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The Development of Memory

Susan E. Gathercole

Centre for the Study of Memory and Learning, University of Bristol, U.K.

This article reviews recent advances in understanding the changes in memory function that take place during the childhood years. Development of the following aspects of memory are considered: short-term memory, comprising phonological memory, visuospatial memory, and executive function; autobiographical memory; episodic memory, including eyewitness memory; and metamemory. Each of these aspects of memory function shows substantial qualitative change from infancy, through the preschool period, to the early school years. Beyond about 7 years of age, however, memory function appears adult-like in organisation and strategies, and shows only a gradual quantitative improvement through to early adolescence.

Keywords: Memory, short-term memory, long-term memory, autobiographical memory, episodic memory, eyewitness testimony.

Abbreviations: SLI: specific language impairment.

Understanding children's memory and the way it develops is of crucial importance for psychologists and other academic and professional groups. From a theoretical perspective, the goal of providing a full account of the many processes and systems involved in human memory can only be achieved if the changes that take place in memory abilities during childhood, which culminate in adult memory function, are also known. There are more practical reasons too for needing to know about memory in childhood. Effective methods of education depend upon teachers understanding the capacities of children of different ages to learn and remember information. Without studying memory development, these capacities cannot be known. Equally importantly, poor memory function can impair a child's opportunities to learn, and can lead to many different profiles of learning disability. The assessment of memory abilities therefore provides a crucial method of understanding the profiles of learning difficulties, and of identifying effective methods for their remediation, in individual children. In addition, understanding the reliability of children's memories is becoming an issue of increasing importance as more children are providing testimony in the courtroom. These issues of current educational and psycholegal relevance underscore the impact of understanding children's memory in everyday life as well as in the laboratory.

It must be emphasised that the singularity of the term "memory" is misleading: there is no single memory store or system that underpins all mnemonic experience. Rather, evidence from a range of sources—experimental studies of adults, neuropsychological patients, brain imaging techniques, as well as investigations of children's memory—indicates that there are many separable memory systems that can function relatively independently of one another. The present review of memory in childhood is organised around widely accepted distinctions between the following memory systems: short-term memory and two long-term memory systems—autobiographical memory and episodic memory. These aspects of memory were selected for review as they reflect areas of significant research activities in children's memory in which important advances in understanding have been achieved in recent years.

Requests for reprints to: Susan E. Gathercole, Centre for the Study of Memory and Learning, Department of Psychology, University of Bristol, 8 Woodland Road, Bristol BS8 1TN, U.K. (E-mail: Sue.Gathercole@bristol.ac.uk).

Short-term Memory

The term "short-term memory" is used to refer to memory for events that occurred in the very recent past, where the delay between presentation of the material to be remembered and remembering is measured in terms of seconds and possibly minutes rather than hours or days. Research on human short-term memory dating back to the early 1960s has led to a bedrock of knowledge about the underpinnings of short-term memory performance. One fact which became apparent relatively early on is that short-term memory performance is not supported by a unitary short-term memory system, but is instead served by a suite of distinct short-term memory systems. The most complete current specification of short-term memory is the working memory model of Baddeley and Hitch (1974), revised by Baddeley in 1986. Although originally devised to account for adult short-term memory performance, this model has proved to be of great value in characterising the development of memory during the childhood years. For convenience, the working memory model is used here as a framework for presenting current understanding of the nature of children's memory development, although it should be noted that it is by no means the only account of short-term memory development (see, e.g., Cowan & Kail, 1996; Kail & Park, 1994; Pascual-Leone & Baillargeon, 1994).

According to this model, working memory comprises three components: the central executive, the phonological loop, and the visuospatial sketchpad. The latter two components, the phonological loop and the visuospatial sketchpad, were characterised by Baddeley and Hitch (1974), as "slave systems" that are specialised for the processing and manipulation of limited amounts of information within highly specific domains. Material is stored in the phonological loop in terms of its sound-based phonological qualities, whereas the sketchpad has the capacity to maintain the spatial and visual properties of limited amounts of information. In contrast to the highly specific informational domains in which these two slave systems operate, the central executive is capable of performing a range of high-level functions. Functions ascribed to the central executive include the coordination of the flow of information through working memory, the retrieval of information from more permanent long-term memory stores, the application of retrieval strategies, logical reasoning, and mental arithmetic (e.g. Baddeley, 1986; Hitch, 1980).

The theoretical specification of each of these three components of working memory is by no means complete, and indeed is undergoing continuous revision in the light both of new research and of the requirement for greater theoretical specification imposed by the development of computational models (Burgess & Hitch, 1992, 1996). It is, however, notable that the basic tripartite distinction between the central executive, phonological loop, and visuospatial sketchpad, based on experimental studies of normal adults, has received substantial independent support in recent years from the developing neuroscience disciplines. Studies of both cognitive neuropsychology and brain imaging have provided convergent evidence that both the brain areas and functional memory systems mediating performance on phonological and visuospatial short-term memory tasks are separate. In the case of the phonological short-term memory system, the left-hemisphere regions of Broca's area and the prefrontal cortex are implicated, whereas visuospatial short-term memory appears to be mediated by parietal and prefrontal areas of the right hemisphere (Smith, Jonides, & Koeppe, 1996). Neuropsychological investigations have yielded findings consistent with this view, that separate functional systems underpin phonological and visuospatial short-term memory. Neurological damage to parietal regions of the right hemisphere has been found to result in marked deficits in visual memory performance while verbal memory skills remain intact (Farah, 1988; Farah, Hamond, Levine, & Calvanio, 1988; Hanley, Young, & Pearson, 1991). Correspondingly, impairments in Broca's area are associated with highly specific verbal short-term memory deficits but normal visuospatial memory function (Basso, Spinnler, Vallar, & Zanobio, 1982). These perspectives provide substantial confirmation that phonological and visuospatial short-term memory performance are mediated by functionally separate memory systems, as the working memory model proposes.

Phonological Short-term Memory

Children's level of performance on tests of phonological memory such as digit span and other serial recall tests increases dramatically over the early and middle years of childhood. Memory span (a measure of the maximum number of unrelated verbal items that can be remembered in correct sequence) shows an average two- to three-fold increase from between two and three items at 4 years of age to about six items at 12 years. Figure 1 illustrates this developmental function with data reported by Hulme, Muir, Thompson, and Lawrence (1984) on mean numbers of items recalled by groups of children aged 4, 7, and 10 years and of an adult group on an auditory serial recall task.

There have been many significant advances in our understanding of the changes in functioning of the phonological memory system that underpin this developmental improvement in memory performance in recent years. Before considering these findings and their implications, it is first necessary to provide a brief characterisation of the working memory component, believed, on the basis of studies of adult memory, to be the most significant contributor to memory span and other serial order tasks: the phonological loop (Baddeley, 1986). This system consists of two subcomponents: a phonological store, and a subvocal rehearsal process. Information gains access to the phonological store either directly, via auditory presentation of speech stimuli, or indirectly via internally generated phonological codes for nonauditory inputs such as printed words or familiar visual objects. Phonological representations of memory items decay rapidly in the phonological store, and typically become indiscriminable within about 2 seconds if unrehearsed (Baddeley, Thomson, & Buchanan, 1975). Subvocal rehearsal occurs serially and in real time, and acts to refresh decaying representations in the phonological store. In this way, decay of representations within the phonological store can be offset if the entire contents of the store can be rehearsed within 2 seconds. The rehearsal process also appears to be the mechanism by which representations in the phonological store are generated for stimuli such as printed words and pictures, which can be recorded in phonological form but are nonauditory in nature.

Evidence that the phonological store is indeed phonological in nature is provided by the phonological similarity effects. Immediate serial recall is substantially impaired if the memory items are similar to one another in their phonological structure (e.g. *B*, *C*, *V*, *G*, *D*), even if the stimuli were presented visually at input (Conrad & Hull, 1964). This finding, replicated many times in the intervening years, provides a clear indication that material is held in terms of its sound characteristics within the phonological loop.

The two key experimental findings in support of the view that the subvocal rehearsal process serves to maintain information within the phonological store are the

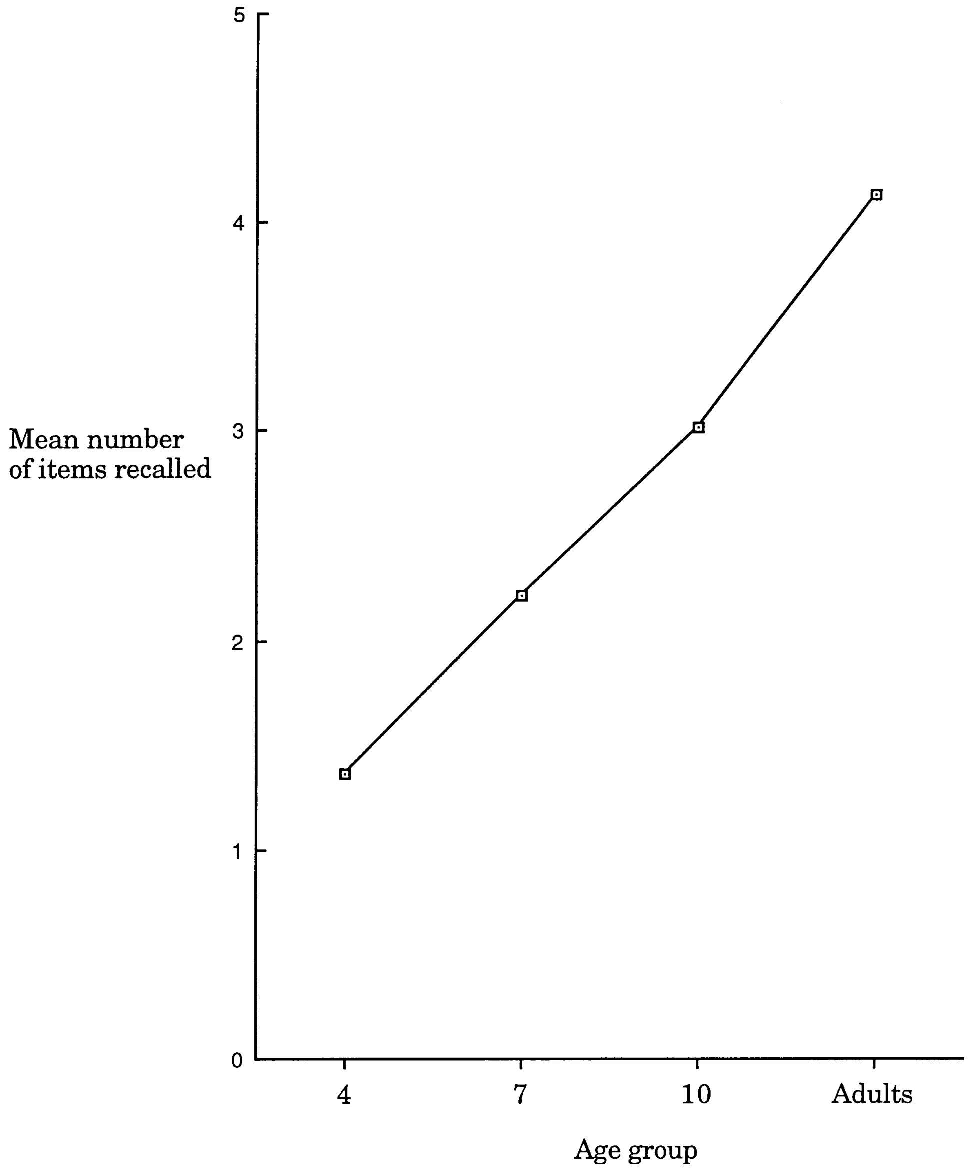

Figure 1. Mean number of items (words) recalled, as a function of age group. Based on data from Hulme, Muir, Thomson, and Lawrence (1984).

word length and articulatory suppression phenomena. The word length effect, initially established by Baddeley et al. (1975), refers to the better serial recall of memory lists containing memory items with short names (e.g. one-syllable words such as *cat*, *sun*, *bat*) than those with long names (e.g. *banana*, *telephone*, *piano*). This phenomenon has been attributed to the subvocal rehearsal component of the phonological loop. As rehearsal is believed to take longer for items of long than short articulatory duration there is a greater delay between successive rehearsals of lengthier items within the phonological store, providing greater opportunity for loss of information due to decay. This account fits well with findings that the word length effect is eliminated when rehearsal is prevented by requiring participants to engage in irrelevant articulation during the memory task, a procedure known as "articulatory suppression" (Baddeley, Lewis, & Vallar, 1984; Baddeley et al., 1975). It is argued that in this situation, the time-based rehearsal process cannot be engaged and so the benefit of short over long memory items in the phonological loop is lost.

The development of the phonological loop. Investigations of the sensitivity of children's immediate memory to these experimental variables have yielded evidence for highly specific changes in phonological loop function with age. It appears that the phonological store component of the phonological loop is present even in very young children, but that the subvocal rehearsal process does not emerge until about 7 years of age (Gathercole & Hitch, 1993). Provided that the memory items are presented auditorily and so do not require subvocal rehearsal to gain access to the phonological loop, children's immediate serial recall is sensitive to phonological similarity and word length at the youngest age groups tested—between 3 and 5 years of age (Ford & Silber, 1994; Gathercole & Adams, 1994; Hitch & Halliday, 1983; Hulme et al., 1984). With pictorial presentation of memory items, however, children of this

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age are not impaired when memory items have labels that are either lengthy in articulatory duration or are phonologically similar to one another, relative to children aged 7 years and older (Hitch, Halliday, Dodd, & Littler, 1989). Rather than recoding the pictures into the phonological form required for entry into the phonological store, younger children appear to attempt to remember such memory stimuli in terms of their visual characteristics (Hitch, Halliday, Schaafstal, & Schraagen, 1988; Longoni & Scalisi, 1994).

Other findings too fit well with this view that young children fail to exploit a rehearsal strategy for non-auditory memory stimuli. One of the earliest methods of identifying rehearsal was to observe whether children performing immediate memory tasks produced any overt signs of rehearsal such as lip movements and whispering in the interval between memory presentations. Using this technique, Flavell, Beach, and Chinsky (1966) failed to find any evidence for rehearsal in children below 7 years of age.

A different approach to the issue of when rehearsal emerges was taken by Johnston, Johnson, and Gray (1987) in a study of 5-year-old children. When their immediate serial recall was initially tested with sequences of nameable pictures, the children showed no sensitivity to whether the pictures names were long or short in articulatory duration. Johnson et al. then gave the children training in the use of overt and covert cumulative rehearsal strategies in serial recall. When tested following this training, the children did show superior recall of pictures with short over those with long names. This study provides direct evidence, first that subvocal rehearsal is not used spontaneously at this age, and second that this strategy can be induced with training. It also fits well with the notion that the word length effect arises from the rehearsal process, which is, as we shall see shortly, a matter of some contention.

A third line of support for the view that rehearsal is not used in early childhood arises from studies in which measures of both auditory memory span and of the rate at which the children can articulate the memory items were taken. According to the view advanced earlier, access to the phonological store for auditorily presented material takes place without rehearsal, although representations in the phonological store do not receive the benefit of constant refreshment provided by rehearsal in younger age groups. Consistent with this view, articulation rate and memory span are not positively correlated with one another for children below 7 years of age (Cowan et al., 1994; Gathercole & Adams, 1993; Gathercole, Adams, & Hitch, 1994; Henry, 1994). For adults, in contrast, strongly positive associations are found (Gathercole et al., 1994). The implication of this developmental change is that young children, unlike adults, do not depend on a time-based (rehearsal) strategy to maintain the contents of their phonological stores; the speed at which they articulate, therefore, does not matter.

Although there is now ample evidence in support of the view that rehearsal does not spontaneously emerge before the middle childhood years, some puzzles remain. One area of uncertainty concerns the source of word length effects in serial recall. With auditory presentation, even very young children show poorer recall of lists of long than short words (Gathercole & Adams, 1994; Hitch & Halliday, 1983; Hulme et al., 1984). This should not be so if the children cannot rehearse. The most likely explanation is that word length effects in short-term memory do not arise solely from rehearsal. There is accumulating evidence that the greater delay in output involved in the spoken recall of lengthy over short memory items may itself be sufficient to cause extra decay in the phonological store and hence impair recall accuracy (Avons, Wight, & Pammer, 1994; Brown & Hulme, 1995; Cowan et al., 1992). Consistent with this view, children below 7 years of age show no word length effect even for auditory material if memory performance is not sampled by a serial spoken recall procedure and hence is not subject to differential output delays for short and long items (Henry, 1991).

The principal developmental change in phonological short-term memory identified so far is that prior to about 7 years of age, serial recall performance is mediated by the phonological store component of the phonological loop. During the preschool and early school years, however, it does not appear likely that children use a subvocal rehearsal strategy to maintain the decaying phonological representations in the store. Rather, they choose to remember pictures by recalling visual features. Beyond 7 years, an adult-like cumulative rehearsal strategy emerges and is employed to maximise retention in the phonological store. From this point onwards, nonauditory memory material is recoded into a phonological code suitable for the phonological loop when possible. The continuing increases in articulation rate up to the late childhood years enhance the effectiveness of the subvocal rehearsal process and hence give rise to further improvements in memory span beyond the onset of rehearsal.

This model of developmental change provides a good account of a wide range of experimental data, although the account is by no means complete. One outstanding issue concerns the fact that memory span increases developmentally even prior to the period at which children learn to use rehearsal (e.g. Gathercole & Adams, 1994). Why is this? One possibility is that span increases during the period up to 7 years of age because older children are able to articulate items more rapidly at recall, and hence are able to reduce the decay of memory items in the phonological store prior to output. The necessary fine-grained analyses of developmental change in immediate memory span in the pre-rehearsal period, which would allow a direct test of this hypothesis, have not, however, yet been conducted.

Note that the account presented above explains developmental increases in memory span in terms of increased rates of articulation, both during the pre-rehearsal period (when its locus is in spoken output) and the post-rehearsal period (when its sources are probably in both covert rehearsal and spoken output). If this account is true, differences in memory span between age groups should be eliminated if their articulation rates are held constant. Two studies have tested this hypothesis, and found that changes in articulation rates provide a significant but only partial account of the increase in memory span during childhood (Henry & Millar, 1991; Roodenrys, Hulme, & Brown, 1993). Even after differences in rates of articulation between younger and older children have been controlled, residual differences in memory span were identified in both studies. Developmental changes in phonological loop function therefore do not provide a full explanation of why memory span increases with age. So what else changes?

Long-term knowledge and immediate memory in children. To explain why the phonological loop might not provide a complete account of age-related increases in immediate memory in childhood, it is necessary to return to the working memory model. Although the phonological loop is the component that is specialised for the retention and manipulation of information in a phonological form, and may be the single most important contributor to immediate memory, other memory systems and processes have also long been known to play a role (Baddeley & Hitch, 1974). One particularly significant source of additional support for immediate recall of verbal material comes from long-term storage of lexical knowledge, or the mental lexicon. Its contribution to immediate serial recall is simply demonstrated by the substantial recall advantage to memory sequences containing familiar words, such as *gorilla*, *radio*, and *botany*, over lists containing nonwords, such as *taffost*, *crepog*, and *teggid* (Hulme, Maughan, & Brown, 1991). As the word and nonword memory stimuli do not differ in articulatory duration or amount of phonological information, the lexicality effect (i.e. the recall advantage to word over nonword lists) must arise from the additional availability of long-term knowledge about the familiar words. A series of studies by Hulme and colleagues suggests that the lexicality effect is mediated by the use of long-term phonological knowledge about the sounds of words rather than stored nonphonological attributes such as word meaning (Brown & Hulme, 1992; Hulme et al., 1991). These researchers suggest that stored phonological knowledge about the structures of words is used to "fill in" incomplete information in representations of words in the phonological store, in a process described as redintegration (see, too, Schweikert, 1993). With nonword stimuli, of course, there is no such existing long-term specification with which to recover missing information in the phonological trace.

The undoubted contribution of long-term lexical knowledge to immediate memory raises an interesting possibility. Could one source of the developmental improvement in verbal memory span, that is not due to increased articulation rate, be the magnitude of the lexical contribution? Findings of Roodenrys et al. (1993) suggest that this might be the case. Comparing memory span in 6- and 10-year-old children, they found a relatively greater advantage of memory for words over nonwords in the older group that could not be accounted for in terms of differences in articulatory speed between the groups or the stimuli. Although narrowly missing statistical significance, this finding provides preliminary support for the view that older children develop more extensive and stable long-term knowledge about words, and that this can be used to increasing benefit to supplement phonological loop representations of lexical items.

There is also evidence that a more basic kind of long-term knowledge about the structure of the native language mediates immediate memory performance, even when nonwords are the memory stimuli: this is knowledge about the probabilistic structure of sound combinations in the language. Across several studies (Gathercole, 1995; Gathercole & Martin, 1996; Gathercole, Willis, Emslie, & Baddeley, 1991), we have found that children are better at repeating multisyllabic nonword stimuli when the wordlikeness of the nonwords, as judged by adults, is high (e.g. "commerine") than low (e.g. "loddernaypish"). Similarly, children recall nonword sequences more accurately if the nonwords contain adjacent phoneme pairs that are high in probability of occurrence within English (Gathercole, Frankish, Pickering, & Peaker, 1997). Thus even for unfamiliar items, an individual's existing knowledge about the structure of the language can be used to enhance recall accuracy.

Perhaps, then, one further component of the increase in verbal memory span with age is that the child's expanding vocabulary allows for better knowledge about the phonotactic properties of the language, and hence can be used more effectively to enhance phonological loop representations of the sound structure of memory stimuli. Consistent with this view, Gathercole (1995) found that 5-year-old children showed a greater advantage in repetition accuracy for nonwords of high compared to low wordlikeness than did 4-year-old children. These findings are encouraging, and a key priority for future research is to provide a much more complete developmental analysis of the use of both lexical and phonotactic knowledge in children's immediate verbal memory.

Developmental impairments of phonological short-term memory. One notable feature of children's performance on tests of phonological short-term memory is the high degree of variability across individuals. Although memory span increases regularly across age when assessed on the basis of group data at each chronological point, very large differences are found in span estimates for individual children at any one age. For unselected cohorts of young children, these differences in phonological memory capacity have been found to relate closely to two important aspects of language development: vocabulary acquisition (e.g. Gathercole & Baddeley, 1989, 1993; Gathercole, Willis, Emslie, & Baddeley, 1992; Michas & Henry, 1994), and speech production (Adams & Gathercole, 1995, 1996; Blake, Austin, Cannon, Lisus, & Vaughan, 1994; Speidel, 1989, 1991).

These and related findings have led to the proposal that a primary function of the phonological loop is to support language learning (Baddeley, Gathercole, & Papagno, in press; Gathercole & Baddeley, 1993). Consistent with this view, children with *specific language impairment* have been found to have extremely poor phonological short-term memory function. The evidence for phonological memory deficits in children with this disorder, and for the possible role of these deficits in the symptomatology of the disorder, is briefly considered below.

It is estimated that despite having normal levels of general intellectual attainment and in the absence of any other problems of a physical, social, or emotional nature, 5% of children fail to develop language normally (Stevenson & Richman, 1976). This condition is widely known as specific language impairment (SLI), and is associated with persisting deficits in the production and comprehension of language, including in particular poor vocabulary development, immature syntax, and impaired grammatical morphology. For many children diagnosed as specific language impaired, a genetic origin seems likely (Bishop, North, & Donlan, 1996; Gopnik & Crago, 1991).

A variety of accounts of the central deficit underpinning SLI have been advanced over many years (see Bishop, 1992, for review). Current influential theories of SLI include those identifying impairments in general processing resource (Ellis Weismer & Hesketh, 1996; Masterson & Kamhi, 1992), rapid perceptual processing (Merzenich et al., 1996; Stark & Heinz, 1996; Tallal et al., 1996), and grammatical morphology (Leonard, McGregor, & Allen, 1992; Gopnik & Crago, 1991). It is noteworthy that research on these aspects of putative SLI deficits typically depends upon a methodology in which SLI children are compared with their age-matched controls. This is problematic, as it is unclear whether it is appropriate to characterise the SLI children as either disordered in this particular aspect of cognitive or perceptual processing, or performing at a language ability-appropriate level. Consistent with the latter "development lag" interpretation, when comparisons are made between SLI groups and language-matched controls the common pattern often yields no differences between groups (e.g. Visto, Cranford, & Scudder, 1996).

On the other hand, the SLI children have consistently been found to underperform even younger language-matched controls on tests of phonological short-term memory. Their deficit is particularly marked when procedures such as nonword repetition that use phonologically unfamiliar stimuli are employed (Gathercole & Baddeley, 1990; Gillam, Cowan, & Day, 1995; Gillam & van Kleeck, 1996; James, van Steenbrugge, & Chiveralls, 1994; Kail, Hale, Leonard, & Nippold, 1984; Montgomery, 1995). For example, the SLI group studied by Gathercole and Baddeley (1990) had a mean chronological age of 8, performed at the level of an average 6-year-old on standardised language tests of vocabulary knowledge, language comprehension, and reading, but had nonword repetition accuracy scores of the typical 4-year-old child. The problems in nonword repetition of this SLI group, as in the groups in the other studies cited above, therefore far outweigh even their poor performance on language measures that are the criterion variables for specific language impairment (e.g. Stark & Tallal, 1981). Furthermore, a recent study of SLI and control twins by Bishop et al. (1996) has yielded high heritability estimates for nonword repetition, which, the authors suggest, may provide an excellent phenotypic marker for the SLI condition.

Although the data on phonological memory in SLI children are largely consistent across studies, theoretical interpretation of the source of the SLI deficits on tests of nonword repetition and serial recall remains at present a matter of debate. The view that we have advanced is that these deficits arise from extreme limitations in phonological loop capacity, probably located in the phonological store rather than in the subvocal rehearsal process, which appears to operate at a language-appropriate level in SLI children (Gathercole & Baddeley, 1990, 1993). It is this poor temporary storage of incoming speech stimuli, we propose, that may lie at the root of the difficulties encountered by SLI children in establishing durable long-term phonological representations of novel words (e.g. Dollaghan, 1987; Ellis Weismer & Hesketh, 1996; Rice, Buhr, & Nemeth, 1991). The phonological storage deficit may also contribute to the impaired abilities of SLI children to learn complex syntactic patterns, in the manner suggested by Adams and Gathercole (1995, 1996) and Speidel (1991). Thus, the suggestion is that impairments in a child's ability to store phonological material temporarily may be sufficient to disrupt many different aspects of language development to a sufficient degree to yield a profile of specific language impairment.

This phonological storage hypothesis is not uncontentious. One problem for the account is that there are some indications that SLI children are impaired in perceptual processing of nonword stimuli as well as in their repetition, raising the possibility that their poor performance on the memory tasks is secondary to poor perceptual skills (James et al., 1994; Montgomery, 1995). The detailed deficits of the SLI children on perceptual discrimination tasks are, however, inconsistent across these two studies. It is particularly notable that Montgomery only found reliable deficits in perceptual discrimination in his SLI group when pairs of lengthy (four-syllable) nonwords were presented for discrimination. But as the eight-syllable memory load involved in maintaining the two stimuli in order to make the comparison is likely to considerably exceed the storage capacity of the SLI children, this finding need not necessarily indicate a perceptual deficit at all. Further investigation of this issue is required, using procedures in which perceptual and short-term storage contributions to performance are varied more systematically.

Analysis of the long-term memory involvement in immediate phonological memory performance in SLI children is also needed in the light of recent advances in understanding the significance of both lexical and phonotactic knowledge to tasks such as nonword repetition and memory span (Gathercole, 1995; Gathercole et al., 1997; Hulme et al., 1991; Roodenrys et al., 1993). It is possible that at least some of the deficiency in the performance of SLI children on these tasks may arise from impoverished use of either of both lexical and phonotactic knowledge to supplement phonological loop storage of memory items. By applying the techniques developed recently in studies of unselected samples of children to SLI groups, these hypotheses can now be readily put to the empirical test.

Summary. Phonological short-term memory abilities develop rapidly through the early and middle childhood years. Much of this development appears to arise from developmental increases in the speed of rehearsing and of retrieving material from memory, and from the emergence of subvocal rehearsal as a strategy for introducing nonauditory material into the phonological loop and for actively maintaining the contents of the phonological store. Children's phonological memory capacity has important consequences for their abilities to learn new words, and the very poor phonological memory skills typically found in children with specific language impairment may lie at the root of their failure to develop language normally.

It is becoming increasingly apparent that immediate memory performance also reflects the contribution to long-term knowledge, both of familiar words and of the probabilistic structure of sound patterns within the native language. New techniques for assessing the extent of these long-term memory contributions should allow systematic evaluation of whether these are the source of age differences in phonological memory that do not reflect changes in the operation of the phonological loop.

Visuospatial Short-term Memory

Baddeley and Hitch (1974) proposed that our capacities to remember and manipulate mentally the physical features and dimensions of events such as shape, colour, and movement are served by a different limited-capacity component of working memory: the visuospatial sketchpad. Subsequent experimental studies have lent strong support to this dissociation between the memory systems contributing to short-term memory for verbal and visuospatial material (e.g. Logie, Zucco, & Baddeley, 1990; Smyth & Scholey, 1996).

Logie (1994) has recently proposed that the sketchpad, like the phonological loop, has two primary subcomponents: a visual store in which the physical characteristics of objects and events can be represented, and a spatial mechanism that can be used for planning movements and that may also serve a rehearsal function by reactivating the contents of the visual store. Although in practice very little memory material can purely be characterised in terms of either visual or spatial features, this distinction between the capacities for visual and spatial processing is certainly consistent with neuropsychological evidence of preserved visual but not spatial memory (Farah et al., 1988) and vice versa (Hanley et al., 1991). It also fits well with selective interference of memory for spatial information by concurrent spatial activity (Baddeley & Lieberman, 1980), and of irrelevant visual material on memory for visual items (Logie, 1986; Quinn & McConnell, 1996).

The development of the visuospatial sketchpad. Although the ways in which the operation of the visuospatial sketchpad changes with age during childhood have not been as extensively researched as those of the phonological loop, there is now a basic understanding of some significant changes in its functioning. One important change is that younger children are more dependent than older children or adults on using the sketchpad to support immediate memory for visual material. Hitch et al. (1988) demonstrated that in a task in which a series of pictures of nameable objects are presented for recall, 5-year-old children are impaired in recalling memory lists in which the objects share many physical features (e.g. *pen*, *fork*, *comb*, *key*) over those with few shared features (e.g. *doll*, *bath*, *glove*, *spoon*). A group of 10-year-old children, in contrast, showed no sensitivity in recall to the visual similarity of the pictures, but were impaired when the pictures had lengthy names (e.g. *umbrella*, *kangaroo*, *policeman*, *banana*). These and other findings reported by Hitch et al. and Hitch, Woodin, and Baker (1989) indicate that older children adopt a strategy of verbally recoding pictures where possible and so use the phonological loop to mediate performance on the "visual" memory task. As young children are not able to generate phonological codes for visual items covertly, they are forced to rely instead on their recall of the purely visuospatial characteristics of the memory stimuli.

In order to provide a pure assessment of the development of visuospatial memory capacities, it is therefore important to use memory tasks in which the stimuli do not correspond to familiar items that can reliably be recoded into phonological form. One such paradigm that has been employed as a means of assessing primarily the visual component of the sketchpad is the pattern span task (Wilson, Scott, & Power, 1987). In this task, a two-dimensional pattern composed of squares that are either filled or unfilled is briefly displayed on each trial. The child is then showed the same pattern with a single filled block missing, and is required to point to its original location. The number of blocks in the test patterns are then increased until memory accuracy falls below a criterion level, yielding for each individual a span measure of number of blocks reliably remembered.

Using this technique, Wilson et al. (1987) showed that visual memory span increases substantially and regularly between 5 and 11 years, by which time adult levels of performance are achieved, as illustrated in Fig. 2. Whereas at 5 years of age mean pattern span was about 4 blocks, span estimates for 11-year-olds and adults had much higher values of around 14 blocks. Similar patterns of development of visual pattern span were also obtained by Miles, Morgan, Milne, and Morris (1996). In their study, the method of memory test was varied from the partial recall procedure used by Wilson et al. to recognition (in which condition the participants had to judge which of a pair of patterns had been studied previously) and free recall (in which a blank matrix was presented, and the task was to point to the squares that were filled in the test stimulus). In each case, relatively steep developmental increases were obtained across groups of children aged 5, 7, and 10 years, and adults, with span estimates lower across all ages in the more time-consuming free recall condition. We have recently replicated the developmental function for the free recall version of the pattern span task (Pickering, Gathercole, & Hall, 1997).

It may, however, be misleading to interpret this developmental profile solely in terms of age-related changes in the capacity of the sketchpad to retain visual information. Despite the apparently nonverbal nature of the pattern span test stimuli, both the Wilson et al. (1987) and Miles et al. (1996) studies provide strong evidence that a substantial component of the developmental increase in pattern span arises from the contribution of memory components other than the visuospatial sketchpad. Wilson et al. (1987) tested pattern span under a variety of concurrent task conditions, and found that interpolating a 10-second interval of spoken arithmetic-related activity (counting backwards aloud for older groups, forward counting for the youngest age group) between presentation of the pattern and recalling it reduced pattern span considerably, and that the magnitude of this disruption increased progressively between 5 and 11 years. Engaging in irrelevant mental arithmetic is widely believed to require the involvement of the central executive (Baddeley & Hitch, 1974), and irrelevant articulation appears to block subvocal rehearsal

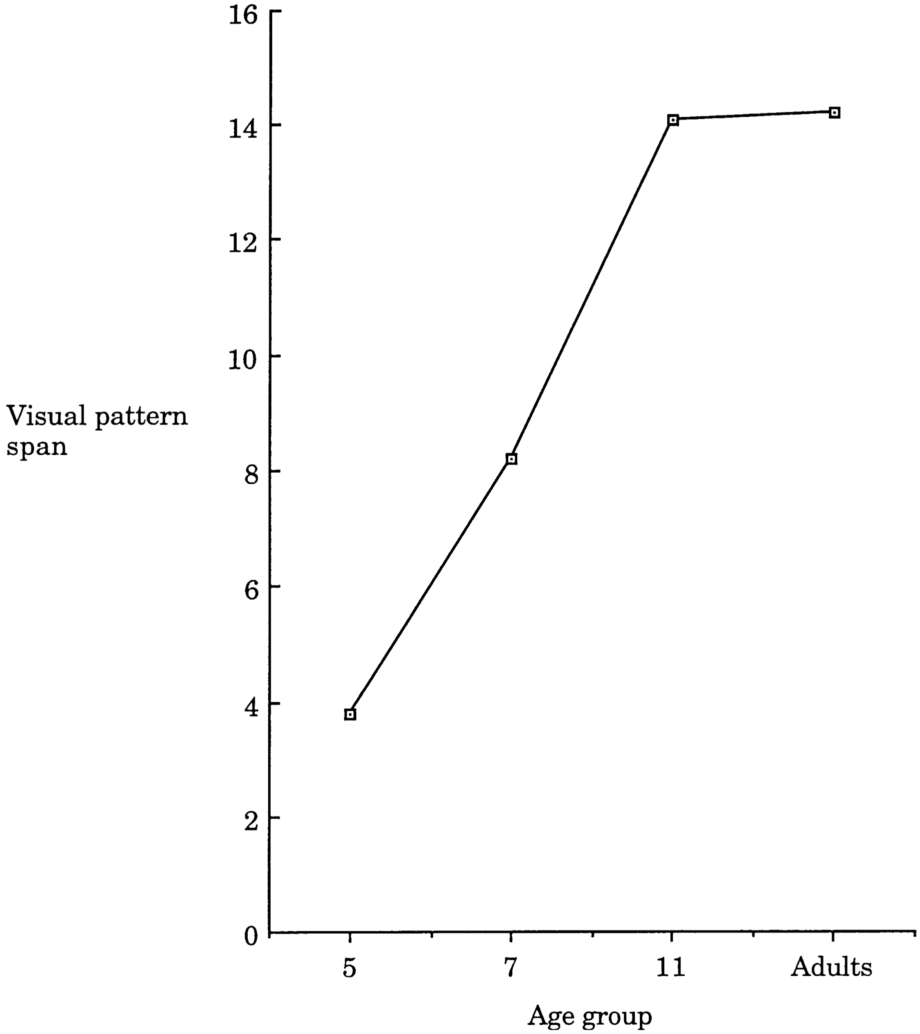

Figure 2. Mean visual pattern span, as a function of age group. Based on data from Wilson, Scott, and Power (1987).

(Baddeley et al., 1975). Thus, the disruptive effect of spoken mental arithmetic on pattern span for older children and adults indicates significant involvement of either or both of these two nonvisual components of working memory in the pattern span task. At least some of the increase in children's capacities to retain visual patterns therefore appears to reflect increasing use of nonvisual strategies to mediate memory performance, rather than enhanced visual memory per se.

Due to the nature of the interpolated task used by Wilson et al. (1987), their data do not identify whether older children are using the phonological loop to supplement the visuospatial sketchpad in the pattern span (by verbally recoding the stimuli) or the central executive. Other findings indicate that both of these components of working memory may play a role. Earlier work with adults had already established that recall of similar matrix-style visual patterns is greatly disrupted by subsequent silent mental arithmetic (Phillips & Christie, 1977), implicating central executive involvement in memory for patterns. And Miles et al. (1996) found that concurrent articulatory suppression, which blocks the use of the phonological loop, significantly impaired pattern spans for the 10-year-old and adult groups, particularly on the recognition and partial recall versions of the task. The disruption in visual pattern span caused by preventing rehearsal in the Miles et al. study was considerably less substantial than that observed by Wilson et al. with a concurrent task loading on both the central executive and the phonological loop. It therefore seems plausible that older participants in these studies were able to engage in a range of nonvisual strategies to supplement the contribution of the sketchpad, which called upon (possibly across different trials and different individuals) both of these nonvisual components of working memory.

So, children's capacities to retain visual patterns over short intervals increase greatly between 5 and 11 years of age, by which time adult levels of performance are more or less achieved. The developmental increase appears to be due in part to a genuine increase in the capacity of the sketchpad to hold material in visual form, but also to increasing use of nonvisual strategies using both the phonological loop and the central executive to supplement memory performance.

One important issue that has not been directly addressed as yet is whether the increased visuospatial sketchpad contribution over this developmental period simply reflects an undifferentiated increase in the capacity

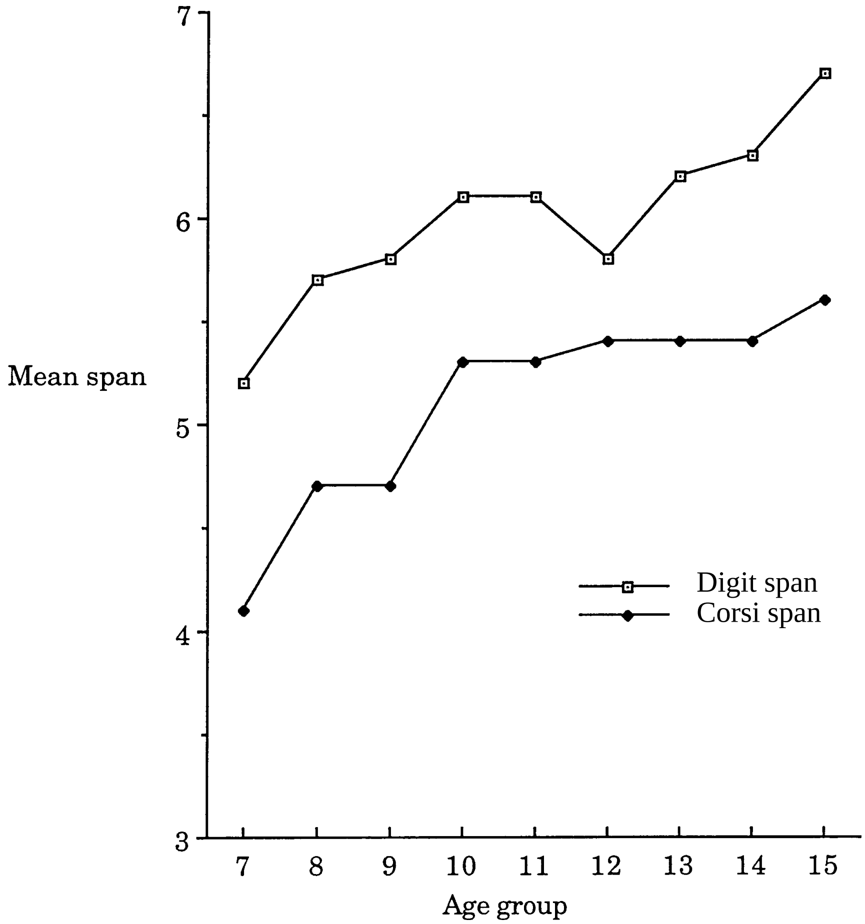

Figure 3. Mean span on the digit and Corsi blocks tests, as a function of age group. Based on data from Isaacs and Vargha-Khadem (1989).

of the visual store component, or reflects changes in either the use or the efficiency of use of the spatial/movement-based process suggested by Logie (1994) to maintain the contents of the visual store. Evidence reviewed above indicates that a significant component of the developmental increase in the neighbouring phonological loop system does reflect the emergence of an active rehearsal strategy, which acts to maintain representations in the more passive store component; this could also be true of the visuospatial sketchpad. There are now concurrent task techniques available that are known to disrupt the two components selectively; the visual store appears to be impaired by irrelevant visual information (Logie, 1986; Quinn & McConnell, 1996) whereas tapping impairs spatial memory (Smyth & Pendleton, 1989). By applying these techniques, it should be possible in future research to analyse the contributions of the visual and spatial components of the sketchpad to the developmental changes in visual memory already established.

Some basic information is, however, known about changes in abilities to retain spatial information with age. The method that has been used to test spatial memory in children is the Corsi blocks task. In this task, a three-dimensional display of nine blocks is placed in front of the participant, who observes the experimenter tapping the blocks in an unsystematic sequence. The task is to repeat the activity, tapping the same blocks in the same sequence. As in the digit span task, the number of memory items (blocks in the case of the Corsi task, numbers in digit span) increases regularly up to the point at which the participant can no longer reliably reproduce the correct sequence, and a span estimate is obtained.

The developmental course of children's memory spans on both the digit span and Corsi blocks tasks was investigated by Isaacs and Vargha-Khadem (1989), in a study of children aged between 7 and 15 years. As shown in Fig. 3, both span tasks showed a regular increase across this age range corresponding to about 1.5 items of span, with Corsi spans at each age lagging about one item of span behind digit span. One interesting feature of this study was that for both the verbal and spatial span tasks, children were tested on their forward and backward recall of the test sequences. Digit span is greatly impaired by the requirement to recall in backwards order, in line with normative data on forward and backward digit span provided by standardised ability tests such as the WISC-R (Wechsler, 1982). What was not known prior to the Isaacs and Vargha-Khadem study was that in contrast, Corsi span is equivalent whether recall is tested in a forwards or backwards order. This indicates that order information is extracted in a fundamentally different manner from spatial memory than from the phonological loop. It should, however, be noted that subsequent findings from adult data suggest that the differential

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impairment with backward recall may be due in part at least to the differential availability of item information in the conventional Corsi blocks and digit span procedures (Farrand & Jones, 1996).

We have recently investigated the relationships between children's capacities to retain phonological, visual, and spatial information in short-term memory (Pickering et al., 1997). In an initial study, 5- and 8-year-old children were tested on conventional measures of pattern span, Corsi block recall, and digit span. Scores on each task were uncorrelated with one another, suggesting that phonological, visual, and spatial memory capacities may be dissociable even in young children (see also, Pickering, Gathercole, & Peaker, in press).

In a subsequent study, we constructed versions of the pattern span and Corsi blocks tasks that were directly comparable except in temporal order. Our pattern span stimuli were arrays of squares containing equal numbers of filled and unfilled blocks, similar to those employed by Wilson et al. (1987). The task of the child was to study each pattern for 2 seconds on a computer screen, and then to indicate on an empty square the locations of the filled blocks in the test item. This method of test corresponds to the free recall technique used by Miles et al. (1996). Span was estimated in the usual way by increasing the number of squares in the test items until the children were unable to perform accurately.

In the corresponding spatial task, the child viewed on the screen an initially empty square, in which blocks became filled one at a time. The child's task at the end of the sequence was to point to the squares that had been filled at presentation in the same order as they had occurred on the screen. This provides a two-dimensional analogue of the conventional three-dimensional version of the Corsi blocks task. Across our pattern and spatial tasks, the item content (i.e. the location of the filled blocks in the squares) was equivalent, as was the method of recall. The tasks only differed in the presence of order information and the requirement to recall it in the spatial version. Children aged 5, 7 and 10 years participated in these tasks.

Two noteworthy findings emerged from the study. First, scores on the pattern span and spatial span were uncorrelated with one another, despite the close correspondence between the information content and paradigms employed in the two cases. This reinforces the conclusion that different memory capacities may underpin memory for visual material with and without a temporal dimension, and is broadly consistent with the distinction between a visual store and a spatial movement-based system in the sketchpad (Logie, 1994).

Second, there was an age-related increase in span in both tasks. This function was, however, much steeper for the pattern span than spatial span task: whereas the two span estimates were similar in the youngest age groups, the benefits to pattern span over spatial span were very substantial indeed by 10 years of age. At a general level, the different gradients of the spatial and pattern span functions lend further weight to the view that they are served by different memory systems. More specifically, the steeper increase in pattern span with age may reflect the increasing use by older children of nonvisual strategies to supplement their memory for the visual patterns (in line with findings of Wilson et al., 1987; and Miles et al., 1996) but not for the temporal order of the elements in the spatial task. This interpretation requires confirmation using dual task techniques; if correct, it indicates that memory for spatial information distributed across time is extremely restricted, and does not enjoy the opportunity for other sources of memory support that are available for purely visual configurations.

In summary, the capacity to retain information about the visuospatial characteristics of events for short periods of time is mediated by a short-term memory system dissociated from the phonological loop, and may consist of dissociable visual and spatial/temporal subcomponents. Although young children can retain both kinds of information in memory, their abilities to do so undergo substantial increases between 5 and 11 years of age, when short-term memory capacity approaches adult levels.

Impairments of the visuospatial sketchpad. The sketchpad, as tapped primarily by tasks requiring the retention of meaningless verbal material such as grids containing cells filled at random, shows a regular developmental increase in capacity during the early school years. What, though, is the sketchpad used for in real life? Why is it there? One potential answer is that the sketchpad provides the facility to engage in mental imagery; the extent to which everyday cognitive activities call upon this facility is, however, unclear.

Another possibility is that the temporary storage capacity of the visuospatial sketchpad mediates the long-term learning of the visual and spatial coordinates of novel objects, in much the same way as the phonological loop appears to be crucial in supporting the learning of the sounds of new words. This idea is supported by a study by Hanley et al. (1991) of a neuropsychological patient, ELD, who had very poor short-term visuospatial memory (including lower Corsi block span) following damage to the right hemisphere. Most interestingly, after sustaining the brain damage ELD was unable to learn new routes such as the way back to her new flat or to learn to recognise the faces of previously unfamiliar people.

Perhaps, then, the sketchpad is used in childhood, as in later life, to support the learning of new visual and spatial information. If this is the case, we might expect that concurrent activities known to disturb selectively the operation of the visuospatial sketchpad should also impair the long-term learning of faces and routes. There has, however, been no systematic evaluation to date of the consequences for either face or route learning of blocking components of working memory.

If the sketchpad is crucial for learning as well as short-term retention, it should also follow that the substantial individual differences in children's abilities to retain such material over short periods of time (Cornoldi, Vecchia, & Tressoldi, 1995) should be closely related to their skills at recognising new faces and learning spatial routes. More specifically, children with severely compromised abilities to maintain visuospatial information temporarily should also be impaired on these real-life visuospatial learning tasks. One group who provide the opportunity to test the latter hypothesis are children with Williams syndrome, a rare genetic disorder leading to learning disabilities that are considerably more substantial in the aspects of visuospatial cognition than language, including short-term memory (e.g. Bellugi, Marks, Bihrle, & Sabo, 1988; Jarrold, Baddeley, & Hewes, in press; Vicari, Brizzolara, Carlesimo, Pezzini, & Volterra, 1996; Wang & Bellugi, 1994). Do these children encounter undue difficulty in learning novel information such as unfamiliar faces and new spatial routes? In terms of faces, the answer is probably "no", as face processing in individuals with Williams syndrome is considered to be relatively spared in comparison with other aspects of visuospatial cognition (e.g. Karmiloff-Smith, Klima, Bellugi, Grant, & Baron-Cohen, 1995). However, their abilities to learn new spatial patterns are certainly impaired, but it is too early to conclude whether this long-term learning deficit is specific to the visuospatial domain (Vicari et al., 1996). Thus, the findings to date are encouraging but incomplete.

The Central Executive

Many different functions have been attributed to the flexible but limited resource of the central executive component of working memory. One general class of functions relate to its putative regulatory and control activities: the central executive has been suggested to be responsible for controlling the flow of information through working memory, for the retrieval of material from more permanent long-term memory systems, and also possibly for the control of action, planning, and goal-directed behaviour (Baddeley, 1986). A second class of function is provided by specific strategies and specialised types of computation ascribed to the executive: these include retrieval strategies (Baddeley & Hitch, 1977, 1993), logical reasoning (Baddeley & Hitch, 1974), and mental arithmetic (Hitch, 1980). Finally, some views of the central executive attribute to it both storage and processing functions that are fuelled by a limited resource (e.g. Case, Kurland, & Goldberg, 1982; Daneman & Carpenter, 1980, 1983; Just & Carpenter, 1992).

Developmental changes and disorders in the higher-level functions of the central executive, related to planning and goal-directed behaviour, have recently been reviewed by Pennington and Ozonoff (1996). The present review, in contrast, focuses on providing a developmental analysis of the "storage and processing" functions of the central executive. One influential research group has provided a systematic analysis of central executive function using tasks that impose combined storage and processing loads on the individual, both independently of the working memory model of Baddeley and Hitch (1974). Daneman and Carpenter (1980) used the term "working memory" to refer to a capacity-limited system in which the resource burdens imposed by processing information and storing it are shared; this limited resource is now termed "activation" (Just & Carpenter, 1992). The crucial point is that if the amount of activation that an individual has available is exceeded by the demands of a task, there will be a trade-off between storage and processing; as storage needs increase, there will be less activation available to support processing, and vice versa. Many studies of adults have shown that there are substantial individual differences in activation levels, as indexed by complex working memory tasks that impose combined processing and storage demands (see Daneman & Merikle, 1996, for recent review and meta-analysis). Typical examples of complex working memory tasks are reading and listening span, in which an individual has to process incoming information (either reading or listening to sentences, according to the version of the task) at the same time as retaining the sequence of the final words of the preceding sentences (Daneman & Carpenter, 1980). Another complex working memory task is backward digit span, in which the task is to recall a digit sequence in backward order. Each of these tasks clearly require both storage and transformation of material. Importantly, individual differences in working memory (i.e. central executive) capacity indexed by such tasks appear to be directly related to abilities to comprehend and manipulate language. Thus, it appears that working memory capacity may have a direct impact on an individual's everyday life.

Performance on complex working memory span tasks improves during childhood. Data from Siegel (1994), summarised in Fig. 4, show a regular increase in listening span between 6 and 15 years of age.

One account of the changes in cognitive functioning underpinning the improvements in working memory span over the childhood years is provided by a neo-Piagetian characterisation of limited *M capacity* introduced by Pascual-Leone (1970) and developed by Case et al. (1982). According to the more cognitive account advanced by Case et al., the total processing space available to an individual can be flexibly deployed as either processing or storage space. The suggestion is that total storage space remains constant over development, but that the operational efficiency of an individual—at executing strategies and processing incoming information, for example—increases, releasing storage space. The task employed by Case et al. to explore this theory was counting span, in which children counted the number of objects in a particular display, and then attempted to recall in correct serial order the number of objects in the preceding displays. Operational efficiency was assessed by measuring the amount of time it took the child to repeat a word they had just heard. Using these techniques, Case et al. provided evidence for a linear relationship between operational efficiency and memory span in children aged between 2 and 6 years; as speed of repetition increased so did memory span, consistent with the view that with increasing age the processing demands diminish, releasing storage space. In a further study, Case et al. also found that once differences in operational efficiency were controlled across children and adults (by requiring adults to count in an unfamiliar language), span differences disappeared. This, they argued, fits well with the notion of a constant limit to processing space across all ages. Independent evidence that counting span provides a measure of working memory capacity that has direct impact on everyday cognitive activities is provided by Yuill, Oakhill, and Parkin (1989), who found that children with poor reading comprehension abilities had deficits in counting span. Thus in children as well as in adults, these capacity limitations appear to constrain complex comprehension processes.

The majority of research on complex working memory tasks focuses on language processing and comprehension,

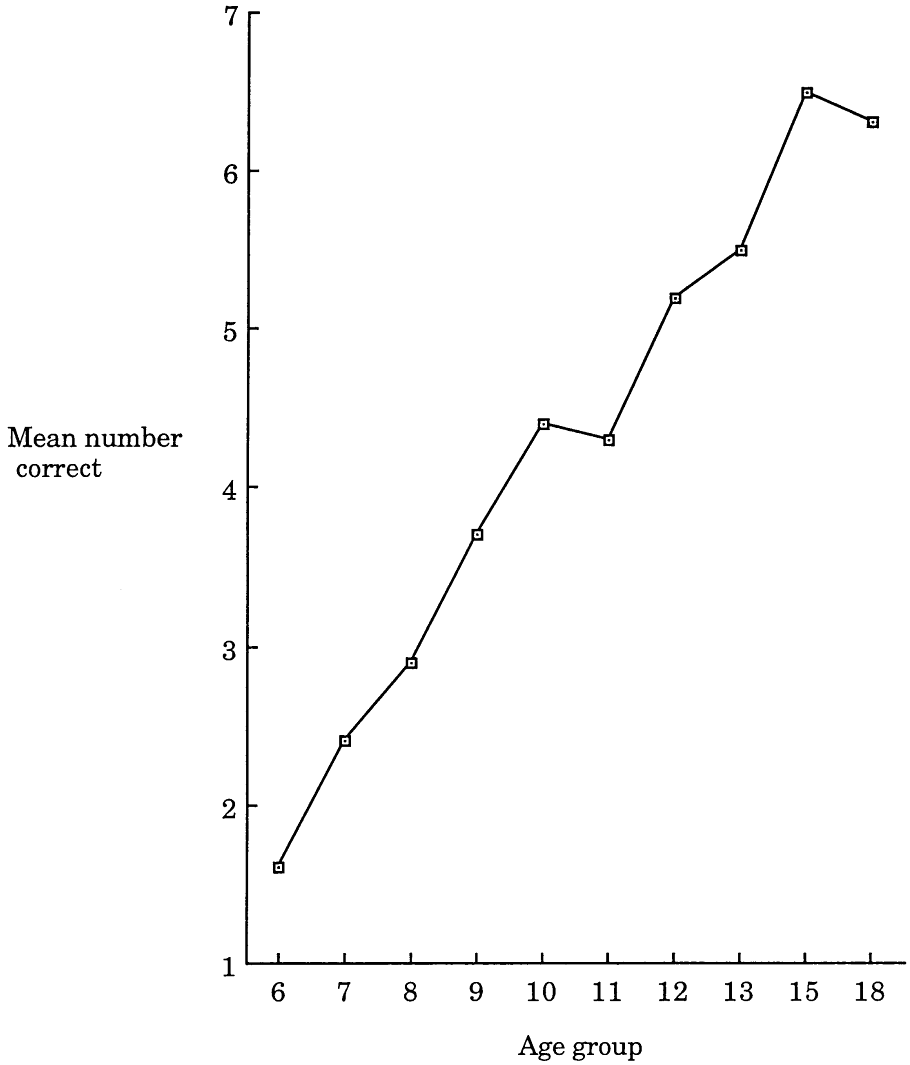

Figure 4. Mean number of items correct on complex working memory task, as a function of age group. Based on data from Siegel (1994).

and this raises some important issues concerning theoretical interpretation of the data. One such issue is whether complex working memory measures and immediate verbal memory span tasks both simply tap the phonological loop. This can clearly be ruled out on several grounds. First, Hitch, Halliday, and Littler (1989) showed that the contributions of Case et al.'s measure of operational efficiency, item identification time, and the phonological loop to immediate memory span can be dissociated experimentally (although see Kail & Park, 1994, for different conclusions based on a correlational approach). Second, Oakhill, Yuill, and Parkin (1986) failed to find any differences between children or good and poor reading comprehension abilities on measures of simple memory span, although working memory span deficits have been found in the poor comprehension group (Yuill et al., 1989). Third, complex working memory measures show consistently higher associations with language comprehension than do simple memory span measures (Daneman & Merikle, 1996). Fourth, complex and simple span tasks show dissociable ageing effects in adulthood: complex span diminishes from early to late adulthood, whereas simple span is maintained (Siegel, 1994). Finally, Morra (1994) administered a wide range of both complex and simple working memory tasks to a large sample of children, and found that individual variability in the complex tasks such as counting span and backward digit span was relatively independent of variability in simple memory span across children. Thus, complex and simple memory span appear to have dissociable origins within short-term working memory.

A further issue, which cannot be answered so readily, is whether complex memory span tasks represent a component of the central executive that is highly specialised for the analysis of language rather than a general purpose processing system. Daneman and Merikle (1996) propose that the equivalent degree of association between measures of language comprehension and both verbal and "math"-based (e.g. counting span) complex span measures rules out an account of the links in terms of a processing system specific to the storage and manipulation of verbal material. This interpretation is not, however, unproblematic as counting, too, is a verbally mediated task. Few if any truly nonverbal analogues of the complex working memory span paradigm have yet been developed to provide the necessary strong test of the linguistic specificity account of the working memory studies conducted to date.

In sum, developmental analyses of the functions conventionally associated with the central executive have provided limited evidence for an increased capacity in older children to conduct complex operations and to store partial products. Whether the actual capacity of the system increases or not cannot be determined unambiguously: one possibility is that the total resource (or amount of activation, in Just & Carpenter's 1992 terms) increases developmentally; another possibility is that processing demands diminish, thereby allowing the system to achieve more on a resource limitation that remains constant across time (Case et al., 1982). An equally important issue is what impact individual and developmental differences in the capacity of the central executive have for everyday cognitive activities. One possibility is that a child with poor working memory capacity will experience learning disabilities of a non-specific nature, and that executive capacity limitations may be particularly influential in preventing children with more specific learning disabilities such as dyslexia from developing alternative strategies to support their learning (Swanson, 1993).

Long-term Memory

We have seen above that children, like adults, have well-marked capacities to retain and manipulate many different types of information in short-term memory, and that differences in these capacities may have direct consequences for the individual's child's abilities to learn in many different ways. So, there appear to be important links between short-term memory and long-term learning. But what about children's long-term memory? The term "long-term memory" is used here to refer to memory for events that occurred hours, days, months, and years ago. What distinguishes long-term memory used in this way from learning is that it refers not to memory for repeated events, but instead for single distant episodes. This type of memory is almost always incomplete, and has not typically been associated with any conscious attempt to "learn".

A number of distinct memory systems or processes appear to support long-term memory for previous events, although the different components and their relationship to one another are generally less well understood than is the case for short-term memory. One important distinction, made originally by Tulving (1972), is between semantic and episodic memory. The term semantic memory refers to the near-permanent knowledge that we have about the world—for example, our understanding of the meaning of individual words, our knowledge of our names, and of facts. Semantic memory is characterised by a lack of recollection about the specific occasions on which the semantic knowledge was established; these are things that we just "know". Episodic memory, on the other hand, refers to our memories for specific episodes previously experienced; our memories for such events are often accompanied by the phenomenal experience of recollective experience (Tulving, 1983).

The principal focus of this part of the review is on the aspect of long-term memory that Tulving characterised as "episodic". Further distinctions are necessary to characterise the salient features of development of long-term memory. For the present purposes, the term episodic memory will be reserved for memory for events that took place relatively recently in time—earlier this morning, yesterday, and maybe even last week. Over these (in lifetime terms) relatively small timescales, we are rather good at being able to retrieve information about mundane aspects of our lives, such as the food we ate at a particular meal, where we parked the car, and who we stood with in the elevator. The majority of experimental studies of long-term memory take place over such relatively short periods, but typically lack much of the self-involvement of long-term, personally salient, episodic memories. Typical episodic memory paradigms involve participants seeing or hearing lists of words, listening to a story, or seeing an enactment of an event in which they play no role. As a consequence, episodic memory as tested in the experimental laboratory is characterised by low self-reference (the participant is usually a passive observer), and rarely yields a personal interpretation in the participant (Conway, 1990, 1996).

In everyday life, of course, specific events are remembered over much longer periods, up to years and decades. Thus, we can often recall some features of salient events that took place a long time ago, such as moving house, a particularly impactful conversation with a colleague, a wedding, or a car accident. Our memories of such events is almost always incomplete, in that we remember much less material than we would if the event had taken place earlier today. Some important information, however, endures over long periods of time, and allows us to reminisce. This type of remembering of genuine events, which can take place over many years, is termed "autobiographical memory". Autobiographical memory is high in self-reference, and frequently accompanied by a personal interpretation, in contrast to laboratory-tested episodic memory described above (Conway, 1990, 1996). There appear to be at least three highly significant aspects of autobiographical memory knowledge: specific events, general classes of events, and lifetime periods, which are organised hierarchically (Conway, 1990). These different sources of knowledge are combined at "remembering" to construct the dynamic representations of specific events that correspond to our phenomenal experience of being able to remember a distant event (Conway, 1996; Conway & Rubin, 1993; Neisser, 1962).

The past decade or so has seen a surge in interest in the development during childhood of both episodic memory and autobiographical memory, motivated both by theoretical concerns and by the increasing need to gauge the validity of testimony by children in the courtroom in cases relating to child abuse. Below, significant findings and advances in understanding both aspects of long-term memory will be presented and evaluated. One of the major difficulties in this area is that for psycholegal purposes we need to understand constraints on children's autobiographical memory: memory for events in which the child was centrally involved and which often evoke a highly emotional response. In practice, the study of real autobiographical memories in children is beset with methodological problems arising from lack of experimental control. In recognition of these problems, the majority of research on this topic has employed laboratory-based paradigms, which allow greater experimental rigour but which have the characteristics of low self-reference and personal interpretation that clearly identify them as assessing episodic rather than autobiographical memory. Thus, the impact of many findings from the laboratory for the development of autobiographical memory is still largely unknown.

The Development of Autobiographical Memory

One extremely important feature of autobiographical memory, which establishes that there are major developmental changes in this type of remembering, is the phenomenon known as " childhood amnesia ". This term refers to the fact, first reported by Henri and Henri in 1897 (see Nelson, 1993a), that it is extremely unusual for an individual to be able to retrieve memories about events that took place before 2 years of age, and that memories for the period between about 2 and 5 years are relatively infrequent. In a recent influential re-evaluation of childhood amnesia, Pillemer and White (1989) obtained an average age of the earliest retrieved memory as 3.5 years, with a range from 2 to 8 years for the earliest memory across individuals.

This scarcity of memories for events in the earliest years of life can be difficult to interpret. In most cases, it is not possible to validate the date of origin of the earliest memories, nor to rule out the possibility that an individual actually remembers later descriptions by others of the key event, or other external prompts such as photographs. A number of studies have, however, found clear evidence of the usual childhood amnesia phenomenon when memories for events were sampled that had a known date of occurrence, such as the birth of a sibling (Sheingold & Tenney, 1982; Usher & Neisser, 1993) and events of national importance (Winograd & Killinger, 1983). Also, dependence on memories for others recounting stories of early childhood or on other external sources of support is clearly insufficient to explain the marked distribution of the memories over early childhood in itself, with the absolute absence of memories for events prior to 2 years of age. Thus, childhood amnesia appears to represent a valid phenomenon.

A number of memory-based accounts of childhood amnesia have been advanced. One possibility that has now been discounted is that the phenomenon is simply a function of forgetting, with the most distant memories of one's life more subject to forgetting than subsequent ones. It has been ruled out both by observations that the period of childhood amnesia does not "spread" with increasing age of the rememberer, and by demonstrations of the failure of mathematical models of forgetting to predict the dearth of memories prior to 5 years of age (Wetzler & Sweeney, 1986).

Another general account of childhood amnesia is that adults' failures to retrieve memories from early childhood and infancy reflects not the absence of memory records or traces, but their inaccessibility. As discussed earlier, remembering memories of personal events that occurred many years ago is not simply a passive act of retrieval, but is instead a reconstructive process in which different types of knowledge about the structure of events and one's life is applied to incomplete memory traces to generate a stable representation (Conway, 1996; Neisser, 1962). Neisser suggested that the adult "schemas" applied at retrieval will fail to make sense of the fragments available for early childhood events, and that this "schema-mismatch" is the source of childhood amnesia. A more detailed version of this account is considered later in this section.

Other more specific accounts of the changes in children's memories during the early part of life and the ways in which these changes may contribute to childhood amnesia have been advanced in recent years. An influential research team headed by Nelson have proposed that autobiographical memories are not formed during the childhood amnesia period, and that is why they are not subsequently available for retrieval in childhood (Nelson & Gruendel, 1981). Analyses of children's memories for events within this critical period of later infancy and the preschool years have yielded mixed results with respect to this hypothesis. There is certainly some evidence that young children are much better at describing the features of familiar, repeated events such as going to nursery and having lunch at MacDonalds than at recalling details of specific incidents that occurred just once (Hudson, 1986; Hudson & Nelson, 1986; Nelson, 1978; Nelson & Gruendel, 1981; Nelson & Ross, 1980). Such findings led to the proposal that, during the early years of life, children incorporate their ongoing experiences into frames of knowledge for familiar events or "scripts", such as going to nursery and eating at MacDonalds, but do not (unlike older children and adults) retain details of specific incidents. By this account, information about specific details of events that depart from the routine are only retained in an emerging autobiographical memory system by about 4 years of age, when the child has developed an extensive repertoire of generic knowledge about the event structure of their life. Nelson (1993a, b) argues that such an evolving system is an efficient use of the child's cognitive resources, as before such generic knowledge has been accumulated, it is not possible for children to judge what is and what is not unusual, and therefore they cannot effectively judge what features of an episode to store in memory.

The problem for the simple view, that children do not have detailed autobiographical memories for specific incidents during the period of childhood amnesia, is that it is at odds with a considerable amount of other evidence. Nelson's (1989) own transcripts and analysis of the bedtime talk of an infant Emily between the ages of 19 and 37 months provides substantial evidence that, at least over short timescales of a day or less, Emily was able to recall many detailed features of the day's activities. And on a larger timescale, Fivush and Hamond (1990) found that at 2.5 years, many children had memories of events that took place 6 months previously and that at 4 years, some children were able to recall events from 2 years of age.

To account for such findings, Nelson (1993a, b) proposed that children's early memories of recent events are served not by autobiographical memory, but by a short-term holding system for recent events—episodic memory. Thus, Emily's crib talk reflects use of this system. How then can children, on occasion, remember details of

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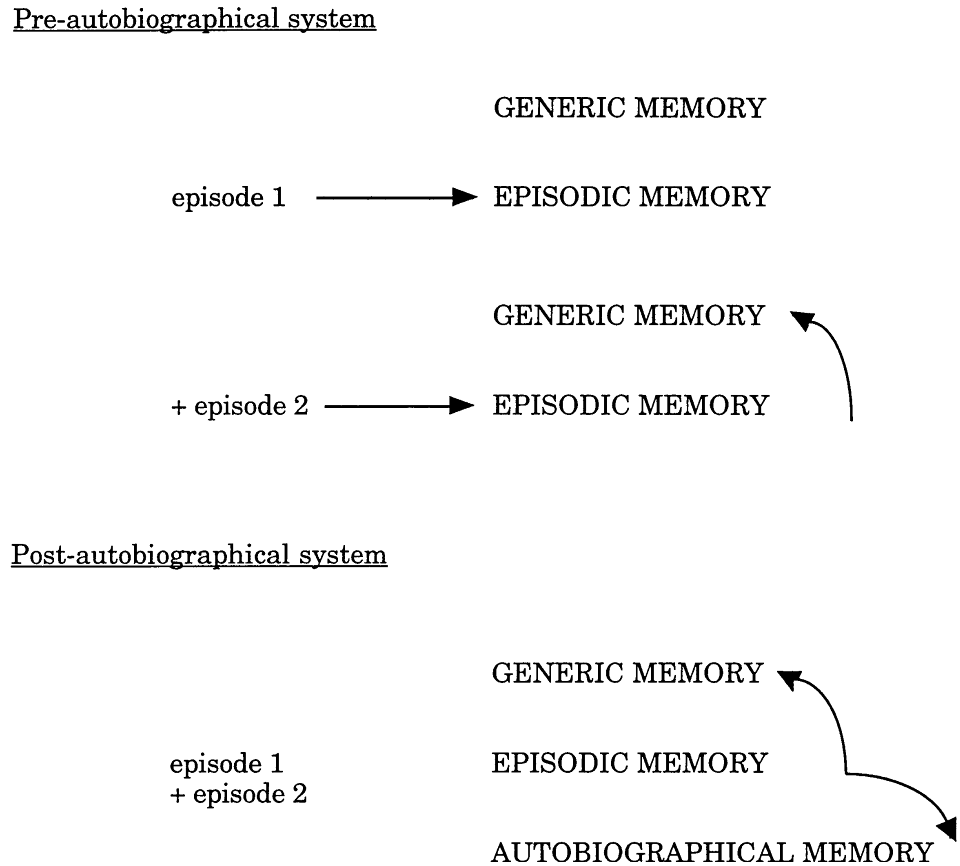

Figure 5. Schematic representation of developmental changes to long-term memory, according to Nelson (1993a). Adapted.

events over much longer periods, as Fivush and Hamond (1990) have shown? Nelson suggests that this might be achieved by the reinstatement of previous event contexts, which appears to prolong very substantially the amount of time that information can be preserved in episodic memory even in young infants. Several studies have now demonstrated that reinstatement, or the re-presentation of an earlier event some time after its initial occurrence, will effectively extend a child's memory for that event (Bauer, Hertsgaard, & Wewarka, 1995; Boller, Rovee-Collier, Gulya, & Prete, 1996; Fivush & Hamond, 1989; Rovee-Collier, Sullivan, Enright, Lucas, & Fagen, 1980).

Nelson's (1993a, b) views of the changes that take place in the types of memory knowledge or systems available to support remembering of distant events are summarised schematically in Fig. 5. In the pre-autobiographical stage that characterises the infancy and preschool period, memory is supported by two systems, episodic memory and generic memory. Repeated encounters with similar events allow access to the generic memory system. Subsequently, in the "post-autobiographical system", autobiographical memory emerges and interacts with semantic, generic, and episodic memory to provide a dynamic and flexible system for remembering both recent and distant events. Why, though, does autobiographical memory emerge when it does?

Using a social-interactional framework, Fivush, Nelson, and colleagues suggest that autobiographical memory emerges because children learn to talk about their memories and learn how to formulate memories as narratives. Fivush, Haden, and Reese (1996) provide evidence that although adults engage children as young as 2 years and below in conversations involving reminiscence of shared events, the young child makes little substantive contribution to the collective activity of remembering, even when cued. By 4 years of age, however, the typical child shows considerable competence in talking within the narrative structure appropriate for shared reminiscence (Fivush, Haden, & Adam, 1995). Fivush et al. (1996) identify two possible contributors to this emerging competence. First, adults gradually introduce children to richer and more complex ways of talking about earlier events. Second, the child's increasing facility at language provides the opportunity for restructuring and understanding past experiences in a way that more closely approximates to the adult narrative form. Via these and other processes, it is proposed that a coherent and organised autobiographical memory system can eventually be developed and used from 4 years onwards, with increasing effectiveness for supporting memory for distant events.

In an important test of whether narrative coherence in talking about memories heralds the end of childhood amnesia, Pillemer, Picariello, and Pruett (1994) provided a detailed investigation of whether the degree of narrative structuring of young children's memory for a recent autobiographical event predicts the likelihood of recall of the same event 7 years later. The children participating in the Pillemer study had attended a preschool centre, and had experienced an unusual event in which a fire alarm

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went off, caused by burning popcorn in another part of the building. As a result, the children were evacuated from the building, following the emergency procedure. Pillemer et al. tested the children's memories for this exciting event 2 weeks later and then again after a delay of 7 years. The most interesting aspect of the findings related to the subdivision of the children as either 3 or 4 years at the time of the original event, two age groups which probably straddle the boundary to the childhood amnesia period. Seven years later, 57% of the older group produced either an intact or fragmentary memory of the event, whereas only 18% of the younger group were able to do so. Similarly, whereas 86% of the older group selected the correct location of classroom from which they were evacuated in a forced-choice test, the younger children performed at chance level on this measure. Thus despite the very long period intervening between the event and the later unexpected memory test, the 1-year age difference at original experience between the younger and older preschool children had powerful consequences for the much later memory of this real-life event.

Pillemer et al. (1994) propose that these findings align readily with the "cognitive developmental" approach to childhood amnesia (Pillemer, 1992; Pillemer & White, 1989; Usher & Neisser, 1993), according to which the possibility and quality of later recall is dependent upon the degree of correspondence between the cognitive mechanisms in place at the time of experiencing the original event and attempting to recollect it. Pillemer et al. suggest that the principal constraining factor at original experience was the degree of causal understanding of the narrative structure of the event, with the older children showing superior understanding of the relationship of the different components of the event to one another. So the greater the narrative coherence at the time, the more organised the resulting memory trace and the closer the match with the narrative schemas applied to interpret the incomplete memory traces many years later.

A rather different perspective on the development of autobiographical memory has recently been advanced by Howe and Courage (1997). They propose that autobiographical memory is present typically by 2 years of age, considerably earlier than Nelson's (1993a, b) estimate of 4 years. According to Howe and Courage, autobiographical memory is present as soon as the "cognitive self", or the awareness of oneself as having specific cognitive capacities, emerges at between 18 and 24 months. A key feature of this account is that there is no developmental discontinuity in memory systems prior and subsequent to the emergence of autobiographical memory. Rather, basic memory systems are in place from early infancy, and the organising structure of the cognitive self acts upon these to generate autobiographical memories. Increases in the accuracy of autobiographical memory subsequent to 2 years are attributed to a variety of developmental changes including increased linguistic proficiency and narrative knowledge, and memory storage capacity.

In addition to these general developmental factors that appear to govern the quality and quantity of autobiographical memories in childhood, emotional experience appears to play a critical role in the establishment of enduring autobiographical memories at this stage. The degree of trauma associated with a personally experienced event has a substantial impact on a young child's subsequent memories. Ornstein (1995) found superior recall in children of experiencing an unpleasant medical procedure than of a routine visit to a doctor. Similarly, Hamond and Fivush (1990) obtained recall protocols from young children for their experience of Hurricane Andrew; these contained over twice the degree of detail as did a comparable group of children's recall of a family trip to Disneyworld. These and other findings indicate that, in children as in adults, the degree of personal involvement and emotional experience accompanying an event are important determinants of its memorability (Conway, 1995).

The evidence presented in this section attests to major developmental changes in the organisation of autobiographical memory in the early childhood years. As adults we remember very little from these years (childhood amnesia). Children clearly do remember some specific details of distant events during the period of up to 4 years or so, but there is some indication that their recall of the memories tends to be either lacking in specific detail or fragmentary and disorganised at this time. Theorists disagree according to whether the changes over these years reflect the initial absence and then eventual emergence of an autobiographical memory system (Nelson, 1993a, b) or gradual changes to the ways in which the child organises his or her experience (Howe & Courage, 1997; Usher & Neisser, 1993). Either way, the consequences for the amount and coherence of material remembered from earlier incidents is clearly subject to enormous change during the period extending from infancy to the preschool years.

One concern is that the conclusion that preschoolers' memories are relatively lacking in both detail and coherence nonetheless stands in direct conflict with the views of parents and carers that, as early as 2 years of age, children produce complex and detailed narrative accounts of prior events. Could it simply be that lack of detail and coherence of the memories is a product of the methodologies used for obtaining memory protocols of young children, which typically involve an unfamiliar person asking the child to remember a particular event? It is at least possible that a close family member would be more successful in eliciting more "mature" memories from 2- and 3-year-old children. If this was found to be the case, the clear implication would be that the complexity of young children's accounts of previous events may be limited not by long-term memory but by lack of development of social narrative skills to guide their interactions with strangers.

The Development of Episodic Memory

The body of evidence reviewed above identifies important developments in the child's abilities over the preschool period to remember specific past events and to organise recall of those events. By school age, the typical child shows good skills both at recalling details of prior experiences and at organising those details into a coherent narrative form. Age affects not only the child's current capacity to remember, but also the likelihood of future successful recall. Memories formed at this age and beyond stand a much better chance of surviving the test of years and being recalled in adulthood than memories for earlier experiences.

In emphasising the growing maturity of children's recollections over the early childhood period, though, it is easy to lose sight of the fact that even very young children in infancy and early childhood are nonetheless capable of remembering and learning many different things. Anyone who has had regular close contact with children between birth and 2 years of age will know that even at these very young ages, children frequently demonstrate surprising and impressive abilities to remember events which have often only been experienced on a single occasion. In the section below, some recent research designed to address this issue is outlined.

Nonverbal memory in infancy and early childhood. One influential group has conducted pioneering studies of children's memories for single distant events experienced as infants and toddlers, and has concluded from their studies that these memory abilities are served by the same memory system that contributes to remembering in older children and adults (e.g., Bauer & Mandler, 1989; Meltzoff, 1988). These researchers used a nonverbal method for assessing the memories of very young and largely preverbal children, known as the elicited imitation paradigm. In this paradigm, the child observes the experimenter using props to model a single action or an action sequence. Examples of action sequences are "put Fozzy bear to bed" and "make a windmill" (Bauer et al., 1995). The props are then given to the child, who is encouraged to imitate the action. The degree of correspondence between the child's sequences of actions with the props and the original modelled sequence is then scored, providing a measure of the extent to which the child remembered the experimenter's actions. Typically, the child's "recall" is sampled after a delay that may range from hours to years.

This paradigm has yielded clear evidence that infants and toddlers do retain a considerable amount of information about earlier events. At 14 months of age, recall can survive a delay of 1 week (Meltzoff, 1988), and some 13-month-old children can remember multi-step sequences up to 6 weeks later. Even more impressively, recollection of action sequences witnessed on a single occasion only has been found to persist for 8 to 12 months in 2-year old children (Bauer, Hertsgaard, & Dow, 1994; McDonough & Mandler, 1994).

Young children's performance on the elicited imitation paradigm is sensitive to at least two important factors. First, the amount of information remembered by the child is increased and the period of time over which it is retained is prolonged if the child passively witnesses the original event in full or in part after a considerable delay. This effect of reinstatement has now been demonstrated on many occasions (Fivush, 1984; Hudson, 1986, 1990; Sheffield & Hudson, 1994), and remarkably was found by Bauer et al. (1995) to operate even when the reinstatement consists simply of a verbal reminder to 15-month-olds of the action sequence accompanied by the props, and not by full re-enactment of the sequence. As noted earlier, similar benefits of reinstatement have also been found in conditioned learning by very young infants (Boller et al., 1996; Hill, Borovsky, & Rovee-Collier, 1988; Rovee-Collier & Fagen, 1981); reinstatement may be one of the mechanisms by which information is transferred from a relatively fragile (in terms of temporal duration, at least) memory holding system into a more durable memory reserve.

A second factor influencing recall in the event memory task is the degree to which the component actions in the modelled action sequence are constrained or enabled by one another. For example, the components in an action sequence containing novel events may have either arbitrary relations of one to another (as in "make a funny clown", which involved various objects that can be applied to a face shape in any sequence). Alternatively, they could have enabling relations in which the sequence the actions are performed in is critical to achieving the end state (as in "make a spinning top", which involves placing toy horses on a base, affixing a plunger, and pressing the plunger to make the horses spin). Recall is superior for the latter "enabling relations" type of events, establishing that in very young children at least, representations of arbitrarily ordered events in memory are not well organised and do not effectively support later recall (Bauer & Fivush, 1992; Bauer et al., 1995; Hudson & Nelson, 1986).

On the basis of this and other evidence, Bauer et al. (1994) and McDonough and Mandler (1994) have argued strongly for continuity in the memory systems underpinning memory for specific distant events from infancy through to the verbally mediated recall which emerges later. A close look at individual studies using this approach, however, reveals substantial inconsistencies in findings. For example, McDonough and Mandler (1994) found that 2-year-olds returning to the laboratory after a 1-year delay showed evidence of recalling a familiar modelled action (of feeding Teddy with a schematic bottle) but not of remembering sequences of unfamiliar actions. In contrast, Bauer et al. (1994) found that toddlers of a similar age recalled novel event sequences (such as "make a rattle"), but not familiar sequences ("feeding Teddy"), 8 months later. Why opposite effects should be found across the two studies is as yet unclear. Furthermore, Boyer, Barron, and Farrar (1994) failed to obtain any evidence, in either verbal protocols or nonverbal imitation, of memory in 2-year-old children of an activity (making PlayDoh spaghetti) learned over a year previously. This result is clearly at odds with other findings. More generally, it seems likely that detailed profiles of memory performance, including retention functions, which emerge from the elicited imitation studies, may be highly specific to the particular memory sequences used. Without some degree of harmonisation of stimuli and methods, it may be premature to draw general conclusions about decay functions and developmental changes in long-term memory from this paradigm.

Nelson (1994) has challenged the view that the elicited imitation task demonstrates that very young children have access to the same long-term memory system as older children and adults. Nelson pointed out that in performing this task, infants and toddlers need not be drawing upon an explicit long-term memory system in which remembering is accompanied by conscious awareness. Rather, very young children's "recall" of modelled sequences may be mediated by an implicit memory system that allows for later actions to be influenced by earlier experiences in the absence of any conscious recollection (see Schacter, 1987). In other words, Nelson's suggestion was that young children are drawing upon a primitive learning system in the elicited imitation paradigm, rather than the episodic or autobiographical memory systems that she considers to support memory in preschool and older children (Nelson, 1993a).

It is relevant at this point to note that in the elicited imitation task, the child passively witnesses the modelling of fairly arbitrary action sequences. This passive nature of the to-be-remembered episode may in itself contribute to a substantial underestimation of the capacities of young children to remember previous events. It is already known that active participation in an event enhances children's recall (Rudy & Goodman, 1991) and this may be because the event, by virtue of its high self-reference and personal relevance, is represented in autobiographical rather than episodic memory (Conway, 1990, 1996). The paradigms described in the previous section, in which children were later asked to recall events in which they played an integral role, such as evacuating a building in an emergency (Pillemer et al., 1994), or a visit to an archaeological museum (Hudson & Fivush, 1991), are similarly meaningful to the child. In contrast, the neutral action sequences employed in the elicited imitation task, modelled by another, will be much lower in self-relevance to the children, and are unlikely to elicit a personal interpretation. Thus the elicited imitation paradigm and memory tasks that require recall of real-life episodes may draw upon fundamentally different memory systems. For this reason alone, direct comparison of long-term memory abilities of very young and older children, confounded as they are both by paradigm and age of the child at test, is probably neither possible nor appropriate.

Although the studies of long-term memory in very young children reviewed above may not provide a convincing demonstration that the same memory systems are in place across the full range of the childhood years from infancy onwards, the findings are nonetheless important. They securely establish that young children can sometimes retain information from specific episodes over very long periods of time. We are, however, a long way from being able to predict in advance what particular information a child of a particular age is likely to retain over different periods of time: this is highly dependent on many detailed aspects of the nature of the memory event, as well as known sources of individual differences such as gender, parental style of communication, and language ability (Fivush et al., 1996; Nelson, 1993a, b; Reese, Haden, & Fivush, 1993).

Eyewitness testimony. The need to understand the quality of children's memory for distant events has become imperative in recent years as a consequence of increasing dependence on testimony provided by child witnesses in the courtroom in cases relating to child abuse, domestic violence, and crime in schools. Appropriate interpretation of such evidence clearly requires evaluation of the reliability of children's memory, and of the developmental changes that occur. As a result of these psycholegal needs, a new tradition of the study of children's "eyewitness memory" has emerged. The principal issues guiding research in this area: are: (1) whether there are age differences in the reliability of children's memory for experienced events, (2) whether there are age differences in the susceptibility of children to misleading suggestions made by others, and (3) which are the best methods of obtaining unbiased memories from children.

Most of the research on children's eyewitness memory uses "episodic memory" type paradigms in which the child either sees an enactment of an event or hears a story in which he or she is not an active participant. Consistent with the findings of other laboratory studies and investigations of children's autobiographical memories reviewed above, it has been demonstrated on many occasions that in these tasks young children (and especially preschool children) recall considerably less of the target events than either older children or adults (e.g. Cohen & Harnick, 1980; King & Yuille, 1987; Oates & Shrimpton, 1991; Ornstein, Gordon, & Larus, 1992). The implication is that young children have relatively impoverished memory representations of events, possibly arising from poor understanding of the causal structure of the events (Pillemer et al., 1994).

Adults' memory for witnessed events is of course also fallible, and has been shown on many occasions to be liable to distortion by misleading post-event information (e.g. Loftus, 1979). Using the eyewitness testimony paradigm developed by Loftus, in which a memory event is followed by some "questions" that incorporate inaccurate information, it has been found that young children (of about 6 years and below) are even more vulnerable to distortion following exposure to misleading information about the memory event than are older children and adults. For example, Ceci, Ross, and Toglia (1987) presented to children a story about a girl who had a stomachache from eating her breakfast too fast. Subsequently, the children were asked a biased question: "*Do you remember the story about Loren, the girl who had a headache because she ate her cereal too fast*?". Still later, the children were given a forced-choice recognition task involving two pictures; in one, Loren was eating her cereal and in the other (incorrect one), she had a headache. In this experiment, the probability of making correct recognition judgements was lower for such biased than unbiased information, and the extent of the biasing decrement decreased regularly from the younger (3–4 years) to the older (10–12 years) children. In a recent review, Ceci and Bruck (1993) found such evidence of increased suggestibility to misleading information in younger children in 88% of such eyewitness testimony studies. According to Ceci (1995, p. 155, original italics), "there *are* reliable age difference in suggestibility, with preschool children's reports being more readily impeded by the presence of erroneous suggestions by an interviewer than older children's reports".

The implication of these findings is that the integrity of young children's memories for real-life events is unlikely to survive detailed questioning in and out of the courtroom. Ceci, Huffman, and Smith (1994) attempted to simulate this by asking children to think, repeatedly over a 10-week period, about both real events and events that never happened. For example, a false event could be cued by the interviewer saying to the child "*Think real hard, and tell me if this ever happened to you. Can you ever* *remember going to hospital with a mousetrap on your finger?*". Over the period of the study, 58% of preschool children produced false narratives and at least one false event description, and a quarter of the children responded with "memories" to the majority of the fictionalised event descriptions. So, mere exposure to adults asking you about events that did not take place is clearly sufficient under some circumstances to yield false memories. Possibly most troubling of all, Ceci et al. videotaped the children in this experiment being given a forensic-style interview about both real and false events, and showed the tapes to psychologists specialising in children's testimony. These professionals were no better than chance at discriminating children's recounting of true over false memories.

The evidence reviewed so far indicates that young children have both relatively poor event memory and high suggestibility to misleading information. For a detailed analysis of the roots of this comparatively low reliability of preschoolers' memories, it is useful to consider possible mechanisms for suggestibility effects. Loftus, Schooler, and Wagenaar (1985) suggested that post-event information (such as a biasing question) may destructively update the original memory trace, replacing the original target information with the later biasing information. Quite plausibly, it could be argued that the lower levels of organisation and integration of information within the original memory trace in younger children might be particularly low in resistance to such updating. Another mechanism considered by Loftus et al. is that the subsequent biased material is retained in a coexisting memory with the original information, but that possibly as a consequence of its more recent date it suppresses access to incompatible material in the earlier memory trace, and hence leads to biasing errors. To account for the greater degree of suggestibility of young children via this mechanism, it would be necessary to make the rather arbitrary assumption that the inhibitory effect of the later memory on access to the original memory trace is more severe in younger children.

There are, however, a range of other possible mechanisms for memory suggestibility effects that make much less strong claims about the impact of later events on original memory representations, and that may, in fact, all plausibly contribute to the observed developmental changes in degree of susceptibility to misleading information. McCloskey and Zaragoza (1985; see also Zaragoza & Lane, 1994) suggested that the later biased information does not either distort or deny access to the original memory information, but instead is used to fill in gaps in incompletely specified memory traces. Thus in very young children, who we already know have particularly poorly specified memories, the probability of misleading information being used in this way to complete earlier memories will be particularly high.

A related view is that the increased suggestibility of young children reflects their response to the demand characteristics of the memory situation, in which the child is provided with new information by the adult experimenter, an authority figure (Poole & Lindsay, 1995). Thus the child may assume that the post-event suggestions are valid and so consciously base their responses on the suggestions rather than the original, and possibly conflicting, memories. In Ceci et al.'s (1994) simulated false memory situation, the child may simply assume that if the experimenter thinks that he or she went to hospital attached to a mousetrap, they must be right. Consistent with this compliance view, the impact of biasing post-event information on young children is now known to be reduced if its source is another child rather than an adult (Ceci, Leichtman, Putnick, & Nightingale, 1993).

A further possibility is that the young child remembers both the critical detail of the original event and the content of the post-event suggestion (in the example of the Ceci et al. 1987 study, this would be the stomachache and the headache), but is uncertain as to which detail occurred in the original story. This represents a failure of what has come to be known as source monitoring, or the ability to discriminate between memories from different sources. Young children have been found to make more errors than adults in discriminating between performed and imagined actions (Foley & Johnson, 1985; Foley, Johnson, & Raye, 1983; Lindsay, Johnson, & Kwon, 1991), although these developmental differences in monitoring do appear somewhat inconsistent across studies (e.g. Foley, Durso, Wilder, & Friedman, 1991; Roberts & Blades, 1995). There is certainly direct evidence that source confusions in eyewitness testimony tasks are greater in younger than older children (Ackil & Zaragoza, 1995), lending further weight to this suggestion that very young children are not necessarily unduly misled, but instead are often unable to remember what detail was supplied by what source.

Thus although the vulnerability of preschool children to misinformation after the memory event is widely accepted, the causes for the apparent memory distortions are still being keenly debated. It certainly seems plausible that much of the apparent distortion of their memories does not necessarily reflect alterations in the original memory representation, but other factors such as compliance to the suggestions of adult authority figures, and uncertainty about the precise source of remembered information. Practical implications follow from this analysis. In particular, incorporating source monitoring questions (e.g. "*did you see that happen, or did somebody tell you that it happened?*") into interviews with child witnesses should lead to an increase in the reliability of their testimony (Poole & Lindsay, 1995).

On the other hand, some of the models increasingly used by professionals in their interactions with child witnesses may be counter-productive. The use of dolls and props in interviews are widely believed to enhance remembering in young children, and to compensate to some degree for the linguistic limitations of the young witness. However, preschool children have recently been shown to have difficulty in using dolls as representations of themselves (DeLoache & Marzolf, 1995). Moreover, although the introduction of props at recall may elicit more information, there is little gain in the amount of accurate recall (Salmon, Bidrose, & Pipe, 1995). The fact that children use dolls and props when allowed therefore provides no guarantee of more accurate memory assessment.

The main conclusions to emerge from this brief review of children's eyewitness testimony, of relatively poor long-term memory and high levels of suggestibility in young children, may be unduly pessimistic for two reasons. First, the focus in the majority of studies is whether there are age-related changes in children's abilities to remember distant events. Although consistent differences are found, in many cases they simply demonstrate that preschool children are *relatively* poorer at remembering material than older children. This age difference notwithstanding, even very young children often demonstrate very reliable memory performance, particularly when optimal methods of sampling memory are used and there is no misleading information presented subsequently (Poole & Lindsay, 1995). Young children also appear to be relatively resistant to biased questioning when the misleading information relates to a central rather than peripheral feature of the original event (Pezdek & Roe, 1995). So, even preschool children are capable of accurate memories given the right circumstances.

The second point relates to more general features of the methods used to assess children's memories for distant specific events. Although much of the research in this area is motivated by the need to understand the reliability of their testimony in court cases, the memory events that they feature differ in many critical features from the real-life events they are designed to simulate. Eyewitness memory research depends largely upon laboratory-style experiments in which the child either hears a story or watches a staged event of neutral emotional valence, typically as a passive bystander. In contrast, the events witnessed in real life by the traumatised child called to provide witness are likely to be high in personal relevance and emotional content, and may well have been repeated on many occasions. So whereas eyewitness memory experiments tap episodic memory, in real life the child's testimony is likely to be supported by the more powerful autobiographical memory (Conway, 1990). Until the contributing memory systems in the two circumstances are aligned, it seems likely that we will inevitably underestimate the quality and organisation of young children's memories for important events.

Knowledge about Memory

The primary emphasis of this article is on changes that take place in childhood in the capacity and functioning of three basic memory systems: short-term memory, autobiographical memory, and episodic memory. Many other important developments in memory also occur across the childhood period, but are unfortunately beyond the scope of the present review. One particular aspect of memory development that warrants at least a brief mention here is "metamemory", which is the knowledge and awareness that an individual has about his or her own memory. Examples of activities involving metamemory include judgements about whether one thing is likely to be easier to remember than something else, knowledge about whether or not you are likely to be able to remember something some time in the future, and knowledge about whether or not you already know a particular fact. The types of metamemory possessed by children of different ages have important practical as well as theoretical implications, as the effective training of strategies for enhancing memory performance requires the child to have some degree of awareness of how memory works and how to influence this process (Pressley, Borkowski, & O'Sullivan, 1985).

Strong positive links between children's metamemory judgements and their actual memory performance has now been established in many tasks, demonstrating that children are able to make reliable explicit judgements about the functioning and capacities of their basic memory systems (Schneider, 1985). The degree of sophistication of metamemory does, however, undergo considerable developmental change: the rudimentary memory awareness demonstrated in preschool children (Schneider & Sodian, 1988) is superceded by increasing knowledge of both general and specific strategies for memory and learning which is more or less fully developed by about 12 years (Schneider & Pressley, 1989, 1997). Detailed accounts of the important changes in metamemory and memory strategy training are provided by Forrest-Pressley, MacKinnon, and Waller (1985), Kail (1990), and Schneider and Pressley (1989, 1997).

Concluding Remarks

The development of memory during childhood represents a crucial area of research both for cognitive and developmental psychology. As indicated in the present selective review of memory development, the emergence in recent years both of techniques for investigating a wide range of aspects of children's memory function and of new theories of memory has mapped out important territory for investigation in coming years. It is important to note, however, that it is not only the theoreticians who benefit from increased understanding of children's memory resulting from this substantial research effort. Memory functioning during childhood has many practical implications, too. Professional groups who work alongside children, such as teachers, educational psychologists, lawyers, and counsellors, also need to know about memory development. Unless members of these professions can readily gain access to current understanding of children's memory and of methods for its assessment, they will be limited in the extent to which they can, for example, make reasonable evaluations of the likely accuracy of eyewitness evidence from a child of a particular age, or judge the likely educational consequences for a child of a specific deficit in memory. Memory researchers therefore have an important responsibility not only to disseminate their findings to the immediate research community, but also to the many other interested parties who need to know about children's memory for practical rather than theoretical purposes.

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