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Speechreading development in deaf and hearing children: introducing a new Test of Child Speechreading (ToCS)

Kyle, Fiona Elizabeth, [1] Campbell, Ruth,[1] Mohammed, Tara, [1] Coleman, Mike, [2] & MacSweeney, Mairéad [3]

[1]Deafness, Cognition and Language Research Centre (DCAL), Division of Psychology and Language Sciences, UCL, UK

[2] Developmental Science, Division of Psychology and Language Sciences, UCL, UK

[3] Institute of Cognitive Neuroscience, UCL, UK

Address for correspondence:

Dr Fiona Kyle

Department of Psychology

University of Bedfordshire

Park Square

Luton

Bedfordshire

LU1 3JU

Fiona.kyle@beds.ac.uk

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Purpose: We describe the development of a new Test of Child Speechreading (ToCS) specifically designed for use with deaf and hearing children. Speechreading is a skill which is required for deaf children to access the language of the hearing community. ToCS is a deaf-friendly, computer-based test that measures child speechreading (silent lipreading) at three psycholinguistic levels: words, sentences and short stories. The aims of the study were to standardize ToCS with deaf and hearing children and investigate the effects of hearing status, age and linguistic complexity on speechreading ability.

Method: 86 severely and profoundly deaf and 91 hearing children aged between 5 and 14 years participated. The deaf children were from a range of language and communication backgrounds and their preferred mode of communication varied.

Results: Speechreading skills significantly improved with age for both deaf and hearing children. There was no effect of hearing status on speechreading ability and deaf and hearing showed similar performance across all subtests on ToCS.

Conclusions: The Test of Child Speechreading (ToCS) is a valid and reliable assessment of speechreading ability in school-aged children that can be used to measure individual differences in performance in speechreading ability.

Typical face-to-face communication is multi-modal and speech perception involves the integration of both auditory and visual information (Rosenblum, 2005). The integration of visual and auditory speech seems to occur very early on as young babies are not only sensitive to the visual component of speech (e.g. Dodd & Burnham, 1988; Kuhl & Meltzoff, 1982; Patterson & Werker, 1999) but can detect visual-auditory synchronisation (Dodd, 1979) and even match visual-auditory vowels (Patterson & Werker, 2003) from 2 months old. The importance of the visual component of speech is clearly demonstrated by the McGurk effect, whereby the overlaying of an auditory syllable with a visual bilabial syllable results in a completely different token actually being perceived (McGurk & MacDonald, 1976). Importantly, McGurk effects have been observed in infants as young as 4.5 months using classic habituation and dishabituation paradigms (Burnham & Dodd, 2004; Rosenblum, Schmuckler, & Johnson, 1997). This suggests that visual speech contributes to speech processing even in pre-lingual children; thereby strengthening the argument that speechreading (visual-alone speech perception) is a natural part of speech processing (e.g. Massaro, 1987). Further support can also be found in recent evidence from neuroimaging studies suggesting that silent speechreading activates similar neural circuitry as audio-visual speech (e.g. Calvert, et al., 1997; Pekkola, et al., 2005).

For many deaf and hearing-impaired individuals, speechreading is the main access to the spoken language of the hearing community and yet historically hearing people have often been reported as having at least equivalent, if not better, speechreading skills than deaf individuals (e.g. Arnold & Kopsel, 1996; Conrad, 1977; Green, Green, & Holmes, 1981; Massaro, 1987; Mogford, 1987). Most of these speechreading assessments were either designed to be used with hearing individuals and therefore contained complex syntax and vocabulary or they required written responses, both typically disadvantaging deaf individuals. Over recent years, there has been a growing body of evidence from adult studies showing a deaf advantage in speechreading skills (Auer & Bernstein, 2007; Bernstein, Auer, & Tucker, 2001; Bernstein, Tucker, & Demorest, 2000; Mohammed, Campbell, Macsweeney, Barry, & Coleman, 2006). The series of studies conducted by Bernstein and colleagues demonstrated that deaf adults had superior speechreading skills to normally-hearing college students in terms of phonetic perception when recalling nonsense syllables and also accuracy for words and sentences. Mohammed and colleagues (Mohammed, et al., 2006; Mohammed, et al., 2005) also reported that profoundly deaf adults were significantly better speechreaders than hearing adults when assessed using a deaf-friendly speechreading test: the Test of Adult Speechreading (TAS). The TAS was a computerised picture-to-video matching task which had been specifically designed to assess speechreading skills in deaf individuals by ensuring the language level of the content was appropriate and the response method was nonverbal. The deaf participants achieved an average accuracy score of 67.8% compared with the mean accuracy score of the hearing participants of 57.7% (Mohammed, et al., 2005).

Although comparatively fewer studies have been conducted with children, two recent studies have also suggested superior speechreading skills in deaf children (Kyle & Harris, 2006; Lyxell & Holmberg, 2000). Lyxell and Holmberg (2000) compared the speechreading skills of moderately hearing-impaired adolescents to those of hearing controls matched for reading and chronological age. The hearing-impaired children were significantly better at speechreading both single words and sentences. Likewise, Kyle and Harris (2006) reported better single word speechreading skills in a group of 29 severely and profoundly deaf 7 year olds when compared with younger hearing children matched on reading ability. In the current study, we investigated the effect of hearing status on children's speechreading skills using the new Test of Child Speechreading (ToCS).

Relatively little is known about the developmental trajectory of speechreading skills in children. Dodd (1987) found that hearing infants aged between 19 and 36 months were able to speechread single words and performed above chance when asked to match silently mouthed words to a choice of three pictures. Davies, Kidd and Lander (2009) recently replicated this finding with slightly older hearing pre-schoolers (2 to 5 year olds). There is slightly more research looking at the development of speechreading skills in hearing-impaired children, although the evidence is rather mixed with respect to the effect of age on speechreading ability. Dodd, McIntosh and Woodhouse (1998) reported the results of a 3-year longitudinal study using the Lipreading Assessment for Children with Hearing Impairment (LACHI) with a small group of 16 deaf children (aged between 30 and 57 months at initial assessment). They found that speechreading accuracy initially increased but then began to plateau between the ages of 5 and 6 years old. Similarly, Evans (1965) reported an effect of age on speechreading whereby deaf children's scores rapidly increased between the ages of 8 and 11 years old but then also started to plateau. Unfortunately, as neither study provides many details about the specific ages at which the children were tested, these findings are difficult to interpret. Although the primary focus of the Kyle and Harris (2010) study was the longitudinal predictors of reading, it included longitudinal speechreading data which also concur with the results above suggesting that deaf children's speechreading scores initially increase and then plateau, at around the age of 10 years old. Conversely, Reid (1946), Alegria, Charlier and Mattys (1999) and Davies et al. (2009) failed to find effects of age on speechreading accuracy for deaf or hearing children. However, it is worth noting that the lack of age effect in the Davies et al. study might be expected given the age of the participating children and the relatively small age range (2 to 5 year olds). Although the idea of a plateau in speechreading skills seems to be supported by research, the age at which it occurs and how speechreading actually develops in school-age deaf and hearing children is unclear. An alternative interpretation of these apparent plateaus is that they could also be reflecting the sensitivity of the test material at different ages.

Speechreading ability can be measured at many different psycholinguistic levels such as the word, phrase, sentence or connected speech, which can lead to variability within as well as between individuals. While the elements of an utterance need to be perceived efficiently, this may not be sufficient to ensure understanding of the utterance as a whole. The identification of words requires that the perceiver has a sufficiently detailed lexicon to distinguish a word – whether by phonetic or semantic features. The identification of a phrase or sentence requires good working memory (see Lyxell, Andersson, Borg, & Ohlsson, 2003). Indeed, Lyxell and Holmberg (2000) found this was a better predictor of speechreading accuracy than word identification alone in children with moderate hearing impairment. Also, the more demanding the perceptual task, the more likely that cognitive resources to support comprehension will be stretched. Thus, both for reasons of ecological validity and for further insights into the cognitive resources used by speechreading, it is important to test lipreading at different psycholinguistic levels.

Green, Green and Holmes (1981) assessed deaf and hearing children's speechreading ability for words, phrases and sentences and found that both groups of children were more accurate at speechreading words rather than phrases or sentences.

Lyxell and Holmberg (2000) reported the same effect of psycholinguistic level on the speechreading accuracy of moderately hearing-impaired children. They used an open-ended speechreading assessment whereby children watched a video clip and then had to write down as much of the sentence as they could. However, this type of response format would not be appropriate for assessing speechreading skills in severely or profoundly deaf children given that they typically have well documented difficulties with literacy (e.g. Allen, 1986; Wauters, Van Bon, & Tellings, 2006). Whilst the design of the Davies et al., (2009) and Kyle and Harris (2006, 2010, 2011) speechreading tests were more suitable for use with deaf children, as children were simply required to match speechreading to pictures, both tests only assessed the ability to speechread single words and, moreover, the Davies test was delivered live rather than via video. Mohammed et al.'s (2006) Test of Adult Speechreading (TAS) used a deaf-friendly nonverbal response format and also measured speechreading at three different psycho-linguistic levels: words, sentences and stories. Mohammed and colleagues found that deaf and hearing adults also speechread single words more accurately than sentences, which in turn were easier than short stories. Their findings were similar to those of Green et al. (1981) and Lyxell and Holmberg (2000) suggesting that speechreading accuracy decreases as the complexity and length of the psycholinguistic unit increases. However, as different routes to speechreading expertise have been identified in adults (Andersson & Lidestam, 2005; Ronnberg, et al., 1999), it is important to be able to identify children who may have difficulties in one aspect of speechreading but not in others in order to be able to target interventions appropriately.

The potential role of speechreading in language development has been demonstrated in a recent study showing that visual speech not only enhances phoneme discrimination in 6 month old infants but may also contribute to the learning of phoneme boundaries (Teinonen, Aslin, Alku, & Csibra, 2008). Speechreading has also been linked with written language as strong predictive relationships have been reported between speechreading skills and word reading ability in deaf children (Kyle & Harris, 2006, 2010), deaf adults (Mohammed, et al., 2006) and in beginning typically-hearing readers (Kyle & Harris, 2011). A recent review of the literature and extant speechreading tests by Woodhouse, Hickson and Dodd (2009) identified the need for a valid assessment of speechreading skills in hearing-impaired children. We argue that the converging findings suggesting that speechreading may play a role in the language and reading development of typically-hearing children combined with the lack of current normative data regarding speechreading skills indicate that there is in fact a need for a valid assessment of both deaf and hearing children's speechreading skills. In the current study, therefore, we present a new Test of Child Speechreading (ToCS), suitable for use with both deaf and hearing children, and developed using a similar deaf-friendly format as the TAS (Mohammed, et al., 2006). ToCS was designed to be sensitive enough to measure both individual differences and the development of speechreading ability at different psycholinguistic levels.

The main aims of the current study were to (1) assess the reliability and validity of ToCS as a measure of speechreading and (2) generate performance norms for speechreading ability as assessed by ToCS in school-aged deaf and hearing children. In addition, we wanted to answer the following research questions: (1) Since deaf adults are better speechreaders than hearing adults using a similar test to TOCS (Mohammed, et al., 2006; Mohammed, et al., 2005) are deaf children also better speechreaders than hearing children? (2) Does speechreading improve with age? (3)

Does speechreading become more difficult for children as the size and complexity of the psycholinguistic unit being tested increases?

Method

Participants

177 deaf and hearing children aged between 5 and 14 years participated in the study. There were 86 deaf children and 91 hearing children. The mean age of the deaf children was 9 years 6 months (SD 31.5 months) and the mean age of the hearing children was 9 years 1 month (SD 30.2 months). Children were predominately from schools in southern England. The hearing children were recruited from the mainstream schools to which the deaf units were attached, thereby ensuring that the groups were similar in terms of background demographic variables. Participant characteristics are presented in Table 1. All children had non-verbal IQ scores within the normal range as assessed through the Matrices subtest from the BAS II (Elliot, Smith, & McCulloch, 1996). Children were from a range of ethnic backgrounds with broadly similar distributions for deaf and hearing: white British and white European (deaf 55%; hearing 58%), black British and Black other (deaf 14%; hearing 19%) and Asian British and Asian other (deaf 27%; hearing 15%). Deaf and hearing children were also evenly distributed across the age range. There were no significant differences between deaf and hearing children in their chronological age, non-verbal IQ scores, gender distribution or ethnicity. There were an additional 28 children (24 deaf and 4 hearing) who had originally been assessed but were excluded due to low scores on the Matrices subtest or suspected additional problems.

Insert Table 1 about here

All deaf children had a severe or profound prelingual, sensori-neural hearing loss greater than 70dB (mean hearing loss 97.7dB). They were from a range of language and communication backgrounds and their preferred mode of communication varied: 44 preferred to use spoken English; 33 preferred to use signing (26 of whom used British Sign Language: BSL); 3 preferred to communicate bilingually through spoken English and BSL and the remaining 6 children preferred to used 'total communication' (a combination of speech and signing). 35 deaf children were fitted with cochlear implants and the remainder (apart from 2) wore digital hearing aids.

A small subgroup of the deaf participants (n = 15) participated in a separate test-retest reliability study with ToCS (8 boys; 7 girls). These children were aged between 6 years 10 months and 11 years 7 months and the majority of them preferred to communicate through spoken English.

Test of Child Speechreading (ToCS)

Design and content

The Test of Child Speechreading (ToCS) is a computer-based, speechreading test designed to be suitable for use with deaf and hearing children aged between 5 and 14 years old. It was presented in a game format through a brightly coloured, child-friendly interface. ToCS uses a video-to-picture matching design in which participants watched a video clip and then selected the item that matched the video clip from an array of four pictures (the target and three distractors). The video clips were recordings of either a male or a female native English speaker speaking the target material. ToCS consists of three core subtests that measure speechreading skills at three different psycholinguistic levels: Words, Sentences and Short Stories.

ToCS was specifically designed so that the lexical content was appropriate for use with deaf children as young as 5 years old. The most important factor when choosing the content for ToCS was to ensure that the items would be in deaf children's vocabularies so that ToCS was an assessment of speechreading ability rather than vocabulary. Therefore items were selected for early age of acquisition (i.e. under 26 months) and for high frequency (mean 524 words per million tokens) using hearing children's norms (Masterson, Stuart, Dixon, & Lovejoy, 2003; Morrison, Chappell, & Ellis, 1997). Since it is likely that norms for familiarity and age of word acquisition might differ between deaf and hearing children (see Fenson, et al., 1994), a pilot study was conducted with 16 deaf and 12 hearing children to ensure that the chosen items were familiar to both groups. After both the pilot study and a discussion with several Teachers of the Deaf over the suitability of the content, several items were removed and the number of experimental trials for both the Words and Sentences subtests was reduced to 15. In addition, all chosen items needed to be unambiguously represented by coloured line drawings.

Words subtest

There were 15 items in the Words subtest. On each trial, the participant saw a silent video clip of either the male or female speaker saying the target word. Then the participant saw an array of four pictures and had to click on the picture that best matched what they had seen. The target word items represented 30 different phonemes and 11 different visemes. Visemes refer to visually confusable phonemes that look the same on the lips, such as /p/, /b/ and /m/ and that are considered to form a phonemically equivalent class (PEC: Auer & Bernstein, 1997). On each trial, the three distractors were related to the target in terms of visemic properties and either shared the same initial viseme, final viseme or vowel sound with the target. For example, the distractors for the target *door* were *duck*, *fork* and *dog* (see Figure 1). Ensuring that the items were appropriate for the vocabularies of typical 5 year old deaf children was prioritised, thus limiting the ability to control the phonemic similarity between targets and distractors. Each picture array was presented on a new screen with three pre-specified novel distractors in a randomised order. A list of the items in the Word subtest can be found in Appendix 1.

Sentence subtest

There were 15 items in the Sentence Subtest. Each of the 15 target sentences in the Sentences subtest contained one of the 15 words from the Words subtest. The length of the sentences ranged from 4 to 6 words (mean 5.1). The participant saw a silent video clip of either the male or female speaker saying the target sentence and then the participant had to click on the picture (out of an array of four) that best matched what they had seen. The majority of the distractor pictures for the Sentences subtest were generated by showing the silent video clips to several deaf and hearing adults and children and asking what they thought had been said. The remaining distractors shared similar features to the target. For example, the distractors for the target "*the baby is in the bath*" were pictures representing an elephant having a bath, a baby reading a book and some pigs on a path (see Figure 1). Each trial was presented on a new screen. Each picture array contained the target and three novel distractors.

Insert Figure 1 about here

Short Stories subtest

The Short Stories subtest consisted of 5 short stories each followed by 2 questions. The short stories each contained between 12 and 22 words (mean 15.6). On each trial, the participant saw a silent video clip of either the male or female speaker telling a short story. The tester then asked the participant, in their preferred language, two questions about the story. The participant answered the question by selecting the correct picture from an array of four. The distractors for the Story subtest were alternate viable answers to the questions asked. For example, one of the questions asked "*where was Ben going?*" The correct answer was "*school*" and the distracters were pictures representing "*cinema*" "*library*" and "*home*".

ToCS Talkers

There were two talkers: a male Caucasian and a female of Sri Lankan descent. They were both native speakers of Southern British English and had clear articulation. They were judged by several deaf and hearing adults to be relatively easy to speechread. During the recording, the talkers were asked to speak naturally and all items were recorded audio-visually in a sound-proofed recording studio. The talkers were recorded in a head and shoulders full-face view with front illumination and a blue background. The sound levels for the video clips were normalised during the editing process so that the test could be used to assess audio-visual speechreading as well as silent speechreading, although the test was not designed or normed for this purpose.

Procedure for ToCS

At the beginning of ToCS, there was a short, silent familiarisation video in which each speaker spoke the days of the week in sequence. The three subtests were then presented and in between the subtests a short distractor task appeared in which a small character called "Charlie" moved rapidly across the screen and the children could try to click on him with their mouse. There were three practice trials at the beginning of each section, during which participants received accuracy feedback. No feedback was provided during the test trials. All video clips were played without sound. Items were only presented once; however, there was a repeat button on the screen (R) which the experimenter could press if the participant had missed the trial due to distraction (see Figure 1). Within each subtest, the order of presentation of trials was randomised, although the male and female speakers were alternately counterbalanced.

Instructions for ToCS

The instructions for each subtest were presented on the screen and delivered by the tester in the participants' preferred language; speech, BSL or a combination of both. The instructions were specifically designed to be equivalent regardless of the language in which they were presented. The instructions for the Words and Sentences subtest were: *"The man or woman will say a word (or sentence). Then you will see four pictures. You have to click the picture that matches what you saw. We will practise first."* The instructions for the Short Stories subtest were: *"Now you will see the man or woman say a short story. Then you will be asked two questions about the story. After each question, you will see four pictures and you have to answer by clicking on one of the pictures. We will practise first."*

Everyday Questions

For the purpose of validating the closed-set format of ToCS as a method of assessing speechreading, we also administered an additional open ended subtest of ToCS: The Everyday Questions subtest. This was an open ended subtest containing 17 questions, in which video clips were played of the man or woman asking a question such as "what is your favourite colour?" or "what did you have for breakfast?" Children had to answer the question and repeat back what they thought has been asked. Their answers were scored for accuracy of the main gist of each sentence.

Procedure

All children were individually assessed for both ToCS and the Matrices subtest from the BAS II (Elliot, et al., 1996). The instructions for the Matrices subtest were the standardised instructions but delivered in the child's preferred language. Testing sessions took place in a quiet classroom usually adjacent to the child's classroom. The 97 children who also completed the additional Everyday Questions subtest completed it in a separate testing session. The 15 children who participated in the test-retest reliability part of the study were seen individually again in an additional testing session three weeks later. The research had been granted ethical clearance from the University Ethics Committee and both parental and child permission was given before any assessments were undertaken.

Results

Reliability of ToCS

ToCS was found to have good reliability. The internal reliability, calculated through Cronbach's alpha, was $\alpha = 0.80$ for the whole sample; 0.81 for the deaf children and 0.79 for the hearing children. ToCS was also found to have good test-retest reliability, as the test-retest value (using a Pearson correlation) was $r = .89$, $p<.001$ for the fifteen children who were administered ToCS again three weeks later.

Validity of ToCS

In order to validate the closed-set picture response format of ToCS as a method of measuring speechreading, we examined the relationship between performance on ToCS and performance on the open-ended subtest of ToCS: the Everyday Questions subtest. 97 children (55% of the sample) completed the Everyday Questions subtest of ToCS. Performance on ToCS was significantly correlated with overall scores on the Everyday Questions subtest ($r = .84$, $p < 0.001$) and for both deaf ($r=.90$, $p<.001$) and hearing children ($r=.76$, $p<.001$) thus showing that ToCS is a valid assessment of speechreading ability. In addition, performance on the Everyday Questions subtest was significantly correlated with scores on the three ToCS subtests: Words, $r = .69$, $p<.001$; Sentences, $r = .78$, $p<.001$ and Short stories, $r = .46$, $p<.001$.

Performance on ToCS

The means and standard deviations for performance on ToCS are presented in Table 2. As clearly demonstrated in Figure 2, the deaf and hearing children showed similar levels of speechreading skills both in terms of their overall scores and in their performance across all three subtests of ToCS. A two-way ANOVA (hearing status x subtest) revealed a main effect of psycholinguistic subtest, $F(1.9, 344) =542.5$, $p<0.001$, but no significant differences between deaf and hearing children in their speechreading skills, $F(1,172) =.06$, ns and no significant interaction, $F(2,344) = 0.14$, ns. Post-hoc Bonferroni tests conducted on the main effect of psycholinguistic subtest showed that deaf and hearing children achieved higher scores on the single word subtest than the sentences ($p<.001$) and short stories ($p<.001$) and in turn scored higher on the sentences than the stories ($p<.001$).

Insert Table 2 about here

Insert Figure 2 about here

There was a significant correlation between speechreading and chronological age for both deaf ($r = .66$, $p<.001$) and hearing children ($r = .60$, $p<.001$) whereby speechreading accuracy increased with age (see Figure 3).

Insert Figure 3 about here

In order to explore age effects further and to create age normative data, children were grouped together in two-year age bands. A two-way ANOVA (hearing status x age band) revealed a main effect of age band, $F(4,177) = 22.47$, $p<.001$ but no significant effect of hearing status, $F(1,177) = 0.80$, ns, or interaction, $F(4, 177) = 1.21$, ns. Post-hoc Bonferroni tests showed the two younger age bands (5-6 and 6-7 year olds) achieved significantly lower overall ToCS scores than all other age bands ($p< .001$), but that whilst the older age bands scored significantly higher than the younger age bands, there were no significant differences within the older age bands, 9-10, 11-12 and 13-14 year olds ($p >.05$).

A mixed design ANOVA was conducted on the combined deaf and hearing data to investigate the effect of age on speechreading skills at different psycholinguistic levels. There was a main effect of age band, $F(4,169) = 20.45$, $p<.001$, a main effect of subtest, $F(2,338) = 537.65$, $p<.001$, and a significant interaction $F(8,338) = 7.65$, $p<.001$. Post-hoc Bonferroni tests revealed that the main effect of age band upon ToCS accuracy differed depending upon the subtest. The greatest effect of age band was observed for the Sentences subtest, whereby the two younger age bands (5-6 and 6-7 year olds) achieved significantly lower overall ToCS scores than all other age bands ($p< .001$) but there were no significant differences between the older age bands, 9-10, 11-12 and 13-14 year olds($p >.05$). For the Words subtest, only the 5-6 year olds were significantly different from all other age bands ($p< .001$) and likewise for the Stories subtest, only the two youngest age bands (5-6 and 6-7 year olds) were significantly different from the oldest age bands, 11-12 and 13-14 year olds, ($p=.007$, $p=.012$ and $p< .001$ respectively). Figure 4 shows the distribution of scores for each age band across the different subtests. Note that none of the outliers was statistically significant (see Clark-Carter, 1997).

Insert Figure 4 about here

As the deaf and hearing children did not differ significantly in performance across the different subtests of ToCS and were also well-matched for chronological age, non-verbal IQ and gender, their scores were combined for the purposes of standardisation. The raw scores were converted into standardised scores and percentiles, which are available to researchers and clinicians as part of the test by contacting the first author.

Discussion

The current study has shown that the new Test of Child Speechreading (ToCS) is a valid and reliable assessment of speechreading ability in school-aged children that can be used to measure individual differences in performance and also map the developmental trajectory of speechreading ability. The most important finding from this study was that, while speechreading improved significantly with age, no differences were apparent as a function of hearing status. Deaf and hearing children performed equally well, at whatever age they were tested. Whilst this supports past findings about comparable speechreading skills in deaf and hearing children (e.g. Arnold & Kopsel, 1996; Conrad, 1977), it contradicts the findings of two recent studies reporting better speechreading abilities in deaf than hearing children (Kyle & Harris, 2006; Lyxell & Holmberg, 2000). It is most likely that this discrepancy can be attributed to the fact that the deaf and hearing children in the current study, and in both Arnold and Kopsel (1996) and Conrad (1977), were matched for chronological age. In contrast, the hearing children in the Kyle and Harris (2006) study were matched to deaf participants on reading age: that is, they were younger than the deaf children. One key finding from the current study is that speechreading skill improves with age. This does not explain the discrepancy between the current findings and those of Lyxell and Holmberg (2000), as they matched children for chronological age and reading ability; however, the hearing impaired children in their study had mostly moderate hearing losses. Moreover, it would be practically impossible to match profoundly deaf and typically developing children for both reading age and chronological age given their widely reported reading delays.

What is not clear from the current results is how this fits in with the findings of Mohammed et al. (2006), who found a deaf advantage for adults (16 to 40 year olds) with an almost identically formatted test. There was no difference between the deaf and hearing teenagers (13-14 year olds) tested in the current study, but yet by adulthood, deaf individuals are more proficient speechreaders. When does this deaf advantage emerge? One plausible explanation is that the deaf speechreading advantage emerges sometime after early adolescence due to a combination of greater functional reliance on seen speech as a way of accessing spoken language and further experience with reading. Although recent evidence suggests speechreading is predictive of reading in children (Kyle & Harris, 2010), it is plausible to suggest that for deaf adolescents and adults, speechreading and reading share reciprocal causation and therefore speechreading skill improves as experience with reading increases, and vice versa. Indeed, recent evidence suggests a strong association between speechreading and reading in deaf adults (Mohammed, et al., 2006) and therefore it is plausible to suggest that although early speechreading appears to be predictive of reading in children (Kyle & Harris, 2010), for adolescents and adults, speechreading and reading share a relation of reciprocal causation and therefore speechreading skill improves as experience with reading increases, and vice versa. A closer examination of the data suggests a trend towards deaf 13-14 year olds being better speechreaders than hearing peers. The mean ToCS performance of deaf 13-14 year olds was 26.8 (n=10), while the mean performance of hearing 13-14 year olds was 23.6 (n=7). However, given that relatively few 13 and 14 year olds participated, it is possible that the lack of significance is due to the small sample size for this age band. Further research is needed to examine the speechreading skills of deaf and hearing teenagers with larger sample sizes to determine when the deaf advantage in speechreading emerges. One possible alternate explanation, that equally warrants future investigation, could be that hearing people gradually lose their reliance upon speechreading from childhood into adulthood whereas deaf adults simply maintain their reliance. It is plausible that deaf and hearing children are equally reliant on visual speech, but that as auditory speech processing becomes more automated for hearing people their reliance on visual speech lessens and as a result they become less proficient speechreaders.

Given that previous research has found that speechreading correlates highly with reading and it is very likely that in the current study the deaf children would be poorer readers than their hearing peers, it is intriguing that the deaf children were as good at speechreading as the hearing children. On the above basis it would be plausible to hypothesise that deaf children would have poorer speechreading skills. However, it is also possible that deaf and hearing individuals could reach similar speechreading abilities through different pathways. The results of Mohammed et al. (2006) provide some clues about potential routes. Their results suggested that hearing individuals tended to employ more bottom-up processing strategies in speechreading in order to segment the speech stream into sub-lexical speech units such as visemes or phonemes whereas deaf individuals tended to utilise more language-based, top-down processing strategies in order to identify lexical units in the speech stream. Additional studies are needed to elucidate any potential differences in the underlying processes in deaf and hearing children's speechreading skills.

Another important finding was the effect of age on speechreading. Deaf and hearing children's speechreading skills showed improvement with age, similar to previous findings from Dodd et al. (1998) and Evans (1965). Speechreading skills developed steadily between the ages of 5 and 14 years old, evidenced by the 5-6 year olds having a mean score of 38 % and the 13-14 year olds having a mean score of 65 %. The present study established that hearing children's speechreading skills also showed steady improvement over the school years and furthermore that deaf and hearing children showed almost identical patterns of speechreading development.

The results of the current study also showed that ToCS is sensitive to deaf and hearing speechreading skills at different psycholinguistic levels, similar to findings with deaf adults (see Mohammed, et al., 2006). Deaf and hearing children exhibited a remarkably similar pattern of performance across the different psycholinguistic levels: they were most accurate at speechreading single words, followed by sentences and then short stories. The identification of the majority of English words is considered to be overdetermined in terms of their visible (speech-readable) phonological properties (see MacEachern, 2000). Although sentences and stories comprise more information, and provide more opportunities for analysis, there are more combinations of valid alternate words that need to be processed, which may cause more difficulty. An intriguing question, therefore, is whether the same cognitive skills are involved in speechreading sentences and stories as in speechreading words, or whether further, higher-order linguistic and memory skills are involved for stories and sentences, and if the relative contributions of these factors differ with age or hearing status.

In summary, the Test of Child Speechreading (ToCS) has been found to be a valid and reliable assessment of children's speechreading skills. The overall picture emerging from the current study of school children suggests that deaf and hearing children have very similar speechreading skills in terms of overall ability levels, performance across different psycholinguistic units and how speechreading develops with age. Additional research is needed to identify the factors associated with good speechreading skills in children and also with older teenagers and adults to pinpoint when the previously reported deaf advantage in speechreading emerges. Of particular interest for future studies is the relationship between speechreading and reading in both deaf and hearing children and the trajectory of this relationship developmentally.

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Figure 1: typical picture array for response choice for 'word' subtest screen (left) and 'sentence' subtest screen (right)

Figure 2: Mean percentage (%) correct on ToCS for deaf and hearing children

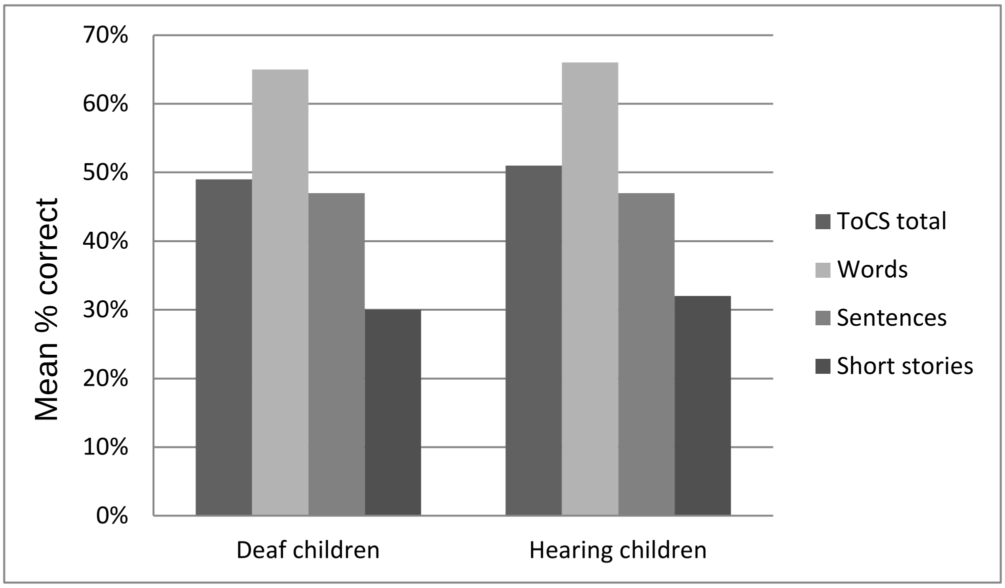

Figure 3: Scatterplot showing the correlation between age and performance on ToCS

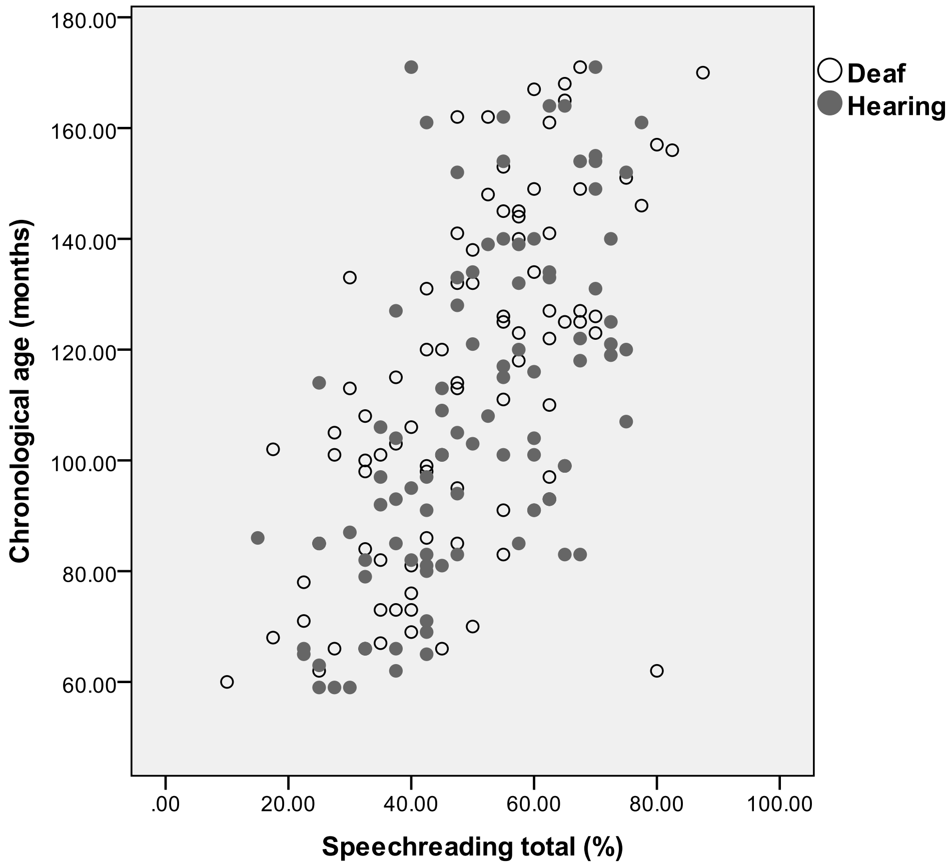

Figure 4: A boxplot showing the distribution of scores across different ToCS subtests presented for each age band

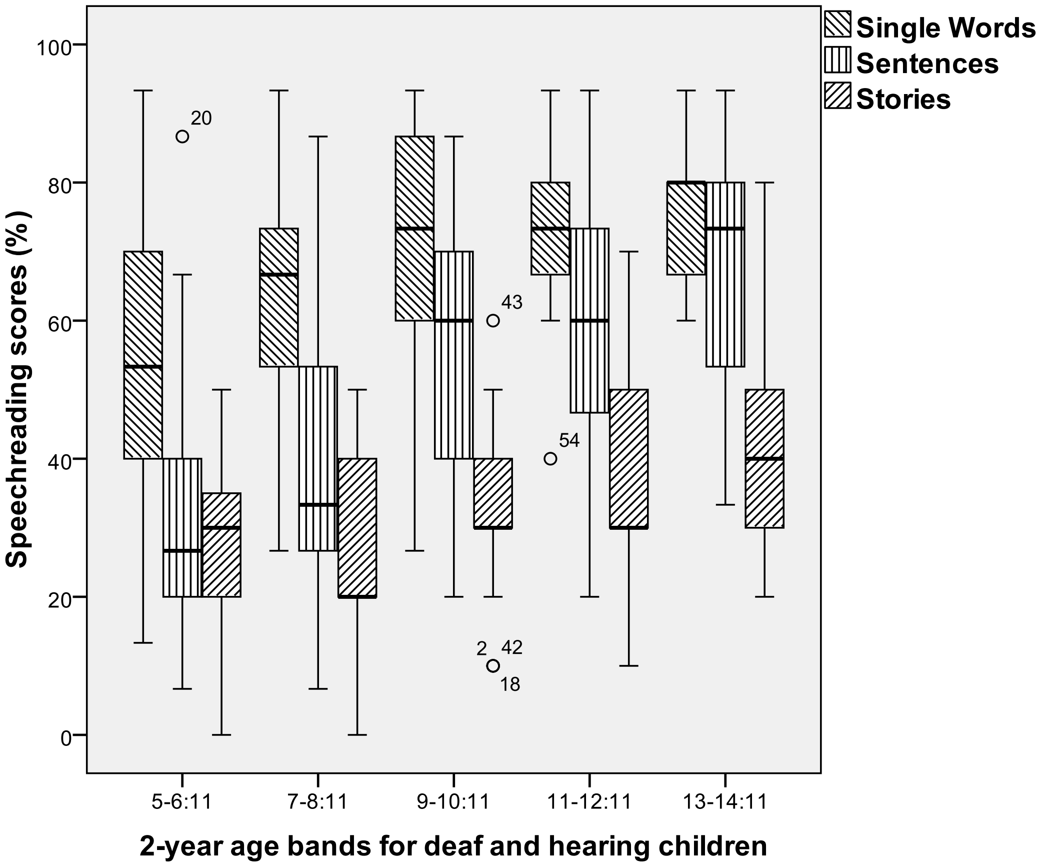

Table 1: Group characteristics for deaf and hearing participants

	Groups		
	Deaf (SD)	Hearing (SD)	Group differences
N	86	91	
Age (years/months)	9:06 (31.5)	9:01 (30.2)	t(175) = .98, ns
Gender (F/M)	47/39	38/53	X^2 (1) = 2.94, ns
NVIQ	50.0 (7.7)	50.6 (7.8)	t(175) = -1.87, ns

Table 2: Means (and standard deviations) for accuracy on ToCS subtests

	Deaf (SD) n = 86	Hearing (SD) n = 91	Total sample
ToCS total (max = 40)	19.6 (6.5)	20.2 (6.1)	19.9 (6.3)
Words (max = 15)	9.7 (2.5)	9.9 (2.6)	9.8 (2.6)
Sentences (max = 15)	7.0 (3.3)	7.1 (3.5)	7.1 (3.4)
Stories (max = 10)	3.0 (1.6)	3.2 (1.3)	3.1 (1.5)
Everyday Questions* (max = 17)	8.1 (4.6)	7.8 (4.5)	8.0 (4.5)

*Deaf n = 54; Hearing n = 43

Appendix 1: Content for Words subtest

Target		Distractors	
Bed	Ball	Pen	Leg
Bike	Bag	Knife	Bus
Book	Milk	Foot	Moon
Butterfly	Banana	Elephant	Telephone
Cat	Hat	Pan	Cow
Cup	Comb	Car	Carpet
Door	Duck	Fork	Dog
Frog	Box	Fish	Fork
Girl	Coat	Skirt	Snail
Horse	Ball	Heart	Church
Key	Knee	Hat	Leaf
Mouse	Bus	Bird	Cow
Sun	Tent	Duck	Dog
Train	Chair	Cake	Hand
Window	Snowman	Kettle	Orange