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On the Auditory Modality Superiority Effect in Serial Recall: Separating Input and Output Factors

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The *modality effect* in immediate recall refers to superior recall of the last few items within lists presented in spoken as opposed to printed form. The locus of this well-known effect has been unclear. N. Cowan, J. S. Saults, E. M. Elliott, and M. Moreno (2002) introduced a new method to distinguish between the effects of input serial position, output serial position, and the number of items yet to be recalled and found that large modality effects occurred only in conditions in which delay and interference at output (from items already recalled) was high. The authors replicated that finding, even when the response period included output interference acoustically similar to the spoken stimuli to be recalled. However, the authors found that output delay and interference act only by lowering the level of performance to a more sensitive range. The modality effect thus originates during encoding of the list to be recalled, not during output.

In research on human cognition, the overwhelming majority of experiments have involved the presentation of stimuli to the eyes, the ears, or both. The manner in which stimuli are processed and remembered often depends heavily on the sensory modality of stimulation. The immediate recall of word lists is usually superior for spoken, as opposed to printed, presentations. This auditory modality superiority is very robust and holds true for a wide variety of memory test procedures (for a review, see Penney, 1989). Despite over 50 years of relevant research, there are still important unanswered questions about modality effects (Gardiner & Cowan, 2003).

Most often, modality effects have been examined within the context of immediate serial recall. A key issue in this regard is whether modality effects can be attributed to the superior encoding of spoken lists as compared with printed lists at input or, instead, to the tendency for the representation of spoken lists to hold up better in the presence of a delay and interference from the response output (DIO; we do not attempt the difficult task of distinguishing between delay and interference effects at output). Ordinarily in serial-recall tasks, these possibilities are confounded. The first item presented has the exclusive attention of the participant at the time of input but is also to be recalled before any other item, the second item is less unique at the time of input but is also to be recalled only after the first one, and so on, through the list. However, Cowan, Saults, Elliott, and Moreno (2002) developed a technique to deconfound input and output effects. In their method, nine-item digit lists were presented and recall began at Serial Position 1, 4, or 7. On some trials, the participant was to stop after the recall of three digits, whereas on other trials, the participant was to cycle back to the beginning of the list and continue until responses were elicited for all serial positions.

Cowan et al. (2002) compared certain serial positions in different recall conditions to assess specific effects of input encoding and of DIO. An estimate of the effect of input serial position, with DIO equated across regions of the list, was obtained by comparing recall of Serial Positions 1–3 when recalled first, Serial Positions 4–6 when recalled first, and Serial Positions 7–9 when recalled first. Effects of DIO were obtained by examining the same serial positions when recalled first and when recalled last. For example, a comparison of Serial Positions 7–9 when recalled first through third versus when recalled seventh through ninth yielded an estimate of DIO in those serial positions. Because of the cyclical method of recall, it was possible to examine DIO effects at all serial positions. (See Figure 1 for an illustration of the method of achieving low- and high-DIO conditions.) Finally, it was also possible to estimate effects of the number of digits yet to be recalled, by comparing results of partial- versus whole-list recall.

A key finding of Cowan et al. (2002) pertained to the modality effect. Under conditions of low DIO (i.e., for the first three digits recalled), the modality effect was very small. Most of the modality effect emerged at the end of the list and only under conditions of high DIO (i.e., in recall of Serial Positions 7–9 only after Serial Positions 1–6 were recalled). Cowan et al. concluded that the modality effect is due primarily to the greater resistance of auditory items to interference and delay during the response output.

The present study reexamines this conclusion, in two ways. First, whereas Cowan et al. (2002) used a silent, typewritten response, the present study used a setup in which a spoken or typewritten response elicited either a tone or a spoken repetition of the recalled digit; the latter was acoustically identical to a stimulus within the set to be recalled on auditory trials. The purpose of this was to determine whether the enlargement of the modality effect

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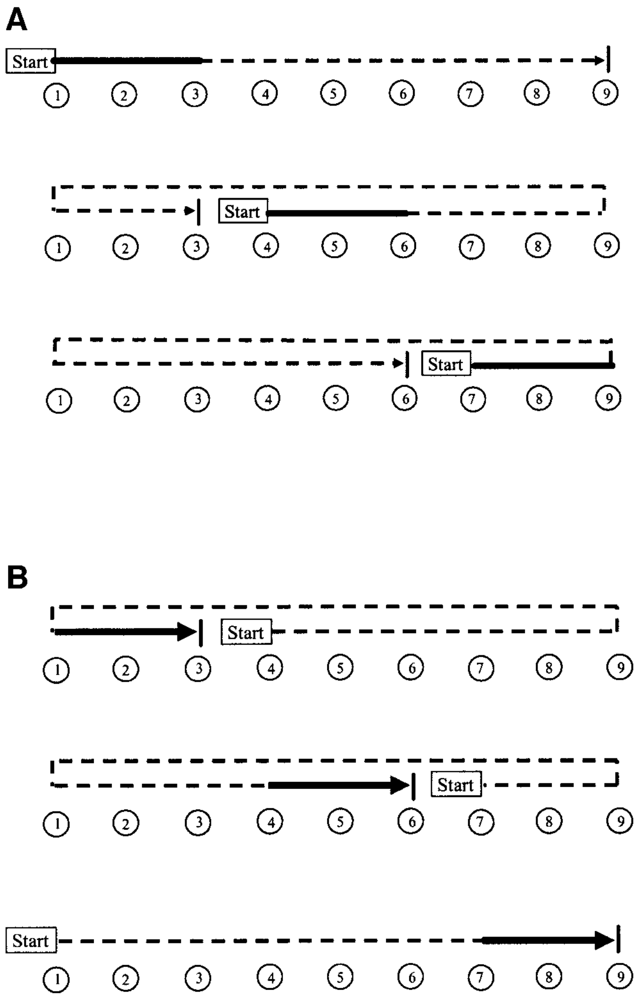

Figure 1. An illustration of the method of distinguishing between effects of input serial position versus delay or interference at output (DIO). Recall begins at the serial position marked "Start," continues through the end of the list, and cycles around to pick up the beginning of the list if the starting position was not Serial Position 1. Solid lines indicate the portions of recall used in the critical comparisons combined across trials to construct entirely low-DIO and high-DIO serial position functions. A: Low DIO. B: High DIO. Partial recall of just three digits (not shown) is sometimes used instead of whole recall.

by DIO depended on an absence of strong acoustic interference during output, along with abundant visual interference from the computer keys and computer screen. If the effects of Cowan et al. are replicated in the present study, the answer is no. Although previous studies have shown that the auditory modality superiority effect survives acoustic interference (e.g., Glenberg, Eberhardt, & Belden, 1987; Glenberg, Eberhardt, & Petersen, 1985; Lowe & Merikle, 1970), no such study has included interference with the same voice quality as auditory stimuli to be recalled.

Second, alternative methods of analysis were used to examine whether the enlargement of the modality effect by DIO can be attributed to psychometric scaling factors. The modality effect was observed in the most recent portions of the serial-position curve. Under conditions of low DIO, performance in those serial positions was very high. It may not be possible to observe large effects of modality under conditions of low DIO because of ceiling effects. The role of DIO may be to lower overall performance levels to a range that is more sensitive to condition differences, enlarging the modality effect. That possibility was assessed in two ways: (a) by examining the end-of-list modality effect in participants with relatively low list-final performance levels, and (b) by examining effect sizes in standard deviation units normalized within serial positions.

Method

Participants

Sixty-four college students (39 female, 25 male; *M* age = 21 years, *SD* = 60.73 months) participated for course credit. Another 4 participants were omitted from the sample because they were not native speakers of English, and 2 others did not complete the study.

Design

One group of 32 participants typed in their own responses and another group of 32 spoke their responses, which were typed in by the experimenter. In both cases, the participants examined the computer screen so as to know which items were to be recalled. The data were used in a 2 × 2 × 3 × 2 × 9 analysis of variance (ANOVA) with the aforementioned between-subjects factor (typed or spoken responses), and with several within-subject factors: the list presentation modality (auditory vs. visual), the DIO situation (low-DIO partial recall, low-DIO whole recall, and high-DIO whole recall), the type of feedback on each keypress in the response (tone or spoken digit), and the serial position in the presented list (1–9). Data from different trials had to be combined to construct these factors, as shown in Figure 1 and as discussed above.

Stimuli, Apparatus, and Procedure

The stimuli were the same as was used by Cowan et al. (2002) with two exceptions: (a) A 560-Hz, 250-ms triangular tone was used as feedback in some conditions, and (b) the digitized speech stimuli (the spoken digits 1–9) were digitally compressed to 65% of their original length without changing their fundamental frequencies, so that each one fit within a 250-ms window. This was accomplished using the SoundEdit program (Macromedia, 1997). The compressed spoken digits were still highly intelligible and sounded natural, though quick (as in some radio and television advertisements). The compression was necessary in order to allow the digits to be presented as speech feedback quickly enough to keep up with the keypress responses reliably when those responses were to be made by the participant. The apparatus was the same as the one that Cowan et al. used, including computer presentation and audiological-quality headphones for acoustic presentations.

The procedure was the same as that of the even-paced presentation trials in Cowan et al. (2002), with two exceptions: (a) half of the participants spoke their response instead of pressing keys, and (b) each keypress (made by the participant or by the experimenter to record a spoken response) was followed immediately by a tone or by a spoken presentation of the digit corresponding to the key that was pressed, whereas Cowan et al. (2002) presented no acoustic stimuli during the recall period. Participants were told that if two keys were pressed too quickly (with less than 250 ms between their onsets), the second keypress would not register and would have to be pressed again.

All trial types were presented in random order, with a complete set of 24 trial types presented within a block and five blocks per participant. When ready, each participant pressed a key to initiate the trial. A ready signal occurred 500 ms later (the word *ready* in the same modality—auditory or visual—as the list that was about to be presented). This ready signal was always accompanied by a large, yellow box (surrounding the printed word on visual trials), and 1 s later the screen display changed to a large, red box. After another 1 s, the first list stimulus appeared. The red box remained throughout the presentation period and surrounded the stimuli on visual trials.

Each trial included the digits 1–9 in random order, presented through headphones or visually, at a rate of 1 digit per s. Spoken digits were presented at 56–58 dB(A) as measured by a sound level meter equipped with an earphone coupler, and printed digits were 9.5 mm high and were presented one at a time at the center of the computer screen. Along with the row of nine boxes within the response screen, a bar above the boxes indicated the serial positions whose digits were to be recalled on that trial. An arrow above the bar always pointed down at the serial position whose digit was to be recalled at that time. The digits appeared in the appropriate boxes as they were typed, corresponding to the input serial positions that were being recalled. It was permissible to use the backspace key to change answers until the complete list was finalized by pressing the *Enter* key. Cowan et al. (2002) showed that the backspace key was used very rarely and that exclusion of such trials had no effect on the results. Participants were to guess if they did not know the answer for a particular serial position and were allowed to use the same digit more than once in the response.

On partial-recall trials, three consecutive digits were to be recalled, which depended on the cue (Serial Positions 1–3, 4–6, or 7–9). On whole-recall trials, the recall of those same digits was to be followed with recall continuing up through Serial Position 9 and then cycling around to Serial Position 1 (if the recall response did not in fact start there) and progressing forward until each digit had been recalled. Participants took breaks as needed between blocks of 24 trials. They could ask questions about the procedure after reading and hearing instructions and again after Trial Block 1. All other methodological details were as in Cowan et al. (2002).

Results

Each digit response was considered correct only if it occurred in the correct serial position. Before examining the separate effects of input and output serial positions it seems important to demonstrate, as Cowan et al. (2002) did, that the unusual method of presentation did not result in an unusual pattern of recall. To demonstrate this, in Figure 2, we have plotted the proportion of correct recall on just those trials in which whole recall began at Serial Position 1, separately for trials with a keypress response and a spoken response, as a function of serial position and input modality. It is clear that the functions closely resemble those typically obtained in studies of the serial recall of spoken and printed lists (e.g., Madigan, 1971). As in the typical studies, however, one must bear in mind that DIO increases as a function of the input serial position and is confounded with it.

To observe the effects of input serial position and output serial position (and thus DIO) separately, we had to rearrange the data as discussed earlier. For each combination of stimulus modality (auditory or visual) and response mode (keypress or speech), we identified 27 (3×9) data points per participant, combining data across trials as was required. Nine of these data points comprised partial recall at Serial Positions 1–9. These made up one type of low-DIO condition. Nine more data points were for Serial Positions 1–9 in whole recall at places in recall for which DIO was low, corresponding to the solid lines in Figure 1A. Finally, nine data points were for Serial Positions 1–9 in whole recall at places in recall for which DIO was high, corresponding to the solid lines in Figure 1B. These data were entered into a $2 \times 2 \times 2 \times 3 \times 9$ ANOVA with the response modality (keypress vs. spoken) as a between-subjects factor and with the stimulus modality (auditory or visual), type of feedback at response (speech or tone), DIO situation (partial recall with low DIO, whole recall with low DIO, or whole recall with high DIO), and serial position (1–9) as within-subject factors. We concentrate on just those effects that include stimulus modality as a factor.

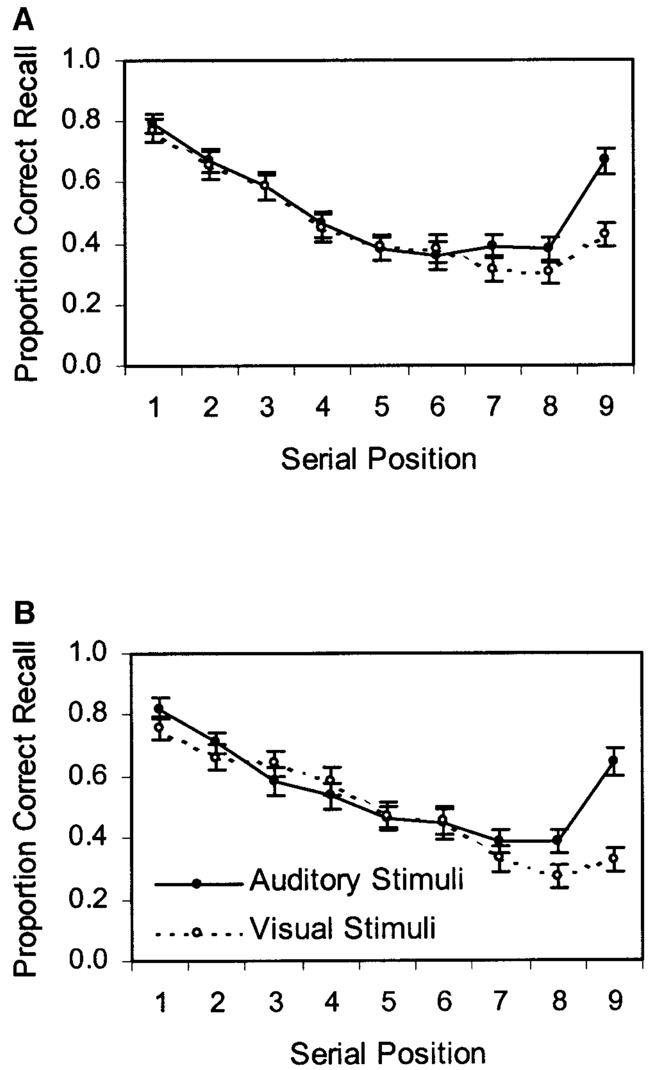

Figure 2. Ordinary forward serial recall of visual and auditory lists, in which recall starts at Serial Position 1 and continues throughout the list, confounding input and output positions. A: Keypress recall. B: Spoken recall followed by experimenter keypress. Error bars represent standard errors of the means.

The basic results are shown in Figure 3 and Table 1. The figure plots the results by serial position separately for trials with speech feedback and tone feedback for each DIO situation. In each panel, the graph parameter is stimulus modality. The table shows the corresponding means collapsed across serial positions and, critically, for the last serial position. The overall effect of stimulus modality was significant, $F(1, 62) = 7.77$, $MSE = 0.19$, $p < .01$, but this overall effect was rather small, with .59 correct for auditory stimuli and .57 correct for visual stimuli. The effect of modality occurred primarily at the final serial positions of the list, resulting in a large interaction of Stimulus Modality $\times$ Serial Position, $F(8, 496) = 20.38$, $MSE = 0.04$, $p < .01$.

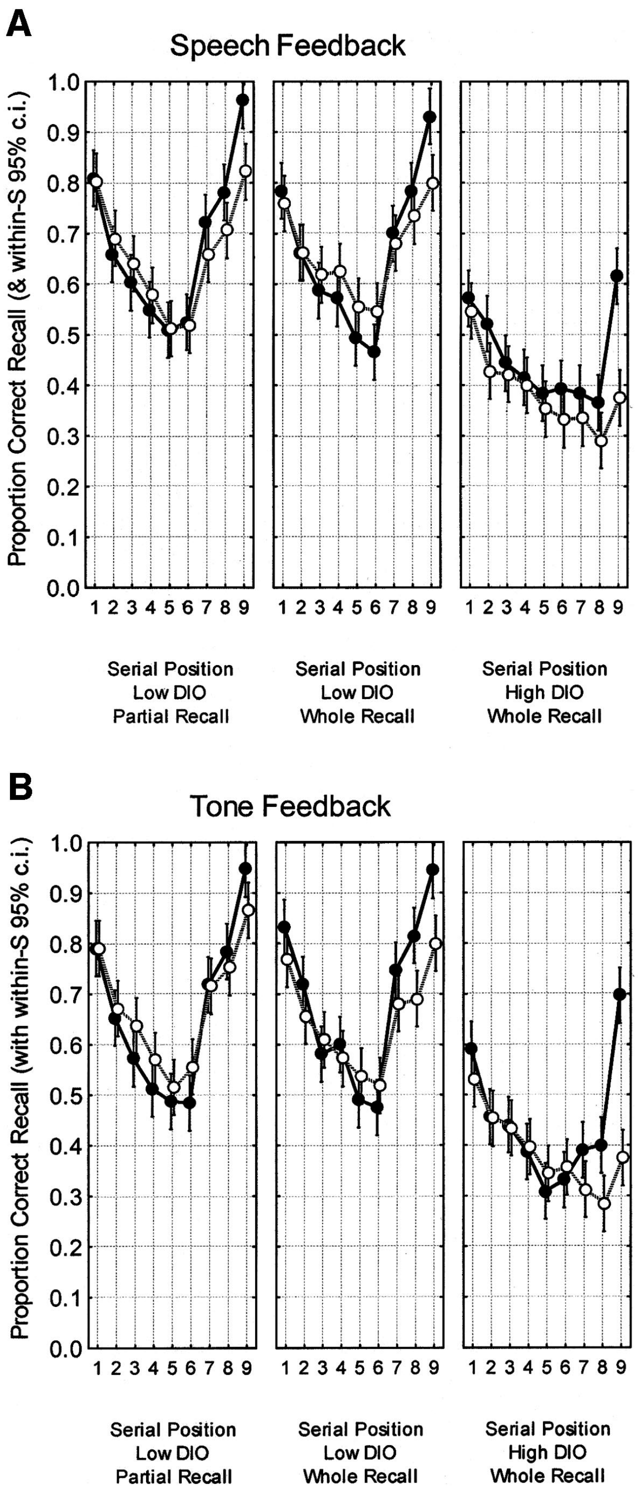

Figure 3. Proportion correct recall of visual and auditory lists by serial position. Solid circles indicate auditory stimuli; open circles indicate visual stimuli. A: Trials with speech feedback. B: Trials with tone feedback. Error bars are 95% within-subject confidence intervals (Loftus & Masson, 1994). DIO = delay or interference at output.

Most important, there was a two-way interaction of Stimulus Modality × DIO situation, $F(2, 124) = 7.66$, $MSE = 0.07$, $p < .01$. The two-way interaction is accounted for by the fact that the auditory modality superiority was much larger in the case of high DIO than it was in either situation in which DIO was low (partial or whole recall with low DIO). This effect was replicated for both the speech-feedback and tone-feedback trials. There was also an overall effect of serial position, $F(8, 496) = 64.56$, $MSE = 0.13$, $p < .001$, and an interaction of Serial Position × DIO situation, $F(16, 992) = 18.62$, $MSE = 0.05$, $p < .01$ (see Figure 3). It is clear that there were primacy and recency effects and that high DIO affected performance much more in the later serial positions than it did in the earlier serial positions, accounting for the interaction.

The Stimulus Modality × DIO situation interaction was by far the largest at the final serial position in the list. For the final serial position under high DIO, the means were .66 for auditory stimuli and .38 for visual stimuli, a 28% effect. The reason for the effect being smaller with low DIO may be related to a ceiling effect. Thus, with low DIO (averaged across partial and whole recall, which yielded similar results), performance means were .95 for auditory stimuli and .82 for visual stimuli, a 13% effect. However, even this smaller effect was highly significant in a separate analysis of the low-DIO, Serial Position 9 data, $F(1, 62) = 47.50$, $MSE = 0.04$, $p < .01$.

We asked if the small modality effects with high levels of performance could occur primarily because of compression of the range of performance. This question was examined in several ways. First, we looked at the final serial position in a particular condition for just those participants whose proportion correct within that condition was .80 or less, averaged across visual and auditory lists. We did so in each of six within-subject conditions in the experiment. Means and statistical tests for those comparisons, shown in Table 2, indicate large, significant modality effects in five or six conditions. The sixth comparison was marginal ($p < .10$).

Another method of investigating the scaling issue was to examine all serial positions and conditions with within-condition *d* scores for each individual, whereby the *d* score represents the magnitude of the auditory-modality advantage in standard deviation units for that condition and serial position. For each condition, the mean and standard deviation of all scores, including trials with both visual and auditory lists, was calculated using all participants' data. These statistics were then used to calculate the magnitude of the modality effect for each individual in standard deviation units, as [(auditory score − visual score)/group standard deviation]. With this method of calculation, the near ceiling compression of scores at the end of the list is corrected because the scores are divided by smaller standard deviation values when the modality-effect size is calculated. These scores were entered into an ANOVA with all of the same factors as the main analysis, except for list modality (given that the dependent measure was a modality-difference measure).

As shown in Figure 4, the results are clear and are consistent with the prior analyses shown in Table 2. There was a large effect of serial position, $F(8, 496) = 23.58$, $MSE = 1.28$, $p < .01$; the modality effect was larger at the end of the list. This effect did not interact with any other factor but is shown in the figure separately for lists with partial report, whole report with low DIO, and whole report with high DIO. It appears that, measured by these within-position standard deviation units, the modality effect was almost as

Table 1
Mean Proportions Correct (and Standard Errors of the Means) in Each Condition, Collapsed Across Serial Positions and for the Final Serial Position

Condition	All serial positions				Final serial position			
	Auditory	*SEM*	Visual	*SEM*	Auditory	*SEM*	Visual	*SEM*
Partial report								
Speech at output	.68	.02	.66	.02	.96	.01	.82	.03
Tone at output	.66	.02	.67	.02	.95	.01	.87	.02
Whole report with low DIO								
Speech at output	.66	.02	.66	.02	.93	.02	.80	.03
Tone at output	.69	.02	.65	.02	.94	.01	.80	.03
Whole report with high DIO								
Speech at output	.46	.02	.39	.02	.62	.04	.38	.03
Tone at output	.44	.02	.39	.02	.70	.04	.38	.03

Note. DIO = delay or interference at output.

large with low DIO as it was with high DIO. Thus, the curves for the three conditions are very similar.

Finally, we explored the use of log-odds probability (Henson, 1999) to analyze the data free of compression effects but we found that the data pattern was to some extent influenced by the particular correction selected to prevent divide-by-zero errors. Therefore, it appeared that our *d* scores offered a more objective estimate of the magnitude of modality effects.

Discussion

Cowan et al. (2002) used a new method to examine the effects of input and output factors in serial recall of spoken and printed lists. They found that the auditory modality superiority effect (see Penney, 1989) occurred only in conditions of high DIO. Ordinary serial recall has high DIO in the most recent portion of the list but Cowan et al. (2002) were able to examine conditions of low DIO throughout the list, by starting recall at different points of the list. Only a small effect of modality was observed under low-DIO conditions, at the end of the list. The present study supplemented these findings in two important ways. First, the effects of Cowan et al. (2002) were replicated even when acoustic interference was present within the recall responses. This acoustic interference was potentially quite strong because it was identical to acoustic stimuli used within the spoken lists to be recalled, unlike previous studies. Despite this acoustic interference, a large, list-final modality effect remained under conditions of high DIO.

Second, a relatively large participant sample allowed an assessment of effects of psychometric scaling factors. When examined in terms of scores standardized according to the variance in the final serial position, the modality effect was of a similar magnitude with

Table 2
Comparisons of Final-Serial-Position Proportions Correct in Each Condition

Condition	*N*	Auditory	Visual	*SEM* (diff)	*t* (*N* = 1)
Partial report					
Speech at output	18	.91	.52	.04	8.80*
Tone at output	17	.85	.69	.08	1.92
Whole report with low DIO					
Speech at output	25	.86	.56	.06	5.02*
Tone at output	24	.88	.59	.05	5.41*
Whole report with high DIO					
Speech at output	60	.58	.33	.05	5.41*
Tone at output	62	.68	.35	.04	8.06*

Note. Comparisons are for participants with combined visual and auditory means of .80 or lower. diff = difference; DIO = delay or interference at output.
* *p* = .001.

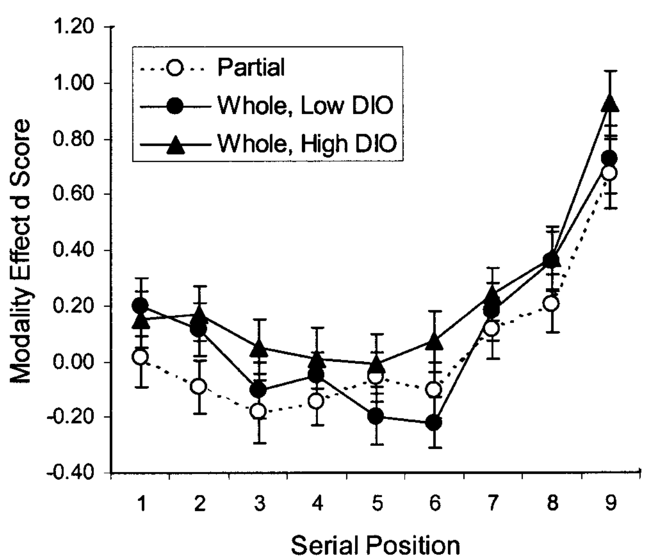

Figure 4. Auditory–visual difference (*d*) scores for the proportion correct in standard-deviation units, based on standard deviations calculated within a condition and serial position. Error bars represent standard errors of the means. DIO = delay or interference at output.

low and high DIO (see Figure 4). Also, a large modality effect was obtained under low-DIO conditions even in the raw proportions correct, in analyses restricted to participants with relatively low performance levels (Table 2). These results indicate that the primary locus of the modality effect is at input, with DIO enlarging the modality effect by increasing the sensitivity of testing for it.

Note that the level of performance was not the only factor determining whether a modality effect would emerge. The performance levels of items in the middle of the list were in a moderate range that was not near ceiling or floor, but modality effects still did not consistently emerge for those serial positions. Thus, input serial position, not output serial position, was the factor most relevant to modality effects. It is still unclear why input serial position makes such an important difference for the magnitude of the modality effect. A temporal-distinctiveness notion (e.g., Brown, Preece, & Hulme, 2000; Crowder, 1993) leads to the concept that items appearing earlier in the list are difficult to distinguish from one another within the memory representation because they are further from the temporal context at the moment of recall. Auditory stimuli may result in higher performance levels than visual stimuli at the end of the list because the temporal representation of auditory stimuli is more precise, reflecting the temporal context more accurately (Glenberg & Swanson, 1986).

Our finding of the importance of psychometric scaling factors in the modality effect is consistent with the finding that the modality effect disappears under the imposition of interfering tasks that eliminate the recency effect for both modalities (Engle & Roberts, 1982).

Our inference that modality effects depend on differential encoding of the modalities during list presentation is consistent with what has been found in studies of memory using methods other than serial recall. Murdock (1968) found an auditory modality superiority effect even in tasks in which there was no DIO (recognition and probed recall; see also Murray et al., 1999). These effects occurred even in the final serial position of the list, for which no stimuli or responses intervened between presentation and memory testing for that last item. Craik (1969) presented spoken or printed lists and required that participants first recall as many items as possible from the beginning of the list or, in a different condition, from the end of the list. For the remainder of the trial, the recall order was free. Recall from the beginning of the list produced much larger modality effects (at the end of the list) than did recall starting at the end of the list. Similarly, Beaman and Morton (2000) examined the order of recall in unconstrained free recall and found that runs of items from the end of the list that were recalled first did not distinguish much between spoken and printed lists; they were recalled almost equally often from lists in both modalities. However, for spoken lists, on some trials the list-final items were recalled later on. This happened only rarely for printed lists. The occurrence indicates that if visual items from the end of the list were not recalled right away, they generally would not be recalled at all, whereas for spoken lists, later recall still was possible. As in the present serial-recall data, there was thus a small modality effect under low-DIO conditions (the first items recalled) and a much larger modality effect apparent under high-DIO conditions (later-recalled items). However, the present analyses with measures standardized within positions lead to the question of whether findings such as those of Craik and of Beaman and Morton would change with such measures.

The present findings, together with others in the recent literature (e.g., Beaman, 2002), suggest that we may be close to understanding a long-lasting mystery regarding the manner in which stimuli are remembered for immediate use. In a nutshell, a large part of the auditory modality superiority in serial recall can be explained on the basis of DIO, regardless of the output modality; the effect of DIO appears to be on the overall level of performance, which modulates sensitivity to the observation of modality effects.

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