Audiovisual Speech Perception Abilities of Children with Normal Hearing in Quiet and in Noise & Comparison to Participants with Cochlear Implants

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Abstract

Previous research suggests that the speech perceptual abilities of children with normal hearing differ from those of children with cochlear implants when auditory and visual information are presented simultaneously. The current study aims to investigate the audiovisual integration abilities of nine children and young people with cochlear implants (aged 6-23 years) and 31 children with normal hearing (aged 7, 11 or 15 years). Participants took part in an audiovisual speech reading assessment and an audiovisual attention task. The audiovisual speech reading task involved listening to and repeating sentences under four different listening conditions; audiovisual, auditory alone, audiovisual+noise and auditory+noise. The audiovisual attention task involved attending to a computer presentation of a sequence of auditory and visual stimuli. For this assessment the participants were required to click the mouse whenever he/she ‘heard’ or ‘saw’ the target ‘1’. For the speech reading task, the addition of visual cues was beneficial for speech perception in ideal listening conditions for both groups. Interestingly the presence of visual cues was neither beneficial nor detrimental to speech perception in poor listening conditions for both groups. The presence of noise had a detrimental affect on the speech perceptual abilities of both groups.

Key words: audiovisual, speech perception, cochlear implants, and noise

Introduction

What is the effect of auditory and visual cues on speech perception for individuals with normal hearing?

The perception of speech involves the listener's ability to use different sources of sensory information to interpret a message (Sommers, Tye- Murray & Speher, 2005). The auditory signal provides the listener with information about the location of the sound, intensity of the signal and temporal spatial information. The visual signal provides the listener with information about the vocal tract and actions and movement of the internal and external articulators (Summerfield, 1987, cited in Lachs, Pisoni, & Iler Kirk, 2001). Sensory exposure helps to focus the listener's attention to the oral and aural components of language, which may help to strengthen one's phonological and lexical representations in memory (Lachs, Pisoni, & Iler Kirk, 2001; Hnath-Chisolm, Laipply & Boothroyd, 1998).

Until recently it was thought that the auditory signal was the main channel for speech perception (Desjardins & Werker, 2004). Research done with hearing impaired and hearing individuals suggested that the visual information provided by the speaker's mouth facilitated speech perception (Desjardins & Werker, 2004; Lachs, Pisoni & Iler Kirk, 2001). McGurk and MacDonald (1976) found that speech perception is strongly influenced by watching the speaker's mouth movements and listening to the auditory signal (cited in Desjardins & Werker, 2004). When a face saying /ga/ was paired in synchrony with a sound track /ba/ the listeners heard /da/. When auditory /ba/ was paired with a face that said /va/, the listener heard /va/. Listeners in both cases report a unified percept; they are unaware that the signals are mismatched. Female listeners had superior lip reading abilities and were better at integrating audiovisual speech information than the male listeners (Johnson, Hicks, Goldberg & Myslobodsky, 1988; Watson, Qui, Chamberlain & Li, 1996; cited in Desjardins & Werker, 2004). The researchers also found that young children aged 3-5 and 7-8 years were less influenced by the visual signals than the adults, particularly when the audio and visual information are mismatched (cited in Desjardins & Werker, 2004).

What is the effect of auditory and visual cues on speech perception for hearing impaired individuals with cochlear implants?

Oral language development in young children with hearing impairments is enhanced with cochlear implants. The auditory information accessed through the cochlear implant appears to provide significant benefits for the development of oral communication domains including sound repertories, speech perception and intelligibility and conversational abilities (e.g., Tobey, Geers, Brenner, Altuna & Gabbert, 2003). Research suggests that exposure to auditory sensory information via a cochlear implant will enhance speech perception over time (Bergeson, Pisoni & Davis, 2003; Horn, Davis, Pisoni & Miyamoto, 2005).

Audiovisual speech perception studies of hearing impaired children with cochlear implants suggest that children with implants are more likely to use both auditory and visual information when perceiving speech. Audiovisual benefit is likely to depend on auditory sensitivity, speech reading abilities, implantation and the integration of the auditory and visual speech information (Sommers, Tye- Murray & Speher, 2005). Erber (1972a) found that children with hearing impairments had increased speech perception performance on an audiovisual condition compared to an auditory alone condition, indicating that children with hearing impairments are able to use and combine both visual and auditory stimuli to process information (cited in Lachs et al., 2001). Lachs, Pisoni and Iler Kirk's (2001) findings were similar to Erber's (1997) results. Lachs et al. investigated the ability of prelingually deaf children with cochlear implants to combine perceptual information from spoken language from two sensory modalities (audition and vision). The children's performance was better on the audiovisual condition than the auditory alone and visual alone conditions (Lachs, Pisoni & Iler Kirk, 2001).

Tyler et al. (1997) found that four years post implant children's performance on consonant recognition in three conditions (visual alone, auditory alone and audiovisual) was better than when the children were two years post implant. Their performance on the audiovisual condition was better than the visual and auditory alone conditions. Geers and Brenner (1994) found that, prior to implantation, children's performance on sentence and word perception tasks for audiovisual and visual alone conditions were similar. Post implantation, their performance on the audiovisual condition was better than their performance on the visual condition. These findings suggest that there is an auditory gain which changes over time following cochlear implantation (Bergeson, Pisoni & Davis, 2003).

Bergeson, Pisoni and Davis (2003) also investigated the development of audiovisual speech perception in children that are prelingually deaf that have cochlear implants. Audiovisual spoken word and sentence recognition skills were assessed using the Paediatric Speech Intelligibility test (Jerger, Lewis, Hawkins & Jerger, 1980) under three listening conditions (auditory alone, visual alone, audiovisual). Their findings suggest that the children's performance in all conditions improved over time following implantation. Performance on the audiovisual conditions were better than the visual alone and auditory alone conditions (Bergeson, Pisoni & Davis, 2003). There is consensus in the literature that the speech perception skills of children with cochlear implants will improve over time, with the addition of auditory information.

Is there a gender difference in speech perception for normal hearing children?

Current literature suggests that males and females prefer different properties of a stimulus (visual versus auditory) when perceiving speech sounds (Cameroon, 2004; Sloutsky & Napolitano, 2003; Stollman, Van Velzen, Simkens, Snik, & Van der Broek, 2004). Young males (aged 6-9 years) are more likely to attend to auditory cues; whilst young females are more likely to benefit from the addition of visual cues when performing a speech perception task (Cameron, 2004).

Sloutsky and Napolitano (2004) investigated the preference for the auditory modality in young children. Their findings indicate that when auditory and visual stimuli are presented separately four year olds are likely to process both stimuli. However, when both stimuli are presented simultaneously four year olds are more likely to process auditory stimuli than visual. When the scores of the young children were compared to that of adults the researchers found that the adults were more likely to respond to visual stimuli when auditory and visual information was presented simultaneously (Sloutsky & Napolitano, 2004). This is consistent with; McGurk and MacDonald's (1976) findings for the so-called "McGurk effect" whereby the visual stimulus dominates when conflicting auditory and visual cues are presented to adults.

Sloutsky and Napolitano (2004) suggested three possible reasons to account for their findings: 1) the auditory system matures earlier than the visual system, 2) the auditory system is also functionally more important for language acquisition than the visual system and this advantage might decrease after the child has mastered language acquisition and 3) the dominance of the auditory system stems from different attentional demands for processing visual and auditory stimuli. Typically, a sound disappears after a relatively short period of time, whereas a corresponding visual scene may be present for a much longer time, so therefore it seems more adaptive to allocate attention to sound before allocating attention to visual scene (Sloutsky & Napolitano, 2004; Sekiyama, Kanno, Muira & Sugita, 2003).

The current study aimed to further explore audiovisual speech perception abilities in children aged 7, 11 and 15 years. It was hypothesised that there would be gender differences in audiovisual speech perception abilities that would differ across age groups. In addition to the three groups of children with normal hearing, children and young people with profound deafness and a single cochlear implant were assessed to determine how their audiovisual speech perception abilities compared to the participants with normal hearing

Method

Study 1: How does access to auditory *versus* audiovisual information affect speech perception in children with cochlear implants?

Participants:

Participants were nine children and young people between the ages of 6 and 23 years. This included one male adult (aged 23) and four male and 3 female children (M= 8.57, SD= 3.31 years). All participants had a unilateral cochlear implant for at least 12 months before participating in the study. The majority of the participants were implanted with Nucleus 24 cochlear implants. The cause of deafness for majority of the participants was congenital. All nine participants had received approximately 45 sessions of auditory verbal therapy prior to testing. They had no reported visual or learning impairments. All except one participant was a native speaker of New Zealand. The non-native speaker spoke Mandarin as a first language and is proficient in English. All participants were recruited through the Hearing House.

Materials:

A DELL desktop computer with a 71 inch screen and external loud speakers were used to play the Bamford-Kowal-Bench (BKB/A) speech reading DVD (Bench, Doyl, & Daly, 1993). For the BKB/A noise conditions a CD of 4-speaker speech babble was played using a compact disc player, Grason Stadler GSI 61 audiometer and two external loud speakers mounted on stands placed at 45 degrees azimuth and 95 cm behind the participant, on the left and right sides. A Bruel Kjaer 2215 sound level meter was used to set the sound levels for the BKB/A test stimuli and speech babble. A DELL laptop computer with a 14 inch screen were used to play the Integrated Visual and Auditory Continuous Performance Test (IVA + Plus) (Sandford & Turner, 2004).

Procedures:

The University of Auckland Human Participants Committee approved the study. Informed consent or assent was gained from all participants and parental consent was obtained for all the children. Testing was carried out in a sound treated room at the Hearing House. The participants were seen for a 1 hour single session of testing. Testing included the four conditions of the BKB/A (speech in quiet and in noise, with and without visual cues) and IVA testing.

BKB/A

The participants were seated directly in front of and 90 cm away from the computer screen and 95 cm away from the external loudspeakers. The loudspeakers were at approximately a 45 degree angle on either side of the participant. The participants were required to view, listen and repeat a series of short sentences spoken by four Australian speakers presented at 65 dB SPL. At the beginning of the session the participant listened to eight sentences in the audio plus noise and audiovisual plus noise conditions as a practice. Noise was played from the audiometer and loudspeakers placed behind the participant. The test sentences were then randomly presented in four different conditions, with one list for each condition. These four conditions were: 1) audiovisual (sentence list 7); 2) auditory alone (sentence list 3); 3) audiovisual with noise (with 0 dB signal to noise ratio) (sentence list 21); and 4) auditory with noise (with 0 dB signal to noise ratio) (sentence list 17). Although order of test condition was randomised, the sentence list associated with each condition was not randomised and hence differences between test conditions may have been affected by differences in list difficulty. These four lists were chosen because the sentences contained vocabulary appropriate for New Zealand children. Each list contained 16 sentences. At the end of each sentence there was an 8 second gap. The participant was required to repeat the sentence during this gap. Participants were encouraged to listen and watch the speakers and to guess if they were unsure. The test was scored by calculating the percentage of key words correct in each sentence for each condition. Each sentence contained three to four key words with a total of 50 key words in each sentence list.

IVA (Integrated Visual and Auditory Continuous Performance Test)

Participants were seated in front of and 15 to 24 inches away from the computer screen. The experimenter adjusted the computer volume to a comfortable listening level for each participant. Instructions were simultaneously presented visually and verbally by the computer. Participants were required to listen and follow the instructions provided by the computer.

The IVA is divided into four subtests: 1) warm up period, 2) practice period, 3) main test and 4) cool down period. In the warm up period the subject is presented with the target stimuli ‘**1**’ visually for one minute followed by a minute of auditory stimuli. The practice period is a combination of auditory and visual targets and foils for one and a half minutes. The main test is also a combination of visual and auditory targets and foils for a period of 13 minutes. This test section consists of 5 quintiles, which consist of 100 visual and auditory trials, making a total of 500 trials. A single trial is 1.5 seconds. The auditory ‘**1**’ and ‘**2**’ last for 500 ms and the visual ‘**1**’ and ‘**2**’ are presented for 167 ms. The cool down period presents the target visually for a minute followed by a minute of the auditory stimuli. In all four subtest the subject is required to click the mouse one time whenever he/she hears or sees the target ‘**1**’ and not to click the mouse when he/she sees or hears a ‘**2**’(Sandford & Turner, 2004) .

At the end of the test the computer formulates a graph of the participant’s performance. The participant’s auditory and visual raw scores for the response control quotient, and the attention quotient, and the fine motor regulation measures are also obtained. According to the manual, the response control quotient is derived from the auditory and visual prudence (measure of impulsivity and inhibition), consistency (reliability and validity of the response) and stamina (comparison of the average score for the first 200 trials with the last 200 trials). The attention quotient is derived from the visual and auditory viligence (measure of inattention), focus (variability of mental processes for all responses) and speed (average time for all the correct response throughout the test)

(Sandford & Turner, 2004). Scores are reported as standard scores, with a mean of 100 and a standard deviation of 15.

Study 2: How does access to auditory versus audiovisual information affect speech perception in children with normal hearing?

Participants:

Eighteen boys and thirteen girls aged 7 (N=10), 11 (N=13) or 15 (N=8) years (M=10.74 years, SD=3.09) were participants for this investigation. All participants had normal pure tone hearing thresholds (less than or equal to 20 dB HL for octaves 250-4000 Hz), normal vision (ability to read size 6 font lettering at a distance of 40 cm) and were native speakers of New Zealand English. All subjects were recruited through colleagues, friends and Willow Park Primary.

Materials:

In addition to the BKB/A and IVA testing that was performed in Study 1, the children in Study 2 received a visual acuity screen and hearing screen. The Grason Stadler GSI 61 audiometer and external headphones was used for the audiometric assessment. A chart containing a size 6 font word ("swim") placed 40 cm in front of the participant was used for the visual acuity screen (Professor Rob Jacobs, personal correspondence, March 2004).

Procedures:

The University of Auckland Human Participants Committee approved the study. Parental consent was gained for all participants and all children signed an assent form after being told verbally about the study. Testing was carried out at the University of Auckland. The participants were seen for a 1 hour single session of testing. Testing included the four conditions of the BKB/A, IVA testing, pure tone audiometry and a visual acuity screen. Procedures for the BKB/A and IVA were the same as the procedures described in Study 1.

Results

BKB/A results for participants with cochlear implants (Study 1) *versus* participants with normal hearing (Study 2)

As anticipated, the performance of the participants with normal hearing on the four conditions of the BKB/A was better than the participants with cochlear implants (see Figure 1). In ideal listening conditions (i.e. absence of background noise) hearing and cochlear implant (CI) participants' speech perceptual abilities improved with the addition of visual cues. The smallest difference between the CI participants and children with normal hearing was for the audiovisual condition. The greatest difference between the CI participants and children with normal hearing was for the two noise conditions (audio+noise and audiovisual +noise). The CI participants had low scores in noise, regardless of the presence of visual cues.

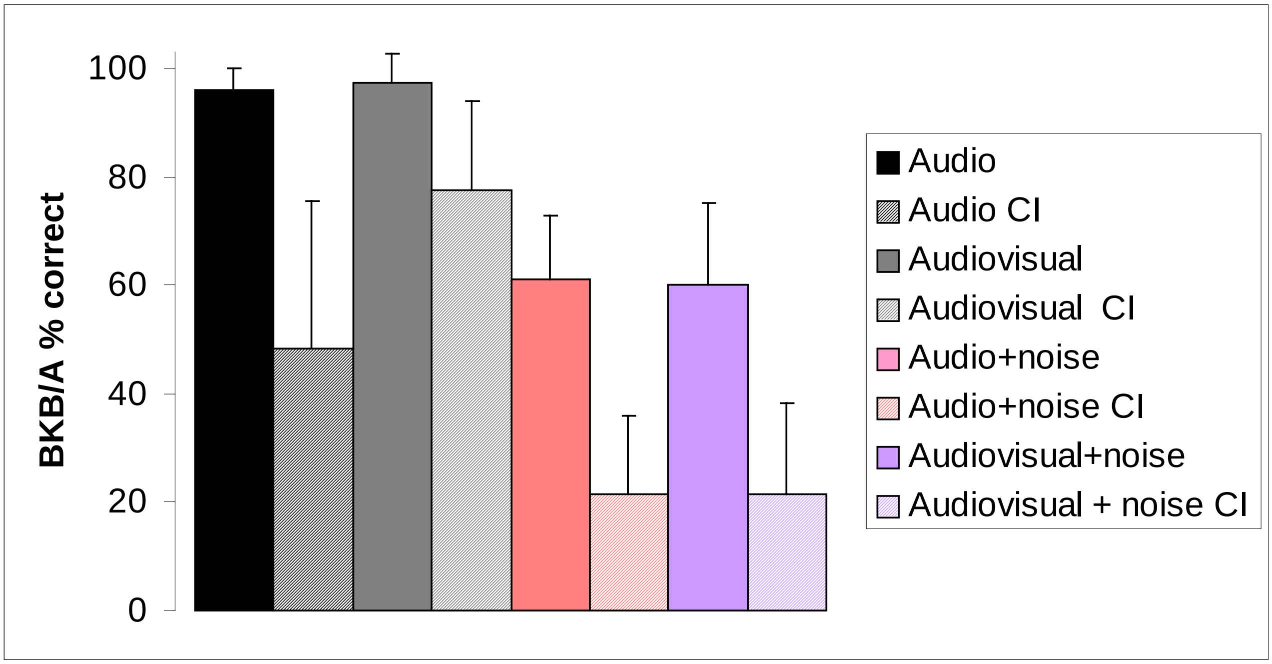

Figure 1. Mean scores (% correct) for all participants for the four BKB/A conditions. Error bars show standard deviations. Solid bars show results for children with normal hearing and bars with diagonal stripes are for participants with cochlear implants.

Table 1 shows results for the children with normal hearing for the three age groups, separately for males and females. The results suggest that normal hearing males and females may use different types of sensory information when perceiving speech. Younger males aged 7 and 11 appeared to prefer auditory cues as they did not benefit from the addition of visual cues, whilst females aged 11 and older males aged 15 did gain slightly from the addition of visual cues in poor listening conditions. Younger females aged 7, like their male counterparts, did not benefit from visual cues in poor listening conditions. It is difficult to see whether visual cues enhanced speech perception in quiet conditions since the scores for these conditions are generally high and there may be a ceiling effect.

Age Group	M/F	N	Audiovisual (AV)	Audio alone	AV +noise	Audio +noise
7 years	male	4	97.5	92.0	52.5	58.0
			(1.9)	(4.3)	(20.4)	(18.0)
7 years	female	6	95.7	93.0	54.0	63.0
			(5.3)	(1.7)	(16.2)	(18.5)
11 years	male	6	99.7	95.3	53.7	56.0
			(0.8)	(5.8)	(11.5)	(5.06)
11 years	female	7	95.4	97.7	68.9	65.1
			(9.5)	(3.1)	(11.8)	(8.2)
15 years	male	8	98.5	98.8	65.0	60.8
			(2.8)	(1.8)	(14.7)	(9.4)
Mean			97.4	95.4	58.8	60.6
SD			3.5	1.7	3.6	6.1

Table 1. Mean scores (% correct) for participants with normal hearing (N=31) on the four conditions of the BKB/A. Standard deviations are shown in parentheses.

As expected the presence of noise had a detrimental affect on the speech perceptual abilities of the listener for all groups. The speech perceptual abilities of the normal hearing participants were reduced on average by about 35-40% with the addition of noise (Table 1). Interestingly the cochlear implant participants' performance reduced on average by 25% for the audio and 58% for the audiovisual conditions (Table 2). Thus the great advantage the CI participants had in quiet with addition of the visual cues was lost when noise was present. Audiovisual integration reduced in the presence of noise and only auditory signals appeared to be beneficial for speech perception for the cochlear implant individuals in noisy listening conditions.

Age (years)	M/F	Audiovisual (AV)	Audio alone	AV +noise	Audio +noise
6	male	80	74	6	32
6	female	72	58	34	10
6	female	40	28	6	**
7	male	92	**	6	**
8	male	88	54	26	22
11	male	78	12	12	14
15	female	90	86	52	44
23	male	80	26	30	6
Mean		78	48	22	21
SD		17	27	17	14

Table 2: Individual and mean scores (% correct) and standard deviations (SD) for cochlear implant participants on the four conditions of the BKB/A. **this condition was too difficult for this participant to attempt

Table 3 shows that the performance of cochlear implant participants for the four BKB/A conditions was worse than that of the youngest normal hearing participants. The smallest gap in performance was for the audiovisual in quiet condition, for which the CI participants were only approximately 15% poorer on average than the children with normal hearing. The average age of the CI participants was 10.25 years and hence the data from the 11 year old participants with normal hearing should be most comparable with that of the CI participants.

Group	Audiovisual (AV)	Audio alone	AV +noise	Audio +noise
7 year olds with	96.4	92.6	53.4	61.0
normal hearing	(4.2)	(2.8)	(16.9)	(17.5)
11 year olds with	97.4	96.6	61.8	60.9
normal hearing	(7.1)	(4.5)	(13.6)	(8.2)
15 year olds with	98.5	98.8	65.0	60.8
normal hearing	(2.8)	(1.8)	(14.7)	(9.4)
Participants with	82.0	46.2	23.6	21.4
cochlear implants	(10.4)	(28.6)	(16.5)	(14.2)

Table 3. Mean scores (% correct) for children with normal hearing and cochlear implant participants on the four conditions of the BKB/A. Standard deviations (SD) are shown in parentheses.

Statistical analysis of BKB/A results

To determine whether the differences in BKB/A scores between children with normal hearing and CI participants a repeated measures analysis of variance was performed with group (CI *versus* normal hearing, NH) as a between-subject factor and noise/quiet and audio/audiovisual as two within-subject factors. Age and gender were included as covariates in the analysis.

As expected there was a significant group effect, with CI participants scoring more poorly than the normal hearing children [F(1,32)=82.03, p<.0001]. There was a significant interaction between group and audio/audiovisual condition [F(1,32)=13.77,

$p=.0008$], presumably because the CI participants benefited much more than the NH participants from the visual cues for the quiet listening conditions.

There was a significant main effect of noise on speech scores [$F(1,32)=61.99$, $p<.0001$] and a significant interaction between quiet/noise and audio/audiovisual conditions [$F(1,32)=8.87$, $p=.0133$]. This two-way interaction reflects the finding that the addition of visual cues did not consistently enhance speech scores for the noisy listening conditions.

The main effect of audio/audiovisual was not statistically significant, but there was significant interaction between participants' age and this variable [$F(1,32)=4.99$, $p=.0327$]. As shown in Table 2 and 3, it was only the participants with normal hearing in the older age groups (11 year old females, 15 year old males [note that 15 year old females were not tested]) that benefited from the addition of visual cues when listening in noise. There was also a three-way interaction between audio/audiovisual, noise and gender [$F(1,32)=11.36$, $p=.0020$]. This three-way interaction is illustrated in Figure 2, which shows that females had higher scores overall, and females improved with the addition of visual cues for both quiet and noise conditions. Scores for male participants only improved with the addition of visual cues for the easier listening condition.

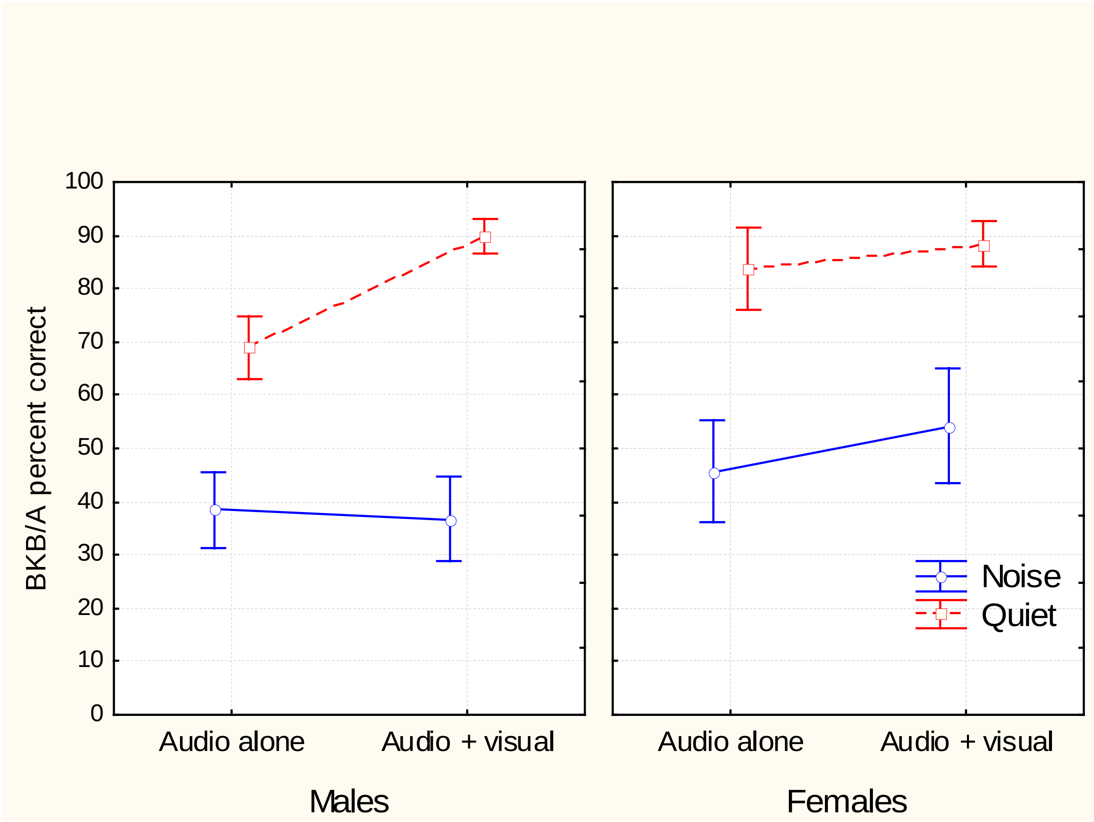

Figure 2. Mean BKB/ scores (%) across all participants showing poorer scores in noise than in quiet, and improved scores with the addition of visual cues for the females for both noise and quiet and for the males only for quiet. Error bars show 95% confidence intervals.

IVA results for participants with cochlear implants (Study 1) *versus* participants with normal hearing (Study 2)

The IVA data in Tables 4 and 5 are standard scores that take into account the age of the participant and hence one can compare the two groups. Overall, normal hearing participants performed better than the cochlear implant (CI) participants on the IVA task, although three of the CI participants did well on this task for all four measures. CI scores on average were more than or equal to two standard deviations below the normative mean of 100 (SD=15). Normal hearing participants' performance on average fell within one standard deviation below or above the mean, supporting the use of the United States norms for this task with New Zealand children. Interestingly, the 11 year old females scored above the mean for both response and attention quotients, suggesting that they may have been an above average "normative" group. Table 5 shows that across the whole group the participants with normal hearing were very close to the normative standard score of 100.

Age (years)	Auditory response	Visual response	Auditory attention	Visual attention
6	92	88	66	86
6	Invalid score	Invalid score	Invalid score	Invalid score
6	99	78	71	85
7	Invalid score	Invalid score	Invalid score	Invalid score
8	122	126	123	115
11	111	130	106	109
15	114	114	102	98
23	58	76	88	101
Mean	75	77	70	74
SD	50	51	47	47

Table 4. Individual IVA standard scores for cochlear implant participants. Standard deviations (SD) are shown in parentheses.

CI participants did not show consistent auditory-visual differences for the IVA task. Two of the younger CI participants could not reliably complete the IVA task and two CI participants who could complete the task scored more than one standard deviation below the normative mean for their age group. There was a very wide range of performance on the IVA task for the CI group.

An analysis of variance showed no statistically significant effects of group, age or gender on any IVA scores. There was also no correlation between any IVA scores and audiovisual speech scores, or audiovisual “enhancement” (average improvement in speech scores with addition of visual cues compared to audio alone conditions). Thus auditory and visual attention and vigilance were not predictive of audiovisual speech perception in the current study.

Age Group	M/F	N	Auditory response	Visual response	Auditory attention	Visual attention
7 years	male	4	99.5 (13.7)	93.5 (12.2)	91.0 (13.2)	94.5 (11.3)
7 years	female	6	93.0 (14.8)	90.5 (16.0)	104.7 (5.8)	99.3 (10.3)
11 years	male	6	96.8 (12.6)	106.7 (15.1)	99.0 (9.9)	102.8 (17.2)
11 years	female	7	107.0 (11.5)	115.0 (9.7)	109.3 (10.6)	112.9 (8.2)
15 year	male	8	94.3 (25.1)	90.8 (11.4)	97.5 (21.1)	101.0 (15.2)
Mean			98.1	99.3	100.3	102.1
SD			5.5	2.6	5.7	3.7

Table 5. Mean standard scores for participants with normal hearing on the IVA. Standard deviations (SD) are shown in parentheses.

Discussion

What is the effect of noise and visual cues on BKB/A speech perception scores and how does this compare for participants with normal hearing *versus* cochlear implants?

Overall, male and female cochlear implant participants and normal hearing participants benefited from the use of visual cues for speech perception. This is consistent with the common belief that access to visual information via the speaker's mouth enhances speech perception (Desjardins & Werker, 2004; Bergeson, Pisoni, & Davis, 2003; Lachs, Pisoni & Iler Kirk, 2001). Interestingly, in the listening in noise conditions the presence of visual cues was neither beneficial nor detrimental to the speech perceptual abilities of the cochlear implant and normal hearing participants. The finding that CI participants benefited from the presence of both auditory and visual cues in ideal listening conditions is consistent with the findings of Lachs et al. (2001), Bergerson et al. (2003) and Geer and Brenner (1994) that audiovisual integration and speech perception improves over time following implantation. One would have expected that the CI participants to be more 'visually aware' than listeners with normal hearing. The lack of visual enhancement for speech perception in noise for the CI participants is counter-intuitive and may be related to the CI participants' experience with auditory-verbal therapy that focuses on listening rather than looking to understand speech (Lachs, et al., 2001; Bergeson et al.,2003).

As anticipated, the presence of noise had a detrimental effect on speech perception for both the cochlear implant and normal hearing participants. Speech perceptual abilities reduced on average by 42% for cochlear implant participants and 37% for normal hearing participants with the addition of noise. Some of the CI participants performed very poorly in noise, which is consistent with the finding in the literature for users of a single cochlear implant (e.g. Hochberg, Boothroyd, Weiss & Hellman, 1992).

There are several possible reasons for the participants' poor performance in noise: 1) participants were less able to extract the desired target from the background noise due to a low signal to noise ratio, 2) participants were less able to make use of the semantic information to assist with audio and audiovisual perception and 3) listener fatigue (although order of test condition was randomised).

Are there developmental or gender effects on speech perception within the normal hearing participants?

Young children (aged 4) tend to prefer auditory stimuli when perceiving speech, whilst older children and adults tend to prefer visual cues (Sloutsky & Napolitano, 2004), indicating a possible developmental affect on speech perception. The results from the current study indicate that in poor listening conditions 7 year olds (males and females) and 11 year old males are more likely to use auditory cues for speech perception, whilst the 11 year old females and 15 year old males used both auditory and visual information. This finding suggests that perhaps there is a sensitive period for audiovisual integration in speech perception (e.g. Schorr et al.2005). Schorr et al (2005) found that children (aged 5-14 years) with normal hearing and poor bimodal fusion (auditory and visual integration) speech perception were dominated by auditory stimuli, whilst those with stronger bimodal integration experienced consistent bimodal fusion. These authors propose that a sensitive period for bimodal fusion also exists for children with cochlear implants (aged 5-14 years). Under bimodal conditions most children with cochlear implants did not experience bimodal fusion and speech perception was dominated by visual stimuli. Consistent auditory visual fusion reduces with the age at which the child is implanted (Schorr et al., 2005).

Cameron (2004) investigated the audiovisual integration of young children (aged 6-9 years) and found that the presence of visual cues did not enhance speech perception scores for male participants. The visual cues seemed to distract the male participants instead of assisting them. Interestingly, in the current study this effect was only seen in young males (aged 7 and 11) and young females (aged 7) in poor listening conditions, whilst females (aged 11 and 15 year old males) benefited from the presence of visual cues (e.g. Cameroon, 2004; Sloutsky & Napolitano, 2003)

The benefit of having visual cues for speech perception is also seen in older people. Hickson, Hollins, Lind, Worrall & Lovie-Kitchin (2004) found that the presence of visual cues benefited speech perception in older people (aged 60-97) when tested on the BKB/A speech reading assessment. Participants with either normal hearing or mild hearing losses had an 86% visual benefit with the addition of visual stimuli in the presence of a zero signal to noise ratio. There was only one male participant that did not benefit from the addition of visual cues.

What is the effect of auditory and visual attention skills on speech perception and how does this compare for participants with normal hearing *versus* cochlear implants?

The participants with normal hearing all performed within the normal range on the IVA task. Surprisingly there were no consistent auditory/visual differences in the cochlear implant participants. There was a wide range of performance, however, with some participants doing very well and others performing well below the norm for both visual and auditory tasks. This is consistent with Pisoni et al.'s (2003) and Lachs et al.'s (2001) findings that hearing impaired individuals performed worse than participants with normal hearing on a range of tasks in both the auditory and visual modalities. This contradicts the common perception that people who are deaf do better in the visual modality. There was no relationship between IVA performance and speech perception scores or audiovisual enhancement of speech perception scores.

Conclusion:

Overall participants with normal hearing performed better than the participants with cochlear implants on all tasks. The presence of auditory and visual information simultaneously was beneficial for speech perception in ideal listening conditions for both groups. As anticipated noise reduced the participants' ability to perceive speech; having a more severe impact on the performance of the cochlear implant participants than those with normal hearing.

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