

Persistence of Memory for Ignored Lists of Digits: Areas of Developmental Constancy and Change

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Contrary to the common belief that sensory memory remains unchanged across development in childhood, there have been several previous reports suggesting that the persistence of sensory memory, at least for sounds, increases with age in childhood. Because those previous studies all used isolated sounds as stimuli, it is not yet clear how this developmental difference influences the recall of sound *series*. The present study adapts the procedure of J. S. Saults and N. Cowan (1996), who studied memory for attended and ignored spoken words, to examine here the recall of attended and ignored lists of digit. A developmental increase in the persistence of memory was obtained only for the final item in an ignored list, which is the item for which sensory memory is thought to be the most vivid at short retention intervals. © 2000 Academic Press

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Considerable evidence suggests that mental representations of acoustic and phonological features of speech signals linger in the brain and help to support performance in comprehension and memory tasks (for reviews see Cowan, 1995; Cowan & Saults, 1995). Therefore, it seems important to understand how these representations survive across time at different ages in childhood. There is a common assumption in the field of developmental psychology that very low-level factors in memory (e.g., sensory memory for information that has little semantic content or has not been analyzed at a semantic level) remain fixed across ages and do not contribute to developmental changes in memory (e.g., Bjorklund, 1995, p. 104; Siegler, 1998, p. 67). However, previous studies examining the development of auditory sensory memory (e.g., Cowan & Kielbasa, 1986; Engle, Fidler, & Reynolds, 1981) were not designed to examine directly age differences in the rate of loss of stimulus information in memory *over retention intervals*. Frank and Rabinovitch (1974) did examine the effect of acoustic interference (the “suffix effect”) occurring 0.5 to 2.0 s after the onset of

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the last spoken digit in an immediate memory task, and found a similar decline in interference across delay intervals for subjects in Grades 3, 5, and 7, though with a larger amount of interference for the list-final item in the youngest group compared to the older groups. This method, however, provides only an indirect measure of memory loss over retention intervals. As Frank and Rabinovitch noted, it is unclear if the decline in acoustic interference across suffix delays reflects the loss of acoustic memory or the formation of modality-independent representations during the delay.

Recently, several studies have shown that this dismissal of sensory memory persistence as a source of developmental change was premature. Keller and Cowan (1994) found that a comparison of tones that could differ slightly in pitch could be accomplished to a criterion level of performance with a longer silent, intertone time interval in older subjects. A 12-s intertone interval produced a performance level in adults roughly comparable to a 10-s interval in 10- to 12-year-old children and an 8-s interval in 6- to 7-year-old children. These age group differences did not appear to be related to rehearsal of the first tone in a pair inasmuch as, in a second experiment, adults' performance was not impaired by a musical imagery task during the intertone interval. Support for a developmental change in auditory sensory memory for tones in childhood also has been obtained in a study based on the mismatch negativity (MMN) component of event-related brain potentials (Gomes et al., 1999). A MMN potential occurs as a response to tones in a series even when it is ignored, at the point at which a sequence of identical standard tones is followed by a detectable deviant tone. This MMN occurs only if the deviant is presented soon enough so that the standard tone representation is still active in sensory memory for comparison with the deviant. A MMN to a pitch-deviant tone was obtained in a condition with an 8-s interval between the standard tones and the deviant in older subjects (11 years and up), but not in younger ones (6–10 years); whereas with a much shorter, 1-s interval between the standard and deviant tones, a MMN was obtained in all of these age groups.

In the closest precursor to the present study, Sauls and Cowan (1996) examined developmental changes in the persistence of memory for ignored speech using isolated, spoken words. That study, in turn, was modeled after an adult study of memory for ignored syllables (Cowan, Lichty, & Grove, 1990). The rationale behind this line of studies is that ignored speech cannot be processed as fully as attended speech and that memory for ignored speech therefore is determined more by memory for sensory features of stimuli, which can be analyzed preattentively (Broadbent, 1958; Cherry, 1953). Cowan et al. had their subjects ignore spoken syllables presented through headphones at irregular intervals while subjects silently read a novel. Although most of the syllables were to be ignored, occasionally a visual cue was presented, at which time the subject was to put down the book and identify (in a forced choice) the last spoken syllable, which had occurred 1, 5, or 10 s before the visual cue, and

then to write a sentence describing the reading just before the memory cue. After that, reading resumed. A final reading comprehension test showed no difference in the efficiency of reading in this group vs a control group hearing no speech sounds. Thus, there was no evidence that attention was diverted from the reading to the spoken syllables that were to be ignored. Memory for ignored syllables declined markedly over a 10-s, reading-filled retention interval and this decline was much more severe for acoustically more complex, consonant phonemes than for acoustically simpler, vowel phonemes. In several types of attended-speech control conditions, in contrast, there was no forgetting of syllables over the 10-s retention intervals. This study established the viability of examining memory for ignored speech without acoustic interference from later sounds, which was not attempted in earlier selective attention studies (e.g., those reviewed by Broadbent, 1958).

Saults and Cowan (1996) modified the procedure of Cowan et al. (1990) for developmental investigation, in several ways. Instead of spoken syllables, spoken words were used and the memory test involved selecting the corresponding picture on the computer screen. Instead of silent reading, the primary visual task was a silent computer game. Saults and Cowan found that memory for the spoken words declined more rapidly across time if the computer game engaged phonological processes (by requiring a match between pictures of common objects on the basis of rhymes between their names) than it did when the computer game failed to engage them (by requiring a physical match between colored designs). This difference was attributed to the need to engage phonological processes if rehearsal of the speech sounds was to be prevented (cf. Baddeley, 1986).

When rhyme matches were required within the visual task, Saults and Cowan (1996, Experiment 2) found that the loss of memory for ignored words was more severe in younger subjects than in older ones. Adults showed the least amount of memory loss across 10 s but the comparison between adults and children was not fully interpretable because the adults' recall was somewhat higher than that of the children even at the 1-s retention interval, making it difficult to tell if their slower rate of memory loss was a secondary consequence of the level difference. However, even though the two groups of children (first and third graders) performed at equivalent levels with a 1-s retention interval, performance declined across 10 s much more severely in the younger children. These results indicated an age difference in the rate of forgetting of ignored speech information in childhood.

In the present article, we examine the rate of forgetting of *multiword* lists of ignored speech items developmentally. One reason to do so is that this can be helpful in the interpretation of the age group differences in memory for ignored sounds obtained by Saults and Cowan (1996) and other previous studies (Gomes et al., 1999; Keller & Cowan, 1994). It is possible that these results depend upon the subjects' memory spans. For example, for a subject with a span of five items, a one-item presentation is four items below span length, whereas for a subject

with a span of three items, a one-item presentation is only two items below span length. Perhaps it is these relative list lengths, and the implied age differences in imposed memory loads, that determine the rate of memory loss. To preclude this possibility, in the present study each subject received lists of digits of a length equal to his or her predetermined memory span (cf. Engle & Marshall, 1983).

A second reason that it is important to examine memory for ignored lists is to determine the pervasiveness of the age difference across serial positions of the list. Cowan, Nugent, Elliott, Ponomarev, and Sauls (1999) adapted the procedure of Sauls and Cowan (1996) in order to study memory for ignored lists of digits, and they did find that this type of memory extended back through the entire list and produced primacy effects (superior recall of the first few list items) as well as recency effects (superior recall of the last few list items). However, Cowan et al. always used the same retention interval. The interesting question yet to be answered is what happens to memory for ignored lists as the retention interval increases. It could be that age differences in the sensory memory persistence underlying the recall of isolated items also applies to entire lists, or it could be much more limited for various reasons (to be discussed below). The present study has possible relevance to any situation in which a series of items or events must be held in mind over a period of some seconds, during which attention wanders elsewhere.

The results of Cowan et al. (1999) help to clarify what processes take place in the memory-for-ignored-speech procedure. The patterns of responses for attended and ignored lists were fundamentally different. Performance was examined across various list lengths and it was found that the number of items recalled correctly from a list increased markedly with list lengths for attended lists, but was constant across list lengths for ignored lists. It is presumed that memory for ignored lists depends on a process in which information is drawn from a large-capacity auditory sensory memory into a small-capacity working memory. The number correct for ignored lists reflects the limited capacity of working memory. This is not true for attended lists because attention during the list presentation allows subjects to group items into larger chunks (Miller, 1956). The constancy of the number correct across list lengths for ignored lists parallels the classic finding of Sperling (1960) that adults recall a constant number of items from a briefly presented visual array, regardless of the array size, because working memory capacity for nonchunked items has a fixed limit and the conditions of presentation do not allow chunking. Thus, a constant number correct across stimulus set size has been presumed in both cases to indicate the absence of grouping processes (explaining why the same number correct is obtained regardless of stimulus set size), no matter whether this absence is achieved by diverting attention from a list at the time of its presentation (Cowan et al., 1999) or by presenting a complex, simultaneous array of stimuli (Sperling, 1960).

In the present adaptation of the Cowan et al. (1999) procedure, only one list

length per subject can be presented, to reserve sufficient time in the session (given the painstaking nature of the procedure) to manipulate the retention interval within subjects. The desired effect of adjusting the list length to equal the longest list that the subject could repeat correctly in a span pretest was to minimize age differences in recall unrelated to retention intervals, so that effects of retention intervals per se could be highlighted.

Cowan et al. (1999) found pronounced primacy as well as recency effects in memory for ignored lists at all ages tested. Primacy effects need not indicate that rehearsal has taken place, given that they can be obtained in infants (Cornell & Bergstrom, 1983) and nonhuman animals (Wright, 1994). Instead, primacy and recency effects both can reflect superior temporal distinctiveness of the sensory memory record for items that are near the beginning or end of a list because the longer, interlist intervals can serve as anchors for the temporal location of nearby items in the list (cf. Nairne, Neath, Serra, & Byun, 1997; Neath, 1993). This special distinctiveness of primacy and recency items presumably is lost over retention intervals, for reasons related to Weber's law (i.e., as the retention interval increases, the ratio of the interitem intervals to the retention interval decreases).

Serial position information can be used to help interpret the processes taking place in memory for ignored speech across several retention intervals. Although attended lists followed by a distracting task produce observable forgetting in serial recall at the recency positions only (Jahnke, 1968), the present ignored-speech condition instead showed marked forgetting at all ages in the primacy positions, in addition to the recency positions, making the pattern of memory for ignored speech different from what one would expect on the basis of an attentional contribution. Thus, as we will argue further below, one cannot look to covert shifts of attention to explain developmental differences in memory for ignored speech.

In contrast to the possibility of age differences in the use of attention and strategies to avoid memory loss over retention intervals, it is possible that there is a nonstrategic source of memory that matures during childhood. If the nonstrategic source were simply the better preservation of distinctiveness across retention intervals in older subjects for some nonstrategic reason, it too should apply across serial positions. However, another possible nonstrategic source is auditory modality-specific features of memory, which are most vivid for the most recent items because they have not been overwritten by subsequent items (Nairne, 1990). Strategic processes do not appear to be very successful in retaining these items from the end of the list (Balota & Engle, 1982; Greenberg & Engle, 1983; Penney, 1985; Penney & Godsell, 1993), which tend to be lost quickly over retention intervals. If there were developmental changes in the rate of loss of auditory features from memory as several recent studies have suggested (e.g., Gomes et al., 1999; and see above), one result that could occur is an age difference in forgetting functions in memory for ignored speech that is most

pronounced at the end of the list (where there is no retroactive interference) and not very pronounced at the beginning of the list (where there is retroactive interference). If that is what occurs, it will at least seem inconsistent with what would be expected on the basis of the covert use of attention or on the basis of distinctiveness factors, yet consistent with a notion that a vivid form of sensory memory becomes more persistent with development.

To investigate these questions, we used a method in which each subject first took a digit span test. The spoken lists in the main experiment were presented at a length equal to the longest list repeated correctly in the span test, and responses were entered using a number keypad. We compared serial recall of attended lists to the serial recall of lists that were ignored during their presentation while the subject performed a visual task involving pictures with rhyming names. Retention intervals of 1, 5, and 10 s were used. In the ignored-speech condition, the difficulty level of the rhyming game was in a sense self-adjusting in that the rhyme responses were to be made as quickly as possible and the response rate determined the presentation rate, compensating for the slightly greater difficulty younger subjects display in the task to some extent (with a slower self-produced stimulus rate for younger subjects). Most spoken lists were not probed; only occasionally, following a list and the postlist test delay, the rhyming game was replaced with a serial recall test screen.

METHODS

Subjects

The sample included 24 from each of three age groups: Grade 2 (15 girls, 9 boys), Grade 5 (14 girls, 10 boys), and college (15 women, 9 men). Mean ages (and standard deviations) in months were, respectively, 90.63 (4.69), 129.58 (5.47), and 243.08 (42.00). The children were recruited from middle-class public schools. The sample was 84% White, 8% Black, and 8% Asian or other. Children received small gifts and college students received course credit for participation.

Apparatus and Procedure

The entire apparatus and procedure were the same as those used by Cowan et al. (1999) except that, in the auditory memory test, the postlist, silent retention interval was manipulated instead of the list length; and the number of trials in each phase was not exactly the same as before. Except for the initial, aurally presented digit span test, all materials were presented, and responses recorded, using an Apple Power Macintosh computer. Spoken digits in a male voice were digitized, and presented via the computer through audiological headphones at 55 dB(A) as measured with a sound level meter and earphone coupler. Children received stickers contingent on successful completion of a certain number of trials in the visual rhyming game. Subjects were instructed not to talk during the computerized portion of the experiment except during optional breaks.

The nine phases of the experiment included the following: (1) an aurally

administered digit span pretest; (2) the first phase of auditory task familiarization and practice; (3) an initial set of attended-speech control trials; (4) a second phase of auditory task familiarization and practice; (5) visual task familiarization and practice; (6) an initial set of visual-task-alone control trials; (7) the main experimental phase, in which subjects carried out the visual task during ignored speech and occasionally were tested on the spoken digits; (8) a second, final set of visual-task-alone control trials; and (9) a second, final set of attended-speech control trials. These phases will be explained in turn.

1. *Aurally administered digit span pretest.* Digits were read by the experimenter at a rate of one item per second, in a monotone with a downward inflection on the last item. An immediate spoken response was then required. Three trials in a row were conducted at each list length, beginning with three-digit lists and increasing until the subject made a mistake on every list. Given that an integer value of span was required, a subject's span estimate was taken as the length of the longest single list that the subject repeated without error, with digits repeated in the presented order. No digit appeared more than once within a list and the longest list length tested was nine items.

2. *Auditory task familiarization and practice, Phase 1.* In this phase, the digits were presented one at a time by the computer and a response was required so that the subject could note the location of the digits on the computer keypad.

3. *Attended-speech control trials, Set 1.* Twelve lists of spoken digits were presented via the computer at an onset-to-onset rate of 0.5 s per item within a list (a rate that was maintained for digit lists throughout the remainder of the experiment). Each list had the same number of digits as the subject's span. The 12 lists occurred with a silent, postlist retention interval (test delay) of 1, 5, or 10 s, with four trials at each test delay, randomly intermixed. The test delay was followed by a series of boxes that were filled in with digits as the subject typed them in using the keypad. The computer program allowed a subject to correct mistakes and press an Enter key when satisfied with the trial's responses.

4. *Auditory task familiarization and practice, Phase 2.* This task introduced the concept that, in the ignored speech phase, a response would not be required following every digit list. Sets of four lists were presented with 1, 5, or 10 s between lists. The last list in a set was followed by a 1-, 5-, or 10-s test delay and then the recall cue (row of empty boxes). A set of three such trials was carried out (one at each delay), and if performance was not perfect a second set of three trials was carried out, but no more after that.

5. *Visual task familiarization and practice.* The computer presented a set of five pictures and their rhyming names (e.g., *nail, pail, tail, mail, snail*). The child was to repeat the five names in the presence of the pictures, and this procedure was repeated until the names could be repeated flawlessly. The computer presented a total of 14 sets of five rhyming pictures.

Next, the subject received practice in the rhyming game. In the four corners of the computer screen, four nonrhyming pictures were presented along with their

names (e.g., *rain, tail, chair, bat*). Then a central picture was presented that had a name rhyming with one of the four peripheral pictures (e.g., *hair*). The name of this central picture was not presented here, though it had been learned in the familiarization phase. The task was to select the peripheral picture that rhymed with the central picture as quickly as possible using the computer mouse, and the response time was recorded. When a response was made, the central picture was replaced with another one (whereas the peripheral pictures remained, and were not renamed). The game continued in this fashion until a criterion was met, consisting of six correct responses, not necessarily to consecutive central pictures.

6. *Visual-task-alone control trials, Set 1.* The rhyming game (just as in practice) was presented alone for a period of just under 1 min. Children were rewarded with the display of a new star on the computer screen after each successful trial, and the stars were later converted to stickers at the rate of one sticker per 10 stars and one for the remainder.

7. *Main experimental phase, with ignored speech.* In this phase, the rhyming game was played in the presence of spoken digits. The instructions were to play the matching game again while hearing groups of numbers, which were to be ignored. Subjects were told that they should not worry about the quality of their memory performance for ignored speech under these circumstances because people remember some of it and they were not expected to do very well on it. (Subjects naturally seem to habituate to the frequent, irregular sounds under these circumstances, as our results will suggest.) The spoken digit lists were presented on the same schedule as before, with 0.5-s onset-to-onset times within a list and 1, 5, or 10 s between lists. The rhyming game was played for periods varying between 40 and 90 s before a memory test probe (row of boxes) occurred. During this period leading up to a memory test probe, there were five to nine ignored lists. The ignored speech phase included 12 memory trials, with 4 trials each at postlist retention intervals (delays) of 1, 5, and 10 s, presented in a random order. Given the time needed for memory responses, the ignored speech portion of the experiment typically took about 20 min.

8. *Visual-task-alone control trials, Set 2.* This task was identical to the first set of visual-task-alone trials and served to reveal any effects of practice or fatigue that otherwise would cloud the comparison with visual task performance during ignored speech.

9. *Attended-speech control trials, Set 2.* This task was identical to the first attended-speech control task and was combined with that task in order to obtain a balanced comparison of memory for attended versus ignored speech.

RESULTS

Memory Span

The memory spans as determined in the aurally presented pretest are shown in Table 1. There was a steady increase in spans across age groups.

TABLE 1
Distribution of Memory Spans for Subjects in Each Age Group

Memory span	Number of subjects		
	Grade 2	Grade 5	Adults
4	7	1	0
5	8	4	1
6	6	9	2
7	1	8	13
8	2	2	5
9	0	0	3

Visual Task Performance

It was assumed that visual task performance would increase with age, which reveals nothing about the allocation of attention. However, a measure that appears relevant to the allocation of attention is performance of the visual task alone versus performance of the visual task in the presence of spoken digits. Like Saults and Cowan (1996) and Cowan et al. (1999), we generally obtained practice effects on visual task reaction times across the extended period during which to-be-ignored spoken digits were presented, along with fairly high levels of performance in all conditions. To compare the two conditions of visual task performance with minimal contamination from practice effects, we compared (1) performance in the initial visual-task-alone sequence, versus visual task performance during the subsequent presentation of spoken digits leading up to the first ignored-speech memory trial; and (2) visual task performance during the spoken digits leading up to the last ignored-speech memory trial, versus performance in the subsequent, final visual-task-alone sequence. These visual task performance means are presented in Table 2, in the order in which testing took place.

An ANOVA of the proportion correct was conducted on the conditions represented in the table, with age group as a between-subjects factor and with the experimental phase (beginning versus end of the session) and the attention condition (visual task alone versus speech present) as within-subject factors. This analysis produced main effects of experimental phase, $F(1, 69) = 19.64$, $MSE = 0.01$, $p < .001$, with a higher proportion correct at the beginning of the experiment ($M = .94$) than at the end ($M = .88$); of age group, $F(2, 69) = 13.37$, $MSE = 0.02$, $p < .001$, with the proportion correct increasing with age ($M = .86$, $.92$, and $.95$ for the three age groups); and of condition, $F(1, 69) = 22.64$, $MSE = 0.01$, $p < .001$, with the proportion correct lower in the visual-task-alone condition ($M = .88$) than in the visual task presented with ignored speech sounds ($M = .94$). These main effects must be interpreted in conjunction with interactions of Age Group \times Condition, $F(2, 69) = 5.60$, $MSE = 0.01$, $p < .01$, and Experimental Phase \times Condition, $F(1, 69) = 7.39$,

TABLE 2
A Comparison of Performance on the Visually Presented Rhyming Task in Each Age Group,
with and without Concurrent Speech

Test phase	Grade 2	Grade 5	Adult
Accuracy (mean proportion correct)			
Initial visual—alone	.87 (.18)	.94 (.09)	.97 (.03)
With speech, first block	.92 (.11)	.96 (.10)	.96 (.06)
With speech, last block	.91 (.11)	.91 (.09)	.96 (.05)
Final visual—alone	.75 (.15)	.86 (.11)	.92 (.08)
Reaction time (mean seconds per response)			
Initial visual—alone	3.16 (0.75)	2.29 (0.46)	1.89 (0.45)
With speech, first block	3.15 (1.41)	2.24 (0.42)	1.93 (0.42)
With speech, last block	2.39 (0.38)	2.00 (0.30)	1.71 (0.38)
Final visual—alone	2.88 (0.81)	1.96 (0.46)	1.52 (0.40)

Note. Standard deviations are in parentheses.

$MSE = 0.01$, $p < .01$. As the means in Table 2 suggest, performance levels in the visual-task-alone condition were relatively low in second-grade children, especially in the final task. This could have occurred in these young children because of the practice effect at the beginning of the session and a fatigue effect at the end. Most importantly, the analysis provides no evidence that scores were superior in the visual-task-alone condition, as one would expect if subjects divided attention between the visual task and the to-be-ignored speech. Newman-Keuls tests comparing the two conditions for each age group separately (pooled across experimental phases) revealed an advantage in second-grade children for the visual task in the presence of ignored speech compared to the visual task alone, $p < .001$, and no significant difference in the older two age groups.

An analysis of the reaction times yielded similar, though not identical, results. There was again a main effect of the experimental phase, $F(1, 69) = 49.36$, $MSE = 0.20$, $p < .001$, but it was an apparent practice effect with slower performance at the beginning ($M = 2.44$ s) than at the end ($M = 2.08$ s) of the session; and there was again a main effect of age group, $F(2, 69) = 33.66$, $MSE = 0.95$, $p < .001$, with performance speeding up across ages ($M = 2.89$, 2.12 , and 1.76 s). Finally, there was again an Age Group \times Condition interaction, $F(2, 69) = 4.84$, $MSE = 0.17$, $p < .05$, which appeared to occur because performance in the second-grade children was slower in the final visual-task-alone condition than in the presence of ignored speech (see Table 2). Newman-Keuls comparisons of the two conditions for each age group separately (pooled across experimental phases) yielded a significant effect for the second graders, $p < .01$, because they slowed down in the final visual-task-alone phase as shown

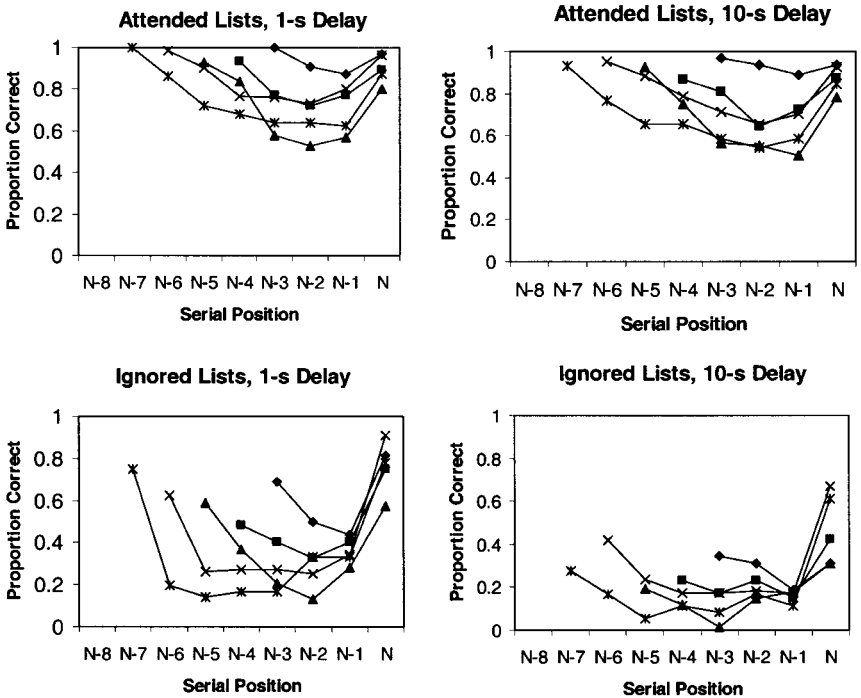


FIG. 1. Proportions of correct digit recall for all subjects with a particular span (which determined list length, the graph parameter), regardless of age. The graph parameter is the list length N . "Serial Position N " refers to the final serial position in the list, inasmuch as serial position curves are right-justified in the figure. *Top left panel*, attended lists at a 1-s test delay; *top right panel*, attended lists at a 10-s test delay; *bottom left panel*, ignored lists at a 1-s test delay; and *bottom right panel*, ignored lists at a 10-s test delay. The pattern was intermediate for the 5-s test delay (not shown), and the pattern was similar for all three age groups. Responses of three adults with a span of 9 are not shown on the graph because of insufficient data for stable means.

in Table 2, but no significant differences in the older two age groups. Thus, as in the proportion correct data, these results provided no evidence suggesting that attention was divided between the visual task and the to-be-ignored speech. In particular, there was no significant effect in which a group's performance was either at a higher level or faster in a visual-task-alone condition than in the adjacent visual task carried out in the presence of ignored speech.

Auditory Memory

Serial position functions. Given that items were drawn from a small set, a digit was counted correct only if it was recalled in the correct serial position. Figure 1 shows the mean pattern of correct responding for every serial position, in subjects of each span, collapsed across age groups (inasmuch as the pattern was

similar for all age groups). The panels of the figure show the 1-s test delay (left-hand panels) and the 10-s test delay (right-hand panels) for attended speech (top panels) and ignored speech (bottom panels). The 5-s delay condition produced a pattern that was intermediate and is therefore not shown. The pattern of responses clearly was orderly. One can observe an advantage for items at the beginning of the list (primacy effect) and at the end of the list (recency effect) in both attention conditions, although performance levels were clearly higher for attended speech. As shown, both the primacy and the recency effects diminished across test delays in the ignored-speech condition, whereas there was little such forgetting of attended speech.

The pattern at the 1-s test delay is very similar to what Cowan et al. (1999) obtained in their study of memory for attended and ignored digit lists varying in list length and using a comparable test delay, and also is similar to what was obtained by Martin (1978) in memory for ignored lists in selective listening. The decrease in primacy effects across test delays without attention during presentation of the lists, in our study, is in striking contrast to previous serial recall results in which the lists were attended during their presentation (Jahnke, 1968), which have shown primacy effects that persist undiminished across filled test delays. This suggests that these types of primacy effects differ in mechanism. (Recency effects, in contrast, are lost over retention intervals in both types of studies.)

Proportion correct across serial positions. For an overall analysis of age differences, we calculated the proportion of correct responding to the spoken digits in each condition, collapsed across serial positions. This is an ability-adjusted measure given that each subject was tested at his or her own span length. The results are shown in Fig. 2 for the second graders (left-hand panel), fifth graders (middle panel), and adults (right-hand panel). As the figure shows, there is a fairly close equivalence between the performance patterns in each of the three age groups. An ANOVA on the proportion correct was conducted with age group as a between-subject factor and with the attention condition (attended or ignored speech) and test delay (1, 5, or 10 s) as within-subject factors. This ANOVA produced a large main effect of attention condition, $F(1, 69) = 1096.95$, $MSE = .02$, $p < .001$, because attended lists were recalled much more successfully than ignored lists. The test delay main effect was significant, $F(2, 138) = 57.804$, $MSE = .01$, $p < .001$, as was the Attention Condition \times Test Delay interaction, $F(2, 138) = 20.99$, $MSE = .01$, $p < .001$. These effects can be attributed to the decline in memory across test delays that is much more dramatic in the ignored-speech condition than in the attended-speech condition. In sum, there was no significant effect involving age and, in fact, the patterns of proportion correct appear remarkably similar across age groups.

Individual-serial-position scores for ignored speech. It is possible that this omnibus test is not sensitive to some more subtle differences between age groups. Recall from the Introduction that previous studies of auditory sensory memory

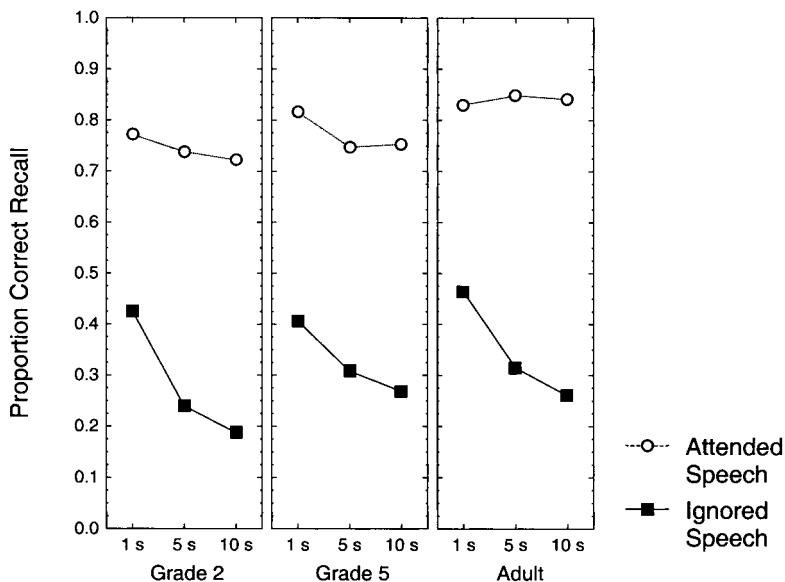


FIG. 2. Proportions of correct digit recall for second graders (left panel), fifth graders (center panel), and adults (right panel), as a function of test delay (x axis parameter) and attention condition (graph parameter).

have detected a special status for the final serial position (e.g., Balota & Engle, 1981), probably because there are no additional items to interfere with the memory representation of the final item's acoustic properties. We therefore examined memory for ignored speech at the final serial position in case there would be an age difference in the vivid sensory memory for that position (a rationale used also by Frank & Rabinovich, 1974). Memory for this serial position also must be viewed as the most similar to memory for the last word presented within an ignored stream of separate words, allowing a comparison with Sauls and Cowan (1996).

The result is shown in the top panel of Fig. 3. It shows that second- and fifth-grade children were at nearly identical levels of performance with a 1-s test delay but that the loss of information about this final list item over test delays was much more severe in second graders. This pattern was confirmed in an ANOVA that included only ignored-speech data for the last serial position. It yielded main effects of age group, $F(2, 69) = 15.54$, $MSE = .16$, $p < .001$, and test delay, $F(2, 138) = 41.99$, $MSE = .03$, $p < .001$, as well as an Age Group \times Test Delay interaction, $F(4, 138) = 2.61$, $MSE = .03$, $p < .04$. (The comparable interaction in the attended-speech data did not approach significance. An analysis including both attention conditions nevertheless did not produce a significant three-way interaction, presumably because of limited power for this effect and

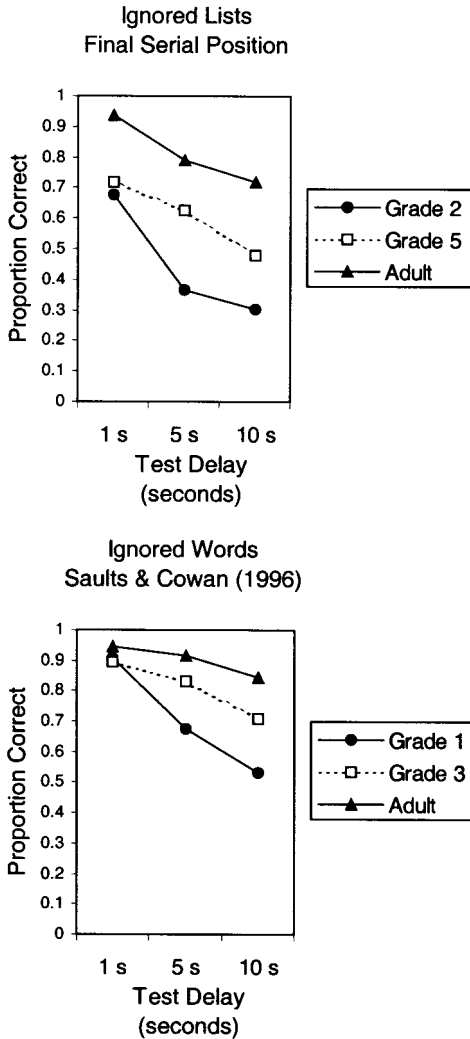


FIG. 3. Indications of developmental changes in sensory memory decay. *Top panel*, proportions of correct digit recall for items in the final serial position at each test delay for subjects in three age groups (graph parameter). *Bottom panel*, proportions of correct recall of isolated words by subjects in the study of Saults and Cowan (1996, Experiment 2). Those data are replotted here on the same scale as the present data.

near-ceiling-level performance in the attended-speech condition.) In the ignored-speech data, separate ANOVAs on adjacent age groups indicated that the Age Group \times Test Delay interaction was significant in a comparison of second- and fifth-grade children, $p < .03$, but not in a comparison of fifth-grade children and adults.

Several additional analyses were conducted to assess the validity of these age comparisons in memory for the final-serial-position digit across retention intervals in the ignored speech condition. In order to observe interpretable age differences in forgetting across intervals, it was necessary to have equivalent levels of performance at the 1-s interval. A one-way ANOVA of the 1-s, final serial position data did reveal a group difference, $F(2, 69) = 6.81$, $MSE = 0.07$, $p < .005$. Newman-Keuls comparisons indicated that although memory was better in adults than in second- or fifth-grade children, all $p < .01$, the second- and fifth-grade scores did not significantly differ (cf. Fig. 3).

Another analysis was conducted to determine if forgetting in the final serial position could have been related to performance on the visual task. For this purpose, the slope of memory in the final serial position across three retention intervals was calculated and was correlated with mean visual task reaction times and accuracy during ignored speech, separately for each age group. None of the correlations with accuracy approached significance. In the adults, memory slope across retention intervals correlated with the visual task reaction times, $r(22) = -.51$, $p < .02$. The direction of the correlation was such that adults with more rapid forgetting had *slower* visual task reaction times. These correlations did not approach significance in the second-grade children, $r(22) = .09$, or the fifth-grade children, $r(22) = -.06$. Similar results were obtained by calculating a correlation across trials within each individual and then averaging the correlations for each age group. The mean correlation in adults was -0.16 ($SD = 0.24$), which is significantly below zero, $t(23) = -3.20$. Again, this mean correlation was in the direction in which an adult had more rapid forgetting on trials in which he or she had slower visual task reaction times, the opposite of what a trade-off between visual and auditory tasks would suggest. (It may suggest, however, that adults have certain more alert periods in which both pictures and sounds can be processed most efficiently.) Second- and fifth-grade children had mean within-subject correlations near zero: Mean $r = -0.01$ ($SD = 0.30$) and -0.04 ($SD = 0.34$), respectively, neither of which was close to being significantly above zero.

Usually, a near-zero correlation is not considered meaningful unless it is possible to verify that the measures feeding into the correlation are reliable, and there may be no way to do so with these trial-by-trial measures. However, consider the purpose of the correlations in this case. They are meant to assess the possibility that trial-to-trial fluctuations in primary task performance account for substantial variance in auditory memory by allowing attention to shift to the spoken stimuli when primary task performance is poor. There is no hint of a correlation in that direction in any group, so the aforementioned possibility can be dismissed.

In light of the difference between adults and children even at the shortest, 1-s delay, and the correlation between forgetting and visual task performance in adults only, it is not clear how to interpret final-serial-position comparisons of forgetting between adults and children. However, the results clearly lend cre-

TABLE 3
 Mean Proportion Correct Auditory Memory for Every Age Group as a Function
 of the Serial Position and Test Delay

Serial position	Test delay (s)	Grade 2 mean	<i>SD</i>	Grade 5 mean	<i>SD</i>	Adults mean	<i>SD</i>
1	1	0.56	(0.30)	0.65	(0.28)	0.66	(0.31)
1	5	0.39	(0.28)	0.39	(0.24)	0.43	(0.27)
1	10	0.24	(0.25)	0.38	(0.29)	0.32	(0.24)
2	1	0.38	(0.24)	0.34	(0.23)	0.30	(0.29)
2	5	0.14	(0.15)	0.21	(0.22)	0.29	(0.27)
2	10	0.18	(0.24)	0.22	(0.26)	0.18	(0.25)
3	1	0.27	(0.28)	0.26	(0.23)	0.28	(0.26)
3	5	0.18	(0.21)	0.20	(0.19)	0.18	(0.21)
3	10	0.13	(0.15)	0.17	(0.26)	0.14	(0.18)
N - 2	1	0.29	(0.27)	0.24	(0.25)	0.30	(0.30)
N - 2	5	0.17	(0.16)	0.21	(0.22)	0.19	(0.25)
N - 2	10	0.20	(0.22)	0.19	(0.25)	0.21	(0.19)
N - 1	1	0.29	(0.27)	0.31	(0.27)	0.50	(0.32)
N - 1	5	0.15	(0.18)	0.22	(0.19)	0.22	(0.20)
N - 1	10	0.10	(0.13)	0.21	(0.23)	0.18	(0.19)
N	1	0.68	(0.31)	0.72	(0.30)	0.94	(0.15)
N	5	0.36	(0.27)	0.63	(0.32)	0.79	(0.20)
N	10	0.30	(0.29)	0.48	(0.34)	0.72	(0.25)

Note. Serial Position N stands for the list-final position, N - 1 for the previous position, and so on. Primacy and recency position data overlap for subjects with list lengths below 6.

dence to the observed difference between second- and fifth-grade forgetting rates across retention intervals at the final serial position.

The pattern at the final serial position is comparable to results obtained by Saults and Cowan (1996, Experiment 2) using a procedure that was very similar to the present one except that memory for isolated words was tested instead of memory for lists of digits. To provide a useful comparison, the Saults and Cowan data are replotted in the bottom panel of Fig. 3 using the same scale as the present data. In both cases, the performance levels of younger and older children diverged across test delays. One advantage of the present data is that the performance levels at the final serial position are much lower than in Saults and Cowan's study and rule out the possibility that the Age Group \times Test Delay interaction could be caused by a ceiling effect at the 1-s test delay.

Other single-serial-position tests showed that the pattern described above was unique to the final serial position (which we will call *Position N*) within ignored lists. The means appear in Table 3. Tests on ignored speech were carried out for Serial Positions 1, 2, and 3 (counting from the beginning of the list) and N - 2 and N - 1 (the two prefinal serial positions) and they yielded no Age Group \times

Test Delay interactions. That is important because the absence of age differences in forgetting across test delays in the first few serial positions, despite high levels of performance at those positions with a 1-s test delay and severe forgetting across delays in all age groups, shows that the age difference in forgetting in the final serial position is not attributable to such scale properties.

Tests of attended speech yielded no Age Group \times Test Delay interaction at any serial position except Position 1, a result that is difficult to interpret because of near-ceiling-level performance for that position in attended speech (as shown in Fig. 1).

Span and auditory memory. It is theoretically possible that young children would be disadvantaged by the use of a keypad response, although Cowan et al. (1999) found that this was not the case. We re-examined the issue by comparing the proportion of trials correct for span-length lists in the initial span task, based on a spoken response, to the proportion of trials fully correct for lists with a 1-s test delay in the attended-speech test condition, the most similar condition based on a keypad response. An ANOVA with age and response modality as factors produced only a marginal effect of the response modality, $F(2, 69) = 2.94$, $MSE = 0.06$, $p < .1$. Both of the effects with age as a factor were nonsignificant, $F_s < 1$. Mean proportions correct (and standard deviations) were as follows: with a spoken response, 0.63 (0.30), 0.57 (0.27), and 0.57 (0.27), for the second-grade, fifth-grade, and adult subjects, respectively; and with a keypad response, 0.50 (0.32), 0.52 (0.32), and 0.54 (0.28) for these three age groups, respectively. Though there may have been a slight drawback of keypad responses overall, it was no worse for younger subjects.

DISCUSSION

In the present study, memory for spoken digit lists, of a length equal to the subject's maximum span, was examined both with attention focused on the lists and with attention diverted from the lists. A postlist recall cue was presented after a variable retention interval of 1, 5, or 10 s. There were several main findings. First, memory for ignored speech was much worse, and much less stable over retention intervals, than memory for attended speech. Second, across the entire list, the proportion of correct recall of the spoken digits presented in these lists of ability-adjusted lengths was remarkably similar across ages for both attention conditions, as was the loss of information across retention intervals. Third, however, an examination of each serial position separately revealed a pronounced age group difference between second- and fifth-grade children in the rate at which information was lost across retention intervals, at the final serial position only. A level difference made it impossible to make a fair comparison between children and adults at this serial position but it remains quite possible that adults had less memory loss than children within 1 s, the shortest retention interval tested. No comparable age difference was found for the other serial positions, despite pronounced forgetting across retention intervals at the primacy and recency positions in all age groups.

It is not yet certain what principle accounts for the loss of sensory information across retention intervals that appears to attenuate with age in childhood. The traditional notion has been that sensory information is lost as a function of decay, that is, the absolute amount of time elapsing since the presentation of the sound (e.g., Broadbent, 1958; Cowan, 1995). According to various principles of grouping and distinctiveness, though, memory loss could occur as a function of the retention interval not on an absolute basis, but relative to the aspects of the timing of the stimuli preceding that retention interval. Recent research tends to support both types of effect (Cowan, Saults, & Nugent, 1997; Nairne et al., 1997). If the basis of an age difference were in the preservation of distinctiveness over time, though, it would have been expected that the longer persistence of memory in older children than in younger ones would apply to the primacy portion of the serial position function as well as to the recency portion, because both of these portions benefit about equally from distinctiveness (Neath, 1993).

If this developmental difference at the final serial position instead resulted from the older children's superior ability to switch attention to the sounds during their presentation or to use encoding strategies, we would expect that it should have applied across the entire list. This did not occur. (Moreover, no correlational evidence of a *trade-off* between auditory and visual task performance was observed.) Instead, it appears that the age difference may reflect a developmental increase in the stability of auditory modality-specific features in memory across retention intervals, which are best seen at the final serial position of the list.

It is alternatively possible that a complex strategy could have produced the pattern of responses that we observed. Older participants could have waited until the end of each spoken list and then turned attention to the sensory trace briefly, thus picking up information about the last item before sensory memory faded. However, that strategy would seem odd in that it produces only a small benefit for recall overall. It also seems inconsistent with the finding that, in adults, on average there was a significant tendency for trials with *better* auditory memory retention to be associated with *faster* primary task performance. Thus, any attention-shifting strategy specific to the final serial position would apparently have to emerge in fourth graders and then disappear again by adulthood, which seems improbable on theoretical grounds.

To summarize the above arguments, our results show large primacy and recency effects that decrease across retention intervals. To account for this pattern, one can identify several types of processes in memory. (1) There are strategic processes that can be carried out only with the use of attention, and (2) there are automatic processes, such as the persistence of auditory memory features, that do not depend on attention. Among the latter, one can distinguish between (2a) temporal distinctiveness factors and their loss as a function of retention intervals, and (2b) the retention and loss of a vivid auditory sensory memory representation during a silent period as a function of time. We argue that developmental changes in processes (1) and (2a) should result in age differences

in retention in both the primacy and the recency portions of the serial position function. It is only the development of (2b) that should result in an age difference restricted to the final serial position, as we found.

Note that it can be assumed that at 1 s, subjects of all ages still have a vivid sensory memory. It can also be assumed that sensory memory extends across all serial positions. However, retroactive interference from subsequent spoken digits severely limits the vividness of sensory memory for all digits except the last one. The conditions of the age advantage in sensory memory retention are apparently limited to memory in this most vivid form (i.e., the last position) and at least in childhood, these age differences accrue across retention intervals.

It should also be considered that codes that are nonsensory could contribute to memory for ignored speech. For example, Cowan et al. (1990) found that even a subtle shift of attention away from the primary task could result in phonological coding of allegedly ignored speech (as evidenced by a level of consonant recall nearly as good as vowel recall). However, the best explanation for a developmental difference in forgetting rates *localized at the final serial position* appears to be that it is a sensory code that develops in childhood. Only a sensory code would be overwritten by masking from subsequent sounds at nonfinal serial positions and thus would be much more clearly observed list-finally. In support of that statement, Cheng (1974) found that speech information conveyed acoustically was best for the recency portion of the serial position curve, whereas speech information conveyed through silent articulation was available more evenly across serial positions.

The present procedure also has implications more broadly for attention-free and attention-demanding processes in short-term recall. Rather little is known about the role of attention in the development of short-term memory. Most investigators have assumed that developmental changes in short-term memory can be attributed largely to improvements in strategies such as covert verbal rehearsal (Cowan et al., 1998; Flavell, Beach, & Chinsky, 1966; Gathercole, Adams, & Hitch, 1994; Henry, 1991; Ornstein & Naus, 1978), which in turn depend on the efficient deployment of attention during encoding (Bjorklund & Douglas, 1997; Guttentag, 1984, 1997). However, there is growing evidence that attention-independent aspects of auditory short-term memory also change with development. Huttenlocher and Burke (1976) found that primacy effects and the beneficial effects of grouped presentation of items in a span task both were equivalent across ages. Under the assumption that primacy effects reflect rehearsal and grouped presentation should be more useful to children who do not spontaneously rehearse items, they surmised that rehearsal could not account for the developmental differences in span. Dempster (1981) reviewed the literature on individual and age differences in memory span and found that strategic factors provided at best modest correlations with memory span, whereas basic factors (involving the speed of processing) correlated more highly with span. Developmental psychologists often have appeared to overlook the message that nonat-

tentional and nonstrategic factors are important in immediate memory performance and its development, as well as in other aspects of intelligence and development (see Dempster & Brainerd, 1995).

In the present study, testing each subject at his or her own span effectively minimized the potential contribution of strategic factors to age differences in memory for attended speech. Surprisingly, though, this procedure also nearly equated performance across ages and retention intervals in memory for *ignored* speech, suggesting that attention during encoding of the list plays roughly the same role at all ages tested. What may account for age differences in span is not mainly the development of attention and strategies, but rather, primarily, development in the working memory capacity limit (Cowan et al., 1999). *Sensory* memory development contributes less but does influence the recency effect substantially and would remove more of the load from working memory in older children.

The finding that attention during reception of the list played little role would perhaps not be true if the stimuli were sets of words that differed from trial to trial and therefore could be combined to form meaningful groups in an elaborated rehearsal process. The present results revealed an increase with age during childhood in the persistence of memory for the last list item, which provides further evidence (along with Keller & Cowan, 1994; Gomes et al., 1999; Saults & Cowan, 1996) for a developmental increase in the automatic retention of auditory sensory memory.

REFERENCES

- Baddeley, A. D. (1986). *Working memory*. Oxford: Clarendon.
- Balota, D. A., & Engle, R. W. (1981). Structural and strategic factors in the stimulus suffix effect. *Journal of Verbal Learning and Verbal Behavior*, **20**, 346–357.
- Bjorklund, D. F. (1995). *Children's thinking: Developmental function and individual differences*. Pacific Grove, CA: Brooks/Cole.
- Bjorklund, D. F., & Douglas, R. N. (1997). The development of memory strategies. In N. Cowan (Ed.), *The development of memory in childhood* (pp. 201–246). Hove, UK: Psychology Press.
- Broadbent, D. E. (1958). *Perception and communication*. London: Pergamon.
- Cheng, C. (1974). Different roles of acoustic and articulatory information in short-term memory. *Journal of Experimental Psychology*, **103**, 614–618.
- Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *The Journal of the Acoustical Society of America*, **25**, 975–979.
- Cornell, E. H., & Bergstrom, L. I. (1983). Serial-position effects in infants' recognition memory. *Memory & Cognition*, **11**, 494–499.
- Cowan, N. (1995). *Attention and memory: An integrated framework*. Oxford Psychology Series, No. 26. New York: Oxford Univ. Press.
- Cowan, N., & Kiehlbaso, L. (1986). Temporal properties of memory for speech in preschool children. *Memory and Cognition*, **14**, 382–390.
- Cowan, N., Lichty, W., & Grove, T. R. (1990). Properties of memory for unattended spoken syllables. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **16**, 258–269.
- Cowan, N., Nugent, L. D., Elliott, E. M., Ponomarev, I., & Saults, J. S. (1999). The role of attention in the development of short-term memory: Age differences in the verbal span of apprehension. *Child Development*, **70**, 1082–1097.

- Cowan, N., & Sauls, J. S. (1995). Memory for speech. In H. Winitz (Ed.), *Human communication and its disorders* (Vol. 4, pp. 81–170). Timonium, MD: York Press.
- Cowan, N., Sauls, J. S., & Nugent, L. D. (1997). The role of absolute and relative amounts of time in forgetting within immediate memory: The case of tone pitch comparisons. *Psychonomic Bulletin & Review*, **4**, 393–397.
- Cowan, N., Wood, N. L., Wood, P. K., Keller, T. A., Nugent, L. D., & Keller, C. V. (1998). Two separate verbal processing rates contributing to short-term memory span. *Journal of Experimental Psychology: General*, **127**, 141–160.
- Dempster, F. N. (1981). Memory span: Sources of individual and developmental differences. *Psychological Bulletin*, **89**, 63–100.
- Dempster, F. N., & Brainerd, C. J. (Eds.). (1995). *Interference and inhibition in cognition*. San Diego, CA: Academic Press.
- Engle, R. W., Fidler, D. S., & Reynolds, L. H. (1981). Does echoic memory develop? *Journal of Experimental Child Psychology*, **32**, 459–473.
- Engle, R. W., & Marshall, K. (1983). Do developmental changes in digit span result from acquisition strategies? *Journal of Experimental Child Psychology*, **36**, 429–436.
- Flavell, J. H., Beach, D. H., & Chinsky, J. M. (1966). Spontaneous verbal rehearsal in a memory task as a function of age. *Child Development*, **37**, 283–299.
- Frank, H. S., & Rabinovitch, M. S. (1974). Auditory short-term memory: Developmental changes in precategorical acoustic storage. *Child Development*, **45**, 522–526.
- Gathercole, S. E., Adams, A.-M., & Hitch, G. J. (1994). Do young children rehearse? An individual-differences analysis. *Memory & Cognition*, **22**, 201–207.
- Gomes, H., Sussman, E., Ritter, W., Kurtzberg, D., Cowan, N., & Vaughan, H. G., Jr. (1999). Electrophysiological evidence of developmental changes in the duration of auditory sensory memory. *Developmental Psychology*, **35**, 294–302.
- Greenberg, S. N., & Engle, R. W. (1983). Voice changes in the stimulus suffix effect: Are the effects structural or strategic? *Memory and Cognition*, **11**, 551–556.
- Guttentag, R. E. (1984). The mental effort requirement of cumulative rehearsal: A developmental study. *Journal of Experimental Child Psychology*, **37**, 92–106.
- Guttentag, R. (1997). Memory development and processing resources. In N. Cowan (Ed.), *The development of memory in childhood* (pp. 247–274). Hove, UK: Psychology Press.
- Henry, L. A. (1991). Development of auditory memory span: The role of rehearsal. *British Journal of Developmental Psychology*, **9**, 493–511.
- Huttenlocher, J., & Burke, D. (1976). Why does memory span increase with age? *Cognitive Psychology*, **8**, 1–31.
- Jahneke, J. C. (1968). Delayed recall and the serial-position effect of short-term memory. *Journal of Experimental Psychology*, **76**, 618–622.
- Keller, T. A., & Cowan, N. (1994). Developmental increase in the duration of memory for tone pitch. *Developmental Psychology*, **30**, 855–863.
- Martin, M. (1978). Retention of attended and unattended auditorily and visually presented material. *Quarterly Journal of Experimental Psychology*, **30**, 187–200.
- Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological Review*, **63**, 81–97.
- Nairne, J. S. (1990). A feature model of immediate memory. *Memory & Cognition*, **18**, 251–269.
- Nairne, J. S., Neath, I., Serra, M., & Byun, E. (1997). Positional distinctiveness and the ratio rule in free recall. *Journal of Memory and Language*, **37**, 155–166.
- Neath, I. (1993). Distinctiveness and serial position effects in recognition. *Memory & Cognition*, **21**, 689–698.
- Ornstein, P. A., & Naus, M. J. (1978). Rehearsal processes in children's memory. In P. A. Ornstein (Ed.), *Memory development in children* (pp. 69–99). Hillsdale, NJ: Erlbaum.
- Penney, C. G. (1985). Elimination of the suffix effect on preterminal list items with unpredictable list

- length: Evidence for a dual model of suffix effects. *Journal of Experimental Psychology Learning, Memory, and Cognition*, **11**, 229–247.
- Penney, C. G., & Godsell, A. (1993). Suffix delay and the terminal and preterminal suffix effects. *Canadian Journal of Experimental Psychology*, **47**, 467–476.
- Saults, J. S., & Cowan, N. (1996). The development of memory for ignored speech. *Journal of Experimental Child Psychology*, **63**, 239–261.
- Siegler, R. S. (1998). *Children's thinking* (3rd ed.). Upper Saddle River, NJ: Prentice Hall.
- Sperling, G. (1960). The information available in brief visual presentations. *Psychological Monographs*, **74** (No. 498).
- Wright, A. A. (1994). Primacy effects in animal memory and human nonverbal memory. *Animal Learning & Behavior*, **22**, 219–223.

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