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Memory Deficits for Heard and Lipread Speech in Young and Adult Poor Readers

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Abstract

Short-term memory for heard and lipread speech was investigated in children and adults who suffered from developmental reading backwardness. The results showed that with heard and lipread lists, both groups had normal recency and suffix effects, but recall of the items from the middle serial positions was relatively impaired if compared with normal readers. It is argued that poor underspecified phonological representations are not the major cause of the reduced span in the poor readers, because such a deficit would be reflected in the recency part of the serial position curve. It is suggested that the memory impairment might be related to a reduced articulation rate.

Introduction

The notion that reading acquisition difficulties are associated with poor memory for verbal material seems well established in studies using a variety of tasks examining short-term memory for letter names, words, or sentences (for example, Shankweiler, Liberman, Mark, Fowler and Fischer, 1979; Gathercole & Baddeley, 1990; see Wagner & Torgeson, 1987 for an overview). This wealth of data contrasts with the persisting uncertainty about the actual nature of the relationship between reading difficulties and memory impairments. Another aspect that is equally unclear concerns the persistence of these memory impairments over time. The present study focuses on the memory problems of disabled readers, this time by introducing two somewhat novel dimensions. The issue is approached by comparing memory performance across two input modalities for speech, an auditory based one, where the materials are heard, and an input modality lacking an auditory component, where materials are lipread. Moreover, by comparing memory performance of young poor readers with that of adult ones, one might get a picture of the possible improvement of memory skills over time and its relation to persistent reading impairments.

Memory deficits in poor readers: cause, consequence, or neither?

With a taste for simple questions in the face of complex issues, one might be tempted to ask whether the memory difficulties of poor readers are a cause or a consequence of their reading difficulties. But it is unlikely that a simple answer on this question will be forthcoming. One critical factor for understanding the role of memory for reading concerns the involvement of immediate memory in reading acquisition. Proposals in this area have greatly benefitted from interaction with models of the reading process (Bertelson, 1986; Seidenberg & McClelland, 1989; Seymour, 1986). But what is needed even more critically is a theory of reading *acquisition* which is different from a theory of the reading process. Presently, partial insight in this critical issue must be sampled from what amounts so far to research traditions with a somewhat different focus. One research tradition considers reading acquisition as a process that builds upon what is made available to fluent speakers as a consequence of their speech competence. Learning to read requires making use of already unconsciously available speech representations by making these available in the course of acquiring grapheme-to-phoneme correspondences (Bertelson & de Gelder, 1989; Bertelson & de Gelder, 1990; Shankweiler et al., 1979; Liberman, this volume). This perspective, popular as it was in the seventies, may not stand up to critical scrutiny, as the notion of becoming aware or ’phonological awareness’ taken as an autonomous and sufficient explanatory factor might well be somewhat misleading (de Gelder, 1990). Still, accepting this perspective it is easy to imagine how reading and memory are linked because learning to read and reading require phonological storage and recoding of the written words (Liberman, Shankweiler, Liberman, Fowler, & Fischer, 1977).

On the face of it, emphasis on the role of memory combines well with evidence from studies on memory performance, investigations of phonological similarity effects, and word-length effects in beginning, poor, and good readers. In turn, one sees how these data might converge with a notion developed in a different context, namely that phonological recoding is the representation format best suited to immediate memory (e.g., Baddeley, 1966; Conrad, 1964; see Baddeley, 1990, for an overview). This does not mean that non-phonetic recoding is ruled out, but it seems to be the more exceptional route, taken only by some populations in some circumstances, for example, to some extent by congenitally deaf readers (Frumkin & Anisfeld, 1977; Campbell, 1989) who were also poorer readers. Against this background there was reason to suspect that poor readers might be impaired in their phonological recoding skills. Developments in memory research brought the notion of specialised subsystems and dissociated impairments to the foreground. Data from poor memory performance of impaired readers fitted this picture well as the poor performance was specific for verbal material (e.g., Shankweiler et al., 1979). Moreover, research on immediate memory showed that, depending on whether the materials to-be-remembered are spoken or not, the memory performance does show a specific pattern, as confirmed again in Crowder and Surprenant (this volume).

Taken together, these developments underscore the notion that reading acquisition might be related to specific phonological aspects of immediate memory. More recent evidence has prompted a more precise focus still. While the original study by Shankweiler et al. (1979) showed that poor readers suffered comparatively less from acoustically confusable materials, later research has challenged that simple picture of poor readers not having a phonological recoding strategy available. A recent study by Brady, Mann and Schmidt (1987) concludes that it is not so much phonological recoding as such, i.e., the reliance upon a phonological code in memory tasks, as the efficiency with which a phonological coding strategy is used by poor readers. More recently, a more specific picture of the involvement of phonological memory has been proposed, implying not so much recoding, but a hypothetical subsystem in the form of a phonological store which might possibly be impaired in poor readers (Gathercole & Baddeley, 1990). On this view specific impairments in immediate phonological memory make the rock bottom of the explanation of reading impairments, to the exclusion of, for example, perceptual or representational problems.

Baddeley and Hitch (1974) and Baddeley (1986) have addressed these structural aspects of working memory and have also dealt with successive discoveries of phenomena pointing to the phonological specificity of the articulatory loop: the acoustic similarity effect and the word length effect. Before raising the issue of impairments, we note some facts that led to a refinement of this approach by proposing a distinction within the articulatory loop, between phonological store and a rehearsal process. While the word length and the acoustic similarity effect are two clear signatures of speech coding in short-term memory, they may correspond to two different dimensions of immediate memory. The former suggests an active process (either of rehearsal when the input is speech or of encoding and rehearsal in the case of written input) weighted down by longer words while the latter is presented as a passive store where similarity between neighbours generates confusion leading to impaired recall (Baddeley, 1986). These various aspects of phonological memory have generated many attempts at finding a locus of memory impairments in poor readers. To summarize the available evidence we mention a couple of highlights. No difference has been found to exist between length of the articulatory loop as such and age or developmental language impairment (Hulme & Mackenzie, 1992). Contrary to initial suspicions, it is now clear that poor readers do encode verbal input phonologically. Their serial recall performance is affected by phonetic similarity of the list items and they do show a word-length effect (Gathercole & Baddeley, 1990). One intriguing recent finding that partly explains earlier contradictory findings with the phonological similarity effect in poor readers is that the negative effect of phonological similarity increases with age (Hulme, 1984).

This newer version of the phonological memory model has been applied to understanding memory problems in language-impaired children. Against this background, Gathercole and Baddeley (1990) argue that the locus of the memory impairment must be the passive phonological input store, a proposal compatible with the repeated observation that no other structural part of working memory seems to be radically impaired in poor readers. However, Hulme challenges the need to appeal to a separate input store arguing that the specific data requiring it can be dealt with by the single notion of an articulatory loop. Confusability would thus be a matter of relative difference in articulatory features as is the case with acoustically similar items (Hulme & Mackenzie, 1992). As a matter of fact, the notion of acoustic similarity is somewhat inappropriate here as we are talking about phonological memory processes and consequently, what must be at stake is phonetic similarity, and thereby independent of input modality whether acoustic or visual. Whether phonetic underdetermination and its consequence, phonetic confusability, has its locus in memory, whether in the phonological input store, or in articulatory rehearsal is a matter for later concern. No doubt it will be hard to pull apart, conceptually as well as empirically, issues of phonological memory and issues of speech representation per se. But we consider that looking at memory for linguistic material in two modalities might be of some help.

Similarities between visual and auditory input modalities for speech in immediate memory

Auditory input is not the only source of speech information. As a mater of fact, for normal subjects whether in normal or in poor auditory input conditions, as well as for subjects with sensorial deficits, lipreading contributes significantly to speech understanding (Summerfield, 1987; Massaro, 1987; Campbell, 1989). An opening for the notion of development in visual speech processing was made by data from Massaro and his colleagues (Massaro, Thompson, Barron & Laren, 1986) showing clearly that visual speech perception develops over time. Summerfield (1991) has shown that large individual variations notwithstanding, lipreading skill is not related to general intellectual abilities but seems to be modular, together with linguistic competence in general. While we are presently still unclear about the visual speech processor, just as we are about the auditory speech processor or about the mechanism whereby visual and auditory input combine, there is general agreement that both input modalities share computational resources like might be provided by a common abstract speech representations of a speech module. Against this background we conjectured that when a memory deficit would be observed with auditorily presented verbal material, a similar deficit would also show up in visual speech processing (e.g., de Gelder & Vroomen, 1988). Besides, the fact of the multimodality of speech input raises the issue whether populations suffering from perceptual or representational problems would gain an advantage from concurrent presentation in two modalities. For example, one might imagine that the extra visual information in audio-visual speech would boost performance if compared with auditory-alone or visual-alone presentation.

The immediate serial recall paradigm offers a chance for an in depth exploration of memory impairments. Recent evidence suggests clearly that immediate serial recall has two characteristics - recency and suffix effects - that might very well be speech specific in the sense that they are only observed when the incoming information is coded as speech (see Crowder & Surprenant, this volume). Results of an earlier study with normal subjects showed that processing of heard and of lipread speech exhibit clear similarities. Recency occurs for lipread input as it is long known to occur for heard input (de Gelder & Vroomen, 1992). This finding underscores the similarities between heard and lipread speech and it thereby makes a study of memory for speech presented in another modality than the more standard auditory one a worthwhile tool. Moreover, it is generally agreed that this symmetry between the heard and lipread input modalities reflects a common underlying linguistic interpretation of these immediate memory phenomena. From this perspective the finding of a symmetrical impairment in memory for heard and lipread speech would surely be understandable.

The why's of poor memory and its persistence over time

To summarize so far, immediate memory as examined by the serial recall paradigm for heard as well as lipread material exhibits a couple of characteristic aspects like good recall of the earliest items (primacy), good recall of the last (recency) item, and in between poorer recall of the intermediate items. Absence of recency would reflect poor phonological storage in working memory. There is, furthermore, a substantial population of adult poor readers (see also de Gelder & Vroomen, 1991) of whom very little is known. The few studies with adult dyslexics, most of them presenting neuropsychological case studies, have not yielded a clear picture. Campbell and Butterworth (1985) reported a case (RE) of developmental dyslexia. RE showed good speech perception going together with impaired phonological memory as manifested in the absence of a word-length effect and a phonetic similarity effect, as well as absence of recency which is of particular interest for the present study. In the domain of acquired disorders this possibility of a dissociation between speech perception and verbal memory has been debated since the patient first presented by Warrington and Shallice (1969). A recent study of patients with short-term memory deficits by Martin and Breedin (1992) presents clear evidence in favour of such a dissociation between memory and speech perception. Of course, whether any symmetry should be expected between developmental and acquired disorders as concerns the relation between speech perception and phonological processing disorders is very much an open issue. And before dealing with it, a clear picture is needed on the memory abilities in adults who suffered from developmental reading disorders.

EXPERIMENT 1

Experiment 1 was undertaken in order to obtain a systematic picture of serial recall for digits that were heard, lipread, or heard-plus-lipread in poor readers and normal children matched on chronological age. Experiment 2 investigated serial recall of normal adults with adults who had suffered from reading backwardness in childhood.

Method and Results

Subjects. Two groups were tested: a group of twelve poor readers (10 male, 2 female) and a control group of twelve subjects individually matched on chronological age with the poor readers (7 male, 5 female). All subjects were given two reading tests which required reading aloud Dutch real words (the Brus 1-minute test) or pseudowords in one minute. The results on these tests are presented in table 1. On the standardized word-reading test, poor readers were lagging more than two years behind their age mates.

Table 1 about here

Design and Stimuli. A video of a speaker reciting digit lists was recorded. In the heard-plus-lipread presentation, one could hear the speaker as well as watch her lips move. For the lipread presentation, the sound track was deleted and subjects had to rely entirely on lipreading. For the heard-only presentation, a soundtrack of the digits was recorded and inserted into the video tape showing the speaker's face while she was sitting quietly. Lists consisted of five monosyllabic digits. The end of the lists could be followed by a speech suffix (the word 'STOP') or a pure tone. The speech suffix was presented in either the heard-only, lipread, or heard-plus-lipread mode. Standard serial-recall instructions were given to the subjects.

Figure 1 displays the mean proportion correct recall as a function of presentation mode and serial position for the two groups. The outstanding result is that poor readers performed worse than controls, but that given this difference, their performance showed all the typical characteristics of normal subjects. Lipread lists were more difficult to recall than lists presented in the other modalities, and suffixes interfered with recall, particularly at the final serial positions.

Figure 1 about here

An ANOVA on the proportion of correct responses indicated that recall of poor readers was worse than that of controls [$F(1,22) = 27.79$, $p < .001$]. There were main effects of the presentation mode of the list [$F(2,44) = 69.67$, , $p < .001$], of the suffix [$F(3,66) = 15.61$, $p < .001$], and serial position [$F(4,88) = 47.36$, $p < .001$]. The interactions between presentation mode of the list and suffix [$F(6,132) = 2.40$, $p < .05$], and list and serial position [$F(8,176) = 2.80$, $p < .01$] were significant, as were the interactions between group and serial position [$F(4,88) = 4.47$, $p < .002$], and between group, modality of the list, and serial position [$F(8,176 = 4.81$, $p < .001$].

In order to investigate the recency part of the serial position curve, recency was calculated as the difference in proportion of correct recall between the ultimate and penultimate item. An ANOVA with group as between-subjects factor and presentation mode of the list and suffix as within-subjects factors indicated that there were no significant differences in the recency scores between the two groups (all $p > .10$)

Discussion

We briefly summarize the main findings, delaying an in depth discussion till after experiment 2. This study shows that poor readers do have memory impairments with heard as well as lipread presentation, while showing normal recency and suffix effects. At first sight then, these results suggest that the locus of impairment is not in the mechanisms or structural dimensions of the phonological store itself, as normal recency and suffix effects are observed. In order to chart the development of the memory impairment over time, we looked in the following experiment at the performance of adult poor readers.

EXPERIMENT 2

The second experiment was conducted to investigate short-term memory for heard, lipread, and heard-plus-lipread lists in adult subjects who suffered from reading backwardness during childhood and to compare it with normal adults.

Method and Results

Subjects. Two groups were tested: a group of adult poor readers and a group of normal adults. The poor readers group consisted of eight subjects (six male and two female) aged between 18;0 and 36;6 yr (mean = 24;1 yr). The normal group consisted of ten adults (seven male, three female), ranging between 25;3 and 46;0 yr (mean age = 34;8 yr). The poor readers all complained about a long and clear history of specific reading-acquisition difficulties during their childhood. The control group consisted of normal adults who were matched as closely as possible with the poor readers on attained school grades. The Brus 1-minute test, the pseudoword reading test, and RAVEN's progressive matrices were administered to all subjects of the normal adult group and to five subject of the poor readers group. The results are summarized in table 2: poor readers were slightly worse in reading words ($t(13) = 1.72$, $p = .10$), significantly worse in reading pseudowords ($t(13) = 5.54$, $p < .001$), whereas there was no difference in the raw scores on the RAVEN ($t(13) < 1$, NS).

Table 2 about here

Design and stimuli. The same as in experiment 1, except that the list length was seven instead of five items.

Figure 2 displays the mean proportion correct recall as a function of presentation mode and serial position for the two groups. As can be seen, recall of the poor readers was worse than that of the controls, particularly at the middle serial positions. Recency effects were present in both groups, and suffices interfered with recency.

Figure 2 about here

Poor readers had poorer overall recall than controls [$F(1,16) = 8.61$, $p < .01$]. There were main effects of presentation mode of the list [$F(2,32) = 18.67$, $p < .001$], suffix [$F(3,48) = 15.05$, $p < .001$], and serial position [$F(6,96) = 34.27$, $p < .001$]. Of interest was an interaction between group and serial position [$F(6,96) = 4.28$, $p < .001$]. Inspection of the figure suggests that, compared with normals, poor readers performed particularly worse at middle serial positions, but not on the initial or final ones. There was a significant interaction between suffix and serial position [$F(18,288) = 4.16$, $p < .001$], and a significant second-order interaction between group, suffix, and serial position [$F(18,288) = 1.83$, $p < .03$]. The interaction between presentation mode of the list, suffix, and serial [$F(36,567) = 1.85$, $p < .002$] was also significant.

The amount of recency was calculated as in experiment 1 by subtracting the proportion of correct recall of the penultimate item from the final one. An ANOVA on the recency scores showed that suffixes interfered with recency [$F(3,48) = 6.37$, $p < .001$], and that the effect of a suffix depended of the modality of the list [$F(6,96) = 2.37$, $p < .05$]. There was also a significant interaction between group and suffix [$F(3,48) = 4.92$, $p < .01$]. As can be seen in figure 2, poor readers had larger recency effects in the no-suffix condition, but this is may be caused by the fact that recall of the final item in control subjects is at ceiling in the no-suffix conditions.

General Discussion

The major question that motivated this study was whether the memory impairments of poor readers already documented for heard speech would also be observed for lipread speech, and whether this would be a permanent feature of poor readers' memory into adult age. If so, the symmetry across two physically very different input modalities would clearly support the notion of a phonological deficit. Of course, our interest was not just establishing the symmetry of the memory impairment. We expected that the comparison between heard and lipread speech, the pattern of recency effects, and the strength of suffix effects within and across modalities would throw a new light on the possible concommitants of the memory deficit. The present results, taken together, are compatible with the idea that reading deficits are associated with a critical impairment in phonological memory but, at same time, they establish clearly that the impairment apparently leaves unaffected the classical signature of immediate memory for spoken material, i.e. the recency effect. The obvious question raised again by these data like by all the previous results on immediate memory impairments is what might explain this impaired memory of poor readers. Some specific aspects of this study throw light on that issue.

We first turn to the critical difference between normals and poor readers. A major finding of the present study is that overall recall performance is worse in the poor readers, whether young or adult, compared to controls. This result does not come as a surprise, but no ready explanation is available. To introduce the discussion on the more critical aspects, we submit that poor readers are not qualitatively different from normals in recall of lists, whether heard, lipread, or heard-plus-lipread, that is if one discounts for the poorer level of performance in the middle positions. Specifically, we see that the shape of the recall curves is the same, that primacy and recency effects are of comparable size, and that a suffix does have the same effect on recency as in normals. This comes out very clearly in the data from the adult populations. We submit then that some aspects of the poor readers' performance which one might call 'structural' for the time being, are present as clearly in poor readers as they are in normals. The recall curves of the latter do show clear primacy and recency effects, and in lists with a suffix we note suffix effects. Speaking at a descriptive level, the only critical difference between the groups is thus one of overall digit span. Our systematic finding contrasts with what precious little there is known on adult developmental dyslexics. Campbell and Butterworth (1985) did find a span reduction of two digits with heard lists and hardly any recency, in contrast with what is observed here both for the young and the adult group. Campbell and Butterworth suggest that their subject might have a deficit in input phonology, but confess to being unable to specify whether such is a matter of representations that are poorly specified, poorly represented, or poorly accessed. Which of these alternatives is favoured by the present results?

We propose that the present results do not contribute, one way or the other, to the notion that poor readers' memory is a function of poor representations. Thus, there is no reason to suspect that serial recall in poor readers is less efficient because the processes involved in the phonetic analysis of speech are more noisy, so that the phonological representations are less discriminable from each other during storage, rehearsal, or retrieval. Poor input representations or imperfect extraction of phonological information are thus not at stake in dyslexics' poor memory performance.

We firstly note that there was no advantage of bi-modal over auditory-only presentation in the poor reader groups. Thus, providing extra visual phonetic information did not improve poor readers' memory performance. Moreover, the hypothetical condition of less discriminability among input representations might actually be realised when subjects have to remember phonetically similar memory items, like for instance in the case of rhyme. It is well known that phonological similarity leads to poorer recall in normals, and, indeed, the phonological similarity effect has also been observed in children with reading disorders (Gathercole & Baddeley, 1990) which might suggest that poor phonological representations are not the major cause of reduced span in poor readers. Even more convincing is the fact that the phonological similarity effect is mostly confined to the final serial positions: recency is almost absent in phonologically similar items, whether heard or lipread, but primacy is unaffected (de Gelder & Vroomen, in press; see also Watkins, Watkins, & Crowder, 1974). One would therefore expect that if reduced discriminability were the cause of the reduced span, it would show up in the recency part of the serial position curve. It is however clear from the present data that the span reduction of the poor readers is not in the recency part of the serial position curve, but that it is much more confined to the middle items.

The basic question on the possible causes of poor memory becomes thus much more focused if we admit that poor performance occurs against a background of memory processes that seem structurally very normal in the sense that they exhibit all the properties that are presently taken to be the signature of immediate memory for spoken language. The present study establishes this finding very clearly. Let us examine two further issues it raises. First, the present data on the similarity of performance in the lipread and the auditory modality may be integrated in the more general context of modality effects in immediate serial recall. Second, these modality effects must be related to current explanations of poor phonological memory. Data from this study together with other results from experiments on modality effects might suggest an explanation for the reduced digit span of poor readers. A candidate here is the notion of efficiency of rehearsal and, what is by some perceived as its cause, speech articulation rate. We examine those two issues below.

The comparison between heard and lipread speech belongs to a larger framework of studies examining the effect of modality of presentation on recall. The classical notion of the modality effect refers to the robust observation of a recall advantage of the terminal item of a memory list as is observed in the auditory, but not in written presentation. The original explanation of this effect invoked a echoic memory facilitation exclusively for the last auditory presented item. The most elaborate approach came from the theory of pre-acoustic storage defended by Crowder and Morton (1969) in the late sixties. This approach elaborates on the notion that the last item advantage derives from sensorial properties present in one modality, but not in the other. It is worth recalling this discussion in the present context because the very facts that challenged this notion of sensory-based advantage, i.e., strong recency effects with lipread material, make the paradigm interesting for the study of memory of impaired readers. Indeed, at present there is no reason to believe that these subjects have an auditory impairment. As a matter of fact, presentation of lipread lists is used to investigate the linguistic as opposed to the sensory locus of the deficit in patients (Howard & Franklin, 1990). The issue of a phonological impairment is, in contrast, still a definite possibility. The similarity observed here between lipread and auditory presentation fits in nicely with a theoretical approach that emphasizes the abstract nature of the mechanisms responsible for recency effects. As far as this storage of the last item is based on an abstract phonological code, no impairment seems to exist in the poor reader population. It is thus not surprising that we observed in another study that poor readers do fully show the classical modality effect (de Gelder, Vroomen, & Popelier, 1994).

Digit span is related to rehearsal and more specifically seems to be a function of the speed of articulation which increases with age in normal subjects, but not with the same ratio in severely language disordered children. One question is then whether the concept of speed of articulation can serve as an explanation for memory impairments in poor readers. The similarity between lipread and auditory presentation must be based in phonological storage in both cases. With this approach we can also analyze the similarities in overall recall across formats. Rehearsal, for example as pictured in a theory of the phonological loop explains well the typical pre-recency shape of recall curves. Such rehearsal engages phonological representation processes. The notion advanced recently is that rehearsal speed increases with age but might increase at a slower pace in poor readers or remain at a lower platform in adult poor readers. So far we have conducted an indirect investigation of this effect in the adult readers. We indeed observed that when normal subjects were given a concurrent articulation task, performance dropped by an overall fifteen percent correct and their recall curves were now virtually identical with those of adult poor readers who were not engaged in a concurrent articulation task (de Gelder and Vroomen, submitted). It indicates that poor rehearsal processes might play a major role in the impoverished memory performance of poor readers.

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References

Baddeley, A. D. (1966). Short-term memory for word sequences as a function of acoustic, semantic and formal similarity. *Quarterly Journal of Experimental Psychology,* ***18***, 362-365.

Baddeley, A. D. (1986). *Working memory.* Oxford: OUP.

Baddeley, A. D. (1990). *Human memory: theory and practice.* Hillsdale: Lawrence Erlbaum Associates.

Baddeley, A. D., & Hitch, G. (1974). Working memory. In G. A. Bower (Ed.), *Recent advances in learning and motivation, Vol. 8.* New York: Academic Press.

Bertelson, P. (1986). The onset of literacy: Liminal remarks. *Cognition, **24***, 1-30.

Bertelson, P., & de Gelder, B. (1989). Learning about reading from illiterates. In: A. M. Galaburda (Ed.), *From reading to neurons.* Cambridge, MA: MIT Press.

Bertelson, P., & de Gelder, B. (1990). The emergence of phonological awareness. In: I. Mattingly & M. Studdert-Kennedy (Eds.), *The motor theory of speech perception.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Brady, S., Mann, V., & Schmidt, R. (1987). Errors in short-term memory for good and poor readers. *Memory and Cognition, **15***, 444-453.

Campbell, R. (1989). Lipreading. In: A. W. Young, & H. D. Ellis (Eds.), *Handbook of research on face processing*. Amsterdam: North Holland Publishing Co.

Campbell, R., & Butterworth, B. (1985). Phonological dyslexia and dysgraphia in a highly literate subject: a developmental case with associated deficits of phonemic processing and awareness. *Quarterly Journal of Experimental Psychology, **37A***, 435-475.

Conrad, R. (1964). Acoustic confusion in immediate memory. *British Journal of Psychology, **55***, 75-84.

Crowder, R. G., & Morton, J. (1969). Precategorical acoustic storage (PAS). *Perception and Psychophysics, **5***, 363-373.

Crowder, R. G., & Surprenant, A. M. (this volume). On the linguistic module in auditory memory. In: B. de Gelder and J. Morais (Eds.), *Speech and reading*.

de Gelder, B. (1990). Phonological awareness, misidentification, and multiple identities. In: J. A. Edmondson, C. Feagin, & P. Mülhauser (Eds.), *Development and diversity: Linguistic variation across time and space*. Arlington: Texas Publications.

de Gelder, B., & Vroomen, J. (1988, august). *Bimodal speech perception in young dyslexics*. 6th Australian Language and Speech Conference. Sydney.

de Gelder, B., & Vroomen, J. (1991). Phonological deficits: Beneath the surface of reading-acquisition problems. *Psychological Research, **53***, 88-97.

de Gelder, B., & Vroomen, J. (1992). Abstract versus modality-specific memory representations in processing auditory and visual speech. *Memory and Cognition, **20***, 533-538.

de Gelder, B., & Vroomen, J. (in press). Memory for consonants versus vowels in heard and lipread speech. *Journal of Memory and Language*.

de Gelder, B., & Vroomen, J. (submitted). Serial recall of poor and normal readers with concurrent articulatory suppression

de Gelder, B., Vroomen, J., & Bertelson, P. (1990, January). *Segmental abilities in bi-scriptal chinese*. Paper presented at the Experimental Psychology Society, London.

de Gelder, B., Vroomen, J., & Popelier, T. (1994, January). *Serial recall of adult dyslexics as a function of input modality.* Paper presented at the Twelfth European Workshop on Cognitive Neuropsychology, Bressanone, 23-28 January 1994.

Frumkin, B. & Anisfeld, M. (1977). Semantic and surface codes in the memory of deaf children. *Cognitive Psychology, **9***, 475-493.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language, **29***, 336-360.

Howard, D., & Franklin, S. (1990). Dissociations between component mechanisms in short-term memory: evidence from brain-damaged patients. In D. E. Meyer & S. Kornblum (Eds.), *Attention and Performance XIV*. Cambridge, Mass: MIT Press.

Hulme, C. (1984). Developmental differences in the effects of acoustic similarity on memory span. *Developmental Psychology, **20***, 650-652.

Hulme, C., & Mackenzie, S. (1992). *Working memory and severe learning difficulties.* Hillsdale: Lawrence Erlbaum Associates.

Liberman, A. M. (this volume). The relation of speech to reading and writing. In: B. de Gelder and J. Morais (Eds.), *Speech and reading*.

Liberman, A. M., Cooper, F. S., Shankweiler, D. P., & Studdert-Kennedy, M. (1967). Perception of the speech code. *Psychological Review, **74***, 431-461.

Liberman, I. Y., Shankweiler, D., Liberman, A. M., Fowler, C., & Fischer, F. W. (1977). Phonetic segmentation and recoding in the beginning reader. In A. S. Reber and D. Scarborough (Eds.), *Towards a psychology of reading: The proceedings of the CUNY conference.* Hillsdale, NJ: Lawrence Erlbaum Associates.

Martin, R. C., & Breedin, S. D. (1992). Dissociations between speech perception and phonological short-term memory deficits. *Cognitive Neuropsychology, **9***, 509-534.

Massaro, D. W. (1987). *Speech perception by ear and eye: A paradigm for psychological inquiry*. Hillsdale, NJ:

Lawrence Erlbaum Associates.
Massaro, D. W., Thompson, L. A., Barron, B., & Laren, E. (1986). Developmental changes in visual and auditory contributions to speech perception. *Journal of Experimental Child Psychology, **41***, 93-113
Seidenberg, M. S., & McClelland, J. L. (1989). A distributed developmental model of word recognition and naming. *Psychological Review, **96***, 523-568.
Seymour, P. H. K. (1986). *Cognitive analysis of dyslexia*. London: Routledge and Kegan Paul.
Shankweiler, D., Liberman, I. Y., Mark, L. S., Fowler, C. A., & Fischer, F. W. (1979). The speech code and learning to read. *Journal of Experimental Psychology: Human Learning and Memory, **5***, 531-545.
Summerfield, A. Q. (1987). Some preliminaries to a comprehensive account of audio-visual speech perception. In: B. Dodd & R. Campbell (Eds.), *Hearing by eye: The psychology of lipreading*. Hillsdale, NJ: Lawrence Erlbaum Associates.
Summerfield, A. Q. (1991). Visual perception of phonetic gestures. In I. G. Mattingly & M. Studdert-Kennedy (Eds.), *Modularity and the motor theory of speech perception.* Hillsdale, NJ: Lawrence Erlbaum Associates.
Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading skills. *Psychological Bulletin, **101***, 192-212.
Warrington, E. K., & Shallice, T. (1969). The selective impairment of auditory verbal short-term memory. *Brain, **92***, 885-896.
Watkins, M. J., Watkins, O. C., & Crowder, R. G. (1974). The modality effect in free and serial recall as a function of phonological similarity. *Journal of Verbal Learning and Verbal Behavior, **13***, 430-447.

Table 1

Details of the Poor Readers and the Chronological Age (CA) Control Group

Group	*N*	*Age (year;month)*		*Reading Words*		*Reading Pseudowords*	
		Mean	Range	Mean	Range	Mean	Range
Poor readers	12	10;2	9;4-11;4	24.4	5-39	11.3	3-16
CA	12	10;2	9;4-11;4	73.6	50-101	45.1	31-62

Table 2

Details of the Adult Poor Readers and the Adult Control Group

Group	*N*	*Age (year;month)*		*Reading Words*		*Reading Nonsense Words*		*RAVEN*	
		Mean	Range	Mean	Range	Mean	Range	Mean	Range
Poor readers	8	24;1	18;0-36;6	79.4	58-103	36.8	26-54	52.2	49-58
Control	10	34;8	25;3-46;0	95.7	68-114	70.2	52-86	50.4	41-56

Figure captions

Figure 1. Mean proportion of correct recall of the poor readers and the CA group for heard, lipread, and heard-plus-lipread lists.

Figure 2. Mean proportion of correct recall of the adult poor readers and the control group for heard, lipread, and heard-plus-lipread lists.

Table 2

Mean Recency Scores for the Chronological Age Controls

Suffix	*Modality of List*			
	Heard-only	*Lipread*	*Heard-plus-lipread*	
Tone	.09	.15	.16	.13
Heard-only	.11	.01	.09	.07
Lipread	.08	.08	.13	.10
Heard-plus-lipread	.19	.07	.06	.11
	.12	.08	.11	.11

Table 3

Mean Recency Scores for the Poor Readers

Suffix	*Modality of List*			
	Heard-only	*Lipread*	*Heard-plus-lipread*	
Tone	.12	.02	.22	.12
Heard-only	.07	.04	.06	.06
Lipread	.16	.08	.13	.12
Heard-plus-lipread	.01	.09	-.01	.03
	.09	.06	.10	.08

Table 5

Mean Recency Scores for the Normal Adults

Suffix	*Modality of List*			
	Heard-only	*Lipread*	*Heard-plus-lipread*	
Tone	.14	.14	.19	.16
Heard-only	.05	.23	.23	.17
Lipread	.18	.15	.10	.14
Heard-plus-lipread	.19	.16	.03	.13
	.14	.17	.13	.15

Table 6

Mean Recency Scores for the Adult Poor Readers

Suffix	*Modality of List*			
	Heard-only	*Lipread*	*Heard-plus-lipread*	
Tone	.39	.25	.41	.35
Heard-only	.14	.13	.17	.15
Lipread	.28	.03	.28	.20
Heard-plus-lipread	.14	.09	.03	.09
	.24	.13	.22	.20