First Language, **13** (1993), 69–91. Printed in England

Phonological short-term memory and individual differences in learning to speak: a bilingual case study*

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ABSTRACT

The language development of two bilingual siblings, who learned to speak at greatly different rates, is briefly described. The child with the delayed onset of speech had difficulty with articulation, syntax, function words and inflections, particularly when speaking in German. Now, as a young teenager, he has no overt speech problem in English, his preferred language, and he does well in school and on standardized achievement tests of language arts and mathematics. Nevertheless, on a storytelling task at age 12;6, he used significantly shorter, less complex sentences than his sister did at the same age. In German, his 'mother tongue' yet less preferred language, he still has major grammatical difficulties. Recent memory tests showed that his early difficulty with immediate verbal repetition is still present. His difficulty is most pronounced on a verbal short-term memory task requiring repetition of unrelated words, whereas on a task where the verbal input can be reproduced nonverbally, his short-term memory is excellent.

Findings from diverse disciplines are brought together to account for these differences observed in learning to speak. The proposed explanation is as follows: there is variation among infants in their phonological memory – their ability to store or readily access speech sounds. This variation may have a neurological basis. A weakness in phonological memory may delay learning to speak, thereby increasing the normal gap between speech comprehension and production; it may cause initial articulatory problems and, in severe cases, continued articulatory difficulties; it may make verbal repetition tasks more difficult, shortening an already limited verbal memory span and impairing verbal imitation; it may thus delay the ability to accumulate a phonological corpus of linguistic patterns from which to acquire the syntactical and grammatical conventions of speech.

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0142-7237/93/1301-0069 $2.00

Individual differences in the very early phases of language acquisition can inform us about language processes and their biological substrate, particularly if the differences are associated with fundamental processing differences still present in the teenage years. This paper is an account of two bilingual children, brother and sister, one of whom learned to speak with ease, the other with great difficulty.

The differences in the children's rate of learning to speak appear to be related to differences in short-term verbal memory – differences which still existed at age 12;6. Research findings from a variety of disciplines (speech pathology, memory, reading research, neuroanatomy) suggest that these differences may be due to neurological differences in a phonological processing system that underlies speech production tasks, including articulation and even reading. Furthermore, since Mark's difficulty with short-term verbal memory is observed on elicited verbal imitation tasks, the present study points to an important role for verbal imitation ability in language acquisition. Moreover, the dissociation observed between comprehension and production in the language-delayed child supports a modular conception of language (e.g., Bates, Bretherton & Snyder 1988).

CASE HISTORY

Sally and Mark were raised bilingually: they learned German at home from their parents and English at the babysitter's home and then at school. I review here only the most relevant features of their early language development since a more complete account up to the age of eight is given in Speidel (1989*a*). I then present some observations of their language behaviours and performance on short-term memory tasks when they were 12;6 years old.

Early language development

There was nothing remarkable about Sally's language development. She began to speak in single words and gradually expanded the length of her utterances: Brown's (1973) description of how children learn their first words fitted Sally's progress well. She separated German and English without any noticeable difficulty.

Mark (two years younger) had great difficulty in learning to speak. The first indication that his speech development might not be typical was the absence of reduplicative babbling; he never said 'dada, baba, mama'. His first intelligible words came when he was around two years old. Previously he had the intonation, the prosody of the language; he spoke in long 'sentences' which could not be understood. Peter's (1977) description of Minh as a 'mush mouth' could have been applied to Mark.

Once Mark was able to speak in somewhat intelligible phrases, he started to stammer. He had difficulty with word order, function words and inflections in both English and German; in both languages his speech resembled the speech of children with expressive language delay (Grimm 1987, Menyuk & Looney 1976). He created new words, such as 'threedary' (analogous to primary and secondary); he substituted phonemic elements, saying for instance, 'I would vote for Reagan because he has much experiment', meaning 'experience'. Even though he virtually never got mixed input, Mark had much more trouble than Sally in separating German from English in his speech. By age 5, he had settled on English as his major language for speaking, although the parents continued to speak German to him. By that time he had overcome most of his noticeable speech problems in English – his articulation problems, stammering and blatant grammatical errors. Speaking German continued to be very difficult for him. In contrast to his problems with speaking, Mark's comprehension of both German and English appeared to develop very well. According to the Bates *et al.* (1988) classification of language learners, Mark would be labelled a *high analytic type*, in English and in German.

These differences between Mark and Sally during their early language development were confirmed by language tests given in German and English at various times (for a description of the tests and results, see Speidel 1989*a*). Sally's comprehension and production were about equally well developed; she scored around the 85th percentile on normed language tests of English comprehension and production, and around the average range in German. Mark, on the other hand, showed good comprehension in English and in German (also scoring around the 85th percentile) but poor production in both languages.

Later language development

At the time this manuscript is being written, Mark is in the seventh grade. Both children, even Sally, now speak mainly English with their parents, while the parents continue speaking German with them. The result is bilingual, German-English conversations. Mark does well in school, getting As and Bs, and is scoring above the 90th percentile on the Stanford Achievement Tests in language arts and mathematics.

Yet in language samples taken when Sally and Mark were 12;6 there were still differences in speaking skill between the two children. This was the case even in English, which Mark no longer had any noticeable difficulty speaking. For the language samples, the children were given individually a picture book without words and were asked to create a story: the first 12 pages they told in English, the last 12 pages in German. Mark no longer showed any speech disfluencies, even in German; but in both languages he spoke more slowly and deliberately than Sally, suggesting that it was a more effortful task for him, requiring all his attention.

The English portion of his story was shorter than Sally's: he used only 195 words, while Sally used 316; his sentences were shorter, on the average a little over 10 words per sentence, while Sally's were over 13 words long (see Fig. 1). Furthermore, he used on average fewer adjectives, fewer prepositional phrases and fewer dependent clauses, particularly adverbial clauses (see Fig. 2). To sum up: his sentence structure, though very adequate, had remained simpler than Sally's.

The German portion of their story-telling was shorter for both children. Since the children were speaking mostly English, even to their parents, it was surprising to see how few English words they used in their German story. Nevertheless, Mark's sentences were even shorter and much more rigid in structure than in English, while Sally's sentence length remained the same (see Fig. 1). The most remarkable difference between the two was in the use of the complex German gender and case marking. Sally had virtually no errors in either gender forms or case endings. Mark typically used a reduced form, 'de', for the definite article, instead of *der, die, das*. When he did use a correct gender and ending in his articles, it was usually in the non-inflected nominative form, but even here there were errors, for instance when he said 'Der (instead of *das*) kleine Mädele heult'. Other examples of errors in case/gender marking were 'Grosse Banane das (instead of *die*) du kannst aufblasen', 'Raus zur (*zum*, or *zu dem*) Schiff', 'Nix an des (*dem*) Kopf fühlen', 'zu de (*dem*) Aff (*Affen*)'. Presented later with the correct form and the form he had used, he chose the correct form on 80 percent of his errors. In other words, even though he made errors in speaking he could identify the correct forms when hearing them.

In summary, in English, which by age 12;6 was the preferred language for both children, Mark showed few grammatical or syntactical errors in his story telling and differed from Sally mainly in using somewhat simpler sentences. However, in German the differences between the two children were still marked: Mark's speech would clearly be seen as deviant, more like that of a foreigner; Sally's could pass for that of a native.

SEARCH FOR THE UNDERLYING CAUSE

Why did Mark have so much more difficulty learning to speak than Sally? Why does he continue to have much more difficulty speaking German than Sally? Differences in quality or amount of German input cannot account for the large differences in their ability to speak German (see also Speidel

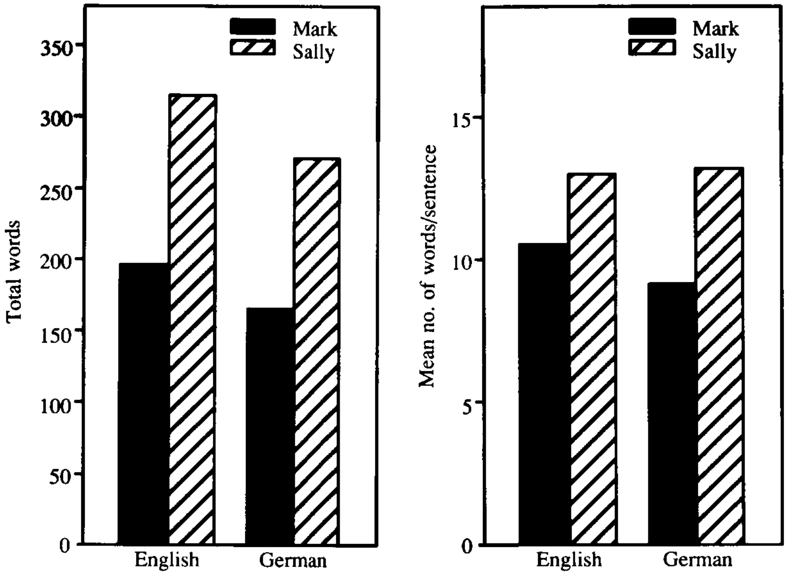

Fig 1. Comparison between Mark's and Sally's performance on English and German story-telling.

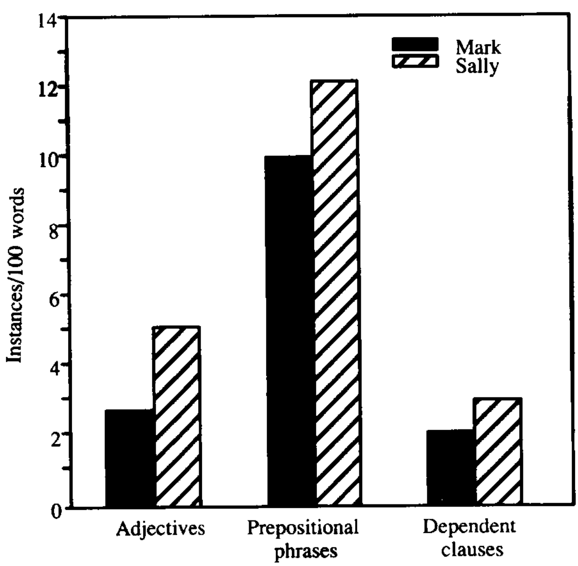

Fig. 2. Comparison between Mark's and Sally's English story-telling.

1989*a*): the only input source for German are the parents, and Mark and Sally have spent a similar amount of time interacting with them.

Intelligence can be ruled out as a cause. Cognitive ability tests showed that Mark at age 2;6 performed, like Sally, in the *Superior* range on the Stanford Binet Intelligence Test and again at age 5, like Sally, he scored at the 99th percentile on the Raven's Progressive Matrices, a non-verbal reasoning test. Recent testing, when Mark was 12, again showed that his cognitive abilities are high, performing in the *Very Superior* range on the Wechsler Intelligence Scale for Children-R (WISC-R).

In Speidel (1989*a*) one reason for the differences in the children's language acquisition was discussed at length: short-term memory storage capacity (i.e., a temporary working memory store, as originally suggested by Atkinson & Shiffrin 1968).

Short-term memory: early years

In this section, I briefly review my earlier findings on short-term memory and then present more recent observations.

Verbal repetition – verbal imitation ability In sharp contrast to his good language comprehension and superior cognitive abilities, Mark had great difficulty with any form of verbal repetition. Between the ages of three and six years, he was given several standardized verbal repetition (elicited imitation) tasks with age performance norms. (The norms allow a comparison of Mark's memory performance with that of children of the same age and with Sally's performance. I report Mark's and Sally's performances, whenever possible, in terms of percentile scores, which can be regarded as performance ranks in a group of 100 children of the same age, where a percentile score of one reflects the lowest possible rank and 99 the highest.) Unless reported otherwise, the tests were given between the ages 6;6 and 7;0.

(a) The earliest test evidence comes from a speech therapy report when Mark was 3 years and 3 months old. The report states that Mark had particular difficulty on the Sequenced Inventory of Communication Development, a test in which the examiner says sentences of different lengths and the child is asked to repeat back each sentence immediately.
(b) At age 4;6 he performed below the 20th percentile for his age group on Auditory Sequential Memory of the *Illinois Test of Psycholinguistic Abilities* (ITPA; Kirk, McCarthy & Kirk 1968), a test where the examiner says strings of digits of different lengths and the child repeats back each string immediately. On a readministration of this test at age 6;6 he scored at the 34th percentile; Sally scored at the 66th percentile.
(c) On the Unrelated Words test of the *Detroit Tests of Learning Aptitude-2*

(DTLA-2; Hammill 1985) Mark obtained a percentile score of 21; Sally obtained a score of 63. On this task, the examiner says strings of unrelated words and the child repeats back each string.

(d) On the *Carrow Elicited Language Inventory* (Carrow 1974) the examiner says sentences and the child is instructed to repeat them back immediately. Unlike the other three tests, however, in which points are given only for accurate repetition of the whole sequence, points are given on the Carrow for accurate repetition of particular grammatical morphemes. Mark performed in the low average range for his age (42nd percentile) whereas Sally obtained a very high score at the 98th percentile.

(e) On a similar elicited sentence task in German, the Heidelberger Sprachentwicklungstest (Grimm & Schöler 1978) Mark performed at the 7th percentile and Sally at the 32nd percentile.

Visual short-term memory Testing showed that Mark's short-term visual memory was excellent. For example, on Visual Sequential Memory on the ITPA, Mark obtained the top possible score for his age group. On this test, a child is briefly shown a sequence of nonsense line drawings and is then asked to reconstruct the sequence from memory by selecting chips with the line drawings printed on them.

Summary These findings from early development suggest Mark has a short-term memory weakness that is specific to verbal tasks. The fact that Mark had difficulty not only with the imitation of sentences, but also with the imitation of digits and unrelated words suggests that his difficulty is not specific to syntax, but is based on a general limitation of his verbal memory span.

Short-term memory tests at age 12;6

Verbal memory tasks At age 12;6, Mark and Sally were given three verbal short-term memory tasks from the DTLA-2 (Hammill 1985) – Unrelated Words, Sentence Imitation, and Oral Directions – and one from the WISC (Wechsler 1974) – Digit Span. Unrelated Words, the immediate repetition of words unrelated to each other, was decribed in (c) above. Digit Span requires the repetition of sequences of digits and is similar to Auditory Sequential Memory described in (b) above. Sentence Imitation requires the immediate accurate repetition of sentences, varying in length. On Oral Directions, the child hears series of verbal instructions that he is to carry out on strips of line drawings placed in front of him, for example, 'Put a circle around the animal, a line under the thing that the animal lays, an x on the tool, and draw a line to connect the things that are worn. The line cannot touch any other object. Do it NOW.' The child must wait to respond

TABLE 1. *Performance on verbal short-term memory tests**

	Unrelated words		Digit span		Sentence imitation		Oral directions	
	%ile rank	standard score	%ile rank	standard score	%ile rank	standard score	%ile rank	standard score
Mark	2	4	16	7	50	10	95	15
Sally	84	13	63	11	63	11	84	13

* The subtests all have a mean of 10 and an approximate standard deviation of 3.

until the examiner has finished saying the instructions and gives the command 'Do it now'. Mark's and Sally's performances are depicted in Table 1. Mark's performance on these short-term verbal memory tasks varied widely, with a score below the 2nd percentile on Unrelated Words (that is, 98 out of 100 children of his age do better than he does) and a score at the 95th percentile on Oral Directions. Sally's performance varied relatively little from one test to the next, which is the typical pattern for normally developing children; some variation across tests is expected due to measurement error.

Visual memory Mark was also given the Design Reproduction subtest from the DTLA. On this task the child is shown geometric figures, one at a time. He is told to look at the figure. After 5 seconds the figure is withdrawn and the child is asked to draw the figure from memory. The reproductions are scored not only for presence of correct components, but also for how well they are drawn. The score, therefore, reflects not only visual short-term memory but also fine-motor skill. Mark excelled on this task, obtaining a percentile score of 98. (He obtained a standard score of 16; the test mean is 10; the standard deviation is 3.) The points he lost were mainly for poor drawing, not for forgetting components. This confirms the earlier finding that Mark has very good visual short-term memory.

Discussion Performance on each of the four verbal tasks draws on verbal short-term memory in that the child must hold in memory briefly the verbal input until the moment for repetition or reconstruction has arrived. Despite this similarity, Mark performed very differently on the four tasks. Why? How do these tasks differ from each other?

Words have two components: the sound – their phonology – and the meaning that becomes associated with the sound through experiences (see Speidel 1989*b*). The first three tasks are similar in that they all require accurate verbal imitation, that is, accurate reproduction of the phonological sequence presented by the examiner. The tasks differ in the degree to which the words are meaningfully associated with each other and therefore the degree to which they draw on long-term memory. On Unrelated Words, although many of the sounds and meanings of the words are familiar to children, the words are not meaningfully related to each other and come from a nearly infinite pool of English words. For Digit Span, we can assume that the numbers are more familiar to children than the unrelated words, and since there are only 10 possible digits/sounds, there should be fewer competing items, making their recall easier than that of unrelated words. In Sentence Imitation, the words are meaningfully and grammatically related. It is well known that we can repeat many more words when they are in a meaningful sentence, indicating that the grammatical information in long-term memory and the meaningful relationship underlying the words in a sentence assist our verbal short-term memory.

Of the three tasks, therefore, performance on Unrelated Words would seem to reflect most purely phonological short-term memory. (An even purer measure would be the repetition of nonsense, i.e., meaningless words.) The fact that Mark had greatest difficulty on this measure suggests that storing the sounds of words in short-term memory underlies his repetition difficulties. His much better performance on Sentence Imitation indicates that he could avail himself of his familiarity with English sentence structure and the meaning of the sentences; indeed, achieving a score at the 50th percentile, rather than the second percentile, suggests that his ability to avail himself of this knowledge compensated for his poor phonological memory.

Mark was given at this age a similar elicited sentence imitation task in German. Again he was able to repeat many more words when repeating sentences than when repeating isolated words, indicating that his knowledge of German syntax and the meaningfulness of the sentences also helped his short-term phonological memory. Nevertheless, his performance relative to other German children of his age was extremely poor, falling below the first percentile. He probably did not have German sentence patterns as readily available in his long-term memory as English ones to support his imitation.

Mark's performance on Oral Directions casts further light on his particular difficulties. In contrast to the other three verbal short-term memory tasks, Oral Directions does not require a *verbal repetition*, but a *visual-motor reproduction*. To follow the directions on this task, moreover, one does not need to hold all the information phonologically in short-term memory since the line drawings upon which to perform the directions are in view: as one hears the verbal input, one can 'translate' the directions immediately into their visual-motor representations and hold them in this form of representation until asked to reproduce. This form of memory processing could account for Mark performing nearly without error on this verbal short-term memory task.

Summary The fact that Mark's lowest performance by far was on the repetition of unrelated words, the test with the most direct assessment of phonological short-term memory, suggests that his difficulty with verbal repetition tasks is associated with a weak memory for the sounds of words i.e., for the phonological component of language. Furthermore it appears that his difficulty does not affect the perception or processing of verbal input, since he had no difficulty when he could store and reproduce the verbal information by visual-motor means. The impairment seems to be related to *holding* the phonological sequence in mind for a short period and/or to *reproducing* the phonological input.

Verbal short-term memory and phonological memory processes

Mark's difficulties are similar to those of a group of children with delayed speech who have what is called *specific language delay* or *developmental dysphasia*. But either his difficulties are less severe than those of children who are thus labelled, or his well developed cognitive and visual abilities have helped him compensate over the years. Although developmentally dysphasic children have no obvious signs of central nervous system dysfunction, are of at least average intelligence and are not deprived of language input, they have severely delayed speech (e.g., de Ajuriaguerra *et al.* 1976, Grimm 1987, Menyuk 1978, Menyuk & Looney 1976). Like Mark, these children have no basic difficulty in comprehending language (see Menyuk & Looney 1976, for characteristics of English dysphasic children, and Grimm 1987, for German dysphasic children), but their verbal short-term memory appears to be shorter than average as they have great difficulty with sentence imitation (Grimm 1987, Menyuk & Looney 1976). In contrast to Mark, these children's expressive language difficulties tend to be still present after the age of five.

Gathercole & Baddeley (1990) studied a group of developmentally language-delayed children, aged seven and eight years. The children in their sample had great difficulty in repeating series of non-words. Indeed, their ability to repeat these non-words was at least one year below their comprehension vocabulary score, suggesting that the 'memory skills tapped by repetition play a central role in language development, and that it is impairment in these skills which is, in part at least, instrumental to the developmental language problems' (p. 343).

The link between verbal short-term memory and rate of speech development is also seen in a group of children with very precocious expressive vocabulary development (Robinson, Dale & Landesman 1990). Chosen for their well developed expressive vocabulary, these children at age 24 months – the age at which Mark spoke his first words – obtained a vocabulary score, on the Stanford Binet IV, that is typical of 62-month-olds! Their imitation of sentences, however, exceeded even their vocabulary performance: it was equal to that of the average 65-month-old child, indicating exceptionally well developed verbal short-term memory. In contrast, their visual short-term memory was not exceptionally high.

Gathercole & Baddeley (1990) have studied the possible causes for the verbal repetition deficits of their developmentally language-delayed group and have concluded that the verbal memory difficulty is not due (a) to a failure to encode phonologically, (b) to impaired rehearsal processes, or (c) to grave deficits in phonological perception. Rather, they believe there is 'impaired efficiency of the processes involved in phonological representation' (p. 351) and 'an impairment in the specialized storage of phonological information in working memory' (p. 357).

Evidence for phonological processes in verbal short-term memory also comes from a group of researchers at Haskins Laboratories – Isabelle and Alvin Liberman, Shankweiler and others – who have studied children with *specific reading delay*, also known as *developmental dyslexia*. There is a close connection between developmental dysphasia described above and developmental dyslexia. In most cases, developmental dysphasia is followed by dyslexia (Njiokiktjien 1990). Mark, too, had great difficulty learning to read (Speidel 1989*a*). One of the outstanding characteristics of children with specific reading delay is that they have poor verbal short-term memory as measured by the repetition of unrelated words (e.g., Mann, Liberman & Shankweiler 1980).

The Haskins group proposes that weakness in a phonological processing system accounts for the reading difficulties of these children. This weakness can result in difficulties in those higher level skills that are based upon this system, such as verbal short-term memory: 'Because short-term memory depends on the ability to gain access to phonological structure and to use it to hold linguistic information (Conrad 1964, Liberman, Mattingly & Turvey 1972), we might expect people who have underlying phonological deficiencies to show various limitations on verbal tasks that tap short-term memory. This expectation is amply born out' (Liberman, Shankweiler & Liberman 1989: 17). They speculate that developmentally dyslexic children have difficulty in setting up the phonological structure of words: 'If the underlying biology tends to set up phonological structures weakly, then it should follow that these structures would be that much harder for the child to bring to a level of explicit awareness' (p. 17), demanded when learning to read.

Although both Baddeley's research group and the Haskins group see difficulty with verbal repetition resulting from a weakness in phonological processes, they differ in their views of the nature of this weakness and of the nature of the phonological store. The Haskins group sees the phonological store as central motor processes; indeed in his motor theory of speech perception, Alvin Liberman (Liberman & Mattingly 1985) has proposed that speech perception is essentially a central motor process involving 'articulatory gestures'.

> This system evolved in the race, and as it develops anew in each child, it employs abstract [neurological motor] structures – let us call them gestures – that ultimately control the movements of the speech organs (Browman and Goldstein, 1985; Liberman and Mattingly, 1985; Liberman and Mattingly, 1989) . . . These gestures are adapted for one purpose and for one purpose only: the production of strings of consonants and vowels at rates many times more rapid than could otherwise be achieved. These rates, which run about eight to ten per second on average, are managed by precisely overlapping and merging the articulatory movements that produce the phonologically significant aspects of the speech sounds. (Liberman *et al.* 1989: 9)[1]

Baddeley had initially also emphasized motor processes in verbal short-term memory, and had hypothesized that one component of working memory was an *articulatory loop* (Baddeley 1986). Baddeley and his colleagues, however, are moving away from this position. In their recent work the articulatory loop has been replaced by the more neutral term *phonological memory* or *phonological loop*, which is thought to consist of a phonological store and articulatory rehearsal processes. This change in the theory stems partly from the study with the language-delayed children who did not appear to have any articulatory difficulties or problems with rehearsal (Gathercole & Baddeley 1990).

[1] Relevant to the discussion about the relationship between the perception and production of speech sounds is the work of Studdert-Kennedy (1986), who believes that speech develops through imitation of an amodal speech percept that directly specifies the pattern of articulatory action to be performed. According to Studdert-Kennedy, in learning to speak a child analyses the words he hears into their component gestures and discovers motorically their spatio-temporal relation, doing first a perceptual analysis and then a motor synthesis. 'A capacity to perceive the pieces of an act and their relations and to reproduce them in our own behavior, rests on some form of structural (anatomical, physiological) correspondence between imitator and model.' In other words, Studdert-Kennedy believes that verbal imitative behaviour is only possible because there are close neurophysiological connections between auditory perceptual processes and motor processes.

We do not at present have sufficient knowledge to draw conclusions about the degree of involvement of central neural motor processes in the functioning of phonological short-term memory. I would like to suggest nevertheless that difficulty with articulation in the initial stages of learning to speak is one of the first overt signs of phonological processing weakness. With practice, the initial articulatory difficulties may no longer be noticeable. Thus Mark showed no reduplicative babbling during infancy; until age two he had great difficulty with producing speech sounds that were intelligible; when he finally began to speak words that could be understood, the articulation problems became evident, and he stammered. At age three he still had numerous articulation errors on a speech screening test, but on a similar test two years later these articulatory problems were no longer evident in English. In German, however, he still has an 'accent'.

Even when articulation difficulties are no longer noticeable in regular speech, they may still surface in tasks that challenge the articulatory processes. Thus, Gathercole & Baddeley (1990) may not have found articulatory and rehearsal difficulties in their language-delayed group because they measured articulation processes with highly familiar and highly practised words – words whose sounds and articulatory patterns were already well established in long-term memory and readily accessible. Evidence that the articulatory system is still functioning less smoothly in these children is found on two tasks of the Gathercole & Baddeley study.[2] (1) The verbal short-term memory performance of the language-delayed children was more impaired compared to that of control children on the *repetition* of three- and four-syllable words (Experiment IB) than on the *reproduction* of word sequences *using pictures* (Experiment II). (Similar variation in verbal short-term memory performance as a function of visual or verbal reproduction was seen in Mark at age 12;6.) (2) The language-delayed children had great difficulty with a Sound Mimicry task, requiring the repetition of unfamiliar phonological forms (non-words) one at a time.

The work of Galaburda (e.g., Galaburda 1988, Galaburda, Corsiglia, Rosen & Sherman 1987) provides evidence for a neurological basis of developmental dyslexics' language difficulties. Galaburda has studied *post-mortem* the brains of individuals known to have been dyslexic and has found that the area of the brain called the *planum temporale*, an area that is

[2] Baddeley himself has suggested that the deficiency in phonological short-term memory may be more evident in the learning of new words than in the use of already learned words: an adult patient who had acquired through trauma to the brain a severe short-term phonological memory deficit was able to learn associations between familiar words, but was unable to learn words in a new language (Baddeley, Papagno & Vallar 1988).

typically associated with language, had a different structure from that of the *planum temporale* in brains of individuals with no known reading difficulties.

Phonological short-term memory, imitation ability and learning to speak

On the basis of their research with language- and reading-delayed children, Gathercole & Baddeley (1990) speculate that phonological short-term storage skills play an important role in the development of a range of complex higher-level linguistic abilities, such as reading, vocabulary, and comprehension; they suggest that phonological short-term memory contributes to learning new words by achieving a stable representation of the initially novel sound sequence in long-term memory.

Mark's difficulty in 'achieving a stable representation' of sounds of words is reflected in the following description (Speidel 1989*a*). Mark had to retell a German story, a story in which a series of items were hidden and which the protagonist found. The concept *found* was consistently encoded in the story as *hat gefunden*. In his story retell, Mark used the appropriate form on the first occasion; next time he switched to *find* (the *i* pronounced as in *in*), the verb stem of the German present tense. The third time he created his own past tense, *gefinden* (the *i* again pronounced as in *in*). Then he created *fund*, and finally he used the English word *found*, all within two minutes!

If a weakness in phonological short-term memory results in difficulties in acquiring the stable sound of a word, would then such a weakness not affect even more the acquisition of syntax? Most researchers of child language, whatever their theoretical positions, have argued that children need to have a corpus, a storehouse, of adult language patterns in order to acquire adult syntax and grammar. For example, Nelson (1987) wrote, 'At some point, the child will accumulate enough related examples for comparison, and the successful abstraction of new structural descriptions will actually occur' (p. 296). Pinker (1984) suggested, 'The child could store auditory templates of words or short phrases' (p. 28). Many years ago Brown & Fraser (1963) wrote about the acquisition of syntax:

> Child speech is a systematic reduction of adult speech largely accomplished by omitting function words that carry little information. From this corpus of reduced sentences we suggest that the child induces general rules which govern the construction of new utterances . . . A child becomes capable through maturation and the consolidation of frequently occurring sequences of registering more of the detail of adult speech (p. 79).

The way in which such a corpus of phrases can be acquired through various forms of imitations – immediate, rote, deferred and expanded, overt and covert – and can lead to spontaneous speech has been described by Speidel (1989*b*).

It seems logical that in order to develop such a storehouse of phrases in long-term memory, the child must first register them in short-term memory or working memory. Brown & Fraser (1963) speculated, 'Span limitation is probably the factor compelling children to reduce adult sentences' (p. 77). From intelligence testing (e.g., Terman 1916), it is well known that verbal memory span not only increases with development, but that it varies from one individual to the next. An infant with a biologically more limited phonological short-term memory than the average child might, therefore, be expected to have greater difficulty holding the sounds of the words in short-term memory and might be expected to have greater difficulty, or require more 'trials' and more input, to build up a storehouse of sentence patterns from which to construct his messages. Such a child may have to build sentences from single meaning/sound units. If the word order is not available as a unit, it will make sentence construction much more difficult than when there is access to ready-made, longer patterns of speech stored in long-term memory.

MODULARITY

Viewing Mark's delayed speech as weakness in short-term phonological memory is relevant to the issue of modularity in language processes. The best-known language module is Chomsky's (1957) Language Acquisition Device, thought to be specifically structured to enable us to acquire grammar from a limited amount of input. Chomsky has modified his conception since then: 'The list of candidate modules changes in each successive version of Chomsky's grammatical theory, as more and more evidence accrues regarding the nature of Universal Grammar . . . Even though the concept of modularity is currently quite fashionable, there is little consensus regarding the nature of linguistic modules' (Bates *et al.*, 1988: 27).

Bates and her associates (Bates *et al.* 1988) have concluded from their studies of individual differences in language acquisition that there are two types of horizontal language modules (modules that cut across the traditional modules of semantics, phonology, and grammar): *comprehension* versus *production* and *rote* versus *analytical* processing. I will attempt to show how a weakness in phonological memory can account for the occasionally observed dissociation between comprehension and production (e.g., Bates *et al.* 1988) and for the difficulty with the acquisition of function words and inflections shown by developmentally dysphasic children.

Comprehension and production: separate processes

The asynchrony in the development of speech comprehension and production was described nearly twenty years ago by Huttenlocher (1974) who noted that in the early phases of normal children's language development, comprehension far exceeded production. Messer & Hasan (1991) have recently shown the same advance of comprehension in Mongoloid children. In second-language learning too, comprehension typically exceeds production; some second language pedagogues even argue for a silent learning period in which the learner is given comprehensible input but is not forced to speak (Asher 1977, Krashen & Terrell 1983).

The work by Bates *et al.* (1988) complicates this picture: the differential rates at which comprehension and production develop may differ from one child to the next. Thus in some children, the *high analytic*, comprehension is relatively high whereas production is relatively low, as in Mark. In other children, the *high rote*, production is relatively high whereas comprehension is relatively low. However, since Bates's classification does not look at the acquisition of the same words or grammatical structures in comprehension and production as Huttenlocher did, but merely compares a child's performance rank relative to other children *within comprehension* to his rank *within production*, we do not know whether production is actually in advance of comprehension in the high rote style, or whether comprehension is usually advanced over production in the high analytic style.

Speidel (1989*b*) presented a processing model in which comprehension is seen as the result of simultaneous activity in an incoming speech-sound or receptive phonological network and a meaning network, while speaking is seen as activation of the meaning network and a speech-planning network. A part of the speech-planning network is a phonological encoding system; efficient storage and retrieval of the phonological structure of words and phrases are important in speaking.

The more rapid development of speech comprehension in infants could come about because (a) the receptive phonological processing network develops more quickly than the phonological memory required for speaking, or because (b) words might be sufficiently familiar to be recognized but not to be produced (Huttenlocher 1974: 365). That is, learning the sounds of words may need to be less complete for comprehension, which is a recognition memory task, than for production, which is a retrieval task. In the first possibility – one phonological memory network for input and another for output – a relative advance of comprehension over production, as the one shown by Mark or by dysphasic children, could be accounted for by selective impairment in the output system. In the second possibility, an impaired phonological memory might not be as detrimental to comprehension as to production, allowing sufficient 'incomplete storage of the sounds' for recognition memory but insufficient for retrieval required in speaking. Thus, in both cases, a weakness of some form of phonological memory could account for an advance of comprehension over production that is even greater than that normally observed. This would then produce the 'dissociation' described by Bates *et al.* where a child ranks much higher in comprehension, compared to his age mates, than in production.

Phonological memory in the acquisition of syntax/grammar

If we accept the idea that the ability to hold phonological sequences in short-term memory is the basis for development of a corpus from which spontaneous speech emerges through various forms of imitation (see Speidel 1989*b*), a weak phonological system would appear to play much more havoc with syntactical/grammatical development than with the production of single words. I would now like to show what aspects in speaking would be affected most by a weakness in phonological memory.

The word order of the main constituents of a sentence – the agent, the action and the object – should be learnable from their ordering in semantic memory. The following anecdote with Mark may make this point clearer. When he was about three years old Mark's mother asked him to say to an auntie on the phone 'I love you'. He complied, calling into the phone, 'Ich love Du'. Since he never heard the sentence he composed, he could not have stored it as a phonological unit. Rather, he must have pieced it together from separate meaning/sound elements, translating *I* into *ich* and *you* into *Du*. How was he able to come up with the correct word order for either English or German in spite of his cross-language construction? How did he accomplish this when the actual imitation of the 3-word utterance was too complex? A possibility is that he may have learned on the basis of meaning the order of the elements: the agent comes first, the action next, and the recipient of the action last. That a certain amount of word-order learning can be supported by semantic processes is suggested also by Menyuk & Looney (1976) in their study of language-delayed children who were able to 'satisfactorily convey the information' in their repetitions and 'retain representations of the semantic aspects of these sentence types, how to express them' (p. 227).

A weak phonological memory would therefore seem to affect the learning of regular, frequently occurring sentence patterns much less than the learning of word orders that are contrary to the typical order. Thus, as English has typically SVO sentences, a child should be able to construct such simple sentences on the basis of single-word phonological/semantic units as Mark did in the example above. But how will a child learn the word order 'How will he do it?' if not by storing longer phonological/semantic sequences with 'How will (he, she, it, etc.) . . .'? Similarly how will a child learn 'Where is he going?' if not by storing longer semantic/phonological sequences from which to generalize the pattern 'Where is (noun or pronoun) . . . ?'?

To learn irregular word orders, longer phonological sequences must be stored for differentiation from the regular order. Someone with a weak phonological memory would have difficulty learning such irregular word orders because they occur relatively infrequently and longer sequences must be stored. Menyuk & Looney's (1976) language-delayed children made most errors in the repetition of the inverted word order of the question structure, using the more common SVO order 'How he will do it?' or 'How he do it?'.

German has varied word orders for the main sentence constituents and, in contrast to the main clause structure, the verb in dependent clauses is placed at the end of the sentence. In such a syntactically varied system, it would again seem that longer semantic/phonological sequences need to be stored in order to develop the corpus from which to generalize the complex word-ordering rules. An impairment in phonological memory would be expected therefore to result in greater problems in learning to speak syntactically correctly among German dysphasic children than among English dysphasics. Indeed the careful analysis of dysphasic German children's speech development by Grimm (1987) shows that these children have great difficulties with word order.

The phonological memory store should be particularly important for learning the appropriate usage of grammatical morphemes, especially those that have little meaning. In English, this prediction is supported by Menyuk & Looney (1976) who report that their language-delayed children had great difficulty with the repetition of function words and with inflections, which they modify, substitute or omit.

The acquisition of the German gender-case system with its seemingly arbitrary rules is another example in which we would expect a weakness in phonological memory to create learning difficulties. In German there are three genders governing different forms of the articles, pronouns and adjectives. Thus in place of the English *the*, German has *der, die, das*; in place of *a*, German has *ein, eine, ein*; in place of *it*, German has *er, sie, es*, the variations being determined by the gender (masculine, feminine or neuter) of the noun. In addition each gender occurs in four different cases which also take different forms for the articles, pronouns, adjectives and nouns. The complexity of the system is seen in the following example. In the nominative, the feminine form of the definite article is *die*, as in *die Butter (the butter)*, and the masculine is *der*, as in *der Baum (the tree)*; but in the dative the feminine is *der* (the same word as for the masculine nominative), as in *der Butter*, and the masculine is *dem*, as in *dem Baum*. Furthermore, prepositions can be combined in different ways with the definite article so that *zu der Butter* becomes *zur Butter (to the butter)* and *zu dem Baum* becomes *zum Baum (to the tree)*.

In his recent work with German developmentally dysphasic children, Clahsen (1988) found that their greatest difficulty was with the gender-case system. This is reminiscent of Mark whose greatest difficulty in his German story retelling at age 12;6 was also with the gender and case endings.

Clahsen argues that the child can only learn the use of this system if he systematically compares the formal contrasts in the input on many grammatical dimensions. Maratsos & Chalkley (1980), writing about German, have made a similar suggestion: 'No semantic or other widely utilizable criterion reliably determines whether a noun takes masculine, feminine, or neuter determiners, adjectives, and pronouns. One must simply *memorize* its gender . . . Gender is . . . not a characteristic of the noun, but a characteristic of how it fits into related . . . patterns' (p. 137).

We would expect phonological memory to play a critical part in this kind of learning that has little semantic information. In order to remember whether one should use *die, der, das, dem, des, zum, zur Butter*, etc., one needs to store phrases or sentences with *Butter* in different grammatical positions. And since the gender markings are not semantic, what then is there to be remembered if not simply the sound of the word in different grammatical patterns? Our personal experience bears this out: if we are unsure about the correct form, what do we do? We do not usually think of the grammatical rule, but say the phrase to ourselves in different ways and ask what *sounds* right.

Finally, I refer to the arguments of several model builders of grammar acquisition. Maratsos & Chalkley in their analysis of acquisition of syntactic categories argued, 'There exists a scanner of incoming speech which analyzes sequential properties of morpheme strings. The use of all kinds of analyses – semantic, pragmatic, distributional, *phonological* [italics added] – find their way into the structure of grammar. Syntactic categories such as verb or adjective, or gender class, are actually summaries of the productive systems of correlated sets of distributional-semantic-*phonological* [italics added] contexts into which such classes of terms fit.' (Maratsos & Chalkley 1980: 191).

Rumelhart & McClelland's (1987) model on the acquisition of the past tense markers, a kind of mathematical parallel to Maratsos's pattern analysers, has as an integral part the *Wickelphones*. These Wickelphones represent the sounds of English verbs and past tense forms. In other words, Rumelhart & McClelland's grammatical model is built on phonological processes. If there is a biologically weak link in the phonological system, can we then not expect that it will delay or perhaps even alter the acquisition of those grammatical/syntactic features which Rumelhart & McClelland and Maratsos & Chalkley tried to explain in their models?

CONCLUSION

Originally the description and discussion of this case study was intended to stimulate research on the role of phonological short-term memory in language acquisition. At the time when Mark's early language difficulties appeared and worried his parents, the work on verbal short-term memory weakness in reading was in its infant stage. The conclusion that Mark's difficulties stemmed from a difficulty with retrieving from memory the sounds of words (Speidel 1990), based upon the early memory data on Mark and Sally was drawn without knowledge of the thorough work of Gathercole & Baddeley (1990) on the phonological memory impairment of language-delayed children. From their report, however, it would appear that phonological short-term memory has an established place in language acquisition research.

The longitudinal description of Mark's language and verbal short-term memory development shows how such a phonological memory impairment may play itself out over the years in a child who is raised bilingually and who does not become labelled 'language impaired'. Mark would not have been included in any of the studies on language deviance after the age of 4 or 5; from that age on his speech would not have been judged sufficiently deviant. Nevertheless Mark is not the 'normal' language processing child. He *had* difficulty in certain stages of development: his learning to speak was markedly delayed and characterized by syntactic, word-finding and grammatical problems; he *had* marked difficulty learning to read. As a budding teenager he still has signs of the impairment: great difficulty with meaningless verbal repetition tasks and great difficulty with *speaking* his mother tongue, but less preferred language, German.

As with any new level of scientific understanding, questions mushroom. Why has Mark overcome his difficulty in speaking and in reading? Why did he always have relatively good comprehension of language? Is it because the phonological memory weakness is not as great as in the language- or reading-delayed children in the literature? Or is the locus of weakness different and related more to speech production than to comprehension? Or does his high general intelligence or visual memory compensate for his phonological difficulty?

In other words, how does intelligence, visual representational processes or degree of impairment affect the language development of children with an impaired phonological short-term memory? Does more intensive and extensive language input lessen the effects of such a weakness? How does this weakness interact with bilingualism and second language learning? Is it better for children with a weak phonological memory to be exposed only to one language in early childhood? Can we predict variations in learning a second language from variations in phonological memory?

How does the pattern of advanced comprehension over production in children with Down's syndrome (Messer & Hasan 1991) relate to the dissociation between comprehension and production observed in Mark or in the high analytic style described by Bates *et al.* (1988)?

What is the relationship between comprehension and production? Since Mark comprehends well in German but typically responds to German input in English, comprehension and production are clearly separate systems with him. But does he process the German input in English or in German? When, where or how does the German phonology get transformed into the English?

This brings us to perhaps the most interesting question: what is the nature of the phonological short-term memory weakness? Is it related to some central neural amodal activity or to abstract 'articulatory gestures'? Does Mark's lack of reduplicative babbling imply a central neural motor weakness? In sum, the concept of individual differences in phonological short-term memory has opened a garden filled with fascinating research questions about language acquisition.

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