Behavioural assessment of listening difficulties in people with unilateral hearing loss

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Introduction

Having two ears provides several benefits such as binaural summation (Hirsh, 1948; Reynolds & Stevens, 1960), the binaural squelch effect (Keys, 1947), reduction of the head shadow and sound localisation (Avan, Giraudet, & Büki, 2015). It has been extensively reported in the literature that people with unilateral hearing loss (UHL) present with major problems recognising speech in challenging environments (Bess, Tharpe, & Gibler, 1986; Ruscetta, Arjmand, & Pratt, 2005) and localising sounds (Humes, Allen, & Bess, 1980; Johnstone, Nabelek, & Robertson, 2010; Newton, 1983), and have greater self-perception of disability in daily life situations than normal-hearing controls (Araujo, Mondelli, Lauris, Richieri-Costa, & Feniman, 2010; Augustine, Chrysolyte, Thenmozhi, & Rupa, 2013; McLeod, Upfold, & Taylor, 2008).

Currently there is no consensus about the most appropriate test battery to assess behavioural and functional auditory abilities in people with UHL. Functional assessment of auditory abilities is widely used for people with bilateral hearing loss when decisions are being made about hearing rehabilitation, but this is less common in people with UHL despite evidence that self-perception of disability may be worse as the interaural asymmetry becomes larger (Noble & Gatehouse, 2004). Protocols for audiological management of children with UHL suggest the use of functional questionnaires to help to establish the individual's needs in comparison with other children with UHL (King, 2010).

The aim of this report is to present a behavioural and functional assessment protocol that was used by the authors to assess auditory abilities in adults and children with UHL. This protocol was developed in a research context but can be used clinically to assess the effects of UHL on sound localisation, speech perception and self-perception of hearing difficulties.

Sound localisation

This test estimates how well a subject can detect where sounds are coming from (direction and distance). The brain utilises subtle differences in intensity, spectral, and timing cues to localise sound sources in the horizontal plane. The test protocol for sound localisation was adapted from Johnstone et al. (2010), Cullington et al. (2011) and Strøm-Roum et al. (2012) and can be used in children as young as five years of age. This protocol utilises a matched five-speaker array that could be set up in a standard audiological test booth.

Test Protocol

Sound localisation ability was tested using a spondee word “Frenchfries" spoken by a female native speaker of New Zealand English, digitally recorded with a sampling rate of 44.1 kHz using Adobe Audition software, stored as a WAV file. Stimulus presentation level was 62 dB SPL on average. The level was randomly varied between 54 and 70 dB SPL (roved +/- 8 dB) to avoid the use of absolute levels for localising the sound. Five loudspeakers were placed at −90°, −45°, 0°, 45°, and 90° azimuth at 1 m distance from the participant with the loudspeaker centres at approximately head height. Participants were instructed to look to the front speaker all the time and to point to the speaker where they heard the sound. Stimuli were presented randomly a total of 6 times to each loudspeaker for a total of 30 trials.

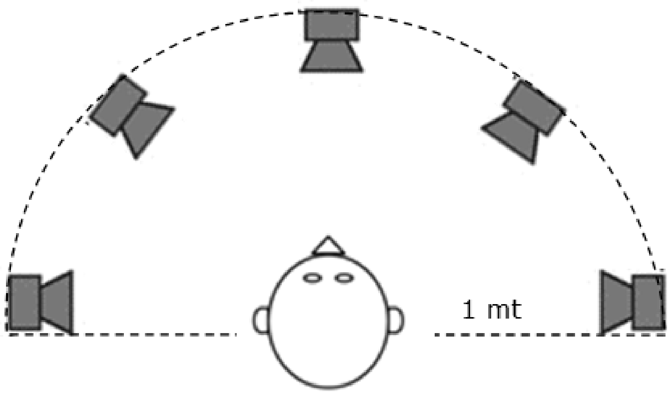


Figure 1. *Sound localisation setup. The five speakers are placed at ear level, 1 meter from the listener.*

Sound localisation errors are quantified by calculating the Root Mean Square Error (RMS) as illustrated in Table 1. The first column corresponds to the trial number for each speaker location (only two included in this example). The second column represents the location (degrees azimuth) of the target sound. The third column represents the perceived location reported by the listener (degrees azimuth). For this example, data are shown for four trials for two angles on the left of the listener (-90° & -45°). The average RMS error for each speaker angle is computed and then the grand average RMS error is computed across the array.

Table 1. *Example of Sound Localisation Scoring (two trials at two locations are shown)*

#Trial	Target	Response	Difference	$Difference^2$ (Square of error)	Mean square	RMS error*
1	-90°	-45	-45	2025		
2	-90°	0	90	8100	5062.50	71.15
1	-45°	-45	0	0		
2	-45°	-45	0	0	0	0
					Overall average RMS error	35.58°

Speech recognition in noise

This test indicates the listener's ability to understand speech in noise when the speech and noise come from the same frontal source and when they are spatially separated. The listener repeats words that are presented at a comfortable level via a loudspeaker in the presence of background noise. The test protocol was adapted from Bess et al. (1986) and Sargent et al. (2001). Normative data available for these speech perception tests for New Zealand adult listeners and information on list equivalence have been reported previously by Cañete and Purdy (2015). One speech perception task utilised Bamford-Kowal-Bench/Australian version (BKB/A) sentences (Bench, Doyle, & Greenwood, 1987) to adaptively determine the 50% correct speech recognition threshold with the noise (speech babble) level fixed at 60 dB SPL. The second speech perception task involved assessment of percent correct scores for Consonant-Nucleus-Consonant (CNC) monosyllabic words (Peterson & Lehiste, 1962) presented at a fixed supra-threshold level (65 dB SPL) with speech babble at 60 dB SPL (+5 dB signal to noise ratio, SNR). Both types of speech material are suitable for adults and school age children (6-7 years).

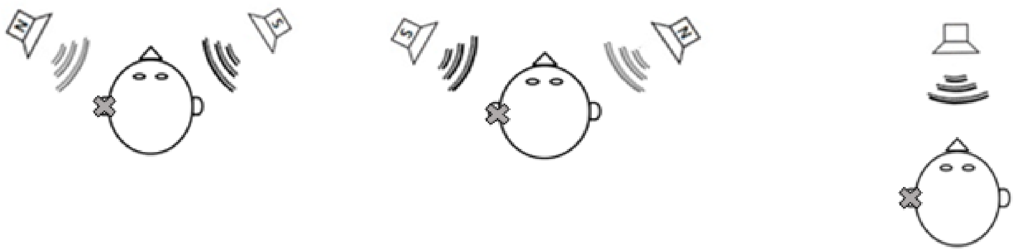
Test Protocol

The BKB/A has 21 lists of 16 sentences each recorded using a female voice (female New Zealand English native speaker). The CNC words test has 10 lists of 50 items each (male New Zealand native English speaker). Speech materials were recorded in a sound studio with 16-bit resolution and 44.1-kHz sampling frequency and normalized to -1 dB. Multi-talker babble was generated using seven seconds of the NOISEX-92 speech babble recording with minimal amplitude variation that was looped to generate several minutes of babble. The NOISEX-92 babble original recording consists of 100 people speaking in a canteen (room radius > 2 m), recorded using a half-inch Brüel & Kjaer condenser microphone onto digital audio tape (Varga & Steeneken, 1993). Speech and noise were presented via a DELL laptop and clinical audiometer.

Speech recognition was measured in the sound field with three loudspeakers placed 1 m from the participant at −45°, 0°, and 45° azimuth, with the centre of the speaker at approximately head height. The following conditions were tested: a) *Monaural Direct* (MD): signal to good ear/noise to bad ear (CNCs, BKB/A sentences), b) *Monaural Indirect* (MI): signal to bad ear/ noise to good ear (CNCs, BKB/A sentences), and c) *signal/noise in front* (SNF) (BKB/A sentences only) (Figure 2).

The level of the speech through the loudspeakers was set at 65 dB SPL for the CNC words, with multi-talker babble noise fixed at 60 dB SPL. Whole word scoring was used and percent correct scores (%) were determined. For BKB/A sentences, the speech recognition threshold (SRT) in noise was defined as the signal-to noise ratio (SNR) producing 50% correct whole sentence recognition, measured using an adaptive (two-up/two-down) procedure (Plomp & Mimpen, 1979; Ruscetta et al., 2005).

For the adaptive BKB/A task noise was at a fixed level (60 dB SPL) and the speech level was adjusted on the audiometer. The two first sentences served as practice, presented at 64 dB SPL and if they were repeated correctly the signal was decreased by 4 dB (initial step size), then if the sentence was repeated correctly the signal was decreased by 2 dB and if repeated incorrectly, the signal was increased by 2 dB. After a complete list was administered (26 sentences), the average presentation level for the last 10 items, corresponding to the 50% correct identification level, was calculated as the speech recognition threshold (50% SRT). The advantage of this adaptive procedure is that it avoids the 'floor' and 'ceiling' effects that can occur for a fixed-intensity-level task.



Monoaural Direct (MD)	**Monoaural Indirect (MI)**	**Signal/Noise front (SNF)**
Speech to the good ear / Noise to the bad ear	Speech to the bad ear / Noise to the good ear	Speech and noise at same location (front)

Figure 2. *Spatial speech (S) in noise (N) test setup for a person with UHL in their left ear showing monaural direct condition (MD), monaural indirect condition (MI) and speech and noise front (SNF)*

Self-reported hearing performance

The purpose of the functional assessment of hearing is to describe auditory behaviour and perceived listening difficulties in different situations of daily life which are not fully described by the pure tone audiogram or speech scores. This is particularly important for establishing the individual's needs for intervention. The following questionnaires are suggested for adults and children.

1. Adults

Speech, Spatial and Qualities of Hearing Scale, short version (SSQ12) (Noble, Jensen, Naylor, Bhullar, & Akeroyd, 2013), available online at https://www.ihr.mrc.ac.uk/pages/products/ssq

The SSQ12 was designed to measure self-perception of auditory disability in three domains (speech recognition, spatial hearing and qualities of hearing), separated into subscales such as speech in noise, multiple speech streams, localisation, segregation, and listening effort. The original questionnaire had 49 items (Gatehouse & Noble, 2004); for our research we used the 12-item short version. Participants rated their responses using a 0-10 scale presented as a ruler, with the left-hand end of the scale representing inability or absence of quality and the right-hand end indicating full ability or presence of quality (Gatehouse & Noble, 2004). This questionnaire is being increasingly used in international studies. Data for normal hearing New Zealand listeners are being collected and are available on request.

2. *Children*

a. *Listening Inventories for Education (LIFE), NZ short version (Barry, Tomlin, Moore, & Dillon, 2015; Purdy, Smart, Baily, & Sharma, 2009)*

This is a student self-report measurement tool that identifies classroom situations which present a listening challenge for a student. The questionnaire comprises seven questions grouped into three subscales; listening in quiet, listening in noise and focused listening. Higher scores indicate more listening difficulty. This questionnaire is suitable for school age children (6-7 years). Normative data are available for typically developing school-aged children with no listening difficulties. This questionnaire has good test-retest reliability (Purdy et al., 2009) and has been shown to be sensitive to listening difficulties experienced by children with reading or auditory processing problems (Purdy et al., 2009; Barry et al., 2015).

b. *Auditory Behaviour in Everyday Life, ABEL (Purdy, Farrington, Moran, Chard, & Hodgson, 2002)*

The ABEL questionnaire examines parental perceptions of their child's auditory abilities, for children as young as 3-4 years. The ABEL has 24 questions grouped into three subscales: aural oral, auditory awareness and social/conversational skills. Higher scores indicate less difficulty. The ABEL has been translated into several languages including Portuguese and Spanish (Herrera et al., 2015; Souza, Marilia Rodrigues Freitas de, Osborn, Gil, & Iório, 2011).

c. *Speech, Spatial and Qualities of Hearing Scale (SSQ), parent and child versions (Galvin & Noble, (2013)*

These versions are adaptations of the original SSQ for parents and children. The child self-report version is suitable for children aged 11 years and older and the parent version is suitable for children from 5 years of age. The instructions for completion of the questionnaire are the same as for the original SSQ form. A period of observation of one week is needed before the completion of each section in the parent version. As there are three sections the parent questionnaire is completed over a three week period. The child version can be completed on site as no observation period is needed.

Conclusion

The following types of assessment are recommended when evaluating the impact of UHL or hearing technology for UHL in children and adults: spatial speech recognition in noise, sound localisation and self-perception of listening difficulties. Procedures for administering these assessments are described here. Further research is needed to establish robust normative for adults and children in New Zealand for these assessments.

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