A preliminary investigation into the determination of the inaudibility level of mechanical plant and music noise in the presence of ambient background noise

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ABSTRACT

Currently there are regulations and guidelines that governing bodies have adopted when dealing with the emission of noise that make reference to or imply the term of inaudibility when setting criteria to be met for mechanical plant and music noise after restricted hours. However, to date no such criteria has been established that can predict the inaudibility of these sources when combined with ambient backgrounds. As a result, stakeholders are met with uncertainty and designers are left with an inadequate subjective term when attempting to meet location-specific noise criteria. This paper involves an investigation into the possibilities of conducting a psychoacoustic experiment that will test for the inaudibility of mechanical plant and music noise in the presence of ambient background noise typical of the home environment situated in urban and suburban locations. This paper attempts to provide the framework for future larger scale investigations and provides the relevant findings and a methodology to assist in reducing the subjective nature of the responses observed. Through these future investigations, objective definable criteria from which to establish the inaudibility of mechanical plant and music noise in the presence of ambient background noise may be established.

INTRODUCTION

Community noise

There are numerous sources of noise when living in suburban and inner city locations. These sources can include animal noise (such as barking dogs), construction noise, motor vehicle noise, aircraft noise, licensed and commercial premises noise and mechanical plant to name a few. This paper will be focusing on the production of noise emanating from both licensed premises and mechanical plant noise; specifically it will be addressing live music and air conditioner noise.

As a response to community noise issues, government authorities such as the Western Australia Department of Environment and Conservation (DEC) conduct surveys with local governments to gauge the impact of noise within the community. The following figure displays data collected by the Western Australia DEC over a number of years regarding activities that regularly attract noise complaints to local governments in Western Australia (Government of Western Australia DEC, 2010).

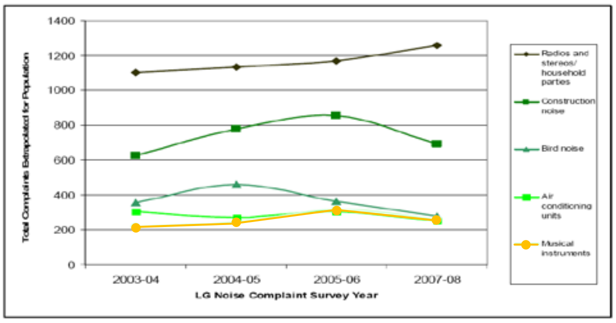

Figure 1. Western Australia Local Government noise survey

Musical instruments and air conditioning units both rank on this list of regular complaints made to local council.

Regulations and guidelines have been developed to combat the problem of community noise. The term inaudibility is implied in many of these documents when setting requirements for noise emitted from mechanical plant and entertainment venues which are located close to noise sensitive receivers. However, this term has not been clearly defined to date. As a result, stakeholders are met with uncertainty and designers are left with an inadequate subjective term when attempting to meet location-specific noise criteria.

THE INADEQUACY OF INAUDIBILITY

The following are a number of current Australian regulations and guidelines that have adopted the terms of "inaudible", "not audible" and the like with regards to mechanical plant and music noise.

NSW Office of Liquor, Gaming and Racing Standard Noise Conditions

The NSW Office of Liquor, Gaming and Racing (OLGR) is governing body in NSW that is accountable for the development, implementation and integrity of the overall regulatory framework across alcohol, licensed clubs, charitable fundraising and gambling activities in NSW (NSW Office of Liquor, Gaming and Racing, n.d.).

When dealing with noise emission from licensed venues, the OLGR adopt the following standard noise conditions as previously applied by the NSW Liquor Administration Board (LAB):

> The L_{A10} noise level emitted from the licensed premises shall not exceed the background noise level in any Octave Band Centre Frequency (31.5 Hz – 8k Hz inclusive) by more than 5 dB between

> 07:00 am and 12:00 midnight at the boundary of any affected residence.
> The L_{A10} noise level emitted from the licensed premises shall not exceed the background noise level in any Octave Band Centre Frequency (31.5 Hz – 8k Hz inclusive) between 12:00 midnight and 07:00 am at the boundary of any affected residence.
> Notwithstanding compliance with the above, the noise from the licensed premises shall not be audible within any habitable room in any residential premises between the hours of 12:00 midnight and 07:00 am.

Protection of the Environment Operations (POEO) (Noise Control) Regulation 2008

The POEO Noise control regulation 2008 commenced on 1 March 2008 and is a regulation under the NSW Protection of the Environment Operations Act 1997. The NSW Office of Environment and Heritage (OEH) is the regulatory authority responsible for regulating noise from activities scheduled under the Act.

This regulation controls noise from motor vehicles and marine vessels and sets community standards on acceptable noise intrusion in homes from such appliances as intruder alarms, music amplifiers, air conditioners and powered garden tools (NSW Office of Environment and Heritage, 2011).

Part 4 of the POEO Noise Regulation 2008 states the following regarding musical instruments and sound equipment:

> (1) A person must not cause or permit any musical instrument or electrically amplified sound equipment to be used on residential premises in such a manner that it emits noise that can be heard within a habitable room in any other residential premises (regardless of whether any door or window to that room is open):
> (a) before 8 am and after midnight on any Friday, Saturday or day immediately before a public holiday, or
> (b) before 8 am and after 10 pm on any other day.

A similar regulation exists for air conditioners and other noise producing equipment.

Interim Technical Guideline for the Assessment and Control of Low Frequency Noise from the Development of Musical Entertainment Venues

This document has been produced by the Newcastle City Council (NCC) in response to concerns with the existing criteria set forth in the OLGR standard noise conditions. The document states that even when the pre-midnight LAB noise conditions are met, intrusive and annoying levels of low frequency noise may still impact affected residencies.

The NCC has adopted the tenth percentile hearing threshold values developed by Kurakata et al (Kurakata, K. 2005) as the appropriate assessment criteria for audibility prediction (NCC 2006). Table 1 is an extract from this document and displays NCC assessment criteria.

Ultimately, the NCC still adopt the OLGR standard noise conditions when assessing noise from entertainment venues. While this guideline is helpful in reducing the potential impacts from proposed developments of new, and redevelopments of existing entertainment venues, it says nothing as to what criteria need be met when determining the inaudibility level of noise produced from entertainment venues when assessed with existing ambient background conditions.

Table 1. NCC Assessment Criteria

1/3 Octave Centre Frequency (Hz)	NCC Assessment Criteria for audibility predictions Lmax, fast or Adjusted Leq30sec (dB)
31.5	50
40	42.8
50	36.2
63	30.6
80	25.6
100	21.3
125	17.2
160	13.1
200	9.5
250	6.5

Summary

The aforementioned regulations and guidelines make reference to 'inaudibility' or some variation of this term, yet they do not provide a clear definition in which to quantify it.

While guidelines have been developed for community noise reaction surveys (Fields, J. 2000), and studies have been conducted into the annoyance of particular noises in the presence of ambient backgrounds (Fidell, 1979), no such guidelines exist for the implementation of a study into the inaudibility of noise sources when heard with ambient backgrounds.

This paper is a preliminary step towards achieving criteria in which to establish inaudibility, which could potentially help the governing bodies to develop stronger guidelines with less ambiguity so that these criteria may be designed.

METHOD

Determining locations for ambient backgrounds and noise sources

Due consideration was taken in determining what types of ambient backgrounds should be used to accurately reflect the types of environments that the public are exposed to when living in typical urban and suburban locations. It was decided that three distinct ambient backgrounds should be used and they are as follows:

- Ambient Background Location 1 (ABL1) - Suburban location with distant traffic noise from a busy main road as the dominate source of noise
- Ambient Background Location 2 (ABL2) – Suburban location in which there is minimal ambient background noise, typical of night time conditions
- Ambient Background Location 3 (ABL3) – Urban location in which the local traffic of a busy main road dominates the ambient background level.

When selecting these three ambient backgrounds it was assumed that they would each have a distinct sound that people living in and around cities should find easily identifiable.

A number of potential noise sources to be used for the experiment were selected in initial discussions with the focus on mechanical plant and music. For the conveinence of recording, live rock style music was selected out of this list as the source of music noise.

A variety of mechanical plant was also selected at this point and included noise sources such air conditioners, ventilation stacks, pool pumps etc. From this list single unit air conditioner was selected to be the source of mechanical plant noise. The air conditioner noise source was selected for both ease of recording and that fact that it is a common noise source that most people would be familiar.

Recording ambient backgrounds

All ambient backgrounds were recorded inside each room with the window open and the microphone approximately 1m away from the window. Windows were left open to meet the criteria of the regulations and guidelines as previously specified. The microphone of the sound level meter was set up 1m from the window to simulate what would be a typical occurrence in a standard bedroom in which the bed (and thus the receiver) would be located in close proximity to the window.

Recording noise source – Live music

The Excelsior Hotel in Surry Hills was selected as the source of the music noise that would be used for the psychoacoustic experiment. This recording was obtained at the rear of the hotel to minimise noise from patrons of the hotel itself, and of traffic noise from the surrounding streets. The rear of the hotel was of solid brick construction with an emergency exit door that was closed during the recording. As a result of the masonry brick wall construction, the frequency spectra of the audio recorded was dominated by low frequency information.

Recording noise source – Air conditioner

Two air conditioners running simultaneously were used for the recorded air conditioner noise; which were as follows:

- Daikin RXD60BVMA
- Daikin RZP71DV1.

The ease of recording and the fact that air conditioner noise is relatively common made them an ideal choice for the experiment. The sound level meter used to record the air conditioners was setup approximately 1 meter from the units.

Recording and applying the outside and inside room spectra

The outside and inside room spectra were needed so that the level differences could be applied to the noise sources in the psychoacoustic experiment to help simulate the sources being heard inside each room. To achieve this, two microphones were set up for each room and simultaneously recorded the ambient background. One microphone was placed inside the room 1m from the open window; the second microphone was fixed to a boom pool outside the window at a distance of 3m from the facade wall to prevent unwanted reflections. All rooms were free of unwanted noise sources and dominated by the ambient background noise.

The spectra were recorded and analysed in one-third octave bands from 12.5 Hz to 31 kHz and these level differences were applied to the noise sources via a 31 band equaliser. All modifications to audio clips were made through the Adobe Audition software package.

This correction muffled the noise sources by reducing the mid-range frequencies while typically having a smaller effect on the lower frequencies. This reduction in mid frequencies helped to simulate the difference between the recorded audio at the source and what would be expected to be heard while listening to the noise source inside the room.

Analysing the audio

The spectra of all ambient backgrounds and noise sources were analysed with the Brüel & Kjær Evaluator Type 7820 software. Audio samples for the experiment were all 1 minute in duration with the exception of the music noise which was 30 seconds in length and then looped to have it play for the entire minute. This was needed as when the music noise was recorded there was no single one minute period in which there was no unaffected audio free from other noise sources (traffic being the primary contributor).

The following table displays the overall levels for each ambient background and noise source as recorded without any manipulation:

Table 2. Raw Ambient Background and Noise Data

Source	Descriptor	Overall level dB
ABL1	$L_{Aeq(1\ min)}$	40
	$L_{A90(1\ min)}$	37
	$L_{A10(1\ min)}$	42
ABL2	$L_{Aeq(1\ min)}$	38
	$L_{A90(1\ min)}$	36
	$L_{A10(1\ min)}$	39
ABL3	$L_{Aeq(1\ min)}$	62
	$L_{A90(1\ min)}$	54
	$L_{A10(1\ min)}$	66
Music	$L_{Aeq(30\ sec)}$	63
	$L_{A90(30\ sec)}$	60
	$L_{A10(30\ sec)}$	64
Air conditioner	$L_{Aeq(1\ min)}$	55
	$L_{A90(1\ min)}$	55
	$L_{A10(1\ min)}$	56

Normalising the recorded audio

This normalising process was needed to combine the ambient backgrounds with the noise sources with known relative differences. It was not possible to use the above raw data in table 2 as a reference, as the audio recorded was not all recorded with the same amplifier gain. Further to this, once the outside to inside spectra correction had been applied to the given noise source, it was unknown what the new level would now be.

To achieve normalisation, all recordings were fed out of the PC via the Behringer U-Control UCA202 Audio Interface into a Panasonic CF-19 Soundbook for analysis with an on board Samurai software package. Through this process the relative differences of the audio clips were established and then used to combine the ambient background and noise sources together.

Selecting the spectra

The spectra selected to combine the audio were the L_{90} for ambient backgrounds, L_{10} for the music and L_{eq} for the mechanical plant noise. The reasons for this are the following:

- For background level: When identifying the underlying background level, it is convention to use the L_{A90} level of the ambient background in the absence of the noise source in question, hence the L_{90} spectrum has been used as the basis of comparison with the noise sources.
- For music: As music is typically dynamic and constantly varying in level, the L_{A10} level is more appropriate for assessing the noise source. The L_{A10} is used to describe the average maximum level of the source. This is why

the OLGR makes reference to the L_{A10} noise level in the standard noise conditions; hence the L_{10} spectrum has been used to combine the music source with the ambient backgrounds.

- For mechanical plant: As mechanical plant noise is typically relatively constant, the L_{Aeq} level is the most appropriate for assessing and hence has been selected to combine the air conditioner noise with the ambient backgrounds.

The 0dB reference for the music noise source would be when a particular octave band of the music L_{10} spectrum matched up in level with the L_{90} of the ambient background, with all other music L_{10} octave bands being less than their corresponding L_{90} octave band for the ambient background. To illustrate this point, the following figure displays the adjusted 0dB reference spectra.

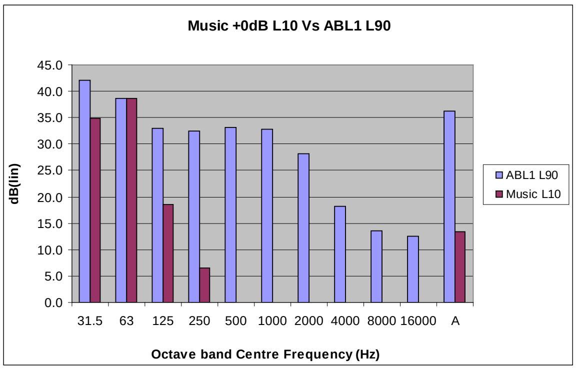

Figure 2. Music +0dB L_{10} vs. ABL1 L_{90}

Figure 2 displays there are no exceedances in any octave band and the spectra are equal in the 63 Hz octave band. With this music source being so highly dominated by low frequency information, the reduction in this instance has created significant level differences between the spectra.

As for the air conditioner noise, the overall L_{Aeq} was matched to the overall L_{A90} of the ambient backgrounds. In doing this, it created a significant difference in relative levels when comparing the 0dB reference levels of the music noise to the ambient backgrounds and the air conditioner noise to the ambient backgrounds.

Audio files for experiment

To create the audio files for the experiment, a judgement call was made as to the variety and number of audio files that would need to be created for each scenario that would be delivered in the experiment. In total, 7 audio files were created for each scenario that had the noise sources spanned over a 30dB range. The audio files began at a particular level above the 0dB reference to the ambient background to be clearly audible and then had the noise source reduced by 5dB with each file.

To achieve a consistent drop in level of the noise source from clearly audible to inaudible over the range of clips, the starting reference point of the noise source above the ambient background were not identical. Noise sources for ABL3 did not need as great of an increase, most likely because it was significantly louder than ABL1 and ABL2. Table 3 below displays this.

Table 3. Noise source levels

Noise source	Location	Noise Source Levels (dB)						
		A	B	C	D	E	F	G
Music	ABL1	+30	+25	+20	+15	+10	+5	+0
	ABL2	+30	+25	+20	+15	+10	+5	+0
	ABL3	+20	+15	+10	+5	+0	-5	-10
Air Con	ABL1	+5	+0	-5	-10	-15	-20	-25
	ABL2	+5	+0	-5	-10	-15	-20	-25
	ABL3	+0	-5	-10	-15	-20	-25	-30

A 5dB level reduction in each audio clip for the noise sources was used as it was thought that this achieved a clear difference with each audio clip without being too significant as to render the results inconclusive or too minor that it may potentially confuse or frustrate the person listening to the tracks. What is also interesting to note is the significant difference between the levels needed for the music relative to the air conditioner noise. As a comparison, the following figure displays the two spectra against each other at 0dB with ABL1 as obtained from the Soundbook. All spectrums have been A-weighted.

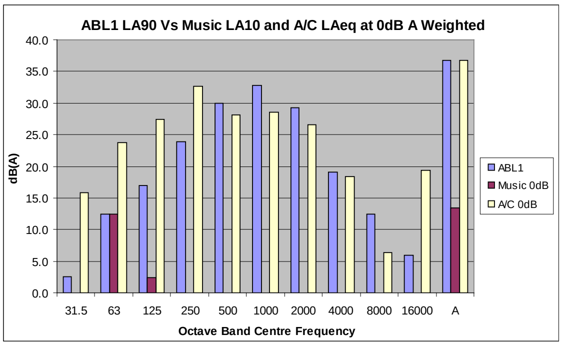

Figure 3. Noise sources at 0dB reference to ABL1

Creating the experiment

It was decided that the easiest way to deliver the experiment was through a PowerPoint presentation that the subjects could work through themselves without any aid. To do this, Microsoft PowerPoint 2010 was used.

A number of trials were performed in an attempt to achieve the correct wording of the questions in the presentation so that they were clear and unambiguous for the subjects. The following figure displays a slide from the presentation.

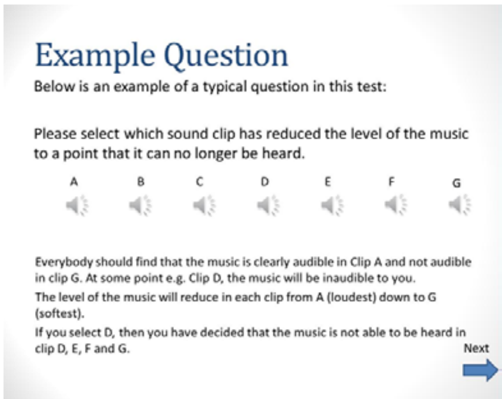

Figure 4. Experiment presentation slide

A questionnaire was created to be used in conjunction with the PowerPoint presentation to enable the subjects to provide answers to the questions asked.

RESULTS

There were 30 subjects in total that were used for the experiment. The results for ABL3 differ to those obtained for both ABL1 and ABL2 and thus shall be analysed separately. The results for the music noise source will be presented first, followed by the air conditioner.

It should be noted that a validation slide was used within the presentation that was used in conjunction with the results provided to remove any significant outliers in which it was assumed that subjects were providing inconsistent answers and overextending on what they believed they could actually detect. If a subject selected a result lower than what I determined to be inaudible and was unable to correctly select if the noise source was audible or inaudible in the validation slide, the answer would be removed. A number of results were removed through this process.

Music noise source results

The following table displays the adjusted results for the music noise source for ABL1 and ABL2.

Table 4. Music noise source results – ABL1 & 2

Noise source	Location	Count						
		+30dB	+25dB	+20dB	+15dB	+10dB	+5dB	+0dB
Music	ABL1&2	0	0	2	20	29	5	0

Table 4 displays that 91% of answers provided for ABL3 were +10dB or above. The following figure displays the music noise source against ABL1 at +10dB in the 63Hz octave band. The spectra have both been A-weighted.

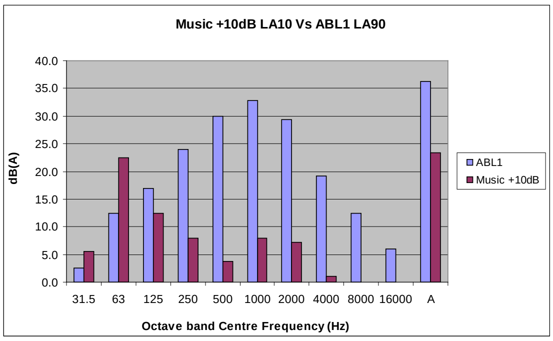

Figure 5. Music noise +10dB L_{A10} vs. ABL1 L_{A90} spectra

It can be seen that the music source L_{A10} spectra is well under 10dB below the ABL1 L_{A90} in each octave band from 250 Hz up. It is likely that a masking effect of the music noise source from the ambient background is the cause of it being selected as inaudible even though it was 10dB louder in the 63 Hz octave band. A similar relationship exists with ABL2.

Table 5 below displays the responses from all subjects for the music noise source when listened to with ABL3. From this table it can been seen that 90% of the subjects found +0dB of the music noise source to be inaudible.

Table 5. Music noise source results – ABL 3

Noise source	Location	Count						
		+20 dB	+15 dB	+10 dB	+5 dB	+0 dB	-5 dB	-10 dB
Music	ABL3	0	0	0	11	16	3	0

The following figure displays the +0dB referenced spectra with A weighting applied.

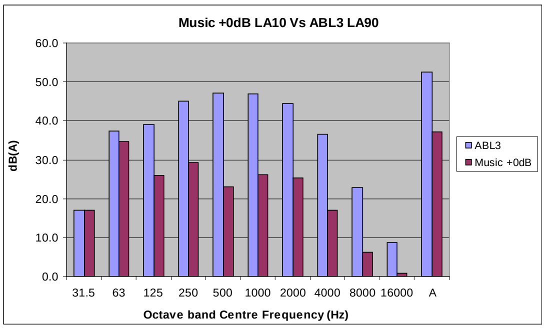

Figure 6. Music noise +0dB L_{A10} vs. ABL3 L_{A90} spectra

These 2 spectra are referenced in the 31.5Hz octave band, and similar to ABL1 and ABL2, with the exception of the 31.5Hz and 63Hz octave bands, all other octave bands of the music L_{A10} noise source are well below that of the ambient background L_{A90}.

Air conditioner noise source results

Table 6. Air conditioner noise source results - ABL1 & 2

Noise source	Location	Count						
		+5 dB	+0 dB	-5 dB	-10 dB	-15 dB	-20 dB	-25 dB
Air Con	ABL1&2	0	0	2	26	26	4	0

From table 6 above, 93% of answers provided for ABL1 and ABL2 were -15dB or above. The following figure presents the -15dB L_{Aeq} spectra of air conditioner noise source against the L_{A90} octave band spectrum of ABL1.

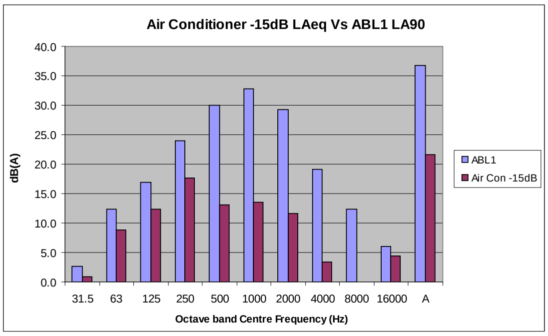

Figure 7. Air conditioner noise -15dB $_{LAeq}$ vs. ABL1 L_{A90}

With the A-weighting applied it shows that the mid frequencies of ABL1 dominate the overall level of the audio when the air conditioner is set to -15dB. With the levels being so low it is unlikely that the fact that the 16 kHz octave bands are approximately equal had much to do with the air conditioner being heard. With the increase from -15dB to -10dB (in which 45% of respondents still found the air conditioner to be inaudible), it is more likely that the air conditioner would have been able to be heard at the lower end of the spectrum around the 125 Hz and 250 Hz octave bands as they would have been approximately equal with the background and up at levels more likely to be in the audible range. However, a combination of the upper and lower frequency bands together may have helped the overall ability to distinguish the air conditioner.

The following table displays the results obtained for the air conditioner noise source when heard with ABL3.

Table 7. Air cConditioner noise source results – ABL3

Noise source	Location	Count						
		+0 dB	-5 dB	-10 dB	-15 dB	-20 dB	-25 dB	-30dB
Air Con	ABL3	0	0	1	7	19	3	0

Table 7 displays that 90% of the subjects found -20dBL_{Aeq} to be inaudible. The following figure displays the air conditioner and ABL3 spectra when referenced at -20dBL_{Aeq}.

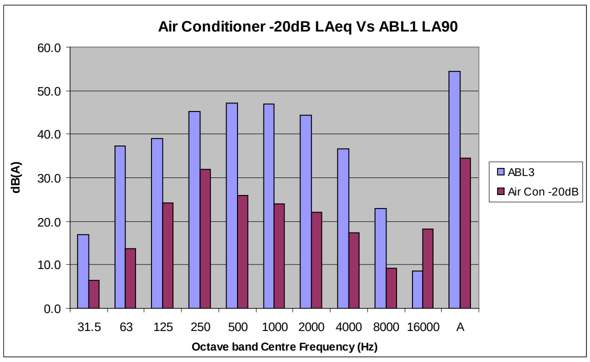

Figure 8. Air conditioner noise -20dB L_{Aeq} vs. ABL3 L_{A90}

It is unclear why subjects were still able to detect the air conditioner in this scenario, as even with a 5dB increase in the air conditioner source, with the exception of the 16kHz octave band, all other octave bands are well below the ambient background level.

DISCUSSION

The testing period of this experiment lasted two months from September 2010 to October 2010. A variety of age groups were tested however due to the limitations of this project only a small sample was obtained and as such deeper analysis of these age brackets has not been conducted. The age of subjects tested ranged from 24 up to 62. No significant difference was observed however this cannot be known for certain. All subjects tested were living in Sydney at the time however a small number tested were migrants (typically from Asia). Once again with the small sample it was not possible to establish any correlation between this variable and the selections provided however in this instance it did not appear to show any difference.

Music noise source

The results of this preliminary experiment show that when ambient conditions are relatively low (below 40dB L_{A90}), an exceedance of up to 10dB can occur at low frequencies (up to 63Hz octave band) of a music noise source emanating from a pub/club venue and the majority of people will still be unable to detect the noise source. It can only be assumed that the reason the music noise source is inaudible when it is 10dB in exceedance of the ambient background in the 63 Hz octave band is by the masking effect that the dominant mid-range frequencies have over the lower frequencies.

The results of this preliminary investigation also indicate that when ambient background conditions are louder (around 55dB L_{A90}), the ability to hear the music noise source over the background becomes easier. The majority of subjects tested found +0dB to be inaudible with regards to the music noise source relative to the ambient background. The assumption for this increase in audibility of the noise source is the increase in overall level allowing the low frequency information to be perceived as being relatively louder thus being heard with more ease.

Air conditioner noise source

The results of the air conditioner experiment indicate that when ambient background conditions are low (under 40dB L_{A90}) the majority of people will find -15dB L_{Aeq} of the overall air conditioner level to be inaudible when compared to the overall L_{A90} level of the ambient background. This result was lower than originally expected. As the air conditioner as a constant sound with a wide frequency spectrum it was believed that -10dB would be sufficient and possibly even -5dB would be adequate to produce inaudibility however results from this experiment indicate that this is not the case.

The results from this experiment also indicate that when ambient background conditioners are louder (around 55dB L_{A90}), a further 5dB reduction of the air conditioner noise source is required to produce inaudibility. It is unclear why such a large proportion of the subjects tested needed such a low relative level to produce inaudibility. One possible answer is that the validation method used was not strict enough to remove the erroneous answers provided. A stronger validation method that links the answer provided into the validation method has been discussed below.

PREREQUISITES AND IMPROVEMENTS FOR FUTURE INAUDIBILITY EXPERIMENTATION

The following presents a brief list of prerequisites and improvements to this preliminary experimentation conducted that could be used for future psychoacoustic experiments that are testing for inaudibility.

Higher quality recording

The recordings for this experiment were done on the minimum standard of 16 bit 44.1kHz. It is recommended that to reduce the noise floor and to be able to reproduce more realistic sounds that a 24 bit, 96kHz or greater should be used.

Larger sample size

With the small sample size, time constraints and the need to remove answers through validations slides, this preliminary experiment was never intended to produce conclusive results, the aim was to establish a trend and identify issues with such an experiment.

The sample size of 30 people for this preliminary investigation was adequate for the intended outcomes, however for more conclusive data; a much larger sample size would be required. The sample should include a number of age brackets with a large enough sample size in each age bracket to draw conclusions as to how significant a factor the age of the subject is to answers provided.

Stronger validation of answers

The validation used in this trial was effective for removing answers in which people far overestimated what they could perceive as audible with regards to the mechanical plant and music noise behind the ambient background; however, it did not go far enough. This was partly caused by the lack of understanding behind the complex psychology of an experiment of this nature. With the presentation validation slides, there was no real link between what the person selected as inaudible and the audio provided on the following slide. If there was a link however, then the validation would become far more effective. The aim would be to make the subject (once they have selected their choice for inaudibility) prove that they could hear the clip that was one increment louder than their inaudibility selection. This would eliminate any need to make assumptions about the subject's selection and would help to remove any bias that may be present within the wording of the questions or set up of the experiment.

Test duration

To maximise the amount of subjects tested, it is recommended that the test be shortened to a maximum of two scenarios and a general time of 10 to 15 minutes to take the test.

Testing the masking effect

The results of this preliminary investigation indicate that for the music noise source, an exceedance of 10dB in the 63 Hz octave band can occur and the noise source is still inaudible for a high percentage of the people who took this test. It would be ideal to check to see how much of an effect the higher level of mid-range frequencies of the ambient background is having on this. To test for this, a low pass filter could be applied at 500 Hz to remove these dominant low frequencies and retest for inaudibility. This would help to simulate a room in which the windows remained closed.

Varying the music spectra

To provide a better understanding of the relationship between the spectra of the music noise source and the ambient background and how much this influences the inaudibility level, it is suggested that for future experimentation, a variety of music noise sources be obtained that are able to be referenced with the 0dB octave band in a number of octave bands. Ideally the octave bands would cover 31.5 Hz to 250 Hz.

Varying the levels

For future experimentation, it would be worthwhile varying the level of the same ambient background to check to see what sort of factor the SPL of the ambient background has on the ability to hear the noise source. As the results from this experiment indicate that an increase in ambient background level leads to an increase in the ability to hear the noise source. Reducing levels of louder ambient background (in 10dB steps for example), or increasing lower ambient backgrounds and retesting for inaudibility would help to confirm whether this is the case.

Binaural recording

Binaural recording could be done to achieve a more accurate representation of the recorded noise sources and ambient backgrounds when played through the headphones.

Open headphones

The headphones used for this experiment were the Sennheiser HD 280 Pro. These headphones are of relatively high quality; however they are 'closed headphones'. The advantage of closed headphones is that the room in which the experiment is taking place does not need to have the same conditions as that of the speakers experiment, as the enclosure of the headphones around the ears offers isolation and attenuation of the ambient noise in the room. As clear sound reproduction is of significant interest in this experimentation, a quiet control room with high quality open headphones would be more ideal for any following experimentation.

CONCLUSION

This preliminary investigation into the possibilities of conducting a large scale psychoacoustic test for inaudibility has uncovered a number of interesting results and issues relating to such a test. The psychology of the test is of much greater importance than originally assumed. It would appear that a number subjects taking the test are inclined to overestimate what they can actually perceive to be audible. This leads to the need for a strong validation method to be able to identify when this is the case.

The results of this preliminary investigation are as follows:

For music noise heavily dominated by bass:

- When ambient conditions are low (under 40dB L_{A90}), 91% of the subjects tested found +10dB L_{10} of the music noise source when referenced to the 63 Hz octave band of the L_{90} of the ambient background be inaudible.

- When ambient conditions are higher (around 55dB L_{A90}), 90% of the subjects tested found +0dB L_{10} of the music noise source when referenced to the 31 Hz octave band of the L_{90} of the ambient background be inaudible.

For air conditioner noise that has a relatively constant level:

- When ambient conditions are low (under 40dB L_{A90}), 93% of the subjects tested found -15dB L_{Aeq} of the air conditioner noise source when referenced to the overall L_{A90} of the ambient background be inaudible.

- When ambient conditions are higher (around 55dB L_{A90}), 90% of the subjects tested found -20dB L_{Aeq} of the air conditioner noise source when referenced to the overall L_{A90} of the ambient background be inaudible.

The results from this preliminary investigation indicate that it could be possible to implement a large scale investigation into a psychoacoustic experiment that would test for inaudibility of mechanical plant and music noise; however there are many variables that need to be tested to determine their contribution to the overall results. It would also appear that inaudibility may be required to be defined in a number of different ways depending on the noise source in question, and the ambient background conditions.

In further experimentation, many of the prerequisites and improvements to the experiment as outlined in this paper would need to be adopted to obtain more conclusive results. If this was to occur, criteria in which to define the inaudibility of mechanical plant and music noise when combined with various ambient background conditions typical of urban and suburban locations may be able to be established.

This paper is based upon my undergraduate thesis which was completed in 2010 and the University of Technology, Sydney (Phillips, 2010).

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