The structure and functioning of phonological short-term memory

Susan E. Gathercole
University of Bristol, England

In this paper, I shall provide an overview of one current theoretical account of the phonological component of short-term memory, and shall then consider the role played by this component in the acquisition of knowledge and skills during childhood. To anticipate, I shall argue that one of the primary functions of phonological short-term memory is to support the long-term learning of the sound structures of new words, which is a key process involved in vocabulary acquisition. Finally, I shall speculate about the possible role of phonological short-term memory in the acquisition of literacy.

The specific account of phonological short-term memory which will be the focus of my talk today is provided by the model of working memory first introduced in 1974 by Baddeley & Hitch (1974), and later developed by Alan Baddeley in 1986. The model is depicted in Figure 1, and has three main components, each of which have limited capacities in terms of processing and storage. The central executive is a flexible system responsible for multiple functions, including regulation of the flow of information through working memory, retrieval of information from more permanent knowledge stores, as well as the manipulation and temporary maintenance of information (Baddeley, 1986, 1996; Baddeley, Emslie, Kolodny & Duncan, in press). The limited capacity of the central executive is supplemented by two slave systems, the visuo-spatial sketchpad and the phonological loop. Each of these slave systems has highly specialised capacities to store and manipulate information within their respective domains.

The phonological loop is my principal concern today. As shown in Figure 2, it consists of two subcomponents, a phonological store and a subvocal rehearsal process. The store holds verbal material in a phonological form, possibly corresponding to phonemes or perhaps to subphonetic features. Phonological material held in the store is subject to decay within about two seconds (Baddeley, Thomson, & Buchanan, 1975). The duration of storage can, however, be prolonged by the subvocal rehearsal of the contents of the phonological store. Subvocal rehearsal involves covert articulation in real time of information held in the phonological store. So providing that the entire contents of the phonological store can be rehearsed within about two seconds, the material can be stored indefinitely, although somewhat effortfully.

It should be noted that information may gain access to storage capacity of the phonological loop in one of two ways. The direct route involves auditory input: all spoken language that is perceived gains obligatory access to the phonological store. The indirect route is available for information which is not presented in spoken form, but which can be recoded internally into a phonological code by accessing stored knowledge of its label. Examples of such inputs are the printed forms of familiar words, and pictures denoting objects with familiar verbal labels. For such inputs, the subvocal rehearsal process generates the phonological form, which is then stored in the phonological store in the same way as spoken language inputs. In this way, the phonological loop can be used to store internally generated phonological sequences as well as sequences of spoken stimuli.

Much is now known about the way in which the phonological loop develops during childhood. Memory span, which measures the capacity to recall verbal material in sequence, provides a useful indication of the capacity of the phonological loop. Between the ages of about four and early adulthood, memory span undergoes a two- or three-fold increase, with span increasing from between two or three memory items up to about six or seven items (Hulme, Muir, Thomson, & Lawrence, 1984). This developmental increase in capacity can be explained quite simply by the phonological loop model. The basic storage component, the phonological loop, appears to be present from at least three years of age (Cathercole & Adams, 1993; Ford & Silber, 1994). The capacity to actively rehearse the contents of the phonological store, on the other hand, does not appear to emerge usually until children reach about seven years of age (Gathercole & Hitch, 1993; Gathercole, Adams, & Hitch, 1994). The dramatic increase in memory span during the childhood years appears to be due to increased speed and efficiency of rehearsal. As children grow older, their rate of speaking increases, and so too does their rate of subvocal rehearsal. Faster rates of rehearsal allow more material to be held in the phonological store and continuously recycled without decay, and so lead to greater memory spans. By about 12 years of age, articulation rates achieve adult levels of speed and hence no further gains in rehearsal efficiency are found.

I shall turn now to consideration of the function of the phonological loop in childhood. A central tenet of the working memory model when first advanced was that short-term memory is not simply there to support performance on highly artificial tasks invented by cognitive psychologists, but actually fulfils crucial functions in supporting complex cognitive processes in our everyday life (Baddeley & Hitch, 1974). However, for many years the actual function of the phonological loop was not apparent, although its theoretical structure was well understood. There were numerous studies of adult neuropsychological patients who had sustained damage to regions of the left hemisphere, which results in highly specific deficits in phonological short-term memory. It was presumed that these individuals, known as short-term memory (STM) patients, had impairments of the brain systems underlying the phonological loop. The logic of studying these STM patients was as follows. If it could be identified what they could not do in everyday life, we would have some idea of the roles served by their (deficient) phonological loops. The problem was that these individuals had no other obvious deficiencies in their everyday cognition. They understood language fairly well, unless the structure of sentences was sufficiently complex in syntactic terms or in length to resemble an immediate memory test (Vallar & Shallice, 1990). They could also produce spontaneous speech perfectly well (Shallice & Butterworth, 1977). So, the phonological loop did not appear to be crucial to either the comprehension or production of spoken language. Why, then, do we have this memory system?

The answer to this question became clear when we started to study children rather than adults, and to focus upon the capacity to learn new linguistic information rather than the ability to perform highly practised language skills. Firstly, we discovered that there is an extremely close relationship between the children's phonological memory skills and their abilities to learn new phonological material. The measure of phonological memory capacity which we have used in many studies now is nonword repetition. In this task, the child simply hears a made-up word such as "doppelate", and attempts to repeat it back. The accuracy of the repetition attempt is scored. You may be interested to note that Annabel Thorn and I have also developed a French nonword repetition test, in which typical stimuli are 'nessupleur' and "lutioniste". As children cannot fall back upon their stored knowledge about the sound pattern to support their repetition attempt, they are forced to rely upon the temporary representation of the nonword in the phonological store. Repetition accuracy increases with word length, as would be expected if scores on this measure tap the limited storage capacity of the phonological loop (Gathercole, Willis, Emslie, & Baddeley, 1991).

Returning to our study, we found that 5-year old children who scored highly on nonword repetition also typically performed well on a standardised test of vocabulary knowledge (Gathercole & Baddeley, 1989). In fact, vocabulary knowledge was much better predicted by nonword repetition scores than by general nonverbal intelligence. This finding has now been replicated several times (e.g., Cathercole, Willis, Emslie & Baddeley, 1992; Michas & Henry, 1994). Work by Service and collaborators in Finland, studying Finnish children learning English as a foreign language in secondary school, has also shown that nonword repetition ability is also an extremely good predictor of a child's capacity to acquire a foreign vocabulary (Service, 1992; Service & Kohonen, 1995).
In a recent study (Cathercole, Hitch, Service, & Martin, 1997), we looked in detail at the relationship between phonological memory and vocabulary learning. To do this, we first assessed the phonological memory skills of 65 5-year old children, who then participated in a number of experimental sessions in which they were required to learn new words. In one condition, the children had to learn to associate w familiar word such as fairy with an unfamiliar sound pattern such as kipser. To be able to generate the new word form when presented with the cue of the paired word, the child had to establish a stable long-term memory representation of the novel phonological form. In another condition, the child again had to learn the pairing of verbal items but the learning involved was mainly semantic. For example, the child would be presented with pairs of familiar but unrelated words, and would be asked subsequently to recall the second member of the pair when cued by the first. An example is the word pair donkey - window. There is no phonological learning involved in the tasks, as the phonological forms of both words were highly familiar to the children. They did, however, have to learn a link between the two, presumably by a process of conceptual elaboration.

The findings were very clear. The children's phonological short-term memory skills was closely related to the number of word-nonword pairs learned over the course of ten experimental trials, with a correlation coefficient of .63. There was, however, no significant association between phonological memory abilities and learning of the word pairs. The implication of these findings is that the relationship between phonological short-term memory and long-term learning is a highly specific one: it is restricted to the acquisition of the phonological, and not the semantic, forms of new words.

Our hypothesis is that adequate temporary storage of the phonological form of a novel word is the first crucial step towards building a stable long-term representation of its structure. The long-term specification is typically built up over multiple exposures to new words, but the better the short-term trace on each occasion, the greater the degree of learning. Children with relatively weak phonological memory skills will therefore require more frequent exposures to interpretation has been borne out by several independent studies in recent years which have demonstrated that severe nonword repetition deficits are a key feature of specific language impairment (Dollaghan & Campbell, 1998; Montgomery, 1995). Findings from a large-scale twin study of specific language impairment conducted by Bishop, North & Donlan (1996) indicate that the poor nonword repetition abilities of children with SLI has a strong genetic origin. Indeed, these authors propose that SLI may constitute an effective phenotypic marker for the disorder.

There is therefore now a substantial body of evidence, which points to extremely close links between the phonological loop and vocabulary acquisition. on this basis, we have recently argued that the phonological loop may have evolved primarily as a vocabulary acquisition device, designed to support the long-term learning of the phonological structure of words within the native language (Baddeley, Cathercole, & Papagno, 1998). By our account, the capacity of the phonological loop to hold telephone numbers and to support serial recall of lists of unrelated words is fortunate for experimental psychologists, but secondary.
So far, I have restricted my discussion of the role of the phonological loop to the acquisition of language. I know that there is a strong interest in this meeting in the acquisition of literacy, so in this final part of my talk I will consider possible links between short-term memory and reading. Perhaps the first point to make is that skilled reading places few if any demands on short-term memory. But how about learning to read? There have been many correlational studies, mostly of children aged between about 5 and 10 years of age, which bear on this issue. The typical findings are that measures of phonological short-term memory correlate moderately with individual differences in reading ability (see Gathercole & Baddeley, 1993, for review). The correlations are considerably less strong than the links found between phonological memory skills and vocabulary knowledge but are nonetheless significant. Children with severe impairments in literacy also underperform dramatically on tests of nonword repetition, which performance falling below the level even of younger reading-matched controls (e.g., Snowling, 1981). Indeed, work by Kamhi and colleagues has indicated that in this respect, children with reading disabilities perform indistinguishably from children with more pervasive developmental language disorders (e.g., Kamhi & Catts, 1986).

So, there are certainly links between reading development and the phonological loop. It has variously been speculated that these links reflect the role of short-term memory in learning letter-sound associations (Gathercole, 1990), and in storing segments generated by a phonological recoding strategy prior to blending (Baddeley, 1978). Interest in short-term memory and literacy development has, however, been dramatically overshadowed by the even stronger associations found between phonological awareness and reading ability. These have led to a sustained interest in the possibility that the core cognitive skill required for a child to learn to become a proficient reader is the metalinguistic awareness of the phonological structure of spoken language (e.g., Coswami & Bryant, 1990). The resulting and burgeoning research literature is of great interest, but 1 would like to raise one reservation which 1 have. It relates to a point made forcefully and eloquently by the Brussels research group of Bertelson, Morais, Content and colleagues. Development of awareness of the phonological structure of spoken language is itself strongly stimulated by literacy instruction (Morais, Cary, Alegria, & Content, 1979), probably due to the explicit focus in alphabetic orthographies at least on exploiting the regularities between spelling patterns and the units of sounds constituting individual words. As the very strong empirical links found between phonological awareness and reading ability reflect this fact that phonological awareness is itself a beneficiary of reading development, it is easy to inflate the importance of the high correlations found in the literature. Of course, there may algo be a genuine precursor to full phonological awareness, possibly related to rhyme and segmentation skills, which genuinely does contribute to a child's early success in reading. The point 1 wish to make here is that when the positive effect of reading development upon phonological awareness is taken into account, the evidence for a causal link between awareness and reading development may be no stronger than the moderate association which is well-established between phonological short-term memory and literacy. A positive feature of phonological memory assessments is that they appear relatively impervious to the child's social and cultural background (Dollaghan & Campbell, 1998). Measures of phonological awareness, in contrast, are strongly influenced by socio-economic status (Raz & Bryant, 1990). What is needed now is a careful examination of the common and dissociable features of phonological memory and phonological awareness, and how they relate to reading achievement in childhood.

In conclusion, development of the phonological component of short-term memory is closely associated with the acquisition of language during childhood.
Findings from studies of normal children and children with developmental language disorders converge on the view that adequate temporary storage of the phonological structure of new words is an important prerequisite for fast learning of the sound structure of the language. Other evidence too which 1 have not have time to summarise, from experimental investigations and studies of neuropsychological patients, points to the same conclusion. Thus, the adequacy of a child's phonological loop is not trivial matter for their language development.

The relationship between this short-term storage system and the acquisition of literacy is less well understood, and has been largely overshadowed by the focus on another phonological skill which develops considerably over the early and middle childhood years, phonological awareness. The time is right, 1 believe, for a new comparison of the roles of short-term memory and phonological awareness in literacy development which draws upon the explicit theoretical model of the phonological loop and the assessment tools which accompany it. With recent gains in understanding both areas, we may now be able to make real progress in identifying the critical cognitive constraints on normal and abnormal reading development.

References

Baddeley, A. D. (1978). Working memory and reading. In P. A. Kolers, M. E> Wrolstad, & Ho. Bouma (Eds), Processing of visible images, Vol 1, pp355-370. New York: Plenum Press.
Baddeley, A. D. (1986). Working memory. Oxford: Oxford University Press. Baddeley, A. D., Emslie, H., Kolodny, J., & Duncan, J. (1998). Random generated -5.9executated -5.9 coatworking -5.9 memoryey
menBalBholB
B35.9 addeley A(D.,Grat)3hvrcoele (1998). Tthe phonolololearnl
holBRievgl
Baddeley, A. Dd, & sit1946). Working memory. In,GD. A.(B)4.2(o)-1.1wver (E.s),
earn(ng and m118.7(o-)27(itilat.)TJ6.5 261 0 TD0.0011 Tc0.0074 Twan,vol. 8. New York Ac ad m123.5ic(Press.)TJ-6.5 261 -
vihop,. D.V.,Mt (1928). Tthe undePlngnratmm
eg(y)4.9(&gPsyM)4.9cee
i(hop,1998)(M,2()16NTJ1, ihperiend.)Non-wo m)2TJ -1.1677 TD0.0017 Tc0.4235 TwlB)412(a)246anguage imme
eaingRleeach
P. (1946). W okingom(e)256om(o)-1.2((y)489 il)423(o)-1.2 chilen(htB)4.2(a)253ed phonolgil
ng ofpictorialg m122(a-1.3terials. erti(h jour.)TJ6.2.575 0 TD0.0043 Tc0.0114 Twalg ofDdedeopom)1489(ntalg.)TJ
at rcoels,(A. (1936). Pphonol)412(gil)413ical.0.1((worki)413(ngom)13.1ea)246omo yMioyM
ngchillB enenBalBholB
at rcoels,(
emenyaBdClgnsit

STM in the development of vocabulary in children: A longitudinal study.

Journal of Memory and Language, -28, 200-213.
Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language-disordered children: Is there a causal connection? Tournal of Memory and Language, 29, 336 -360.
Gathercole. S. E., & Baddeley, A. D. (1993). Working memory and language
Hove: Lawrence Erlbaum Associates.
Gathercole, S. E., & Hitch, G. J. (1993). Developmental changes in short-term memory: A
revised working memory perspective. In A. Collins, S. E.
Gathercole, M. A. Conway, & P. E. Morris (Eds.), Theories of Memory, pp 189-210. Hove, U.K.: Erlbaum.
Gathercole, S. E., Hitch, G. J., Service, E. & Martin, A. J. (1997). Phonological shortterm memory and new word learning in children. Developmental Psychology, 33, 966 -979.
Gathercole, S. E., Willis, C., Emslie, H., & Baddeley, A. D. (1991). The influences of syllables and wordlikeness on children's repetition of nonwords. Applied Psycholinguistics, 12, 349 -367.
Gathercole, S. E., Willis, C., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. Developmental Psychology, 28, 887 -898.
Goswami. U. & Bryant, P. (1990). Phonological skills and learning to read. Hove, UK: Lawrence Erlbaum Associates Ltd.
Hulme, C., Thomson, N., Muir, C. & Lawrence, A. (1984). Speech rate and the
development of short-term memory span. Journal of Experimental.Child Psychology, 38, 241 -253.
Kamhi, A. G., & Catts, H. W. (1986). Towards an understanding of developmental language and reading disorders. Journal of Speech and Hearing Research,28, 337-347.
Michas, 1. C. & Henry, L. A. (1994). The link between phonological memory and vocabulary acquisition. British journal of developmental Psychology,12, 147-164.
.Montgomery, J. W (1995). Examination of phonological working memory in specifically language-impaired children. A1212lied Ps cholinguisi 16 355-378.

Morais, J., Cary, A., Alegria, J. & Bertelson, P. (1979). Does awareness of speech as

a sequence of phones arise spontaneously? Cognition, 7, 323-331.
Raz, I. S., & Bryant, P. (1990). Social background, phonological awareness and children's reading. British journal of Developmental Psychology, 8, 209-225. Service, E. (1992). Phonology, working memory, and foreign-language learning.
Quarterly journal of Experimental Psychology, 45A, 21-50. Service, E. & Kohonen, V. (1995). Is the relation between phonological memory and foreign-language learning accounted for by vocabulary acquisition?
Applied Psycholinguistics, 16, 155-172.
Shallice, T. & Butterworth, B. (1977). Short-term memory impairment and spontaneous speech. Neuropsychologia, 15, 729-735.
Snowling, M. (1981). Phonemic deficits in developmental dyslexia. Psychological Research, 43, 219-234.
Vallar, G. & Shallice, T. (1990). Neuropsychological impairments of short-term memory. Cambridge: Cambridge University Press.

DISCUSSION / QUESTiONS

Question à Mrs. Gathercole

Phonological short-term memory appears to enable storage of phonological material in the long-term memory, thus enabling an improvement (an increase) in linguistic representations.

Can it be assumed that this phonological memory is used by readers with normal hearing when they read ? And that it enables « durability » of the stimulus ?

No, there is little evidence for phonological memory mediation in skilled reading. It may, however, be important at the early effortful stages of literacy acquisition when a phonological decoding strategy is used.

What about the effectiveness of visual memory that is mainly in play during the act of reading ?

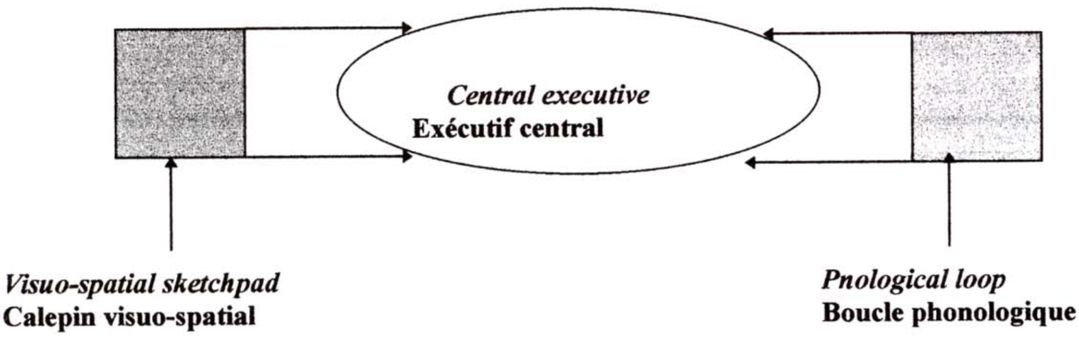
We have never found any evidence for this.

It is possible that the lack of reading effectiveness in deaf people commes from the fact that they are unable to replace visual information by a phonological code that ensures that it is maintained in their long-term memory ?

Yes, this could wall be the case. Certainly, only a small proportion of deaf people appear to have been able to develop to support their reading. As I said before, in skilled hearing readers this strategy appears to be relatively unimportant in adulthood. For deaf individuals, however, the absence of access to such a strategy may mean that they never acquire the higher mevels of reading competence.

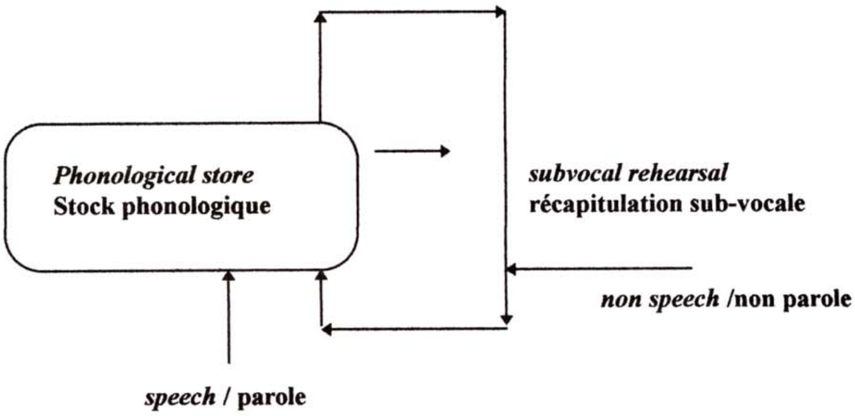
Is the very nature of visual memory detrimental to reading skills in deaf people ?

I'm not sure.



Baddeley & Hitch (1974)

FIG. 2 -



after Baddeley (1986)