Author final version of accepted manuscript Kyle, F. E., & Trickey, N. (in press). Speechreading, phonological skills and word reading ability in children. *Language, Speech, and Hearing Services in Schools* https://doi.org/10.1044/2024_LSHSS-23-00129

Speechreading, phonological skills and word reading ability in children

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Conflict of Interest Statement: There are no relevant conflicts of interest.

Data sharing: The data supporting the findings of this study are openly available in the Open Science Framework at https://doi.org/10.17605/OSF.IO/SN95P

Funding Statement: This study was not funded.

Ethics statement: This study was granted ethical approval from the Language and Communication Sciences Proportional Review Ethics Committee at City, University of London.

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Abstract

Purpose: The purpose of the present study was to investigate the relationship between speechreading ability, phonological skills, and word reading ability in typically developing children.

Method: Sixty-six typically developing children (6-7 year olds) completed tasks measuring word reading, speechreading (words, sentences, and short stories), alliteration awareness, rhyme awareness, nonword reading, and rapid automated naming (RAN).

Results: Speechreading ability was significantly correlated with rhyme and alliteration awareness, phonological error rate, nonword reading, and reading ability (medium effect sizes), and RAN (small effect size). Multiple regression analyses showed that speechreading was not a unique predictor of word-reading ability beyond the contribution of phonological skills. A speechreading error analysis revealed that children tended to use a phonological strategy when speechreading, and in particular, this strategy was used by skilled speechreaders.

Conclusions: The current study provides converging evidence that speechreading and phonological skills are positively related in typically developing children. These skills are likely to have a reciprocal relationship, and children may benefit from having their attention drawn to visual information available on the lips while learning letter sounds or learning to read, as this could augment and strengthen underlying phonological representations.

Keywords: speechreading; reading; phonological awareness, audiovisual speech; phonological skills

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Introduction

Phonological skills are strong predictors of reading development, and children with better phonological awareness skills tend to learn to read more easily than do children with weaker phonological awareness skills (Caravolas et al., 2012; Castles & Coltheart, 2004; Melby-Lervåg et al., 2012). In turn, phonological awareness skills and reading ability are supported by underlying speech-based (phonological) representations of the sound structure of words stored in long-term memory. It is likely that these underlying phonological representations include both auditory and visual speech information, because speech perception in typical face-to-face communication involves the integration of auditory and visual components of speech (Kuhl, & Meltzoff, 1982; Rosenblum, 2005). The ability to perceive the visual component of speech (i.e., lipreading) is more commonly known as speechreading because it refers to the ability to understand speech by visually interpreting the movements of the lips, tongue, and cheeks in the absence of speech sounds (Campbell et al., 1998). Speechreading ability has been found to be a consistent correlate and predictor of phonological awareness and reading ability in deaf children (Arnold & Kopsel, 1996; Buchanan-Worster et al., 2020; Geers & Moog, 1989; Harris et al., 2017; Kyle et al., 2016; Kyle & Harris, 2006; 2010; 2011). The role of speechreading in hearing children's phonological and reading skills has received little attention. The aims of the present study were to further explore the relationship between speechreading ability, phonological skills, and reading ability in typically hearing children, and to investigate whether children who are better speechreaders have better phonological skills.

Although speechreading is most often associated with deaf individuals, typically hearing individuals process visual information from a speaker's mouth and face when perceiving and understanding spoken language (Dodd, 1987; Massaro, 1987). In adults, the contribution of visual speech to speech perception is clearly demonstrated by the 'McGurk effect' (McGurk & MacDonald, 1976), in which the overlay of an auditory syllable (e.g., /ba/) with a visual bilabial syllable /ga/ results in a completely different syllable /da/ being perceived by the participants. The McGurk effect is not as robust in children as in adults (Hirst et al, 2018; Sekiyama & Burnham, 2008). However, evidence from a range of other experimental paradigms suggests that auditory and visual integration occurs young in typical development, and visual speech has been found to enhance phoneme discrimination ability and contribute to language acquisition (e.g. Burnham & Dodd, 2004; Davies et al., 2009; Erdener & Burnham, 2018; Jerger et al., 2018; Lalonde & Holt, 2015; 2016; Teinonen et al., 2008). For typically developing children, visual speech makes an even larger contribution to speech perception under degraded auditory conditions (Gijbels et al., 2021; Knowland et al., 2016), or when the discrimination contrasts are more visually salient (Lalonde & Holt, 2015). This audio-visual gain is not limited to typically developing children. The presence of visual cues when completing speech in noise listening tasks also benefits children with developmental language difficulties (Knowland et al., 2016), despite them having weaker speechreading abilities than hearing peers. Furthermore, children with mild to severe levels of deafness were significantly better than age-matched hearing controls at using visual cues to understand masked speech and compensate for degraded auditory input (LaLonde & McCreery, 2020).

Several authors have argued that a phonological code can be abstract and not necessarily tied to the auditory domain, meaning it could be derived through speech and/or speechreading input (see Alegria, 1996; Campbell, 1997). Indeed, the motor theory of speech postulates that speech is a string of co-articulated abstract phonetic features that represent motor movements and articulatory gestures (Liberman, 1997; 1998). If visual information about speech derived through speechreading contributes to the development of phonological representations, it could be reasoned that children who are better at speechreading would have more accurate and distinct underlying phonological representations.

For deaf children, there is convincing evidence that speechreading ability is positively associated with performance on tasks that directly exploit these underlying representations, such as phonological awareness and reading ability (Arnold & Kopsel, 1996; Buchanan-Worster et al., 2020; Geers & Moog, 1989; Harris et al., 2017; Kyle et al., 2016; Kyle & Harris, 2006; 2010; 2011). Deaf children have also been found to make speechreading-based errors in phonological awareness and spelling tasks, suggesting that they use information from speechreading to complete these tasks (e.g., Dodd, 1980; Dodd & Hermelin, 1977; Hanson et al., 1983; Leybaert & Alegria, 1995; Sutcliffe et al., 1999). Jerger and colleagues (2009) found that deaf children's ability to name pictures aloud was adversely affected by the presence of concurrent visual speech distractors implying that their underlying phonological representations were disproportionally structured in terms of visual speech. In support of this, a recent speechreading training study reported improvements in the audio-visual accuracy of deaf children's speech production after completing 12 weeks of daily speechreading training, suggesting that training speechreading enhanced their underlying phonological representations (Pimperton et al., 2019).

Turning to the relationship between speechreading and phonological skills in typically hearing children, the findings are less consistent. While some studies have reported evidence of an association between speechreading and phonological awareness or phonological skills (e.g. Buchanan-Worster et al., 2020; Davies et al., 2009; Heikkilä et al., 2017; Kyle & Harris, 2011; Lyxell & Holmberg, 2000), others have not (e.g. Harris et al., 2017; Kyle & Harris, 2006; Tye-Murray et al., 2014). To date, some of the strongest evidence of an association between speechreading and phonological skills in typically developing hearing children comes from a longitudinal study of deaf and hearing beginning readers by Kyle and Harris (2011). At the beginning of the study, when the children were between 4 and 5 years old, the authors reported a large concurrent association (r=.59) between word- level speechreading and rhyme and alliteration phonological awareness in hearing children. Over the subsequent two years of the study, they reported a large longitudinal association (r=.58) between earlier speechreading ability at age 4 to 5 years and later phonological awareness ability at age 6 to 7 years. Buchanan-Worster et al. (2020) also reported a large concurrent correlation (r=.56) between sentence-level speechreading and phoneme deletion in a large group of hearing children aged 5-8 years old. Similarly, Heikkilä et al. (2017) and colleagues reported large correlations (r=.52) between speechreading and two phonological tasks for a group of typically developing children and children with specific language impairment (SLI) aged between 6 and 11 years. However, data were analyzed for the two groups combined, so it is unknown whether the correlation patterns hold for each group independently, or whether the association was driven by weak language skills in the SLI group, in particular, low nonword repetition scores.

In contrast, both Kyle and Harris (2006) and Harris et al. (2017) failed to find a significant association between phonological awareness and speechreading in groups of five- to 7-year-old hearing children, despite using some of the same tasks as in Kyle and Harris (2011). Similarly, Tye-Murray et al. (2014) found no relationship between a blending phonological awareness task and speechreading of words and sentences in a combined group of deaf and hearing children aged between 7 and 14 years. It is difficult to fully explain these discrepant findings because there are many methodological differences between the studies, including the variety of speechreading tasks and components of phonological awareness measured.

The results are similarly inconsistent from the few studies that have investigated the relationship between speechreading and reading in typically developing children. If speechreading is associated with phonological skills in children, it is plausible that speechreading might also contribute to their reading ability, and thus children who are better speechreaders may find learning to read more easily. The potential role of speechreading in reading development can be explained through the Simple View of Reading (Hoover & Gough, 1990) which proposes that successful reading requires two components: decoding and linguistic comprehension. The decoding component focuses on skills that support word decoding, including phonological skills that can encapsulate visual speechreading. In support of this, Kyle and Harris (2011) found that typically developing children who had better speechreading skills at school entry made more progress in their reading ability over the first two years of school. The authors reported a large longitudinal correlation (r=.58) between earlier speechreading and later reading ability, even after controlling for non-verbal intelligence (NVIQ) and earlier levels of reading ability. Interestingly, earlier speechreading was also found to be a strong longitudinal correlate of later spelling ability (r=.54). Similarly, in a larger study, Kyle et al. (2016) reported that speechreading was a small yet significant predictor of reading ability in a large group of typically developing children (n=91) aged between 5 and 14 years. After controlling for chronological age and NVIQ, which together accounted for 68% of the variance in the reading accuracy scores, speechreading accounted for an additional 3%.

Perhaps unsurprisingly, the two studies that found no significant relationship between speechreading and phonological skills in typically developing 5-7 year olds, also reported no significant relationship between speechreading and word reading ability (Harris et al., 2017; Kyle & Harris, 2006). One factor that might explain the disparity in results between the studies that found a relationship and those that did not is within-group variation in reading ability. In the two studies that did not find a relationship between speechreading and reading (Harris et al. 2017; Kyle & Harris, 2006), the typically developing children were all reading age-appropriately because they were selected as reading-age-matched controls for deaf children. In contrast, children in studies that reported a relationship (Kyle et al., 2016; Kyle & Harris, 2011) were chronological-age-matched controls with varying levels of reading ability and thus not necessarily age-appropriate reading.

A plausible interpretation of the direction of the relationship between speechreading, phonological skills, and reading is that speechread information is incorporated into underlying phonological representations that are used to support phonological judgements and reading. To date, only one study has directly tested the theory that speechreading is related to reading ability because better speechreading ability is associated with better quality phonological representations, which in turn are associated with better reading ability (Buchanan-Worster et al., 2020). They found that while sentence level speechreading and word reading were significantly related in children aged 5- 7-year-old hearing children, this relationship was fully mediated by phonological awareness. This demonstrates that speechreading is related to phonological awareness but suggests that any role speechreading might have in accounting for individual differences in reading ability is most likely to be an indirect effect via phonological awareness.

Other authors have argued for an alternative interpretation of the relationship between phonological skills and speechreading, in that children who have high-quality phonological representations are able to use their knowledge of phonemes (including place of articulation) to understand speechreading (e.g. Heikkilä et al., 2017; Tye-Murray et al., 2014). The corollary of this position is that children with weak phonological representations or phonological skills should find speechreading difficult. Studies on children with dyslexia or language impairments provide evidence that supports this argument. Both groups of children, who are characterized by weak phonological representations and/or weak reading skills, have been found to have lower speechreading ability compared to typically developing children (e.g. de Gelder & Vroomen, 1998; Heikkilä et al., 2017; Knowland et al., 2016; Meronen et al., 2013; van

Laarhoven et al., 2018). However, these are cross-sectional studies, which makes it difficult to determine the direction of this relationship, possibly because having weak phonological representations hinders speechreading ability, but it could equally be that having less proficient speechreading skills is a contributing factor to weak phonological representations.

A recent speechreading training study with typically developing hearing children found that training improved phonological awareness skills, but only for children with weak initial phoneme blending skills (Buchanan-Worster et al., 2021). Therefore, speechreading ability might be able to support the development of phonological awareness skills in children with weaker phonological skills. This has important implications for speechreading-based interventions for children with dyslexia. In order to understand more about the potential compensatory role of speechreading for augmenting phonological skills in children with weak phonological representations, it is important to know more about the relationship between phonological awareness and speechreading for typically developing children.

The main aim of the current study was to further investigate the relationship between speechreading ability, phonological skills, and word reading ability in children with typical hearing. One potential reason for the discrepancies in findings between existing studies is the use of different tasks that measure a range of phonological awareness components. To examine whether the relationship between speechreading and phonological skills is task-independent, we included tasks measuring a broad range of phonological skills within the same study: alliteration awareness, rhyme awareness, nonword reading, and Rapid Automatized Naming (RAN). The relationships between speechreading and nonword reading and speechreading and RAN have not been explored previously. Since children cannot rely on lexical knowledge to read nonwords because the letter strings are not real words, nonword reading requires the explicit use of phonemic decoding, which entails accessing underlying phonological representations. RAN measures the speed of access to underlying phonological representations, and performance on a RAN task is highly predictive of reading ability (Caravolas et al., 2012; Georgiou et al., 2013; Wagner et al., 1997). Therefore, if associations are found between speechreading and performance on the nonword reading or RAN tasks, it could suggest a link between speechreading and underlying phonological representations.

Furthermore, we take a novel approach to investigate the relationship between speechreading and phonological skills by examining whether children make phonological errors during speechreading. Both Davies et al. (2009) and Dodd (1987) reported that typically developing preschool children made phonological errors while speechreading. Davies et al. (2009) found that the mean phonological error rate was 67%, which was positively associated with early phonological skills (using a nonword repetition task). It is unknown whether school-age hearing children would also use phonological strategies during speechreading and whether this is linked to speechreading proficiency. If speechreading and phonological awareness are related, then it is reasonable to expect that better speechreaders would have better phonological skills and might use phonological information to support speechreading judgements, which would be evident through the presence of phonological errors. We will compare skilled and less-skilled speechreaders on their phonological skills and whether they make phonological-based errors while speechreading. We address four specific research questions:

(1) How is speechreading ability related to performance on tasks measuring a range of phonological skills?
(2) Do typically-developing children use phonological information when making speechreading judgements?
(3) Is speechreading related to word reading ability in typically-developing children?
(4) Do children who are skilled speechreaders have better phonological skills than children who are less skilled speechreaders?

Based on existing research, we predict that speechreading ability will correlate with performance across different phonological tasks, and children will make phonological-based errors; speechreading will correlate with word reading but will not be an independent predictor of word reading ability over and above phonological skills, and skilled speechreaders will have better phonological skills and use phonological strategies to a greater extent during speechreading than less skilled speechreaders.

Method

Participants

Sixty-six children aged 6–7 years participated in the study (mean age, 6 years 9 months, SD = 5.4 months). The study included 36 boys and 30 girls. The children were recruited from three mainstream primary schools in Southeast England. Almost all the children were of White British ethnicity, with English as their first language. The only exclusion criterion was that the children had no significant additional educational needs or known hearing difficulties. Written parental consent and verbal assent were obtained from each child before the assessment commenced.

Materials

Children completed six short tasks measuring phonological skills, word reading, and speechreading ability.

Phonological tasks

Four subtests from the Phonological Awareness Battery (PhAB; Frederickson et al., 1997) were used to assess a range of phonological skills. The *Alliteration subtest* assessed the children’s ability to make alliteration judgements. In each trial, the children were verbally presented with three words, and they had to say which two began with the same sound. The *Rhyme subtest* assessed the children's ability to make rhyme judgements. Similar to the alliteration subtest, the children were verbally presented with trials of three words and had to decide which two words rhymed. The *NonWord Reading* test measured children's ability to read aloud nonsense words. The children were presented with a list of pronounceable letter strings and asked to read them aloud. The *Naming Speed Test* measured rapid automatized naming (RAN). The children were asked to name an array of pictures as quickly as possible. Children were presented with a familiarization card showing pictures of a ball, hat, door, table, and box. The task required the child to name a random sequence of 50 pictures as quickly as possible. The internal consistency for these four subtests range from $\alpha=0.90$ to $\alpha=0.95$.

Single word reading

The children completed the single-word reading subtest from the British Ability Scales 3 (BAS3; Elliott & Smith, 2011). This is an untimed task in which children are asked to read single words aloud with no context. Children stopped when they made eight or more errors in a block of 10 items. The internal consistency was 0.97.

Speechreading

Speechreading ability was measured using the Test of Child Speechreading (ToCS; Kyle et al., 2013). This is a computer-based assessment of silent speechreading at three psycholinguistic levels: words, sentences, and short stories. The test was developed and normed for use with both hearing and deaf children. For the word and sentence subtest, children saw a silent video clip of either the male or female speaker saying the target word or sentence and had to click on the picture that best matched what they had seen (out of an array of four pictures). In the short stories subtest, children saw a silent video clip of either the male or female talker telling a short story. The experimenter then asked the child two questions about the story. The children answered by selecting the correct picture from an array of four pictures. The ToCS is scored per subtest and then the total raw score across the three subtests (maximum score of 40) is converted in to a standardized score. Internal consistency was α=0.80.

Procedure

The children were individually assessed over two short sessions in a quiet room, usually adjacent to their classrooms. Standardized tests were administered according to the instruction manuals. This study was approved by the University Research Ethics Committee.

Analysis

Descriptive statistics were examined for performance on all the tasks. To investigate whether children use phonological information to support their speechreading judgements, speechreading errors on the word subtest were examined for evidence of a phonological strategy. As described by Kyle et al. (2013), all distractors in the word subtest shared visemic information with the target: either the initial viseme, final viseme, or vowel. Visemes refer to sets of phonemes that are visually confusable and look the same on the lips, i.e. /m/, /p/, and /b/ (see Auer & Bernstein, 1997). The distractor categories were not mutually exclusive because some distractors shared more than one visemic property with the target (i.e., the target 'sun' shares both the initial viseme and the final viseme with the distractor 'tent'). While all distractors were visemic distractors for the target, some distractors also shared phonemic information with the target. In 62% of the trials, there was an initial visemic distractor that began with both the same initial viseme and the same initial phoneme as the target. These could be considered phonemic distractors. Examples of phonemic distractors and their TARGETS include bag/BIKE; duck/DOOR; and heart/HORSE. In contrast, non-phonemic distractors began with the same initial viseme as the target but not the same initial phoneme. Examples of non-phonemic distractors and their TARGETS include moon/BOOK; coat/GIRL; and hat/KEY. The phonological error rate was calculated per child as the number of initial phonemic distractors chosen divided by the total number of errors made on trials that contained an initial phonemic distractor. The phonological error rate was based upon initial phonemic similarity to allow for comparisons with the error analyses reported by Davies et al. (2009) and Dodd (1987).

To address the first and third research questions, bivariate correlations were conducted to examine the relationship between speechreading, the four phonological skills, and reading ability. A multiple regression analysis was used to determine if speechreading explained variance in word reading scores, over and above any variance explained by phonological skills. To address the fourth research question, we identified two subgroups of children based on their speechreading ability: skilled speechreaders with standardized scores on the ToCS above 115 (n=8) and less skilled speechreaders with standardized ToCS scores below 85 (n=8). Differences between the two groups were examined using t-test and Cohen's d.

Results

Table 1 presents the means and standard deviations for the speechreading, phonological skills, and reading tasks. Standard scores were reported for all tests to show that the children had scores within the expected range as a group. The mean standard score for speechreading was 100.0 (SD=12.7) and the mean word reading standard scores was 102.8 (SD=13.4).

<Table 1 about here>

Relationship between speechreading and phonological skills

Table 2 presents the concurrent correlations between the speechreading and phonological awareness tasks. According to Cohen (1988), a correlation of 0.2 is a small effect, 0.3 is a medium and 0.5 is a large effect. Speechreading ability (total raw score summed across the three subtests) showed a moderate correlation with alliteration awareness (r=.42, p<.001), rhyme awareness (r=.35, p=.004), and nonword reading (r=.36, p=.003), and a small negative correlation with RAN (r=-.29, p=.021). A negative correlation with RAN was expected because a faster reaction time, indicating better naming skills, is represented by a lower score.

The mean phonological error rate on the word subtest of the speechreading task was 66.0% (SD=26.3), although there was considerable variation, with the error rate ranging from 0% to 100%. There was a significant correlation between overall speechreading ability and the phonological error rate on the word subtest, whereby children who were better speechreaders (i.e. had higher overall scores) made more phonological errors on the speechreading word subtest (r=.39, p=.001).

<Table 2 about here>

Relationship between speechreading and reading ability

Speechreading ability showed a medium size correlation with word-reading ability (r=.35, p=.004). A multiple regression analysis was conducted to investigate whether speechreading ability was predictive of word-reading ability over and above the contribution of phonological awareness. The dependent variable was word reading scores, and the predictor variables entered into the analysis were chronological age, composite phonological awareness score (averaged across the four tasks), and overall speechreading ability. The assumption of no multicollinearity was tested by examining the variance inflation factor (VIF) for the potential predictor variables. The highest variance inflation factor (VIF) was 1.4 indicating little evidence of multicollinearity in the model. As shown in Table 3, chronological age entered in

Step 1 accounted for 23% of the variance in word-reading scores. When phonological awareness and speechreading were entered in step 2, phonological awareness accounted for an additional 50% of variance in the word reading scores, but speechreading was not able to explain any further variance above that already explained by phonological awareness. The final model accounted for 73% of the variance in word-reading scores, $F(2,62) = 56.33$, $p<.001$.

<Table 3 about here>

Skilled and less skilled speechreaders

As Table 4 shows, there were no statistically significant differences between skilled and less-skilled speechreaders in their phonological awareness scores or reading ability. An inspection of the effect sizes suggested that skilled and less-skilled speechreaders differed in their alliteration skills (d=.56, medium effect) and rhyme awareness and nonword reading (d=.45, d=.36, respectively, small effect sizes). Skilled speechreaders were significantly more likely to make phonological errors on the word subtest of the speechreading task than less-skilled speechreaders (92.7% vs. 55.4%, $t(10.0) = -3.30$, $p=.008$, $d=1.76$).

<Table 4 about here>

Discussion

This study aimed to investigate the relationship between speechreading, phonological skills, and reading ability in children with typical hearing. A group of six- and 7-year-old typically-developing children completed tasks measuring speechreading ability, word reading, and four different phonological skills: rhyme awareness, alliteration awareness, nonword reading, and RAN. The first research question examined whether there is a relationship between speechreading ability and a range of phonological skills. We found that speechreading and phonological skills were significantly correlated, in line with previous studies on hearing children (Buchanan-Worster et al., 2020; Davies et al., 2009; Heikkilä et al., 2017; Kyle &

Harris, 2011; Lyxell & Holmberg, 2000), deaf children (Kyle & Harris 2006; 2010; 2011), and deaf adults (Mohammed et al., 2006; Rodríguez-Ortiz et al., 2015). Our results extend previous findings by demonstrating that the relationship between speechreading ability and phonological skills is task-independent and holds across a range of phonological tasks (alliteration and rhyme awareness, RAN, and nonword reading), and even when speechreading is measured across different psycholinguistic levels: words, sentences, and short stories. The correlations were broadly similar across the range of different phonological tasks, including nonword reading.

Turning to the relationship between speechreading ability and reading, few existing studies have looked at speechreading, reading, and phonological awareness within the same study. We found a moderate correlation between speechreading and word reading ability, in line with previous findings with hearing children from Kyle and Harris (2011) and Kyle et al. (2016); however, multiple regression analyses showed that speechreading ability did not explain any additional or unique variance in word reading ability, over and above the contribution of phonological skills. While the current analysis is unable to show that the relationship between speechreading and reading ability is mediated through phonological awareness, the results support the mediation analyses undertaken by Buchannan-Worcester et al. (2020), in which phonological awareness fully mediated the link between reading and speechreading.

It is worth noting that the correlations between speechreading and word reading ($r=.35$, $p<.01$) and speechreading and nonword reading ($r=.36$, $p<.01$) were almost identical in strength. The association between speechreading and nonword reading is likely to have a phonological basis because nonwords are not lexical items and therefore require decoding and access to underlying phonological representations. Vocabulary knowledge is known to be important for speechreading ability (e.g. Davies et al., 2009; Kyle et al., 2016). It is therefore surprising that the correlation between speechreading and word reading was not stronger than the correlation with nonword reading because the former association could be underpinned by vocabulary knowledge in addition to phonological knowledge.

The most novel finding from the current study comes from the speechreading error analysis, which revealed that when typically developing children made errors on the word subtest of the speechreading task, they tended to choose distractors that shared phonemic as well as visemic information with the target. The current phonological error rate of 66% is virtually identical to the 67% phonological error rate reported in younger preschool children by Davies et al. (2009), thus extending this finding to typically developing school-age children who are learning to read. There was also a moderate correlation between phonological error rate and overall accuracy on the speechreading task, suggesting that the use of a phonological strategy is linked to speechreading proficiency. In further support of this, skilled speechreaders were found to be significantly more likely to make phonological errors on the word subtest of the speechreading task than less skilled speechreaders, with a mean phonological error rate of 93% compared to 55%.

We also predicted that skilled speechreaders would have significantly better phonological awareness skills than less-skilled speechreaders. We did not observe statistically significant group differences, most likely due to the small group sizes, yet the effect sizes were moderate, indicating that skilled speechreaders had better phonological skills. While the proportion of the overall sample that fell into each ability-based category was as expected (15% in each), the size of the two subsamples of skilled and less-skilled speechreaders was small (n=8 in each). This limits the conclusions that can be drawn from this analysis because of the possible bias introduced by splitting the group. Future studies should replicate this analysis by using a larger sample size. Notwithstanding this limitation, the findings from the phonological error analysis, the skilled and less-skilled speechreader comparison, and the correlational results converge to provide some of the strongest evidence to date that speechreading and phonological skills are positively associated in typically developing children, and that school-age children who are better speechreaders utilize phonological knowledge when speechreading.

Speechreading and phonological skills are positively related in typically developing hearing children. One possible interpretation of the task-independent association between speechreading and phonological skills is that these two skills share a common, phonological-based underlying construct. This is in line with the interpretation of research findings from deaf children, and children with language impairments, suggesting that the association between speechreading and phonological skills is underpinned by phonological representations (e.g. Buchanan-Worster et al., 2020; Heikkilä et al., 2017; Kyle & Harris, 2010). However, the direction of the relationship is difficult to ascertain from a correlational study: is speechreading associated with phonological skills because information derived from speechreading contributes to underlying phonological representations and phonological skills (Buchanan-Worster et al., 2020; Kyle & Harris, 2011) or is it because good speechreading requires good phonological representations (e.g. Heikkilä et al., 2017; Tye-Murray et al., 2014). The current correlational data support both directions equally well, since speechreading was positively associated with phonological skills in all tasks.

Our results partly support the viewpoint that children who are good at speechreading would have well-specified phonological representations combining auditory and visual information about phonemes, which in turn leads to better reading and phonological processing. This was because skilled speechreaders had better phonological skills on some but not all phonological tasks, yet there was no effect on reading ability. The finding that skilled speechreaders used phonological information when making speechreading judgements fits in with both directions, but perhaps leans more to suggesting that phonological skills support speechreading ability. In all probability, it is likely that the relationship is reciprocal, whereby better speechreading skills can augment phonological information derived through auditory channels and support the development of high-quality underlying phonological representations, which then support speechreading and other phonological and language skills that rely upon them.

It is equally possible that the association between speechreading and phonological skills in hearing children is reflecting overlapping function in another domain such as linguistic skills, or working memory or attention. For example, working memory is predictive of speechreading ability (e.g. Lyxell & Holmberg, 2000; Tye-Murray et al., 2014), and it is also predictive of performance on phonological awareness tasks similar to those used in the current study (e.g. Oakhill & Kyle, 2000). Further longitudinal studies are needed to untangle these issues and clarify the nature and direction of the relationship between speechreading, phonological awareness, and reading in typically hearing children, and critically whether the direction or nature of these relationships change with development or proficiency.

To further explore the nature of the relationship between speechreading, phonological skills, and reading development, future research could include a sublexical assessment of speechreading (i.e., speechreading of phonemes or minimal pairs). In addition, the current study only looked at word-level reading, and it is possible that supra-lexical speechreading might be more related to sentence- or text-level reading skills, reflecting the potential contribution of broader linguistic knowledge. This, together with the inclusion of a vocabulary assessment, would help determine whether speechreading can contribute to reading ability through non-phonological and phonological language processes.

It is also important to note that the speechreading test used in this study was not created to examine speechreading strategies. While the speechreading error analysis in this study provides a first step towards exploring whether phonological representations might support speechreading skills, future research would benefit from using a bespoke speechreading test with carefully controlled stimuli to test fully this hypothesis. A final limitation of the current study was that we did not include a control assessment of cognitive ability or working memory. The teachers had deemed participating children to be typically developing and NVIQ was not linked to speechreading in previous studies (Kyle et al., 2016; Rodríguez-Ortiz et al, 2015), but speechreading ability has been linked to individual differences in working memory (Lyxell & Holmberg, 2000; Tye-Murray et al., 2014).

These findings have several practical implications for teachers and other practitioners. The main implication for practitioners is that since speechreading and phonological skills are related in typically developing children, children might benefit from having their attention drawn to the additional information that can be derived from the lips while learning letter sounds and learning to read. Highlighting the visual component of speech could provide additional information to help children disambiguate speech sounds and facilitate the development of high-quality phonological representations. Practitioners and teachers can combine information on how phonemes and words look on the lips with how they sound when teaching phonological and reading skills. Indeed, Novelli and Sayeski (2022) discussed the possible benefit for children of having "sound walls" in their classrooms that incorporate visual information about how phonemes look on the lips, in addition to the usual "word walls" depicting phoneme-grapheme correspondence information. It is worth noting that Carroll and Breadmore (2018) found that 25% of children with reading difficulties had a previously undetected mild hearing loss. This means that, in a typical noisy classroom environment, there could be a handful of children with unreliable auditory input who might benefit from paying attention to visual speech as a supplementary source of information. Both typically developing children and children with language impairments benefit from visual cues in noisy or degraded auditory environments (Gijbels et al., 2021; Knowland et al., 2016; Lalonde & Holt, 2015).

Additionally, speechreading or visual speech components could be incorporated into interventions to support the development of phonological representations in hearing children with weak phonological representations (see Buchanan-Worster et al., 2021; Heikkilä et al., 2018).

In summary, the current study contributes to growing evidence suggesting that speechreading and phonological skills are related in typically developing children, but speechreading does not make a unique contribution to their reading ability. The inclusion of tasks measuring broader phonological skills such as RAN and nonword reading, in addition to phonological awareness and word reading, provides converging evidence of a relationship between speechreading and phonological skill. This relationship could be underpinned by phonological representations or equally, cognitive abilities including working memory or attention skills. Good speechreaders use phonological information to support their speechreading, but the developmental pathways to this association are unknown. Further longitudinal research is required to understand and determine the causal directions of the relationship between speechreading, phonological skills, and reading in typically developing children.

Data Availability Statement

The data supporting the findings of this study are openly available in the Open Science Framework at https://doi.org/10.17605/OSF.IO/SN95P

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Table 1: Means, standard deviations, minimum and maximum scores for all tasks

	Mean	SD	Min/Max
Speechreading raw (max = 40)	15.6	4.6	7-27
Word reading raw (max =90)	41.4	18.7	7-75
Alliteration awareness raw (max =10)	7.5	2.8	0-10
Rhyme awareness raw (max =21)	11.8	6.1	0-21
Nonword reading raw (max =20)	12.8	4.8	3-20
RAN raw (seconds)	97.7	48.4	36-290
Speechreading phonological error rate (%)	66.4	22.4	0-100
Speechreading SS	100.0	12.7	74-134
Word reading SS	102.8	13.4	69-141
Alliteration SS	97.1	9.2	67-106
Rhyme SS	101.8	14.1	69-131
Nonword reading SS	110.5	8.8	94-131
RAN SS	111.4	21.5	69-131
Phonological skills SS composite	105.2	10.2	82.3-123.8

Note: SS = standard scores; all others are raw scores

Table 2: Correlations between speechreading, phonological awareness and reading

	Alliteration	Rhyme	RAN	Nonword reading	Reading	Phonological error rate
Speechreading	.42***	.35**	-.26*	.36**	.35**	.39**

Note: all scores are raw scores

* p<.05 **p<.01 ***p<.001

Table 3: Multiple regression analyses for word reading scores

		Word Reading			
Step	Predictor	B	SE B	β	Δr^2
1	Chronological age	1.67	.379	.48***	.23
2	Phonological skills composite	1.44	.134	.78***	.49
3	Speechreading	-.040	.103	-.03	.00
	Total R^2				.73

* p<.05 **p<.01 ***p<.001

4: Descriptive statistics for skilled and less-skilled speechreaders

	Skilled speechreaders N=8		Less-skilled speechreaders N=8		p value	Effect size
	Mean (SD)	Min-Max	Mean (SD)	Min-Max	p	d
Word reading raw	50.3 (17.9)	26.0-73.0	48.4 (18.0)	17 - 65	.839	0.11
Alliteration raw	9.4 (1.1)	7.0-10.0	7.0 (3.9)	0 -10	.131	0.56
Rhyme raw	15.5 (6.7)	0 - 21	12.9 (5.7)	5 -19	.415	0.45
Nonword reading raw	15.6 (4.2)	10 - 21	14.1 (4.8)	7 - 20	.517	0.36
RAN raw (seconds)	73.1 (37.2)	38 - 152	70.8 (32.6)	36 - 133	.894	0.07
Phonological error rate (%)	92.7 (13.7)	67.0 – 1.00	55.4 (28.9)	33.0 – 1.00	.008	1.76