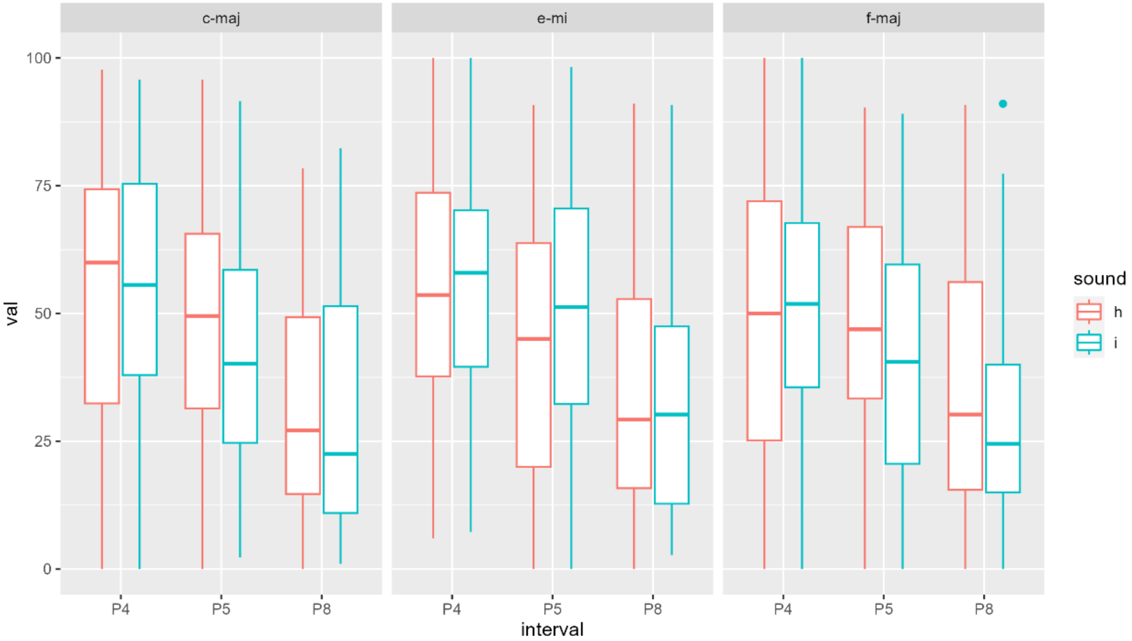

Figure 3: Interaction effect of interval, sound (harmonic, inharmonic) and key (C – major, F – major, e – minor).

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