Proceedings of 20th International Congress on Acoustics, ICA 2010

23-27 August 2010, Sydney, Australia

Wide band pneumatic sound system for MEG

Raicevich, G. (1), Burwood, E. (1), Dillon, H.

Johnson, B. (2), Crain, S. (2)

(1) Hearing CRC, National Acoustic Laboratories, Chatswood, NSW, Australia
(2) Hearing CRC, Macquarie Centre for Cognitive Science, Macquarie University, NSW, Australia

PACS: 43.80.VJ, 43.80.QF, 43.64.RI, 43.66.YW, P43.38.-P, 43.38.VK, 43.58.-E, 43.38.SI, 43.75.TV

ABSTRACT

Magnetoencephalography (MEG) is a non-invasive technique for 3D brain imaging. This imaging system measures extremely weak magnetic fields emerging from the head that are associated with brain electrical activity. Cortical brain responses to sound can be measured using MEG to detect these magnetic fields. Sound is piped to the subject's ears while observing the magnetic activity surrounding the brain. The sound system used must not produce magnetic fields which interfere with the MEG sensors. For this reason the transducers are located outside the MEG sensor room and pneumatic tubes are used to deliver sound to the subject. The tubes are made of a non-magnetic material and can be up to four metres in length. The use of long pneumatic tubes leads to some loss of high frequency components in the audio signal. The type of transducer chosen to drive the tubes will also affect high frequency signal content. When the sound has a deficit in the high frequency range, it is perceived to be muffled and speech intelligibly suffers. Speech stimuli such as fricatives that contain high frequency content become degraded and the range of useful speech stimuli tests for auditory brain function assessment using MEG becomes restricted. The Speech Intelligibility Standard set out by ANSI requires a minimum high frequency response of 8000 Hz for 100% intelligibility. The frequency response of a new audio system that was developed extends to 9000 Hz. This system is compared with an existing commercial sound system for MEG with a high frequency roll-off occurring at 2000 Hz.

INTRODUCTION

Motivation

Electroencephalography (EEG) is a well established non-invasive technique used to measure electrical activity around the brain. Electrical potentials are measured using multiple electrodes placed on the head. A newer technique is Magnetoencephalography (MEG). This non invasive method is used to measure the magnetic field activity around the brain. Magnetic fields are measured using multiple magnetic sensors called SQIDs (superconducting quantum interference detectors). MEG and EEG have been used independently and together to measure auditory evoked cortical activity. Cortical activity represents higher informational processes within the brain. In comparison, Magnetic Resonance Imaging (MRI) is more often used for spatial imaging to identify normal brain structure and abnormal structure such as a tumour.

The use of MEG requires extremely sensitive magnetic sensors. When a sound system is used with MEG it must not produce any interfering magnetic fields. For this reason the sound producing transducers are located outside a magnetically shielded sensor room. Pneumatic tubes are used to deliver sound to the subject inside the sensor room. The tubes are made of a non-magnetic material with a length of up to four meters. Long tubes as well as transducer limitations have been found to contribute to high frequency signal loss.

Aims

The high frequency response of one commercial audio system for MEG was limited to 2000 Hz according to the manufacturer. In response, the aim of this work was to develop a pneumatic sound system for MEG with extended high frequency response.

Two sound systems were built with progressively improved high frequency responses and these are presented in this paper. The frequency response of the final sound system is compared to the response of a commercial sound system. The spectral response for a vowel and fricative are used to show how the limitations in the sound system frequency response can affect speech intelligibity. Examples of measured system responses are presented.

Background

It is known that limited high frequency response affects speech intelligibly. The Speech Intelligibility Index, SII S3.5 ANSI (1997) tells us that a frequency response of at least 160 to 8000 Hz is needed to transmit all the speech that contributes to intelligibility. High frequency loss results in the perception of a muffled sounding signal. Speech stimulus such as a vowel (a, e, i, o, u) contains spectral energy predominantly below 2000 Hz. Consequently, vowel type sounds pass through a sound system with little attenuation if the system's response is good to at least 2000 Hz.

Fricative speech stimuli contain higher frequency components, usually above 2000 Hz. These sounds can be described as envelope modulated white noise. Examples include the sounds 's' and 'f'. When a sound system fails to deliver higher frequencies, fricatives become attenuated and easily confused. Speech intelligibility will suffer.

A sound system with limited high frequency response can affect the results of a mismatch negativity test used for MEG. A train of vowel sounds such as an "e" may contain an embedded change of sound, such as a fricative “s”, as for example the sound train "e e e S e e e". In a sound system lacking high frequency response, the fricative becomes attenuated relative to the baseline of repeating vowels. The results for auditory evoked cortical potential measured using MEG will be affected by the unwanted change in sound level for the fricative. Näätänen et. al., (2007) and Phillips et. al., (2001) describe mismatch negativity tests in greater detail.

In the first prototype, it was found that hard tubing made fitting the ear-tips to a subject problematic. When the subject moved, the ear-tips were prone to pop out of the subjects’ ear canals. To avoid this problem, softer silicone tubing was tried. However, this produced deep notches in the audio frequency band, a problem that is detailed in this paper. The final device went back to using hard tubing. The way that the system was improved and the frequency response obtained is the subject of this paper.

METHOD

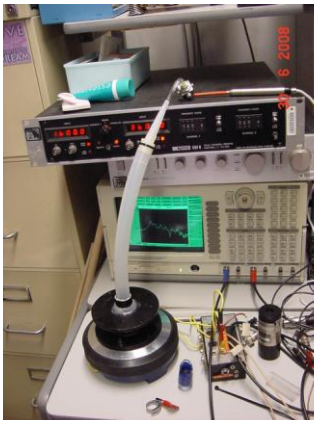
The frequency response of soft silicone tube systems with a long length of tube (4m) and shorter lengths (approximately 0.15 m and 0.26 m) were measured while the tube was excited with sound using a compression driver. The tubing terminated in a Zwislocki coupler and ½ inch microphone. Two tube diameters were used. The large diameter silicone tubing measured 18mm ID and 24mm OD. The smaller diameter silicone tubing measured 11mm ID and 15mm OD.

When the frequency response of the system with soft long tube was measured it was found that a substantial notch in the frequency response occurred. Measuring the response of a shorter length of tubing was used to establish how the notch filter behaved with respect to tubing length. The effect of tube diameter on frequency response was also examined.

Hard wall tubing was also used in developing the sound system and two pneumatic systems were characterised. The first system was a NAL prototype and the second system was the final device called a “G-tube”. The use of the stiffer hard tubing re-introduced a problem of ear sound-tips sometimes popping out of the ear when the subject moved. Figure 1 shows a tube immobiliser developed to counter the problem. The immobiliser clamps the stereo tubes at the waist and the leg. This system secured the tubes to the body, increasing the stability and reliability of the ear-tip fitting.

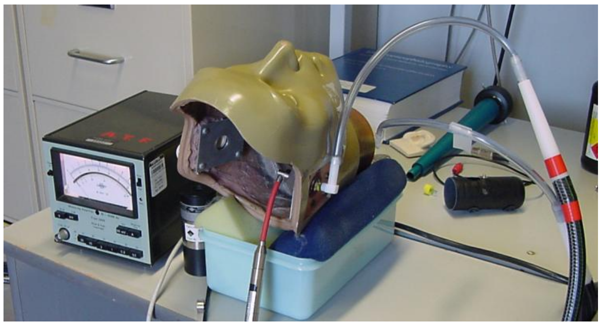
Source: (Raicevich)
Figure 1 Tube immobilisation at the waist and leg reduced the problem of the ear-tip popping out of an ear.

Figure 2 shows measurement of a short piece of soft tubing used for testing signal effects. A compression driver is used to provide signal while a Zwislocki coupler is used to measure the response with an SR785 spectrum analyser seen in the lower part of the background.



Source: (Raicevich)
Figure 2 Measuring signal absorption notch frequency

Figure 3 shows the pneumatic tube is reduced down from 11 mm ID to 6 mm ID using a gradually reduced diameter horn to avoid an abrupt change in acoustic impedance and therefore acoustic reflection.



Source: (Raicevich)
Figure 3 The ear tip end of the final NAL system

The final NAL sound system was compared to a commercial system from Etymotic (model ER-30).

A recording was made using a sample of a vowel-fricative combination of sounds to demonstrate the effect of frequency response limitation. The sounds were “played” through each sound system by convolving samples of sound with the impulse response of the Etymotic system and the final NAL sound system.

To create the time domain representations of the original sounds “played” through each system using the following method. The speech sound samples were digitised and convolved with the measured impulse responses for the final NAL sound system (called a G-tube) and the Etymotic ER-30. The reason for using impulse responses rather than the actual sound systems was that it was that the sound systems were often in active use, precluding their use. The results are presented in this paper.

RESULTS

Soft tube sound system

Figure 4 shows the frequency response for the large diameter tube. The graph vertical axis shows acoustic signal in dB SPL re 0.1 Pa. The horizontal axis shows frequency from 100 to 10,000 Hz. A long tube (4 m) and a short tube (0.26 m) were used. No acoustical dampening was used in the sound system. Lack of damping can be seen from response ripples measured for both the short and long tube measurements in Figure 4 and Figure 5.

Figure 4 shows the frequency notch at 1600 Hz for both long and short tube.

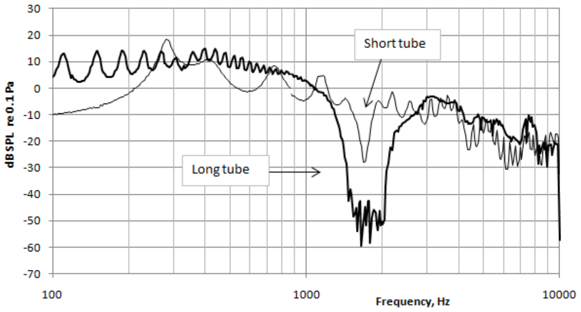


Figure 4 Frequency response notch for large diameter silicone tubing

Figure 5 show measurements repeated using a smaller diameter silicone tubing. The short tube length measured 0.15 m while the long tube length measured 4m.

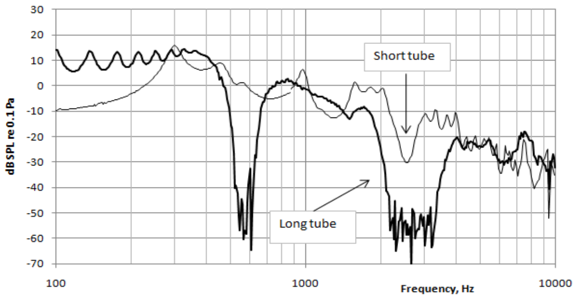


Figure 5 Frequency response notch for small diameter silicone tubing

The responses show a notch at 2600 Hz for both long and short tubes. A lower notch frequency also occurred at 550 Hz with the long tube. Two notches suggest tube oscillation with two modes of behaviour.
In Figure 4 and 5 the notch frequency did not change with tube length. However from Figure 4 to 5, the notch frequency did change with tube diameter. This suggests the notch frequency depends on transverse or radial rather than the axial properties of the combined tube (wall) and the air column within the tube.

Stiff tube sound system

Harder tubing was used to remove the absorption notch found with soft tubes. Figure 6 shows the hard tube connected to a stepped acoustical coupler used with driver (A).

Source: (Raicevich)
Figure 6 Stepped coupler and hard tube

The simplest way to change from a large to smaller diameter tube was to use a stepped series of tubes for the acoustical coupler. From an acoustical perspective, the steps presented discontinuities and an opportunity for acoustic reflections to form.

Figure 7 shows the frequency response of a system using the stepped coupling. Tube lengths used were 4 m and 0.26 m. The stiffer tube shows an absence of the signal absorption notch.

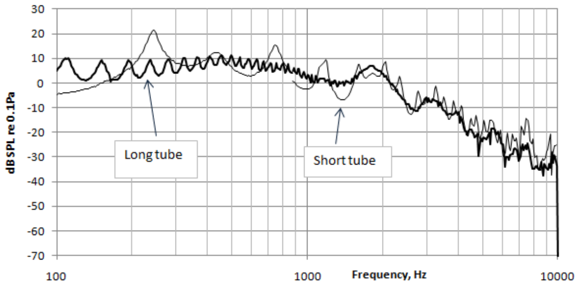


Figure 7 Frequency responses for small diameter, long and short tube

The sound levels for the two systems were normalised for approximately equal mid band gain. With this arrangement, the longer tube system showed slightly increased attenuation in frequencies above 2000 Hz. Both rippled responses indicate an absence of acoustical damping material.

Acoustical damping of tube

Figure 8 shows effective smoothing of rippled response obtained by inserting acoustical damping material into the tube. The damping material, polyester wool, was lightly packed at both ends of the tube to reduce the reflection of acoustic signals at the compression driver and the microphone diaphragm within the Zwislocki coupler. Compression driver (A) gave the good low frequency response seen in this graph.

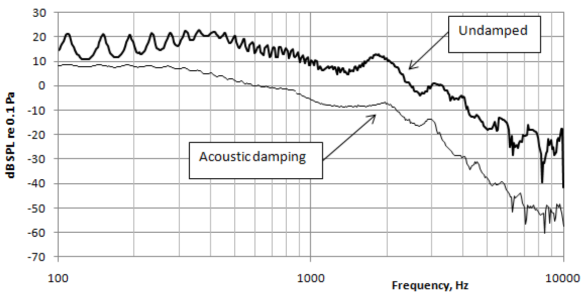
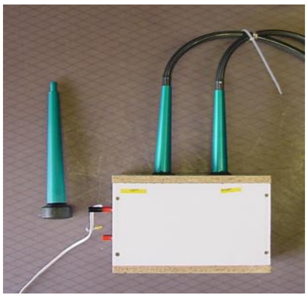


Figure 8 Effects of acoustical damping using large diameter, long tube

Figure 8 shows a system resonance at 1.9 kHz in the undamped response. After inserting an appropriate amount of acoustical damping material into the tube, the resonance has been significantly damped. A trade-off for smoothing the frequency response is an increase on the pass band attenuation. For example, some 15 dB of attenuation at 1 kHz can be seen when the original undamped and damped responses are compared.

For the next prototype, a different compression driver (B) was selected for improved high frequency response. It was desirable to reduce pass band ripple without unduly attenuating high frequency content by reducing the need for damping. The tube formed an acoustical transmission line and any discontinuity such as an abrupt change in pipe diameter would cause signal reflections and amplitude ripple in the signal passed through the tube. Changing the stepped coupler to a tapered horn reduced one source of stepped discontinuities, reducing the need for damping material.

Figure 9 shows long coupling horns with a smooth and gradually tapered diameter used in the final sound system.



Source: (Raicevich)

Figure 9 Improved horn couplers from driver to tube

In-situ tests of the sound system also revealed ambient noise from the MEG control room would leak into the rear of the compression driver. To address the problem, a noise attenuation box was built around the two drivers.

Figure 10 compares two NAL systems. The thin line graph shows the prototype driver (A) with stepped horn and damping. The thick line represents the final sound system using a different driver (B), a long smooth horn (as shown in Figure 9) and damping. The low frequency response of driver A was sacrificed for the improved high frequency of driver B.

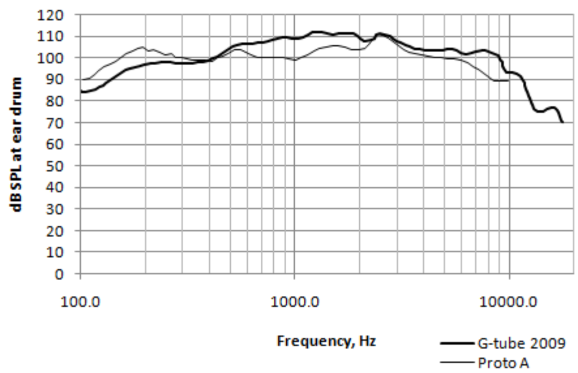


Figure 10 Compares prototype (A), thin line, with final system (B) the G-tube, thick line

Figure 11 shows a commercial pneumatic system, the ER-30 model from Etymotic.

Source: (Raicevich)

Figure 11 Etymotic ER-30 pneumatic sound system

Figure 12 compares the Etymotic model ER-30 and the NAL G-tube 2009. The high frequency response of the ER-30 is described as 2000 Hz by the manufacturer. The frequency response for the final system was overlayed with the ER-30 and 1 kHz levels were matched. With a pass band amplitude variation of approximately 12 dB, the G-tube high frequency response extended to 9000 Hz. Low frequency response rolled off at 200 Hz

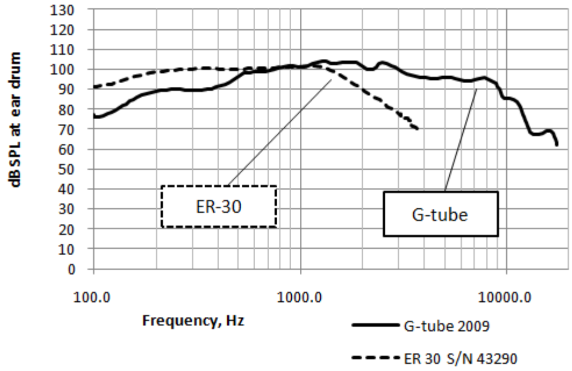


Figure 12 Compare ER-30 and G-tube frequency response

Samples of sound were played through the two systems. The vowel sound "e" provided a very satisfactory reference sound that both systems could reproduce. The fricative sound "s" had spectral energy peaking around 8000 Hz.

Figure 13 overlays the spectra for the two sounds with the frequency responses for the ER-30 and the G-tube. This graph shows the G-tube is capable of reproducing the fricative sound.

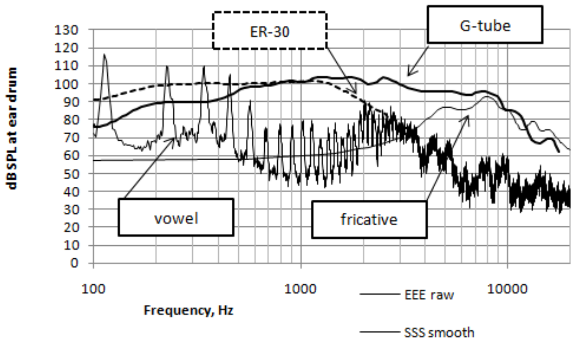


Figure 13 Spectra for vowel "e" and fricative "s" along with G-tube and ER-30 sound systems

The effect of sound system response on speech intelligibility can be appreciated using time domain signals passed through each sound system. Figure 14 shows the time domain representation of the vowel "e" followed by the fricative "s".

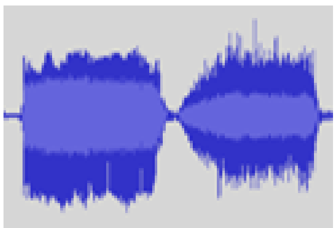


Figure 14 Original sound "e" then "s"

Figure 15 shows the sound passed through a simulation (using measured impulse response) of a G-tube sound system. The image shows fricative amplitude relative to the vowel mains relatively unchanged.

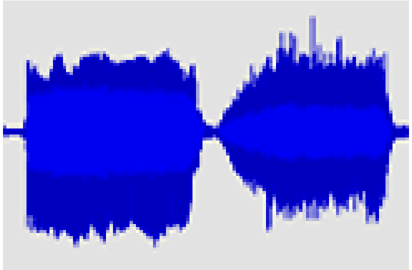


Figure 15 Sound played through G-tube

Figure 16 shows the sound passed through a simulation (using measured impulse response) for a ER-30 sound system. The fricative amplitude shows attenuation, relative to the vowel.

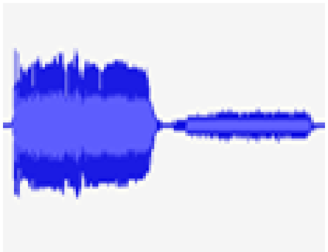


Figure 16 Sound played through ER-30

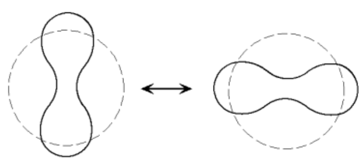
DISCUSSION

Soft Wall Tube behaviour

Figures 4 and 5 showed that soft wall tubes were compliant enough to vibrate, causing signal absorption when excited by the sounds played through the tubes.

Measurement of the notch frequency for both long and short tubes of different diameters suggested transverse rather than longitudinal tube wall movement was associated with the signal notch. Sound was absorbed, in narrow frequency bands, with as much as 30 to 50 dB of signal loss.

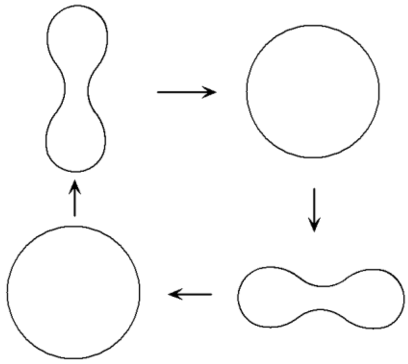
Figure 5 showed two notch frequencies simultaneously occurring. With reference to this measurement, Heil and Waters (2006) give two examples of transverse tube-wall modes of vibration. Figure 17 reproduces one of the figures showing simple transverse wall movement.



Source: (Raicevich, interpretation of Heil and Waters, 2006)

Figure 17 Tube simple mode, transverse vibration

Figure 18 reproduces one other figure from Heil and Waters (2006). This tube cross-section displays a more complex mode of oscillation.



Source: (Raicevich, interpretation of Heil and Waters, 2006)

Figure 18 Tube cross-section with complex behaviour

CONCLUSION

The Speech Intelligibility Index shows that one of the factors required for transmission of 100% of speech information is a frequency response of at least 160 Hz to 8000 Hz.

The final sound system reported in this paper measured 200 Hz to 9000 Hz bandwidth when assessed with a 12 dB pass band variation.

Mismatch negativity tests rely on change in repeating patterns of stimuli presented to a subject. A change in a sound pattern activates a change in cortical behaviour. It is desirable that the sound system should not spectrally distort the acoustical stimuli and hence the associated cortical potentials.

ACKNOWLEDGEMENT

We would like to thank Jorge Mejia, National Acoustic Laboratories, for help with coding and convolving sound system impulse responses.

REFERENCES

ANSI S3.5-1997, “Methods for the Calculation of the Speech Intelligibility Index” (American National Standards Institute, New York), (2007)

Heil, M. and Waters, S.L “Transverse flows in rapidly oscillating elastic cylindrical shells" J. Fluid Mech. 54, 185–214 (2006)

Näätänen, R., Paavilainen, P., Rinne, T., & Alho, K.. The mismatch negativity (MMN) in basic research of central auditory processing: A review. Clinical Neurophysiology, 118, 2544-2590, (2007)

Phillips, C., Pellathy, T., Marantz, A., Yellin, E., Wexler, K., McGinnis, M., Poeppel, D., & Roberts, T.. Auditory Cortex Accesses Phonological Category: An MEG Mismatch Study. Journal of Cognitive Neuroscience 12:6. 1038-1055, (2001)