INT. J. LANG. COMM. DIS., MARCH–APRIL 2009,
VOL. 44, NO. 2, 164–174

Investigating the psycholinguistic correlates of speechreading in preschool age children

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(*Received 22 June 2007; accepted 2 February 2008*)

Abstract

Background: Previous research has found that newborn infants can match phonetic information in the lips and voice from as young as ten weeks old. There is evidence that access to visual speech is necessary for normal speech development. Although we have an understanding of this early sensitivity, very little research has investigated older children's ability to speechread whole words.
Aims: The aim of this study was to identify aspects of preschool children's linguistic knowledge and processing ability that may contribute to speechreading ability. We predicted a significant correlation between receptive vocabulary and speechreading, as well as phonological working memory to be a predictor of speechreading performance.
Methods & Procedures: Seventy-six children ($n=76$) aged between 2;10 and 4;11 years participated. Children were given three pictures and were asked to point to the picture that they thought that the experimenter had silently mouthed (ten trials). Receptive vocabulary and phonological working memory were also assessed. The results were analysed using Pearson correlations and multiple regressions.
Outcomes & Results: The results demonstrated that the children could speechread at a rate greater than chance. Pearson correlations revealed significant, positive correlations between receptive vocabulary and speechreading score, phonological error rate and age. Further correlations revealed significant, positive relationships between The Children's Test of Non-Word Repetition (CNRep) and speechreading score, phonological error rate and age. Multiple regression analyses showed that receptive vocabulary best predicts speechreading ability over and above phonological working memory.
Conclusions & Implications: The results suggest that preschool children are capable of speechreading, and that this ability is related to vocabulary size. This suggests that children aged between 2;10 and 4;11 are sensitive to visual information in the form of audio-visual mappings. We suggest that current and future therapies are correct to include visual feedback as a therapeutic tool; however, future

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International Journal of Language & Communication Disorders
ISSN 1368-2822 print/ISSN 1460-6984 online © 2009 Royal College of Speech & Language Therapists
http://www.informahealthcare.com
DOI: 10.1080/13682820801997189

research needs to be conducted in order to elucidate further the role of speechreading in development.

Keywords: Speechreading, receptive vocabulary, phonological memory.

What this paper adds
This paper adresses a gap in the literature on the development of speechreading. Our results show that preschool children are capable of speechreading, and that this ability is best predicted by children's current vocabulary knowledge. The results suggest a role for visual information even in young children's language processing, raising the possibility that future therapies could make use of the visual modality during language intervention.

Introduction

Visual information from a speaker's mouth and face plays an important role in the perception and understanding of spoken language (for a review, see Massaro 1998). Under noisy conditions visual cues provided by the face and mouth supplements the auditory signal, increasing perceptual accuracy (e.g., Sumby and Pollack 1954). The visual advantage has been estimated to be equivalent to increasing the auditory signal by around 15 db (Nielsen 2004). Importantly, we also make use of visual information during the understanding of clear and unambiguous speech (Reisberg *et al.* 1987, Arnold and Hill 2000). Campbell *et al.* (1998) suggested that speech perception may not solely rely on auditory processing structures. A review of the experimental literature on speech perception suggests that the visual and auditory inputs are integrated early in processing, and are then projected and fused into an amodal space (Schwartz *et al.* 1998, also Campbell 2007).

Campbell (2007) identifies two ways by which visual information may aid speech perception. The first is *complementary*, whereby speech provides essential information in addition to the acoustic signal, which for some reason may be degraded. In this instance visual information is compensatory. The second is *correlational*, whereby a 'hearer' can utilize high levels of audio-visual phonemic mapping consistency. In this instance, visual information can be either compensatory or redundant. As in the complementary mode, it can be compensatory when there is a degraded acoustic signal. However, the redundancy of the audio-visual phonemic mapping also makes it possible for people with hearing problems to use spoken language since, as in the case of English, most individual words are visually unique despite the language only using some 40-odd phonemes (MacEachern 2000).

There is evidence that access to visual speech is necessary for normal speech development (Mills 1987). Even young infants appear sensitive to the synchrony between visual and auditory information. For instance, Dodd (1979) reported that 10–16-week-old infants attended to asynchronous nursery rhymes (delay between the voice and mouth movements) significantly less than to those where the auditory and visual presentation was synchronous, suggesting that vision plays an important role in the acquisition of speech perception abilities in young children. Later work by Dodd (1987) tested older children (aged 19–36 months) to investigate how speechreading ability relates to language acquisition. Children were given sets of three pictures and had to point to the picture that they believed the experimenter had mouthed. The pictures consisted of a target word (e.g. *duck*), a phonologically similar word (e.g. *fork*), and a phonologically and semantically unrelated word (e.g. *doll*). The results showed that the target picture was selected more often than chance and that when errors were made they were most often phonologically related. It was concluded that speechreading was important for language acquisition, as it would increase both awareness and experience of language, and therefore give a better grounding for language to be acquired. However, beyond the demonstration that young children are capable of speeachreading, it is unclear what predicts their ability to do so.

More recent work has investigated the relationship between speechreading ability and other cognitive and linguistic abilities. Lyxell and Holmberg (2000) investigated the performance of hearing impaired and normally hearing 11–14 year olds on a series of cognitive tasks, including a reading span test, a rhyme judgement task, and a speechreading task. They reported that performance on all other cognitive tasks correlated with speechreading performance, for both hearing and hearing impaired participants. More specifically, they reported a strong correlation between speechreading sentences and a visual word-decoding task. They suggested that it is not just visual skills that are related to speechreading performance, rather, successful performance depends on the activation of items in the lexicon, implicating children's vocabulary knowledge.

Other findings suggest that reading ability predicts speechreading ability in some special populations. Mohammed *et al.* (2006) tested prelingually deaf adults, normally hearing adults, and adults with a history of dyslexia on a speechreading task. Additionally, the participants' reading ability, vocabulary knowledge, and phonological awareness skills were measured. The groups differed in their speechreading ability: the deaf adults performed significantly better than the normally hearing adults, who in turn performed significantly better than the adults with a history of dyslexia. Reading ability did not predict speechreading performance in the normally hearing group; however, reading ability and speechreading were correlated in the deaf and dyslexic groups. In particular, this relationship for the dyslexic group was mediated by phonological awareness, whereas this was not the case for the deaf group. Additionally, vocabulary knowledge was related to the speechreading ability in the deaf group only. The authors suggested that speechreading ability is mediated by speech-based phonological representations, which is consistent with the notion that reading ability is predicted by phonological awareness (Ziegler and Goswami 2005). In the case of the dyslexic group, their phonological awareness was the only predictor of success. However, the deaf participants further relied on their vocabulary knowledge, suggesting that they perhaps compensated for their poorer ability to decode the phonemic structure of words by utilizing visual mappings at the word level.

These results suggest two implications for development of speechreading ability. First, despite a history of phonological insensitivity it is possible to break into a spoken language using visual cues, as is the case for the deaf speakers, and this ability appears to be in part related to vocabulary knowledge in the spoken language. Second, phonological awareness continues to predict speechreading in adults whose phonological systems have at one point lagged behind their other linguistic abilities, raising the possibility that phonological knowledge predicts speechreading in children.

In the current study we address a gap in the literature on speechreading. The early literature suggests that infants are sensitive to the synchrony between sound and mouth movements. The literature on older children suggests that variables related to literacy, in particular, phonological awareness, predict performance on speechreading tasks. Mohammed *et al.* (2006) also showed that reading ability also predicted speechreading performance in deaf adults and those with a history of dyslexia; however, performance in the two groups was attributed to different factors, notably, phonological awareness (dyslexic, deaf) and vocabulary (deaf). In an functional magnetic resonance imaging (fMRI) study Capek *et al.* (in press) showed that deaf and hearing adults use overlapping brain areas during speechreading, suggesting that speechreading in these populations is a qualitatively similar process.

Therefore, in the current study we investigated the contribution of children's phonological and vocabulary knowledge to their performance on a speechreading task. These are two variables that are closely coupled in development. Gathercole and colleagues (e.g., Baddeley *et al.* 1998, Gathercole 1999, 2006) argue that phonological working memory plays a significant role in vocabulary acquisition. In an attempt to clarify this relationship, Bowey (2001) reported on a longitudinal study that showed that the association between phonological working memory and vocabulary reflects a latent phonological processing ability that is also manifest in phonological sensitivity. On the other hand, an alternative school of thought argues that phonological representations are constructed during the process of vocabulary acquisition (Walley 1993, Metsala and Walley 1998, Metsala 1999, see also Vihman and Croft 2007). Therefore, it is unclear which particular variables, phonological or vocabulary knowledge, would best predict speechreading in preschool children. We tested children aged 2–5 years using a similar speechreading task used by Dodd (1987). In addition, we tested the children's receptive vocabulary and phonological working memory. We predicted that, since phonological working memory and vocabulary are closely related, both would significantly predict speechreading ability. However, we also aimed to investigate which variable best predicted speechreading by performing a number of regression analyses.

Methods

Participants

There were 76 participants (38 boys and 38 girls) ranging in age from 2;10 years to 4;11 years. The participants were all members of preschool classes in three separate nursery schools in Warrington, UK. None of the children tested had any known learning or developmental difficulties. The children were tested individually in a quiet room, in the presence of a nursery nurse. It should be noted that only 56 participants completed The Children's Test of Non-Word Repetition (Gathercole and Baddeley 1996), since some of the younger children failed to understand the requirements of the task.

Materials and procedure

All participants were tested individually. They were first tested on The British Picture Vocabulary Scale II (Dunn *et al.* 1997) and The Children's Test of Non-Word

Repetition (Gathercole and Baddeley 1996). Approximately one week later they were tested on the speechreading test.

The British Picture Vocabulary Scale II (BPVS-II; Dunn et al. 1997)

The BPVS-II is a standardized test of receptive vocabulary. Children are presented with an array of four pictures and are required to identify the correct picture for the word that the experimenter reads to them. The test is standardized from the age 3;0 onwards; therefore, only raw scores are reported here because some of the participants were younger than 3;0.

The Children's Test of Non-Word Repetition (CNRep; Gathercole and Baddeley 1996)

The CNRep is a measure of children's phonological working memory. This test was chosen because the children were of preschool age, and other tests of phonological sensitivity that have a metalinguistic component, such as a phoneme identity tasks (e.g., Bowey 2001), would be too difficult for our youngest children to complete. Since Bowey (2001) has shown that non-word repetition and phonological sensitivity are highly correlated, we decided that the CNRep was the most appropriate test of phonological knowledge, broadly defined, given our age group (also Coady and Evans 2008).

Speechreading ability test

Before any testing was conducted, a pre-test was carried out to determine the appropriateness of the words and pictures selected for the speechreading test. A total of 70 pictures were shown to 35 children. The children ranged in age from 2;10 to 4;9. They were simply asked to name each picture, to ensure that the pictures were recognizable. All of the children correctly named all the pictures shown to them.

In the speechreading test, 63 pictures (from the 70 pre-tested) were used in total, with three practice pictures and 60 test pictures. Each picture was sized approximately 10 × 6 inches, printed on A4 paper. The pictures were either colour versions of Snodgrass and Vanderwarts' Picture Set (Snodgrass and Vanderwarts 1980, Roisson and Pourtois 2004) or were colour clipart pictures downloaded from http://office.microsoft.com/clipart (Clipart Gallery, n.d.) (Figure 1). The picture words were chosen by matching for age of acquisition and concreteness using the University of Western Australia MRC Psycholinguistic Database (University of

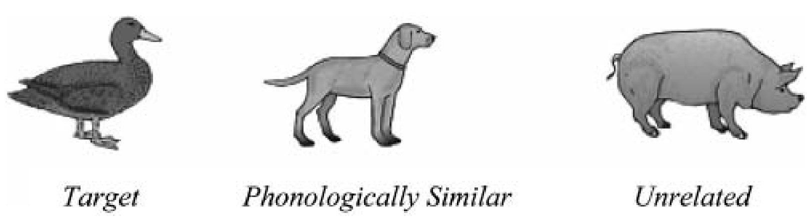

Figure 1. Example of a picture set (shown in colour to participants) given in the speechreading test.

Western Australia, n.d.). The age of acquisition range was set from 100 to 200, corresponding to an age rating of zero to 4 years. The concreteness range was set from 500 to 700 out of a maximum of 700, ensuring that the words were all at the top end of the concreteness range. We selected very concrete words (e.g. dog) as it is known that they are better recalled, acquired earlier in life, and named more rapidly than abstract words (e.g., love) (Walker and Hulme 1999).

The 60 test pictures were grouped into 20 sets of three, with a target word along with a phonologically similar and an unrelated distracter word (for example, participants heard word 'bucket' and were then presented with pictures of a bucket, a button and a carrot). Participants were told that they would be shown three pictures and would be asked to point to the picture that corresponded to the word named by the experimenter. They were also told that the experimenter would sometimes pretend to say a word and that they would have to look at her lips to guess what was being said. Each child was presented with a silently mouthed practice trial to ensure that they understood the instructions (up to three practice trials). After this practice, there were 20 trials per child, ten of where the target word was spoken aloud, and ten where it was silently mouthed by the experimenter. While the 20 target words and associated picture sets remained the same for all participants, the order of the pictures in any one trial was randomized for each participant. In addition, the allocation of trials to the spoken and silent trials was counterbalanced across participants. Each word, whether spoken or silent, was repeated up to three times (repeated by experimenter if participant made no response) and after this it was marked as an incorrect response. The responses made were recorded on a scoring sheet as either correct or incorrect, and if incorrect the picture that they pointed to instead was noted.

Unlike other tests of speechreading, the task was not presented on a computer. It is true that recorded speechreading tests have more validity than live tests; however, we decided to use a live test because we were working with young children, who often require a degree of scaffolding during experimental tasks. The results should therefore be interpreted with this caveat in mind.

Results

The mean values for all tests administered to the participants are displayed in Table 1, along with the ranges and standard deviations. The spoken aloud trials were included to ensure the participants could successfully complete the task when the

Table 1. Means and standard deviations for all tests and age

	Mean	Range	Standard deviation	*n*
Speechreading (silently mouthed trials)	47.89	0.00–80.00	18.35	76
Spoken word trials	99.87	90.00–100.00	1.15	76
BPVS-II	43.49	26.00–77.00	10.30	76
CNRep	15.56	8.00–26.00	4.86	57
Phonological error	66.74	16.66–100.00	20.59	76
Age (years;months)	3;6	2;10–4;11	0.48	76

BPVS-II, British Picture Vocabulary Scale II; CNRep, The Children's Test of Non-Word Repetition.

Table 2. Pearson correlations between all tests and age

	Speechreading	BPVS-II	CNRep	Phonological error	Age
Speechreading					
BPVS-II	0.28 (*) $n=76$ $p=0.01$				
CNRep	0.33 (*) $n=57$ $p<0.01$	0.50(**) $n=57$ $p<0.001$			
Phonological error	0.12 $n=76$ $p=0.31$	0.26 (*) $n=76$ $p=0.03$	0.28(*) $n=76$ $p=0.04$		
Age	0.16 $n=76$ $p=0.17$	0.64 (**) $n=76$ $p<0.001$	0.39(**) $n=76$ $p=0.003$	0.11 $n=76$ $p=0.35$	

BPVS-II, British Picture Vocabulary Scale II; CNRep, The Children's Test of Non-Word Repetition.
*Correlation significant at the 0.05 level (two-tailed).
**Correlation significant at the 0.01 level (two-tailed).

word was heard. Here, performance was at ceiling (mean performance 99.9% correct). The silently mouthed trials were used to measure speechreading. As such, speechreading score was 47.89% showing that the children did speechread at a rate greater than chance (33.33%). A paired samples t-test revealed that participants performed significantly above chance ($t(76)=6.92$; $p<0.001$). The mean number of phonological errors was 66.74%, indicating that the children made phonological errors more frequently than unrelated errors. We present overall correlation data before discussing multiple regression analyses conducted to investigate which variables contribute to speechreading ability.

There were some significant relationships reported between variables using Pearson's product moment correlation coefficient (Table 2). There was a highly significant and positive correlation between The British Picture Vocabulary Scale II (BPVS-II) score and Non-Word Repetition score (CNRep) ($r(56)=0.50$, $p<0.0001$) and also a positive correlation between BPVS-II and speechreading score ($r(75)=0.28$, $p<0.05$). BPVS-II score was also found to have a significant positive correlation with the number of phonological errors made ($r(75)=0.26$, $p<0.05$) and also with age ($r(75)=0.64$, $p<0.0001$). The results show that a higher BPVS-II score is related to higher scores in other tests of language ability and, unsurprisingly, that vocabulary increases with age.

CNRep score was significantly and positively correlated with speechreading score ($r(56)=0.33$, $p<0.05$). There was also a significant positive correlation between CNRep and phonological errors made ($r(56)=0.28$, $p<0.05$) and also with age ($r(56)=0.39$, $p<0.005$). As with BPVS-II score, it appears from the results that non-word repetition ability is related to speechreading ability.

To investigate these relationships further a multiple regression analysis was carried out on the data to determine which factors predicted speechreading ability in the preschool children that were tested (Table 3). The dependent variable in this regression analysis was speechreading score with BPVS-II score, CNRep score, and age (in months) being the independent variables. Using the standard multiple regression method, the model proved to be significant overall ($F(3, 50)=4.03$;

Table 3. Regression analysis when predicting speechreading or phonological error score

	Speechreading			Phonological error		
	Multiple R (R^2)	β	p	Multiple R (R^2)	β	p
	0.44 (0.20)			0.38 (0.14)		
BPVS-II		0.489	0.009*		0.345	0.049*
CNRep		0.108	0.476		0.163	0.271
Age		−0.310	0.059		−1.84	0.242

BPVS-II, British Picture Vocabulary Scale II; CNRep, The Children's Test of Non-Word Repetition.

p=0.012, adjusted R^2=0.146). This followed the deletion of three outliers whose residual errors were greater or less than two standard deviations outside of the solution. From the data shown in Table 3, only BPVS-II score was a direct predictor of speechreading ability, although age approached significance.

A second multiple regression was performed to determine what factors predicted phonological error rate amongst the participants (Table 3). The dependant variable in this instance was phonological error score and the independent variables included BPVS-II score, CNRep score, and age. Using the standard multiple regression method, the model was shown to be significant (F(3, 53)=2.983; p=0.039; adjusted R^2=0.096). The data in Table 3 show that BPVS-II score was the only significant predictor of phonological error rate.

Discussion

The main finding to emerge from the current research is that preschool children aged from 2;10 to 4;9 do have the ability to speechread words. The mean speechreading score of 47.89% suggests a correct answer being chosen at a rate greater than the chance. This ability was not related to age, but instead mainly to vocabulary knowledge. In addition, the mean phonological error rate (66.74%) suggests that children confuse similar sounding words. This suggests that when children err they do not do so at random, but identify a word in the same phonological space as the target. This tendency was also significantly related to children's vocabulary knowledge.

The second aim of this study was to determine psycholinguistic predictors of speechreading ability. The results from our multiple regression analyses suggested that although phonological working memory correlated with performance, vocabulary knowledge was the best predictor of speechreading, and also predicted the tendency to make phonological errors. As would be expected if a larger vocabulary predicts correct performance, a larger vocabulary increases the possibility that children's errors will be phonologically related, since lexical access involves the parallel activation of items from the same phonological neighbourhood; in particular, activating a cohort of items based initially on the onset of the word (Marslen-Wilson 1987, Gaskell and Marslen-Wilson 1997). Therefore, a naïve conclusion would be to suggest that vocabulary size best predicts speechreading; however, the conclusions must be tempered by a number of issues.

Firstly, as outlined in the Introduction, the relationship between phonological working memory and vocabulary acquisition is a complex issue (see Gathercole 2006, and accompanying commentaries). Children's phonological knowledge is acquired during the business of word learning, since words are the smallest psychologically meaningful unit of language. Therefore, a child's lexical knowledge will also be a reflection of their phonological knowledge (Vihman and Croft 2007). Consequently, the closely coupled relationship between these two measures makes it difficult to tease apart totally each individual contribution without using alternative research designs, such as a longitudinal study. Secondly, we suspect that it is likely that speechreading taxes phonological working memory, at least in the case of hearing participants, since a capacious phonological working memory store means that more resources are available to make inferences about phonemic information missing from the speech stream. Since our items were all highly frequent short words (mainly monosyllabic), it is possible that the current study did not tax the phonological working memories of the participants enough to detect an effect over and above that which could be explained by their vocabulary knowledge.

Therefore, we suggest that vocabulary plays a key role in the development of speechreading ability, but the extent of its contribution is a matter for future research. Another matter for future research concerns the exact role of visemic information in the development of speechreading. In this study we did not systematically manipulate visemic information. The target-competitor pairs differed on a number of different dimensions; for instance, most differed in their visemic offset, but some differed in their vowel duration (e.g., *hat–hand*). This was because the initial goal was to determine whether preschool children were in fact capable of speechreading. Future research that systematically manipulates the phonemic and visemic properties is required to tease apart the contribution of audio and visual information in the development of speechreading abilities.

There are some practical implications that may result from the present findings. At a very basic level, the results demonstrated that speechreading ability and other language abilities were related; the results support the notion that the role of vision when processing spoken information should not be underestimated. We have suggested that good vocabulary knowledge results in good speechreading ability; however, children of this age are still rapidly learning language, and therefore may use visual information to learn new words. In contexts where input may be degraded or suboptimal, such as in a noisy classroom, speechreading ability may therefore be important. From a therapeutic perspective, the suggestion is that children can attend to visual information. Indeed, speech therapy for speech production problems does focus on visual information.

To conclude, we have shown preschool children are capable of speechreading and that this skill is related to their existing vocabulary knowledge. The results constitute an initial attempt to explore the speechreading abilities of children at this age, and in doing so begin to bridge the gap between early infancy research and research on older children and adults.

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