Deaf Children’s Use of Phonological Coding: Evidence from Reading, Spelling, and Working Memory

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Two groups of deaf children, aged 8 and 14 years, were presented with a number of tasks designed to assess their reliance on phonological coding. Their performance was compared with that of hearing children of the same chronological age (CA) and reading age (RA). Performance on the first task, short-term recall of pictures, showed that the deaf children’s spans were comparable to those of RA controls but lower than CA controls. For the older deaf children, short-term memory span predicted reading ability. There was no clear evidence that the deaf children were using phonological coding in short-term memory when recall of dissimilar items was compared with recall of items with similarly sounding names. In the second task, which assessed orthographic awareness, performance of the deaf children was similar to that of RA controls although scores predicted reading level for the deaf children but not the hearing. The final task was a picture spelling test in which there were marked differences between the deaf and hearing children, most notably in the number of spelling refusals (which was higher for the deaf children in the older group than their RA controls) and the percentage of phonetic errors (which was considerably lower for both groups of deaf children than for any of the hearing controls). Overall these results provide support for the view that deaf children place little reliance on phonological coding.

Many previous studies have shown that the great majority of deaf children find reading difficult (see Marschark & Harris, 1996; Musselman, 2000, for reviews). In this context, deaf children are those with a congenital or early-acquired hearing loss of 85dB or greater in the better ear. Reading at an age-appropriate level is an exceptional achievement for such children, and the majority do not attain a level of literacy that enables them to cope with the daily demands of modern society.

Although there is widespread agreement about the difficulties that deaf children encounter in learning to read, there remains considerable doubt about why reading is so difficult. There are undoubtedly many different factors, as a number of authors have argued (e.g., Marschark & Harris, 1996; Musselman, 2000), but one key issue concerns the kind of reading strategies that deaf children develop. There is considerably more heterogeneity among the deaf population in this respect than among typically developing hearing children, for whom it is well documented that learning the relationship between letters and sounds is important for both spelling and reading. This is the case even for English, where the letter-sound correspondences are relatively inconsistent compared to those that occur in an orthographically regular script such as Italian (Harris & Hatano, 1999). The importance of establishing early awareness of letter-sound (or grapheme-phoneme) correspondences has been highlighted in the UK National Literacy Strategy, where training in phonics forms an important part of the “literacy hour” in the first years of primary school. Specific phonics training has also been successfully used in a number of recent studies (see, for example, Connelly, Johnston, & Thompson, 2001).
What is not yet clear is whether deaf children can also develop a successful phonological strategy for reading and spelling. A number of studies of deaf children in primary school have found little or no evidence for phonological coding in either reading or spelling across a range of tasks (Waters & Doehring, 1990; Merrills, Underwood, & Wood, 1994; Leybaert & Alegria, 1995; Beech & Harris, 1997; Harris & Beech, 1998; Nielsen & Luetke-Stahlman, 2002). For example, Beech and Harris (1997) compared hearing and deaf children (aged between 7;0 and 7;11) on a lexical decision task. Hearing children were more likely than deaf children to mistakenly identify a pseudohomophone (such as *werd*) as a real word and also to incorrectly reject a real word with an irregular spelling (e.g., *once*). Both the incorrect acceptance of pseudohomophones and the incorrect rejection of irregular words are hallmarks of the use of a phonological strategy for reading. Leybaert and Alegria (1995) found similar evidence of a lack of phonological coding in spelling in French-speaking 11-year-old deaf children, and Harris and Beech (1998) found that 5-year-old deaf children showed poor performance in a task in which they had to identify pictures with similarly sounding names (such as *gun* and *sun*).

There is, however, some evidence for phonological awareness in primary-school deaf children. Sterne and Goswami (2000) used a task in which children had to select a homophone to match a picture (e.g., *boiz* as a match for a picture of two *boys*). The correct homophone had to be distinguished from three distractor items that differed by one letter (i.e. *roiz*, *beiz*, and *boin*). Although the deaf children were not as accurate as their hearing peers, Sterne and Goswami found that the performance of the deaf children was above chance, suggesting that some phonemic knowledge may be available to deaf children in primary school. The authors also found that the deaf children had syllabic knowledge that was equivalent—on both syllable tapping and comparison of the length of picture names—to hearing children of comparable RA, and their ability to make rhyme judgments was above chance even though it was inferior to that of RA controls. Harris and Beech (1998) also found that a small number of deaf children performed well on their sound-similarity task, and in Beech and Harris (1997) there was a small but significant effect of homophony for the deaf children, with homophonic nonwords producing more errors than nonhomophonic nonwords.

Studies of older deaf children—adolescents and college students—have found much more consistent evidence of phonological coding, although such a code is generally recognized as being different and less accurate than that available to hearing children (Dodd, 1980; Hanson, Shankweiler, & Fischer, 1983; Hanson, 1986; Campbell, 1992; Burden & Campbell, 1994; Leybaert & Alegria, 1995). Again, there are significant individual differences that may arise, in part, from variations in educational practice. For example, in a recent study, LaSasso, Crain, and Leybaert (2003) described the superior rhyming abilities of deaf adults who had been exposed to cued speech since the age of 5 years.

There are two notes of caution that must be applied to these studies of older children. First, many of the studies have tested deaf college students, who are unlikely to be representative of the population as a whole since only a small proportion of deaf adolescents receive a college education. Secondly, the availability of phonological information during reading does not imply that it is actually required (Musselman, 2000), so the presence of some phonological ability does not preclude the possibility that deaf children and adults may be reliant on other strategies when they read. For example, those who are fluent signers may use these skills in reading and writing, especially when higher-level, text-based skills are required (see Wilbur, 2000, for a review). It nevertheless remains pertinent to ask about the development of phonological skills since, in spite of the number of previous studies of deaf children’s reading and spelling strategies, it is difficult to gain an overall picture of how well these develop. Furthermore, the increased availability of cochlear implants has given new impetus to this issue. If it is the case that deaf children’s poor phonological skills lie at the heart of their difficulties in reading, then the improved speech perception afforded by cochlear implantation should have a direct effect on deaf children’s reading progress by enabling them to make use of phonological coding. Studies of children who
have received an implant suggest that there are direct effects on reading. Spencer, Tomblin, and Gantz (1997) studied a cohort of children with profound prelingual hearing loss who had been implanted between the ages of 2 and 13 years. Nearly one half of the children were reading within 8 months of their CA, a proportion that is considerably higher than that reported in studies of deaf children with conventional hearing aids.

There are two significant problems in making comparisons among the various studies that have been carried out. First, individual studies have tended to focus either on younger or older children and few have made direct age comparisons. Second, and more importantly, different measures of phonological coding have been used in different studies. Two things are needed: first, clear evidence about which tasks best measure the phonological coding abilities of deaf children; second, reliable comparisons between the abilities of younger and older children from the school population. With a view to providing clearer evidence about developmental changes in the phonological coding skills of deaf children, this study used three different measures of phonological coding and compared children at two different ages (8 and 14 years).

The first measure involved short-term memory (STM). Coding of information in STM has been shown to be phonologically based as the term “phonological loop” in Baddeley’s original model implied (Baddeley, 1990). For obvious reasons, much of the research on the STM abilities of deaf children has focused on the recall of visual stimuli. When asked to remember a series of pictures that can be named, deaf children typically have shorter STM spans than their hearing peers (Campbell & Wright, 1990). However, they show comparable recall of pictures that cannot be easily named, such as unfamiliar faces (O’Connor & Hermelin, 1973), geometric designs (McDaniel, 1980), and locations (Sterne, 1996). Deaf children have special difficulty with serially ordered presentation and recall, performing better when items are presented simultaneously and when free recall is allowed (Todman & Seedhouse, 1994). Overall this set of findings suggests that deaf children have difficulty in remembering ordered sequences of items that are phonologically encoded by hearing children, and relatively poor performance on an STM task might indicate a difficulty with the deployment of phonological coding.

STM span can also provide a more direct test of the extent to which deaf children use a phonological code. Span for phonologically similar and dissimilar items can be compared in order to see whether there is an effect of phonological similarity on recall. This approach has been used by MacSweeney (MacSweeney, Campbell, & Donlan, 1996; MacSweeney, 1998) to investigate STM coding in deaf 8-year-old children and a group of deaf teenagers. She compared their performance with that of hearing peers and younger hearing children of equivalent RA. Her rationale was that children who were using phonological coding to remember sets of pictures would show reduced performance in a phonological similarity condition compared to a control condition in which items were unrelated. MacSweeney found evidence for phonological coding in her group of deaf teenagers but not in her younger group. She also found that both groups of deaf participants performed more poorly with visually similar items. She concludes that, “The developmental progression in the use of visual and speech-based STM codes by deaf children was similar to that of hearing children of similar reading age.” Similar evidence comes from Campbell and Wright (1990). Evidence from STM would thus suggest that deaf children do have access to a phonological code although it would appear that there are significant individual differences, as first reported by Conrad (1979). He found that around 45% of children with hearing losses of at least 85dB showed evidence of using a speech-based (i.e., phonological) code in STM, but the other children he tested did not.

The second method of assessing phonological coding in this study involved judgments of orthographic legality. The rationale for this approach came from a study of dyslexic children by Siegel, Share, and Geva (1995). Many dyslexic children have poor phonological coding skills and so Siegel et al. argued that, in compensation, dyslexic children might develop better knowledge of other aspects of words, namely probable letter sequences. As predicted, Siegel et al. found that children with dyslexia performed better than typical readers of similar RA on a task in which
they were required to judge the orthographic legality of
a nonword. We thought that deaf children might show
a similar superiority in their orthographic knowledge.

The final source of evidence about deaf children’s
phonological coding was their spelling. For typically
developing children between the ages of 7 and 11, there
is a high reliance (i.e., an over-reliance) on phonetic
spelling (Frith, 1985). Between these ages, children
make a large number of phonetic errors, in which they
attempt to represent all the sounds in a word but do not
respect the rules of English orthography when they do
so. Thus they might spell liquid as likwid or lion as lyn,
thus indicating the use of letter-sound correspond-
ences in spelling.

Sutcliffe, Dowker, and Campbell (1999) gave
a picture-spelling task to a group of deaf children
(mean age 10;7). Their performance was compared to
that of a group of hearing children of similar age who
had acquired English as a second language (ESL). Both
groups of children were better at spelling words of high
frequency than low frequency and also words that had
a regular (rather than an irregular) spelling pattern.
In this respect, both deaf and ESL hearing children
showed sensitivity to English phonology. However,
the pattern of errors was very different for the two
groups. The ESL children produced a large number
of phonetic errors while the deaf children’s errors
were mainly non-phonetic. A detailed analysis of the
nonphonetic errors revealed that the deaf children
frequently omitted consonants—something that the
ESL children seldom did. Sutcliffe et al. concluded
that the deaf children were less phonologically aware
than the ESL group. Evidence from spelling thus
supports the view that deaf children do not make use
of a phonological strategy in their spelling though it
is noteworthy that there may be a difference between
being sensitive to phonology and actively using it in the
spelling of unfamiliar words.

The aim of the present study was to compare
deaf children’s performance in three tasks, all of which
were designed to shed light on the children’s use
of phonological coding. Performance across the three
tasks—STM, orthographic legality, and spelling—was
also compared with that of hearing peers. The study
also examined the relationship between performance
in these tasks and children’s score on a standardized
reading test.

### Method

**Participants**

There were six groups of children in this study,
three younger and three older, and approximately 30
children in each group (see Table 1). For both older
and younger groups, deaf children with a severe/
profound hearing loss were selected first. The younger
children, who were aged between 7 and 8 years, were
recruited from a total of 10 schools and units for deaf
children of primary school age. The older children
were aged between 13 and 14 years and came from 6
secondary schools and units. The criteria for selection
were that they had an unaided hearing loss of at least
85dB in the better ear and a nonverbal IQ above 85,
assessed using three tests from the revised British
Ability Scales (BASII; Elliott, Smith, & McCulloch,
1996). These were Matrices, Recall of Designs, and
Block Design. Across the sample as a whole there was

<table>
<thead>
<tr>
<th>Group</th>
<th>Chronological age (months)</th>
<th>Reading age (months)</th>
<th>Matrices score (scaled)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-year-olds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deaf children ($n=29$)</td>
<td>95.39 (6.46)</td>
<td>80.03 (13.49)</td>
<td>51.55 (8.11)</td>
</tr>
<tr>
<td>RA controls ($n=30$)</td>
<td>80.63 (6.86)</td>
<td>82.13 (14.94)</td>
<td>51.33 (8.20)</td>
</tr>
<tr>
<td>CA controls ($n=30$)</td>
<td>96.33 (6.86)</td>
<td>96.37 (7.95)</td>
<td>54.37 (9.65)</td>
</tr>
<tr>
<td>14-year-olds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deaf children ($n=33$)</td>
<td>170.39 (6.08)</td>
<td>117.06 (26.44)</td>
<td>49.36 (9.39)</td>
</tr>
<tr>
<td>RA controls ($n=26$)</td>
<td>114.65 (23.78)</td>
<td>114.69 (24.06)</td>
<td>51.88 (7.33)</td>
</tr>
<tr>
<td>CA controls ($n=31$)</td>
<td>169.87 (6.00)</td>
<td>170.19 (11.53)</td>
<td>48.45 (9.06)</td>
</tr>
</tbody>
</table>
wide variation in educational regime. Some of the
children (notably in the older group) made extensive or
exclusive use of oral language in the classroom. The
most common pattern, however, was the use of Total
Communication, in which spoken English and Signed
English were used together. The signing skills of the
children were highly variable, with only a small number
being fluent users of British Sign Language (BSL).

Two comparison groups of hearing children were
then chosen for both the younger and older groups of
deaf children, matched on Matrices score and on either
RA or CA. The hearing children came from a number
of different schools. Where possible, these were the
schools to which the special units were attached but it
was also necessary to use a number of other
mainstream schools, from the same or similar geo-
graphical areas, in order to recruit sufficient hearing
children. For matching purposes, RA on the BASII
single-word reading test was used. Details of the mean
CA, RA, and Matrices score for the six groups of
children are shown in Table 1. It will be seen that the
mean RA of the hearing children is close to their CA.
This reflected the fact that we only selected typical
hearing readers who had an RA that was within 8
months of their CA.

T-tests confirmed that there were
no differences between the BASII Matrices score of the
deaf children and their comparison groups.1

Design

There were two between-subjects factors in this study:
age (younger/older) and type of child (deaf, RA
control, CA control). All children completed two
reading assessments in addition to the BASII single-
word reading test—the Primary Reading Test and the
Neale Reading Analysis2—and an STM task. In the
STM task there were four similarity conditions which
were presented as a repeated measure (see below). In
addition, all children except for the 14-year-old CA
controls, whose reading and spelling were too pro-
ficient, were given an orthographic awareness test and
a spelling test.

Short-term memory span. Four different sets of
pictures were created, based on MacSweeney, Camp-
bell, and Donlan (1996). The first three groups
comprised pictures that were either visually similar
(e.g., long, thin items), had similarly sounding names
(e.g., hat, bag, cat) or were formationally similar when
produced in BSL (e.g., toothbrush, pan, and comb,
which are all made using an A handshape). The fourth
set of pictures acted as the control items since they
were chosen to be dissimilar from each other in
appearance, spoken name, and BSL name. The item
names in all conditions contained either one or two
syllables, with a majority containing one syllable. They
were also equated across the sets for age of acquisition.
In order to ensure that the children could recognize all
of the pictures, these were presented before the start of
the test trials and the children were asked to name each
one.

The task was administered to the children using
a laptop computer. The four conditions were presented
one after another, the order of presentation being
counterbalanced across the sample. Each condition
contained a number of trials.

On the first trial, the first picture was presented for
2 s on the left side of the computer screen. Then the
first picture disappeared and the next picture was
presented for the same length of time in a position
immediately to the right of the first picture. Sub-
sequent pictures were presented to the right of the
preceding picture. The experimental trials were pre-
ceded by a practice session using two pictures. Once
the child had responded by correctly naming the
pictures in the order that they had been presented,
presentation of experimental trials began, starting with
two items and continuing to a maximum of six. There
were three trials for each span length and, if a child
correctly responded to at least two of the three trials,
they proceeded to the next span length.

Memory span was determined from the maximum
span length at which a child was successful on all three
trials. In addition, a further credit of 0.5 was given for
successfully recalling one or two sets of items from the
next highest span length.

Orthographic awareness task. This task was adapted
from Siegel, Share, and Geva (1995). It assesses
awareness of probable sequences and position of letters
within words by presenting legal and illegal letter
strings and asking the child to choose the legal one.
Illegal strings contained a bigram that never occurs in English in a given position. For example, filv is an illegal string because lv never occurs without a following e. This can be contrasted with filk where the final bigram can occur in English.

Our version of the task used pictures of aliens to make the task more appealing and presented the child with four options (rather than two) on each trial. We used the original stimuli from Siegel et al. and created two additional foils (i.e., illegal letter strings) by rearranging the letters of the original target and foil (see Appendix 1). Stimuli were presented on a laptop computer, and children made their choices using a mouse.

The children were shown a picture of a boy talking to an alien (see figure 1). They were told:

This is a story about aliens. This boy met an alien and asked it’s name. The alien said that its name was blti. The boy said that he was very sorry but he couldn’t say his name. He asked if he could change the alien’s name a little bit so that he could say it. The boy changed it to bilt.

Children were then presented with another example. Testing was begun with the following explanation:

So this is a game all about the names of the aliens and monsters that you are going to meet. You have to find the new English name for them. Only one is the new name and you have to find it.

The children were then given two practice trials and feedback was given. The children then completed

Figure 1  Example of stimulus used in orthographic awareness task.
17 trials, each involving a picture of different alien. The alpha (Kuder-Richardson) reliability of the task was .82 for the deaf children and .77 for the hearing children. Both alpha coefficients were above .7, which is regarded as the statistical criterion for reliability.

Spelling test. The spelling test comprised 39 words. Since a spelling-to-dictation procedure was not considered appropriate for deaf children, all words were depicted by line drawings. (For a list of the words see Appendix 2.) The words were selected to produce a large number of spelling errors so that, in addition to some common monosyllabic regular words such as car and fish and some monosyllabic irregular words (e.g., eye and door), there were several multisyllabic items such as television, aeroplane, telephone, giraffe, and squirrel. The majority of the words were irregular. Of the 39 words selected, 23 came from a set of items being used by Ruth Campbell in an analysis of deaf children's spelling (personal communication).

The spelling errors were analyzed in two different ways that were both designed to uncover the children's use of a phonological strategy. First we compared the total number of spellings attempted, since children who are using a phonological strategy will often attempt to spell an unfamiliar word. Then we calculated the percentage of phonetic errors produced by each child. An incorrect spelling was classed as containing a phonetic error if there was at least one instance in which a sound was incorrectly represented by a letter or letters that sounded correct. Thus, in the case of battery, the following incorrect spellings were classified as containing at least one phonological error: baterre, battrary, battrry, battrry, bachrey. Since it was not always easy to decide whether a spelling error was phonological, this part of the analysis was checked by a second rater (who was familiar with spelling errors), and all discrepancies between the two raters were resolved by discussion.

Results

Short-Term Memory Task

Table 2 shows the scores obtained on the span task. Figures 2 and 3 show the distribution of span scores in the dissimilar condition. It can be see that, for both the younger and older children, the scores of the deaf children were similar to those of younger, hearing peers. This was confirmed by analysis using one-way ANOVA. For the younger children, there was a marginally significant effect of group, $F(2, 83) = 2.60, p = .04$, one-tailed. For the older children, for whom the discrepancy in span length was much greater, there was a highly significant effect of group, $F(2, 89) = 18.19, p < .001$. A Scheffe test revealed the presence of two distinct groups at $p < .05$, with the deaf children and the RA controls forming a homogeneous subset.

Scores from all four STM conditions were subjected to a mixed-design MANOVA with age (younger, older) and group (deaf children, RA match, CA match) as between-subjects factors, and similarity
of items as the within-subjects factor. There were highly significant effects of age, \( F(1, 172) = 96.85, p < .001 \); group, \( F(2, 172) = 19.10, p < .001 \); and similarity, \( F(2, 172) = 17.74, p < .001 \). There was a significant Age \( \times \) Group interaction, \( F(2, 172) = 5.26, p = .006 \), but the other two-way interactions (Age \( \times \) Similarity and Group \( \times \) Similarity) and the three-way interaction (Age \( \times \) Group \( \times \) Similarity) were not significant.

Contrast analyses for each group revealed that, for the 8-year-olds, the overall pattern of results across the four similarity conditions was essentially the same for the deaf children and CA controls in that the dissimilar condition produced a longer span than all other similarity conditions. For the deaf children, the differences between the dissimilar condition and the other conditions were as follows: visually similar, \( F(1, 28) = 14.20, p = .001 \); sound similar, \( F(1, 28) = 11.41, p = .002 \); and sign similar, \( F(1, 28) = 7.04, p = .013 \). For the CA controls the pattern was visually similar, \( F(1, 29) = 8.83, p = .006 \); sound similar, \( F(1, 29) = 10.5, p = .001 \); and sign similar, \( F(1, 29) = 10.59, p = .003 \). For the RA controls there was a significant difference between the dissimilar items and items that were visually similar, \( F(1, 29) = 7.07, p = .01 \), or had similarly sounding names, \( F(1, 29) = 15.67, p < .001 \). However, the difference between the dissimilar items and those with a similar sign did not reach significance, \( F(1, 29) = 3.55, p = .07 \). For the older children, there were differences among the three groups. The deaf children showed significant differences between recall of dissimilar items and items that were visually similar, \( F(1, 31) = 5.39, p = .03 \), but no difference for items that had similarly sounding names, \( F(1, 31) = 2.57, p = .12 \) or similar signs, \( F(1, 31) = 1.73, p = .20 \). The RA controls showed a significant difference between recall of dissimilar items and those with similarly sounding names, \( F(1, 25) = 4.28, p = .05 \), but there was no difference between dissimilar items and items that were visually similar, \( F(1, 25) = 0.89, p = .36 \), or had similar signs, \( F(1, 25) = 0.23, p = .64 \). The CA controls showed an effect of visual similarity, \( F(1, 30) = 7.96, p = .008 \), and also similarity of spoken name, \( F(1, 30) = 9.44, p = .004 \). They also showed an effect of sign similarity, \( F(1, 30) = 4.77, p = .04 \). Significant differences are highlighted in Table 2.

Orthographic Awareness Task

Mean scores on the Orthographic Awareness task are shown in Table 3. A one-way ANOVA revealed a highly significant effect of group, \( F(1, 143) = 22.20, p < .001 \). Posthoc Tukey tests revealed significant differences between the younger deaf group and the younger CA controls (\(-3.09; p = .001\)), the younger deaf and the older deaf group (\(-6.32; p < .001\)), the younger deaf and the older RA controls (\(-4.77; p < .001\)). There were no significant differences between the older deaf children and the older RA controls.

Spelling Test

One of the youngest children in the younger RA control group was unable to write and so did not complete the spelling test. The mean number of words spelled correctly by children in each group is shown in Table 3. A one-way ANOVA revealed that there was
a large effect of group, $F(4, 143) = 44.47, p < .001$. Scheffe tests (at $p < .05$) revealed that the five groups constituted four homogenous subsets with the younger deaf children and their RA controls, forming a single subset, and each of the other groups forming a distinct subset. Table 3 shows this pattern clearly. The younger deaf children and the younger RA controls had very similar mean scores, spelling an average 7–8 words correctly. The younger CA controls were significantly better than this ($p = .017$) but significantly worse than the older RA controls ($p = .049$). The most notable difference was that between the older deaf children and their RA controls ($p = .02$). The deaf children had a mean score of 29/39 while hearing children matched for RA scored 22/39.

The children also showed differences in the number of words that they attempted to spell (see Table 3). A one-way ANOVA revealed a highly significant effect of group, $F(4, 142) = 36.64, p < .001$. Posthoc analysis using Scheffe tests showed that younger deaf children formed a distinct subset while all the other children formed a single subset ($p < .001$).

The final analysis of spelling compared the percentage of phonetic errors for each group (see Figure 4). Since some of the older children spelled all 39 words correctly, they were excluded from the analysis. A one-way ANOVA revealed a highly significant effect of group, $F(4, 137) = 109.33, p < .001$. Posthoc analysis using Scheffe tests revealed the presence of three distinct subsets at $p < .01$. The deaf children formed a single subset, as did the young RA controls, with the young CA controls and the older RA controls forming the final subset.

Regression Analyses

In order to determine the predictive value of each of the three tasks, a forced entry regression analysis was carried out for each group of deaf children and their RA controls. The dependent measure was RA on the BASII, and memory span (in the dissimilar condition), orthography score, and percentage of phonological errors were the predictor variables. Age and BASII Matrices score were entered in the first step.

The results of the regression analyses are summarized in Table 4. It can be seen that, for the 8-year-old deaf children, age, Matrices score, and orthography score were significant predictors, and the percentage of phonological errors was a marginally significant predictor. For both groups of hearing children, age was the only significant predictor, accounting for almost all the variance.

### Table 3

Mean ($SD$) number of items correct on the tests of orthographic awareness and spelling and total spelling refusals

<table>
<thead>
<tr>
<th>Group</th>
<th>Orthographic awareness (Max = 17)</th>
<th>Correct spellings (Max = 39)</th>
<th>Total spelling refusals</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-year-olds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deaf children</td>
<td>5.38 (2.88)</td>
<td>8.28 (7.14)</td>
<td>14.07 (12.50)</td>
</tr>
<tr>
<td>RA controls</td>
<td>6.03 (1.48)</td>
<td>6.83 (7.58)</td>
<td>0.21 (0.56)</td>
</tr>
<tr>
<td>CA controls</td>
<td>8.47 (3.48)</td>
<td>15.53 (5.91)</td>
<td>0 (0)</td>
</tr>
<tr>
<td>14-year-olds</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deaf children</td>
<td>11.70 (2.63)</td>
<td>29.36 (7.27)</td>
<td>1.03 (2.43)</td>
</tr>
<tr>
<td>RA controls</td>
<td>10.15 (3.65)</td>
<td>22.15 (11.17)</td>
<td>0.04 (0.20)</td>
</tr>
</tbody>
</table>

![Figure 4](http://jdsde.oxfordjournals.org/)

Figure 4 Percentage of phonetic errors in older and younger children.
Discussion

The STM task revealed that both groups of deaf children had span scores that were in line with those of hearing children of similar RA rather than similar CA. In the younger groups, there was a marginally significant difference between the CA controls and the other two groups. In the older group, there was a very clear difference, with the performance of the deaf children and their RA controls being indistinguishable. Regression analysis showed that STM span was a significant predictor of reading performance for the older deaf children even when age and nonverbal IQ had been accounted for. These results are in line with MacSweeney (1998), who reports a correlation of 0.53 between STM span and reading ability in her sample of 14-year-old deaf children.

What does this relationship between STM and reading ability imply? It is tempting to conclude that there is a causal link between the two and that deaf children who develop age-appropriate spans are more likely to read better. Such causal links have been proposed for hearing children, and poor STM has been seen as a contributory factor in developmental dyslexia, especially when children are reading an irregular orthography like English (Wimmer, Landerl, & Frith, 1999). Notably, however, difficulty in STM recall has been seen as symptomatic of an underlying problem with phonological representation for dyslexic children (see Snowling, 2000, for a review). The argument is that dyslexic children have poorly specified phonological representations and these, in turn, lead to a number of consequences, including limitations of verbal STM and difficulties in naming (especially speeded naming) and nonword repetition (see, for example, Snowling, van Wagtendonk, & Stafford, 1988; Hulme & Roodeyns, 1995; Gathercole, Hitch, Service, & Martin, 1997).

Can the same argument be applied to deaf children? Part of the answer lies in the data from comparative performance in the various conditions of the STM task. For the older children, there was good evidence that the deaf and hearing groups differed in their use of phonological coding. Both groups of older hearing children showed reduced span lengths for
items that had similarly sounding names, but the 14-year-old deaf children did not. In other words, the recall of the deaf children was not affected by sound similarity, strongly suggesting that they were not using phonological coding when remembering items. This finding is not in line with MacSweeney et al. (1996), who found an effect of speech similarity for their older deaf children. While it is possible that this difference between the two studies might stem from differences in the samples of children tested, this does not seem likely since the children were recruited from similar schools in the south of England. Another explanation may lie in methodological differences between the two studies. MacSweeney et al. (1996) tested recall by using lists of fixed length (six items for the older children) whereas the present study presented children with lists of increasing length up to the maximum of six items. Recall scores could therefore range between 2 and 6. Hitch, Halliday, Dodd, and Littler (1989) note that the sensitivity of the measure of STM used in a particular study can affect the outcome, and they advocate the use of a span measure rather than a list of fixed length, which may distort the results.4

As in the original study by MacSweeney et al. (1996), the data from the younger children are more equivocal. Overall, the pattern of performance was very similar for the three groups, with the dissimilar items producing better recall than the similarity conditions. Both the deaf children and the CA controls showed effects of sound similarity, visual similarity, and sign similarity, and the RA controls showed effects of sound similarity and visual similarity. It is easy to explain why all three groups showed an effect of visual similarity since this was a picture recall task, but it is not clear why hearing children should show an effect of sign similarity. What is particularly puzzling is that these effects were not present in the older children even though items from the same pool were used. One possible explanation could be that the younger children were not using any systematic strategy and so recall was facilitated by happenstance links between items. What does seem clear, however, is that no firm conclusion can be drawn about the kind of encoding that was being used by the younger children.

Turning to the orthographic awareness task, the main conclusion to be drawn is that there were no differences in performance between the deaf children and their RA controls. Unlike the dyslexic children in the original study by Siegel et al. (1995), the deaf children did not show superior orthographic skills compared to hearing children of similar RA. However, the regression analysis revealed that performance in the orthography task was a significant predictor of reading ability for both older and younger deaf children but not for either group of RA controls. It is tempting to conclude from this result that the deaf children were placing greater reliance on their orthographic knowledge than hearing children of similar reading ability. However, in order to draw this conclusion, it would be necessary to test hearing children of differing reading abilities to see whether orthographic skills predicted their reading success. It will be remembered that all the hearing children who took part in the study were “typical” readers in that they were reading within 8 months of their RA. This is why the regression analysis showed that age was such a strong predictor of their reading ability since, for typically developing children, reading progresses steadily with development. Given that age and non-verbal IQ accounted for 90% of the variance for the younger RA controls and 97% of the variance for the older RA, controls there was little scope for any other predictor variables to reach significance. So, until there is firmer evidence, we must conclude that our results are open to two different interpretations: either deaf children’s orthographic knowledge increases as they learn to read more words; or orthographic knowledge drives the process of learning to read. The growth of orthographic knowledge with reading can be clearly seen in the finding that, overall, the performance of the older children was significantly higher than that of the younger groups. However, only a longitudinal study will unambiguously determine the causal role of orthographic knowledge.

If the data from the orthographic awareness task do not provide clear evidence about whether deaf children were more reliant on a non-phonological strategy than hearing children, the same cannot be said of the spelling data. Analysis of spelling showed that the deaf and hearing children were behaving very differently.
For the younger group, it was notable that the deaf children had more spelling refusals than the hearing children; and, in the older group, the deaf children were more accurate at spelling than the RA controls. Most revealing of all was the marked difference in the proportion of phonetic spelling errors. For the hearing children, between 60% and 80% of the errors produced included at least one phonetic error, while for the deaf children fewer than 20% of errors could be classed as phonetic. This is a striking difference, and it reflects the pattern reported by Sutcliffe et al. (1999).

It is also worth noting that the percentage of phonetic errors was a weak predictor of reading ability for the deaf children, which supports the idea that deaf children may be learning to read in much the same way as hearing children, as argued by Perfetti and Sandak (2000).

Taken together, the different measures used in this study lead to the conclusion that, as a group, deaf children do not make use of phonological coding to the same extent as hearing children. Furthermore, our data suggest that a similar pattern exists for younger and older deaf children. Nevertheless, in spite of the relatively poor phonological skills that many deaf children possess, it is important to remember that phonological awareness and phonological coding remains a strong predictor of reading ability in deaf children, as a recent paper by Dyer, MacSweeney, Szcerbinski, Green, and Campbell illustrates (2003; but see Izzo, 2002). Perhaps, as Musselman (2000) advocates, the challenge is to find alternative ways for deaf children to learn to read. This is a viable approach, especially for children who are able to access the curriculum through signing (Wilbur, 2000). However, for the many deaf children who do not begin reading from a secure sign language base, allowing better access to a phonological code should have a marked effect on reading development. It is from this perspective that the growing number of studies that examine the impact of cochlear implants on learning to read offer both theoretical insights into the nature of deaf children’s reading and the potential for a dramatic change in the landscape of deaf education. Almost certainly, the most striking improvements lie ahead as implantation by the age of two years becomes the norm (Rubinstein, 2002).

Not all deaf children, however, are candidates for cochlear implants and for them the task of learning to read will remain daunting unless some alternative approaches can be encouraged. One approach that does not rely on secure signing skills is to develop deaf reader’s knowledge of English orthography. Gaustad (2000) has argued for the explicit teaching of morphological skills to deaf students so that they can develop a reading strategy that makes less use of letter-sound decoding. Such an approach might work well in English because it has a deep orthography. Pilot work by Burman and Nunes (2002) suggests that deaf children can be taught specific morphological rules, such as the use of the final “s” to denote noun plurals, which then improves their performance in spelling and reading. It remains to be seen, however, whether such an approach can be used with beginning readers since the real challenge is to enable young deaf children to gain confidence in reading.

Appendix 1: Nonwords Used in Orthography Task

<table>
<thead>
<tr>
<th>Correct response</th>
<th>Original distractor</th>
<th>Additional distractors</th>
</tr>
</thead>
<tbody>
<tr>
<td>filk (4.9)</td>
<td>filv (3.8)</td>
<td>flk flvi</td>
</tr>
<tr>
<td>tolb (4.4)</td>
<td>tolz (4.3)</td>
<td>zlot tbo</td>
</tr>
<tr>
<td>Powell (4.6)</td>
<td>lowp (2.8)</td>
<td>wopl wplo</td>
</tr>
<tr>
<td>Lund (5.0)</td>
<td>dlun (2.0)</td>
<td>dunl ulnd</td>
</tr>
<tr>
<td>Faint (5.0)</td>
<td>tanf (3.6)</td>
<td>fnu antf</td>
</tr>
<tr>
<td>Minn (4.4)</td>
<td>milg (3.7)</td>
<td>gml mlni</td>
</tr>
<tr>
<td>Togn (2.4)</td>
<td>togd (2.3)</td>
<td>tgtogd</td>
</tr>
<tr>
<td>Wolt (4.9)</td>
<td>wolg (4.0)</td>
<td>gwo owlt</td>
</tr>
<tr>
<td>Moke (5.0)</td>
<td>mojc (3.0)</td>
<td>cmko ojme</td>
</tr>
<tr>
<td>Jofy (3.9)</td>
<td>fojy (2.9)</td>
<td>fyjy ojyf</td>
</tr>
<tr>
<td>Crif (2.1)</td>
<td>cnif (4.6)</td>
<td>fnic ircf</td>
</tr>
<tr>
<td>Blad (2.0)</td>
<td>bnad (4.8)</td>
<td>abd abdl</td>
</tr>
<tr>
<td>Hift (4.8)</td>
<td>hifl (2.9)</td>
<td>fih ihft</td>
</tr>
<tr>
<td>Gnup (2.7)</td>
<td>gwup (2.7)</td>
<td>gnuw gwpu</td>
</tr>
<tr>
<td>Nilt (4.9)</td>
<td>nilt (2.6)</td>
<td>nilt litn</td>
</tr>
<tr>
<td>Clid (4.6)</td>
<td>cdil (1.6)</td>
<td>cldl dlic</td>
</tr>
<tr>
<td>Vism (4.4)</td>
<td>visn (3.5)</td>
<td>isvn svim</td>
</tr>
</tbody>
</table>
### Appendix 2: Words Used in Spelling Task

<p>| | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Aeroplane</td>
<td>Battery</td>
<td>Bear</td>
<td>Bed</td>
</tr>
<tr>
<td>Biscuit(s)</td>
<td>Boat</td>
<td>Cake</td>
<td>Car</td>
</tr>
<tr>
<td>Church</td>
<td>Circle</td>
<td>Clown</td>
<td>Comb</td>
</tr>
<tr>
<td>Door</td>
<td>Elephant</td>
<td>Envelope</td>
<td>Eye</td>
</tr>
<tr>
<td>Flute</td>
<td>Fox</td>
<td>Giraffe</td>
<td>Gloves</td>
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</table>
Appendix 2: Continued

<table>
<thead>
<tr>
<th>Heart</th>
<th>Key</th>
<th>Kite</th>
<th>Leopard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mouse</td>
<td>Mushroom</td>
<td>Onion</td>
<td>Orange</td>
</tr>
<tr>
<td>Owl</td>
<td>Piano</td>
<td>Scissors</td>
<td>Shoe</td>
</tr>
<tr>
<td>Snail</td>
<td>Sock</td>
<td>Square</td>
<td>Squirrel</td>
</tr>
</tbody>
</table>
Notes

1. The t values for the comparisons of Matrices scores were as follows:
   Younger deaf—RA Controls: t(57) = 0.57, p = .57
   Younger deaf—CA Controls: t(57) = 0.23, p = .82
   Older deaf—RA Controls: t(62) = 0.36, p = .72
   Older deaf—CA Controls: t(62) = 0.35, p = .73

2. The pattern of results from the Neale Test was essentially similar and so only the single-word reading scores are reported here.

3. In the case of both television and aeroplane, it was made clear to the children that we wanted them to spell the whole word rather than a short form such as TV or plane.

4. I am greatly indebted to Mairead MacSweeney for suggesting this explanation.

References

Harris, M., & Hatano, G. (1999). Introduction: A cross-linguistic perspective on learning to read and write. In M. Harris & G Hatano (Eds.), Learning to read and write: A cross-linguistic perspective (pp. 1–9). Cambridge: Cambridge University Press.


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