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Rethinking Speed Theories of Cognitive Development: Increasing the Rate of Recall Without Affecting Accuracy

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Abstract

Researchers have suggested that developmental improvements in immediate recall stem from increases in the speed of mental processes. However, that inference has depended on evidence from correlation, regression, and structural equation modeling. We provide counterexamples in two experiments in which the speed of spoken recall is manipulated. In one experiment, second-grade children and adults recalled lists of digits more quickly than usual when the lists were presented at a rapid rate of 2 items per second (items/s). In a second experiment, children received lists at a 1 item/s rate but half of them were successfully trained to respond more quickly than usual, and similar to adults' usual rate. Recall accuracy was completely unaffected by either of these response-speed manipulations. Although response rate is a strong marker of an individual's maturational level, it thus does not appear to determine immediate recall. There are important implications for developmental methodology.

The length of word lists that can be recalled verbatim immediately after they are presented, or short-term memory span, increases as children mature (Bolton, 1892). This increase is important because memory span indexes intelligence and mental maturation (Sattler, 1992). Researchers have proposed that span increases because of growth in the speed of mental processing (Cowan et al., 1998; Kail & Park, 1994; Fry & Hale, 1996; Kail & Salthouse, 1994). However, the evidence for this account has been limited to correlations between memory span and the speed of speech (and related approaches, including regressions and structural equation models). In two experiments, we managed to increase dramatically the speed of spoken recall in children but, counter to speed-of-processing accounts, found no accompanying improvement in short-term memory.

An argument for how processing speed could affect serial recall stems from evidence that individuals recall as many stimuli as they can recite in about 2 s (Baddeley, Thomson, & Buchanan, 1975; Hulme & Tordoff, 1989; Schweickert, Guentert, & Hersberger, 1990). The assumption has been that temporary memory representations are lost within about 2 s unless covert rehearsal refreshes them quickly enough; recitation speed presumably estimates covert rehearsal speed. Representations might also be lost while recall of the list is under way, which would place a premium on recall speed (Cowan et al., 1992; Dosher & Ma, 1998; Hitch, Towse, & Hutton, 2001).

Consider, though, that a relation between a speed variable and a memory variable need not reflect an effect of speed on memory, though that hypothesis is attractive. A famous counterexample is the linear relation between orienting-task decision speed for a word and

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later recognition of that word. Equating the speeds of several orienting tasks did not eliminate their effects on memory (Craik & Tulving, 1975).

One way to test the effect of response speed on short-term memory is to speed up spoken responses in children to see if there are commensurate improvements in recall. It has proven infeasible to train children to increase the maximum speed of recitation (Hulme & Muir, 1985). However, until now, there has been no attempt to speed up recall itself. We did so in Experiment 1, by presenting at a rapid pace some of the lists to be recalled (by children and adults); and, in Experiment 2, simply by instructing children to recall quickly.

EXPERIMENT 1

Previous manipulations of presentation rate have yielded inconsistent effects on recall accuracy (cf. Engle & Marshall, 1983; Murray & Roberts, 1968; Sarver, Howland, & McManus, 1976). However, they have not examined whether the rate of presentation influences the rate of recall. If it does, it is possible to examine whether the accuracy of recall is also influenced. The simple prediction from a speed theory is that faster recall should lead to commensurately better recall (e.g., Cowan et al., 1992; Dosher & Ma, 1998).

A contrasting expectation comes from considering that memories might be reactivated during inter-item gaps during presentation (Baddeley, 1992; Barrouillet, Bernardin, & Camos, 2004) or recall (Cowan, 1992). Barrouillet et al. found that what was important for recall was the proportion of the presentation time in which the subject was free to concentrate on the memoranda as opposed to distracters. From that perspective, slower rates of recall would not necessarily produce poorer performance because decay could be at least partly offset by additional reactivation occurring between items. However, no previous study has examined whether this principle applies to the recall period.

Method

Subjects—The subjects were 18 second-grade children (5 female, 13 male; mean age = 102.11 months, SD = 3.62) and 18 college students (13 female, 5 male; mean age = 262.53 months, SD = 60.71).

Apparatus and Stimuli—Subjects were tested individually in a sound-attenuated chamber. A computer was connected to audiological headphones for presentation of the spoken stimuli and to a microphone, mounted on the monitor, through which responses were saved digitally for later timing analyses.

The main visual stimuli were the digits 1 through 9, presented individually in the center of the computer monitor in a 30-point Helvetica font (0.75 cm high) for 0.4 s. The sounds were the digits 1 through 9 spoken in a male voice, ranging in length from 223 to 394 ms (M = 327 ms), digitally recorded on the computer and played at an intensity range of 77 - 82 dB(A). Stimuli were presented at three different paces: 0.5 s/item (i.e., 2 items/s), 1 s per item (1 item/s), and 1.5 s/item (0.67 items/s).

To signal different portions of the session, a 7.4-cm-wide × 2.4-cm-high rectangle with a colored border and a dark inside was used. A yellow border served as a ready signal for 1 s. Then the border changed to red during the to-be-recalled stimuli in either modality. When the presentation modality was visual, printed digits were presented in the center of the red border for 0.4 s. When the presentation was acoustic, the red rectangle was left empty during the presentation of spoken digits. 500 ms after the onset of the last list item, the border turned green to serve as a recall signal, along with a 100-ms, 440-Hz, triangular wave tone.

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As the response was spoken, it was recorded by an experimenter behind the subject with a clipboard, who then typed responses into the computer after each list recall was completed.

Procedure—Children received a book and a $10 reward, whereas adults received credit toward successful completion of their introductory psychology course. Each subject took part in two test sessions on separate days. One session was for spoken lists and the other was for printed lists, with the order counterbalanced across subjects. Each session included three phases, for lists of three different presentation rates (presented in a Latin square order). The instruction for each trial was to wait until the list ended and then repeat the digits aloud in the presented order, "as fast or as slow" as the subject thought best, and not to talk during a trial otherwise.

Each phase of the experiment began with a span-determination procedure for that particular rate and presentation modality. Four trials were presented at a list length of 3 digits, with the length increasing by one until the subject made a mistake on all four trials at that length. The longest length at which at least one list was recalled correctly was taken as the span. Each span determination procedure was followed by a post-span sequence of 12 additional lists at the same presentation rate, in random order: 4 at a length equal to the just-determined span, 4 at a length one item shorter (span - 1), and 4 at a length two items shorter (span - 2). This post-span procedure provided information about memory performance and verbal response rates with the difficulty level comparable for all subjects. Altogether, each subject received 6 span-determination tests (for spoken and printed lists at three presentation rates) and 72 post-span test trials (12 per span type).

Timing Analysis—The spoken response for each trial was saved in a separate computer file and later analyzed with a waveform editing program allowing the measurement of each utterance with millisecond accuracy. The rater highlighted the relevant segment of the sound file on an oscillographic display on the computer monitor and then listened to the highlighted segment to verify its beginning and ending points. Cronbach's alpha measure of reliability of the total duration of the response was .91 (calculated for the post-span data with trials within a subject alternately assigned to three subsets).

Trials in which the response contained an error were not used for timing. Consequently, only short lists had enough trials for timing analyses. In the span task, trials with 3-item lists were used and, in the post-span task, trials with a list length two less than span were used. In previous studies of response timing in short-term recall (Cowan, 1992; Cowan et al., 1994, 1998; Hulme, Newton, Cowan, Stuart, & Brown, 1999) we focused on inter-word pauses to examine the details of retrieval processes. In the present study, however, the intent was to examine relations between recall response rate and performance. Therefore, the key timing measure was the rate of recall, defined as the number of items divided by the time between the end of the stimulus list and the end of the response.

Results and Discussion

The results are summarized in the four panels of Figure 1, for span-determination trials (left column) and post-span trials (right column). The top panels show recall rates and the bottom panels show measures of recall performance. The clear result is that the presentation-rate parameter influenced the rate of recall, but had no effect at all on either memory span or the post-span level of recall. Notice that the span measure was quite precise (with small error bars) and was grossly affected by the developmental manipulation, even though it was unaffected by presentation rate.

These observations were born out by inferential statistics. An ANOVA of recall rates was conducted with age group between subjects and with presentation modality (auditory or visual) and presentation rate (2, 1, or 0.67 items/s) as within-subject factors. Recall speeds for auditory and visual lists did not differ overall. The rate of recall was slower in children (M = 1.50 items/s, SEM = 0.08) than in adults (M = 1.74 items/s, SEM = 0.08), $F(1, 34) = 4.89$, $p < .05$, $?_p^2 = .13$. More importantly, the rate of recall was fastest with a 2 items/s presentation rate (M = 1.75 items/s, SEM = 0.06), slower with a 1 item/s rate (M = 1.58, SEM = 0.06), and a 0.66 item/s rate (M = 1.54, SEM = 0.07). That main effect was significant, $F(2, 68) = 8.36$, $p < .001$, $?_p^2 = .20$. Newman-Keuls pairwise post-hoc tests indicated that the fastest presentation rate resulted in significantly faster recall than either of the other two presentation rates, which did not differ.

Only interactions with presentation rate as a factor are relevant to the hypotheses, and only these interactions will be reported in this article. However, there were no such interactions in the present analysis.

Unlike response rates, a comparable analysis of memory span yielded no effect of presentation rate. The analysis yielded only main effects of age group, $F(1, 34) = 45.42$, $p < .001$, $?_p^2 = .57$, and modality, $F(1, 34) = 35.25$, $p < .001$, $?_p^2 = .51$. Children had lower spans than adults (M = 5.44 vs. 7.32, SEM = 0.20 in each case) and span for spoken lists (M = 6.69, SEM = 0.14) exceeded span for printed lists (M = 6.07, SEM = 0.16).

In one condition (lists spoken at the fastest rate), children's rate of recall (1.73 items/s, SEM = 0.12) was nearly the same as adults' rate (1.79 items/s, SEM = 0.10), yet children's span (6.06, SEM = 0.25) was well below adults' span (7.56, SEM = 0.25).

In an analysis of the rates of recall of lists 2 items below span in the post-span trials, the results were for the most part similar to those for recall rates in span trials. Recall was slower in children (M = 1.45, SEM = 0.09) than in adults (M = 1.91, SEM = 0.09), $F(1, 33) = 14.04$, $p < .001$, $?_p^2 = .30$, and it slowed down as the presentation rate slowed (M = 1.80, 1.62, & 1.63 for lists of 2, 1, and 0.66 items/s, respectively; SEM = 0.06, 0.07, & 0.07), $F(2, 66) = 9.05$, $p < .001$, $?_p^2 = .22$. (One adult had no post-span timing because of a recording problem and was omitted from the post-span analyses.) Newman-Keuls tests showed that, as in the span-determination timing data, response rates in the fastest presentation condition were significantly faster than in the two slower presentation conditions, which did not differ from one another. Unlike the recall rates in the span-determination procedure, though, in the post-span measure the presentation rate interacted with the presentation mode, $F(2, 66) = 5.36$, $p < .01$, $?_p^2 = .14$. As a function of decreasing presentation rates, the decreases in response rates were more pronounced for spoken lists (1.86, 1.62, & 1.59 items/s) than for printed lists (1.74, 1.63, & 1.66 items/s).

In the post-span proportion of trials correct, the only main effect was an effect of list length, $F(2, 66) = 199.97$, $p < .001$, $?_p^2 = .86$. Recall of span-length lists was correct on 0.34 of the trials (SEM = 0.03); of lists one below span, 0.63 (SEM = 0.03); and of lists two below span, 0.82 (SEM = 0.02). The absence of age effects was as expected, given that list lengths were ability-adjusted. There were no effects of presentation rate.

In sum, for both age groups, in both span-determination and post-span trials, presentation rates had strong effects on response rates, but no effects on immediate memory performance levels.

Finally, offering more insight into developmental improvement in span, each subject was questioned post-experimentally as to how the digits were recalled. Most (16 of 18) adults alluded to some sort of grouping strategy, whereas only 2 of 18 children did so, a difference highly significant by Fisher's Exact Test. This suggests that memory development could have resulted at least partly from improved strategies (cf. Flavell, Beach, & Chinsky, 1966;

Ornstein, Naus, & Liberty, 1975). It is however noteworthy that, even with rehearsal and strategies during presentation blocked, age differences in capacity for spoken lists can be observed (Cowan, Nugent, Elliott, Ponomarev, & Saults, 1999).

EXPERIMENT 2

Experiment 1 showed that a manipulation in the stimulus presentation rate greatly affected the timing of recall, but nevertheless did not influence recall accuracy. This rules out the possibility that the accuracy of recall is a direct result of the recall rate. However, it leaves intact another possibility. Perhaps it is the response speed relative to the stimulus speed that matters for recall. This could happen, for example, if rapidly-presented lists lose their temporal distinctiveness in memory more quickly than do slowly-presented lists (Nairne, 2002; Neath & Surprenant, 2003). To assess this account, we conducted a second experiment with children, in which items were presented at a 1 item/s rate and, in a critical block of trials, half of the children were instructed to repeat the items as quickly as possible. This procedure is reminiscent of the training procedure of Hulme and Muir (1985) except that they attempted to train the rapid, overt recitation of small groups of words, which was largely unsuccessful. Our attempt to train children to hasten responses in the recall task itself was, in contrast, highly successful.

Method

Subjects—The subjects were 38 second-grade children (20 females and 18 males; mean age = 96.95 months, SD = 4.11) who did not participate in Experiment 1.

Procedure—The procedure was the same as in Experiment 1 with three exceptions: (1) digit stimuli were always presented in the auditory modality at a rate of 1 item/s; (2) the entire basic procedure, in which span determination was followed by a post-span test, was repeated three times in successive phases of the experiment; and (3) the children were randomly divided into two groups of 19, who received different instructions in Phase 2. In *Phase 1*, the instruction for all subjects was to repeat the lists at whatever speed seemed best. In *Phase 2*, critically, half of the children were instructed to speak their responses as quickly as possible without making errors. In *Phase 3*, to observe aftereffects, all children could again speak at whatever speed seemed best to them. The post-span portion of each experimental phase included 12 trials.

Two scorers measured the same 100 trials and the inter-scorer correlation in total response durations was .99. Cronbach's alpha measure of reliability calculated from the post-span data (divided into 3 subsets) was .95.

Results and Discussion

Figure 2 shows the timing of 3-word lists in the span-determination procedure (top left), the timing of lists 2 below span in the post-span procedure (top right), the mean span (bottom left), and the mean proportion of trials correct in the post-span procedure (bottom right). In each panel, the results are shown for the three experimental phases. It is clear that responses sped up in Phase 2 among children instructed to recall quickly in that phase, and stayed fast in Phase 3 even though rapid speaking was no longer required. For comparison, results for adults in the comparable condition of Experiment 1 (stimuli spoken at a 1/s rate) are presented as unconnected points, and it can be seen that the instructions were so successful that children sped up to an adult-like rate of recall. Nevertheless, the bottom panels of the figure show that this speedup was not accompanied by an increase in performance levels across experimental phases.

Inferential statistics on the children's data verified these observations. In the span-determination response rate data, an ANOVA with instructions as a between-subject variable and with experimental phase within subjects indicated that there was an overall advantage for the group instructed to speak quickly in Phase 2, $F(1, 36) = 16.03$, $p < .001$, $?_p^2 = .31$, and an advantage for Phases 2 and 3 over Phase 1, $F(2, 72) = 38.93$, $p < .001$, $?_p^2 = .52$. However, those main effects are not meaningful. What is important is an interaction of the instruction group with the experimental phase, $F(2, 72) = 12.53$, $p < .001$, $?_p^2 = .26$. Newman-Keuls tests showed that the instruction groups differed in recall rates in Phases 2 and 3 (i.e., after instructional differences had been introduced) but not in Phase 1 (baseline performance). In contrast to this result, a comparable analysis of digit span showed no differences between the instructional groups or experimental phases.

The post-span timing analysis (for lists 2 items below span) yielded the same effects: inconsequential main effects of the instruction group, $F(1, 36) = 11.71$, $p < .001$, $?_p^2 = .25$, and the experimental phase, $F(2, 72) = 33.61$, $p < .001$, $?_p^2 = .48$, modified by a critically important interaction of these variables, $F(2, 72) = 20.00$, $p <.001$, $?_p^2 = .36$. Newman-Keuls tests again showed that the instruction groups differed in Phases 2 and 3, but not in Phase 1. A comparable ANOVA of the proportion of trials correct yielded no effects.

In sum, then, simply instructing children to recall quickly was sufficient to achieve a dramatic increase in response speed, but with no accompanying change in short-term memory performance.

GENERAL DISCUSSION

We manipulated recall speed in two ways and related it to recall accuracy, in two immediate-memory experiments. In Experiment 1, we found that adults and children repeated lists much more quickly with rapid (2 items/s) list presentations than with slower presentations. This does not appear to reflect a simple imitation process, inasmuch as the 1 item/s and 0.66 item/s presentation rates resulted in recall rates that did not differ significantly. However, lists presented at the 2 items/s rate may be perceived as having no inter-word pauses, and that perception may be imitated in the response. Recall accuracy was unaffected.

In Experiment 2, we found that children could be taught to repeat lists at speeds much faster than they ordinarily use in immediate recall. The striking outcome was again that this speedup did not improve recall accuracy at all (or impair it, either). This outcome runs counter to what would be expected if the key constraint on recall is decay of a temporary memory representation that is strictly time-limited (e.g., Cowan et al., 1992; Dosher & Ma, 1998), although it still could be accounted for with a decaying temporary memory if, between words recalled, periods of rehearsal (Baddeley, 1992) or reactivation (Cowan, 1992) can renew the memory trace.

The research has strong implications for development. From previous research, it is clear that developmental changes in the speeds of processing on various tasks co-occur with developmental changes in immediate-memory ability, and with many other cognitive skills (Cowan et al., 1998; Fry & Hale, 1996; Kail & Park, 1994; Kail & Salthouse, 1994; Salthouse, 1996). Given the success of structural equation models in this previous research, in which immediate memory performance is predicted from processing speed generally or from verbal speed in particular, it has been appealing to speculate that speed moderates the accuracy of recall. For example, Cowan et al. (1998) described two separate speed measures (the maximal speed of overt recitation of sub-span lists, on one hand, and the speed of the spoken recall response, on the other hand) that did not correlate with one another, but together accounted for 85% of the age-related variance in digit spans within a structural equation model. It was proposed that, whereas recitation speed reflected the efficiency of a verbal rehearsal process (cf. Baddeley, 1992), recall speed might reflect the efficiency of a lexical search process. Now, however, the reason for the correlation between recall speed and accuracy must be re-examined, given that speeded responses did not improve recall as was anticipated. More broadly, inasmuch as conceptions of rehearsal speed and other processing speeds as mediators of cognition have depended on similar arguments, the causal properties of these other types of processing speed also must be called into question.

This is not the first observation that a processing speed can be a marker of maturation without being a causal variable. Basak and Verhaeghen (2003) examined the ability of young and elderly adults to enumerate sets of items in an array, a task executed rapidly for small set sizes inasmuch as several items can be apprehended concurrently (the *subitizing range*), but more slowly for larger set sizes (the *counting range*). Elderly adults had response times that increased as a function of the set size 1.5 times as quickly as the younger adults in the range of 1-3 items. However, it turned out tha t the actual subitizing range included fewer items in elderly subjects. Consequently, their responses in the range of 1-3 items were more likely to include a mixture of subitizing and counting processes. An analytic model showed that neither the subitizing speeds nor the counting speeds of young and elderly adults differed; just the subitizing ranges differed. This is in keeping with a theoretical view in which capacity, rather than speed, may be the primary change in working memory during life span deve lopment (cf. Cowan et al., 1999; Cowan, 2001).

One must still ask why process times strongly index subjects' developmental levels. One possible factor is that, if a task is for any reason difficult, the subject may keep trying for a while. For example, if an item is in working memory with a relatively low activation level, the decision process may be difficult and the response consequently will be slow. However, that sort of account cannot explain the present finding that immediate-memory responses can be speeded up without a loss in mnemonic capability. Perhaps recall speed theoretically is constrained by mnemonic factors such as the speed of memory search (Cowan et al., 1998) but, if so, individuals apparently carry out those processes at a more leisurely pace than the maximum speed of which they are capable. Response speeds may serve as markers of development not because they reflect individuals' maximal processing speeds but, rather, because they indicate what speeds the individuals find comfortable. Rates were increased both by using stimuli that naturally elicit faster rates (Experiment 1) and by asking for faster rates (Experiment 2), yet neither of these manipulations affected memory performance.

It remains possible that speed failed to affect recall because equally successful recall can take place either speedily, or through slower recall punctuated by reactivation processes (e.g., Cowan, 1992). However, the present results demonstrate that the speed hypothesis, stating that correlations between speed and memory reflect effects of speed on memory, must be assessed with great caution (cf. Conway, Cowan, Bunting, Therriault, & Minkoff, 2002).

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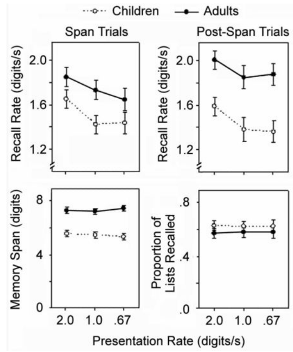

Figure 1.

Performance of children and adults in Experiment 1 as a function of the three presentation rates (x axis). *Top left*: recall rates in the span-determination period. *Bottom left*: mean memory spans in each group. *Top right* : recall rates in the post-span period. *Bottom right*: the proportion of trials recalled correctly in the post-span period. Error bars are standard errors.

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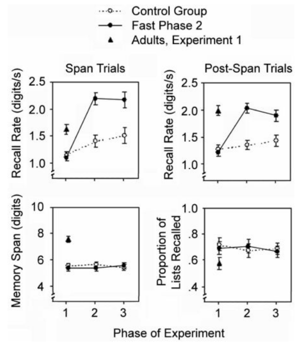

Figure 2.
Performance of children in Experiment 2 as a function of the three phases of the experiment (x axis). Half of the children were instructed to speak as quickly as possible, without making errors, in Phase 2. *Top left*: recall rates in the span-determination period. *Bottom left*: mean memory spans in each group. *Top right*: recall rates in the post-span period. *Bottom right*: the proportion of trials recalled correctly in the post-span period. The unconnected points reflect adult means from the comparable condition in Experiment 1 (spoken lists presented at a 1 item/s rate). Error bars are standard errors.