New Zealand Acoustics, vol. 25, no. 2, pp. 14-17, 2012

Understanding the Lombard Effect

J. Whitlock

Marshall Day Acoustics Limited, Auckland, NZ

An original contribution to New Zealand Acoustics

Abstract

The Lombard Effect continues to breed noisy spaces, and as the current trend towards open plan spaces (particularly offices and classrooms) continues, understanding this effect so we can predict activity noise levels in reverberant spaces becomes all the more crucial. In this paper, we review previous work on experimental testing of the Lombard Effect in children and adults and the resulting prediction model. We highlight the limitations and unexpected outcomes of that work and investigate a new testing method that will lead us towards more robust real-life Lombard Effect data, which can be used to refine our prediction model.

INTRODUCTION

In 1911, French otolaryngologist Étienne Lombard discovered a psycho-acoustical effect, whereby a speaker involuntarily raises their voice level when speaking in a loud environment (Lombard, 1911).

The ramifications of this 'Lombard Effect' on speech communication are immense, particularly in a modern society tending towards ever-increasing noise levels and chock-a-block social calendars.

Our research focus is on primary school classrooms, where a tendency for crude (and cheap) room design, teaching philosophies which favour group-work activities, and the natural effervescence of children result in high noise levels through the Lombard Effect. However, a classroom cannot afford to have issues with speech communication!

MEASURING THE EFFECT

In 2002 we began investigating the acoustical mechanisms that affect speech intelligibility for children in primary school classrooms, and undertook measurements of the Lombard Effect in children (Whitlock, 2003).

These early measurements were undertaken in an anechoic chamber. Subjects were asked to wear a set of insert earphones and read a book out loud while a white noise masking signal was delivered to them at increasing levels (10 – 90 dB L_{Aeq}). The subjects' voice levels were measured in free-field at 1 metre and correlated with the masking noise level.

The slope of this correlation (approximated as a linear fit) was termed the 'Lombard Coefficient' and the value for children was measured as 0.19 dB/dB (i.e. 0.19 dB rise in speech level for every decibel rise in masking noise).

We then developed a prediction model which predicts speech noise level in an occupied room, using this Lombard Coefficient in addition to some other parameters measured during the experiment. The model is as follows:

$$F = \frac{B - SL + 10\log N - 10\log V + 10\log T + 25}{(1-L)}$$

Where:
F = Final L_{Prev}
B = Base (resting) Voice Level
S = Masking level at which Lombard Reflex starts
L = Lombard Coefficient
N = Number of speakers
V = Room Volume (m^3)
T = Reverb Time (s)

Equation 1: Model for predicting speech level in a room with multiple talkers

For a typical classroom (i.e. V = 200m^3, T = 0.6 s, N = 30) this model predicts F = 74 dB which correlates well with actual measured levels in classrooms e.g. MacKenzie & Airey (1999), Wilson et al. (2002), Lubman & Sutherland (2002) and Shield & Dockrell (2003).

In 2005 the exact same method was used to measure the Lombard Effect in adults (Francis, 2005). Francis discovered a lower Lombard Coefficient (0.13 dB/dB) for adults, indicating that children are more susceptible to the Lombard Effect (highlighting the need for well designed classroom acoustics!). The results of both experiments are shown in Figure 1.

IDENTIFYING THE LIMITATIONS

Subsequent experiments (Whitlock & Dodd, 2009) showed that the Lombard Effect may be heavily dependent on the type of masking signal.

Figure 2 below shows the results of the same Lombard experiments, but with a speech babble masking signal (four-person multi-talker babble) instead of white noise.

The results are surprising in two ways:

- The Lombard Effect on adults was greater than on children i.e. the opposite to the white noise results
- The adults were more affected by speech babble than white

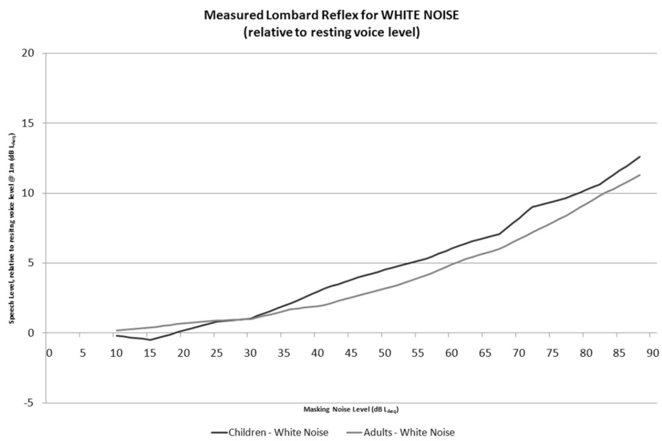

Figure 1. Lombard Effect curves for Children and Adults – White Noise Masker.

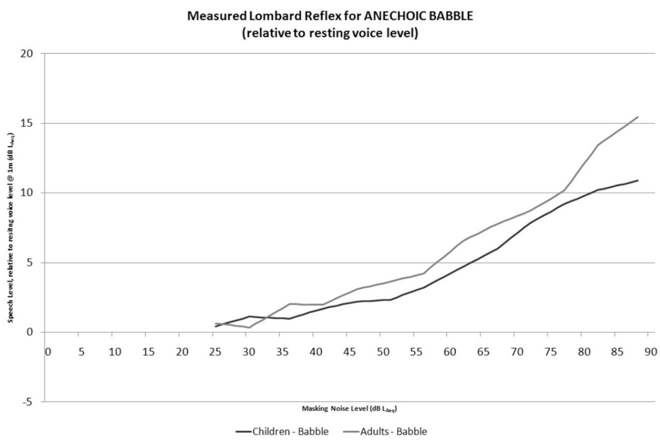

Figure 2. Lombard Effect curves for Children and Adults – Babble Masker.

noise, whereas the children were less affected

Possible explanations for these results are:

- The adults were more distracted by the information content of the speech babble i.e. they were more able to isolate and discriminate individual words etc.
- The children (all primary school age) may be accustomed to operating in the presence of masking speech sources in their classrooms. Perhaps classrooms are training children to ignore speech babble..?
- The masking for children may have been less because the babble signal spectrum had a greater low-frequency component c.f. white noise, which may have had less masking effect on their self-hearing ability as a child's voice spectrum is typically richer in higher frequencies
- Experimental limitations giving rise to skewed results

To investigate these unexpected findings further, we decided that the experimental limitations should be addressed. Testing in a laboratory environment could be giving rise to results which do not translate back to the actual situation we experience every, so we started to look into a 'real world' testing method.

REFINING THE TEST METHOD

The challenge in a real world test method is isolating the speaker's voice level from the masking (or any other background) noise. Previously, this was successfully achieved in the anechoic chamber, using insert earphones to deliver the masking noise,

Figure 3. E2 Earset microphone by Countryman Associates.

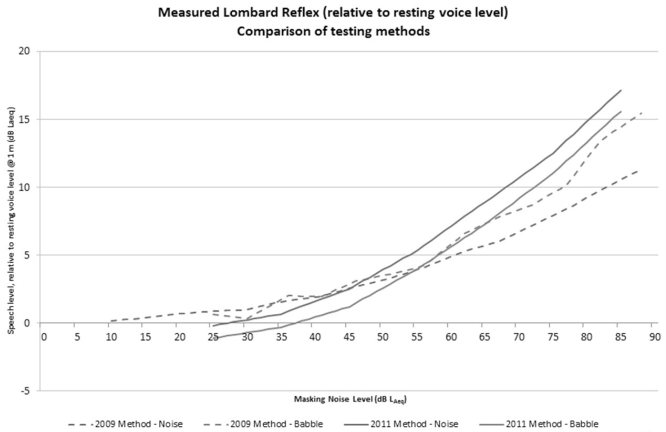

Figure 4. Lombard Effect curves for Adults, using 2009 method (dashed) and 2011 method (solid).

but we want to make use of real masking noise and measure the voice levels independently.

In our most recent work (Whitlock, 2011) we tested a solution in the form of a headset microphone (E2 Earset by Countryman Associates – See Figure 3). This is a small discrete mic., worn on the ear and positioned close to the edge of the mouth.

The idea is to isolate the speaker's voice level from the background noise simply through proximity to the mouth. Of course there will be a limit to this isolation, so part of the recent work has been to identify how loud the background noise can be before it starts affecting the speech level measured in the microphone.

Experiments were undertaken with adults only this time (because of the relative ease of working with them, compared with children!) in a standard living room environment. Both speech babble and white noise were used as masking signals. The L_{Prev} of the masking signal was measured using a Type 1 sound level meter, and to enable comparison with our previous experiments the levels measured at the microphone position were corrected to 1 metre.

The results (in Figure 4) indicate the following:

- The speech/noise correlation has flipped again i.e. noise elicits a higher Lombard Effect
- Lombard Coefficients are the same for noise and babble, and higher than previously measured (0.3dB/dB)
- Stunning consistency between the two 'new method' curves
- Subjects with higher resting voice levels showed less Lombard Effect

In terms of microphone limitations, Figure 5 below shows that signal to noise ratio (i.e. subject's voice to masking L_{Prev} ratio) was generally greater than 10dB for masking levels up to 75dB. Generally speaking, 10dB is the minimum separation between two noise levels to ensure their energies do not significantly add together. So, this apparatus can be used for Lombard field tests in sound environments up to 75dB, and possibly higher if we correlate the L_{Aeq} and L_{Amax} speech levels to artificially produce a greater headroom.

We have identified a viable method of measuring the Lombard Effect of subjects in real world environments. This paves the way to large scale experimentation involving a range of noisy

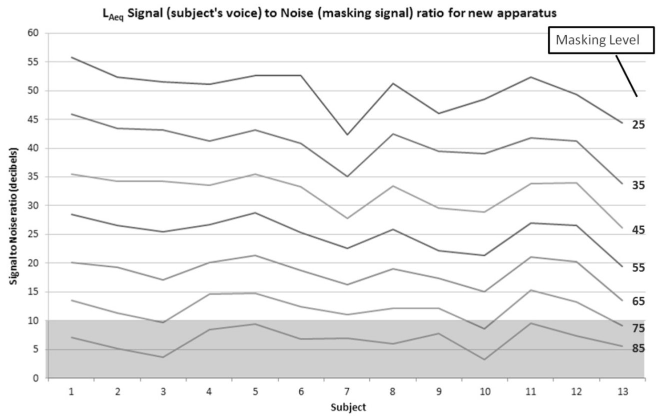

Figure 5. Signal to Noise correlations for each subject, highlighting the 10dB SNR level.

environments such as cafes, restaurants and most importantly, classrooms. Once collected, this data will provide more accurate values for the Lombard Coefficient that can be used to continue validation of our prediction model.

ACKNOWLEDGEMENTS

Thank you, as always, to Dr. George Dodd, my research collaborator and mentor and Gian Schmid of the Acoustics Centre at the University of Auckland, and the willing participants of the numerous listening experiments we have conducted throughout the years.

REFERENCES

Francis, R., "The Influence of the Lombard effect on Speech Level in Adults", Research Paper, School Of Music, University of Auckland, 2005.

Lombard, E., "Le signe de l'élévation de la voix" Ann. Maladies Orielle Larynx Nez Pharynx, 1911, 37, 101-119 [Translated into English by T. Scelo, 2003).

Lubman, D., Sutherland, L., "Role of Soundscape in Children's Learning", Proceedings of First Pan-American/Iberian Meeting on Acoustics, Cancun, Mexico, 2002.

MacKenzie, D., Airey, S., "Classroom Acoustics, A Research Project", Heriot-Watt University, Edinburgh, 1999.

Shield, B., Dockrell, J., "The Effects of Noise on the Attainments and Cognitive Performance of Primary School Children – Executive Summary", South Bank University, 2003.

Whitlock, J., "Acoustical Mechanisms Influencing Speech Intelligibility for Primary School Children", Masters' Thesis, Acoustics Research Centre, University of Auckland, 2003.

Whitlock, J., Dodd, G., "Recent New Zealand initiatives towards understanding classroom acoustics", Proceedings of Internoise 2009, Ottawa, Canada, 2009.

Whitlock, J., "Speaking in a Babble – Further Research on The Lombard Effect", EIAS Conference, Båstad, Sweden, 2011.

Wilson, O., Dodd, G., et al., "Classroom Acoustics – A New Zealand Perspective", The Oticon Foundation, Wellington, NZ., ISBN 0-473-08481-3, 2002. ¶