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Effects of Same-Modality Interference on Immediate Serial Recall of Auditory and Visual Information

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ABSTRACT. Two studies investigated the effects of same-modality interference on the immediate serial recall of auditorily and visually presented stimuli. Typically, research in which this task is used has been conducted in quiet rooms, excluding auditory information that is extraneous to the auditorily presented stimuli. However, visual information such as background items clearly within the subject's view have not been excluded during visual presentation. Therefore, in both the present studies, the authors used procedures that eliminated extra-list visual interference and introduced extra-list auditory interference. When same-modality interference was eliminated, weak visual recency effects were found, but they were smaller than those that were generated by auditorily presented items. Further, mid-list and end-of-list recall of visually presented stimuli was unaffected by the amount of interfering visual information. On the other hand, the introduction of auditory interference increased mid-list recall of auditory stimuli. The results of Experiment 2 showed that the mid-list effect occurred with a moderate, but not with a minimal or maximal, level of auditory interference, indicating that moderate amounts of auditory interference had an alerting effect that is not present in typical visual interference.

A SUPERIORITY IN THE RECALL of terminal over preterminal items (i.e., a recency effect) is generally found in immediate serial recall of auditorily presented information but not of visually presented information. This robust advantage for terminal recall of auditory over visual information has been called the *modality effect* (Conrad & Hull, 1968; Crowder & Morton, 1969; see Penney, 1989, for a review).

One explanation for the superiority of auditory over visual recall avers that some resource is available for the recall of auditory information that is not available for the recall of visual information (Crowder & Morton, 1969). Another model of recency and modality effects that also emphasizes the superiority of auditory processing assumes that information received through different sensory modalities is processed by completely separate systems. This theory suggests that there are separate capacity limitations for the different sensory and perceptual pathways (e.g., auditory and visual short-term memories; Frick, 1984; Penney, 1975, 1985, 1989). The presentation modality is considered to determine the system through which information is processed. Auditory information is automatically encoded into the auditory short-term memory (STM), requiring little use of memory resources, and is thus available to provide the superior recall of auditory over visual information. Visual items, however, are not automatically encoded into the visual STM. Moreover, the processing of visual information can be easily disrupted (Penney, 1989).

Nairne (1988) proposed that the recency effects found in immediate serial recall are partially determined by the amount of interference that is encountered during the encoding of stimulus information. Immediate memory representations have two types of features. Modality-independent features are not associated with physical features and therefore are not limited to any particular presentation modality, whereas modality-dependent features are encoded at input and are unique to a particular presentation modality. Both auditory and visual features are modality-dependent, and auditory features are not superior in any way to visual features.

One reason auditorily presented lists consistently generate recency effects and visually presented lists do not is that items at the end of a visually presented list are overwritten (i.e., interfered with) by extraexperimental visual stimuli. And, as Nairne (1988) argued, "The subject is performing in a visual world, and there is every reason to suppose that his/her visual fixations following the list have the potential to overwrite the modality-dependent features of the last list item" (p. 348). The nature of the task allows the subject to look at many salient visual events, such as the computer screen, keyboard, answer sheet, or lines and edges in the room. On the other hand, few external

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salient auditory stimuli are present in the task environment, and thus, there is less potential for auditorily presented terminal list items to be overwritten.

Following this argument, recency effects could reasonably be assumed to occur in any modality, if the immediate, serial-recall task is designed so that during stimulus presentation, subjects are induced to encode modality-dependent features in a task environment that eliminates any background interference. The possibility then exists that visual recency effects could be nearly as large as auditory recency effects in immediate, serial-recall tasks, thus reducing the modality effect, if subjects encode modality-dependent features of visual information and if this process of visual encoding is not interrupted.

Glenberg, Eberhardt, and Belden (1987) tested the elimination of ambient visual interference to determine whether it would generate visual recency in a long-term memory task. Their subjects recalled and orally reported pairs of nouns that had been presented visually and auditorily. Subjects saw and recalled the stimuli through masks so that the changing ambient visual field was blocked from their vision. Consequently, the majority of visual interference during presentation and recall was eliminated. This procedure successfully generated a visual recency effect but did not eliminate the modality effect. However, the Glenberg et al. task was not an immediate memory task, and it remains to be seen whether the elimination of extraneous visual noise in an immediate, serial-recall task leads to a visual recency effect.

The purpose of the studies reported here was to investigate the effects of same-modality interference on the immediate serial recall of auditorily and visually presented stimuli. If interfering visual events in an immediate memory task overwrite visual features of items in the list, as Nairne suggested, or disrupt the encoding of these features into STM, as Penney suggested, then eliminating that interference should improve terminal visual recall. Further, if encoding auditory features into an auditory STM is not easily disrupted, then introducing auditory interference into the task environment should not affect recall of auditorily presented stimuli.

Therefore, our first experiment was designed to eliminate all visual events that could possibly interfere with recall of visually presented stimuli and to introduce auditory events that could interfere with recall of auditory stimuli. Furthermore, if recall of visual information is affected by visual interference, then more visual interference effects should be found with a background of many distracting visual stimuli than with a background of few visual distractions. Accordingly, immediate serial recall of discernible auditory stimuli should not be affected by varying the number of auditory distractions. Thus, we varied the magnitude of same-modality interference allowed in the auditory and visual task situations in our second experiment, testing whether the magnitude of recall would be affected. In both experiments, the subjects were to recall familiar verbal stimuli (i.e., a limited set of eight digits).

Experiment 1

The main purpose of this experiment was to test whether immediate serial recall of visual or auditory items is affected when the stimuli are familiar and when ambient same-modality noise is present in (or absent from) the task situation. Therefore in the condition without visual interference, an apparatus that eliminated all interfering light patterns was used during the presentation of visual information; the apparatus was not used in the visual interference condition. In addition, auditorily presented items were recalled against either silence or a background of random auditory sounds.

Method

Subjects and design. Forty-eight students from Wichita State University participated to satisfy a course requirement. Four between-subjects conditions crossed presentation modality (visual/auditory) and level of interference (present/absent). Subjects in the auditory condition were instructed to read digits aloud; those in the visual condition silently read them without any lip movements or any other articulatory motions. In addition, half the subjects saw the items with, and half the subjects saw the items without same-modality interference. The within-subject variable was serial position of the test items.

Apparatus. In the visual-without-interference condition, the subjects silently read stimulus items within a black, velcro-covered hood attached to the monitor of a Zenith microcomputer during stimulus presentation and recall (see Figure 1).

The 20-in. (1 in. = 2.54 cm) long hood was made from black fiberboard and had two openings. One opening was constructed to attach to the front side of the computer monitor with an elastic band, restricting subjects' visual field to an 8-in. × 10-in. area on the monitor. The other opening (3 in. × 10 in.) was fitted with goggles, covered with black velcro, and attached to the hood in a position that constrained subjects' distance from the computer monitor from 18 to 20 in. The goggles were securely fastened on each subject's head with a small elastic headband. The computer monitor had a swivel base, allowing the attached hood to be raised or lowered to adjust for individual height differences. The lenses were removed so that subjects could wear glasses, and visual interference for subjects with normal vision was eliminated.

Stimuli and procedure. Each stimulus trial consisted of eight digits, 1 through 6, 8, and 9, randomly chosen without replacement and presented one at a time on the computer monitor. An experimenter remained with each of the individually tested subjects to be sure that all recall was written in serial order,

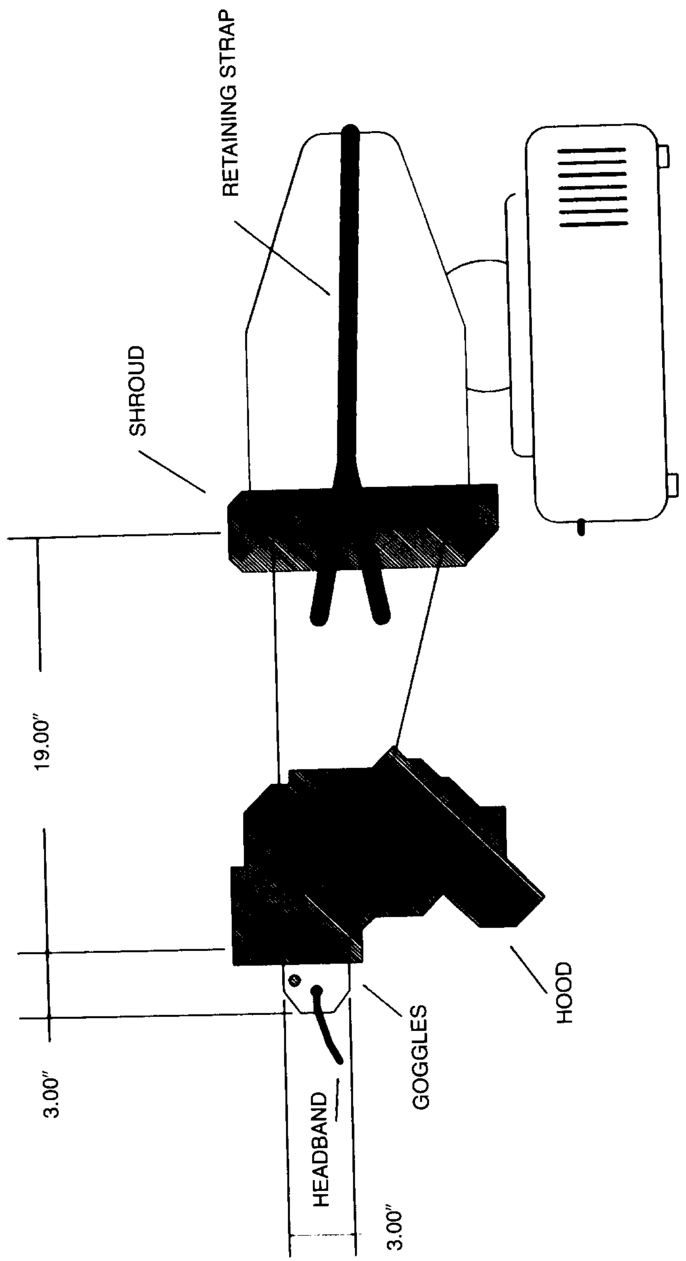

FIGURE 1. Hood used to eliminate visual interference during presentation and recall of visual items.

that those in the visual conditions read the digits silently, and that those in the auditory conditions read them aloud.

In the visual-with-interference condition, the subjects read the digits silently without being under the hood. Thus, the computer, table, experimenter, walls, and the subject were all visual stimuli distractions available to interfere with encoding and recall of list items. These background visual stimuli were eliminated in the visual-without-interference condition by requiring subjects to read and recall the visually presented digits under the black velcro hood.

In the auditory-with-interference condition, the subjects read the digits aloud and wrote their recall in the presence of random, recurring sounds of a knock on wood that was pre-taped and heard from a speaker positioned 2 ft. in front of the subject, behind the computer and out of the subject's visual field. In the auditory-without-interference condition, these extraneous knocking sounds were eliminated by disconnecting the recorder, so that the room was quiet.

On each of the 60 experimental trials, all subjects saw eight digits sequentially at a rate of two per s, with an interitem duration of 200 ms and an item duration of 300 ms, followed by a blank screen. When the blank screen appeared, the subjects wrote the digits in the same serial order as presented, leaving a blank space for any forgotten items. The subjects performing under the hood wrote on a pad of paper they could feel but not see. After each trial, the experimenter immediately rewrote the responses on an answer sheet. When the subject indicated that he or she was ready, the experimenter initiated the next trial.

Results and Discussion

The subjects' responses were counted as correct only if they were recalled in the correct serial position. Planned comparisons were made using an F ratio (Hays, 1981) for the specific hypotheses regarding same-modality interference effects. Tests for recency were computed for the difference in recall between items in the preterminal (seventh) and terminal (eighth) serial positions.

The major goal of Experiment 1 was to find the effects of interference on immediate serial recall of auditory and visual stimuli. Specifically, we hypothesized that eliminating ambient visual noise by using an appropriately designed apparatus would produce a visual recency effect in this experiment. Figure 2 shows large auditory and small visual recency effects, which are components of the overall three-way interaction central to this question, Presentation Modality × Interference Condition × Serial Position.

Although this interaction was significant over all serial positions, $F(7, 308) = 2.72, p < .0093, MS_e = 53.91$, it was not significant in the separate analysis of the seventh and eighth positions, $F(1, 44) = 3.20, p > .0804$,

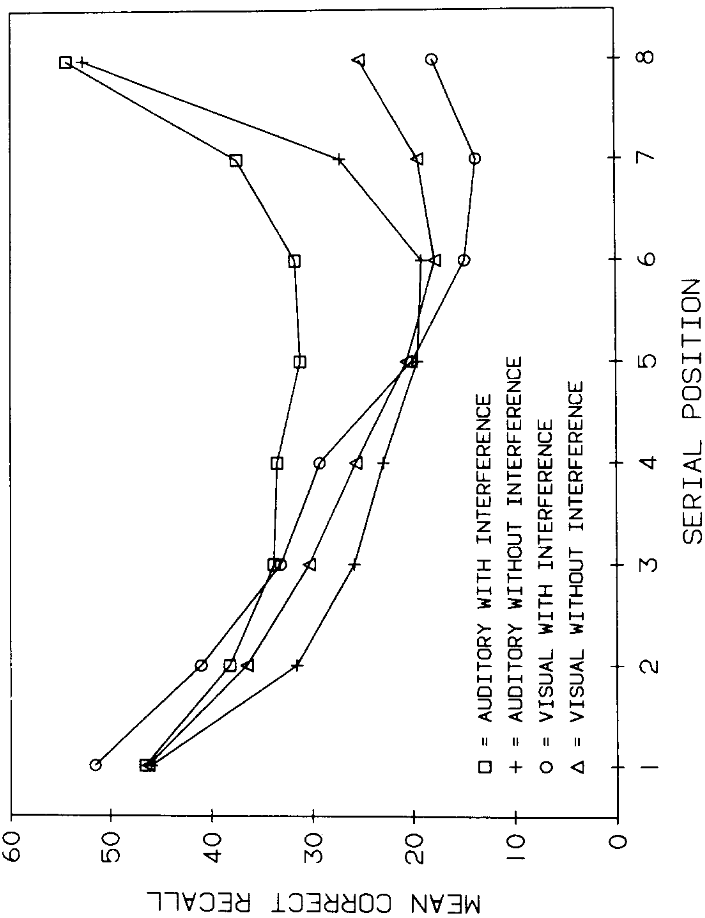

FIGURE 2. Mean correct recall as a function of modality of stimulus presentation and presence of same-modality interference.

MS_e = 22.95. Furthermore, the comparison of the effects of visual recency with and without interference was not significant, $F(1, 22) = 1.23, p > .12$, MS_e = 22.95, suggesting that visual recency was not affected by the presence or absence of visual interference. Mean recall in the visual-without-interference condition increased 5.85 items between the seventh and eighth position, $F(1, 22) = 16.29, p < .005, MS_e = 22.95$, but only 4.25 items in the visual-with-interference condition, $F(1, 22) = 8.66, p < .01$, MS_e = 22.95. Thus, visual recency enhancement occurred both without visual interference and with interference.

On the other hand, there was a strong effect of modality whether visual interference was eliminated or not, $F(1, 44) = 68.32, p < .0001$, MS_e = 22.95; that is, a comparison of auditory and visual recall in the two no-interference conditions showed that the increase in recall from the seventh to the eighth position was greater in the auditory (mean increase, 25.5 items) than in the visual condition (mean increase, 5.83 items), $F(1, 22) = 14.56, p < .0004, MS_e = 79.72$. Also, the increase in auditory recall was greater (mean increase, 16.91 items) than that in visual recall (mean increase, 4.24 items) during interference, $F(1, 22) = 13.65, p < .0013$, MS_e = 35.25.

As expected, an auditory recency effect was found in the auditory interference condition, $F(1, 11) = 54.67, p < .0001, MS_e = 57.59$, and in the condition without auditory interference, $F(1, 11) = 139.53, p < .0001$, MS_e = 51.28. Differences between Positions 7 and 8 were similar with and without auditory interference; furthermore, the interference condition did not affect eighth position recall. Recall of auditory stimuli at the eighth position was similar in the conditions with and without auditory interference.

On the other hand, Figure 2 clearly shows that the interaction between interference and all serial positions was significant, $F(7, 308) = 2.16$, $p < .0378, MS_e = 53.9$. The finding that auditory recall at different serial positions could be affected differentially by auditory interference condition was expected. Moreover, serial position analyses indicated that auditory interference actually increased mid-list and preterminal recall of Positions 3 through 7. Tukey's HSD pairwise comparisons indicated that recall of auditorily presented stimuli was significantly greater in the interference condition than in the without-interference condition at Position 3 (Ms = 34 and 26, respectively), Position 4, (Ms = 34 and 23), Position 5, (Ms = 31 and 20), Position 6 (Ms = 32 and 19), and the preterminal Position 7, (Ms = 37 and 27). Recall at the first, second, and eighth positions were not significantly affected by the interference condition. Auditory recency was greater in the condition without auditory interference (M = 25.50) than in the condition with interference (M = 16.91), $F(1, 22) = 35.37, p < .0001, MS_e$ = 22.95; however in reality, recency was reduced because preterminal recall was improved during interference.

The typical modality effect was not eliminated by blocking visual interference. With or without interference, terminal list items were recalled better when they were presented auditorily than when they were presented visually. Furthermore, visual recall, especially recall at the terminal position, was not affected by visual interference. Small visual recency effects were obtained with or without visual interference. On the other hand, auditory recall was affected by auditory interference. Although large auditory recency effects were found with or without auditory interference, recall of mid-list and preterminal auditory items was greater with than without interference; differences in auditory recency were not determined by recall at the eighth position but by recall at the seventh, and possibly earlier, positions.

Therefore, we did not find an increased visual recency effect by eliminating all visual interference and allowing subjects to see only the stimulus items against darkness, but we did find increased mid-list and preterminal auditory recall by requiring subjects to recall auditorily presented stimuli against a background of random auditory sounds. Thus, in Experiment 2 we further tested our hypotheses by introducing varied amounts of auditory interference into the auditory task environment and varied amounts of visual interference into the hooded, controlled visual environment used in Experiment 1.

Experiment 2

In this experiment, our purpose was to find whether differing quantitative amounts of auditory interference systematically affects auditory recall in an immediate, serial-recall task. We also wanted to compare these effects with those found in visual modality. Therefore, we varied the quantity of visual interference during the presentation and recall of visually presented digits and the quantity of auditory interference during presentation and recall of auditorily presented digits.

Method

Subjects and design. Forty-eight students from Wichita State University participated to satisfy a course requirement. Eight students were randomly assigned to each of six between-subjects conditions created by varying the modality (visual/auditory) and level of interference (minimal/moderate/maximal). The subjects were instructed to read digits silently during minimal, moderate, or maximal levels of visual interference or to read digits aloud during minimal, moderate, or maximal levels of auditory interference. The within-subject variable was the serial position of the eight items in each list.

Stimuli and procedure. The stimuli and hood apparatus of Experiment 1 were used in this experiment. Digits were presented one at a time in the center of the computer monitor with a minimal, moderate, or maximal level of interference.

In the three visual conditions we controlled the level of visual interference by requiring the subjects to silently read and recall the digits inside the hood apparatus. Minimal visual interference consisted of a 2-in. × 2-in. square outline that appeared an inch to the right of the stimulus during the 300-ms stimulus presentation and recall. In the moderate visual interference condition, two of these 2-in. × 2-in. outlines appeared during stimulus onset, one an inch to the left and one an inch to the right of each stimulus digit. In the maximal visual interference condition, a third geometric outline appeared during the onset duration of each stimulus digit. A 1-in. × 3-in. rectangular outline was positioned 1 in. below the stimulus digit, along with the two square outlines positioned 1 in. to the right and 1 in. to the left of each stimulus digit. We instructed the subjects to ignore the geometric pattern(s) and to concentrate on remembering the digits.

In the three auditory conditions, the subjects were required to read the digits aloud, and we controlled the degree of auditory interference by varying the location of three speakers. Auditory interference was minimal when subjects heard a 400-Hz tone emanating from only one speaker located behind the right side of the subject. Interference was moderate when the 400-Hz tone was generated from one speaker behind the right side and from another speaker located behind the left side. Interference was maximal when the 400-Hz tone was generated through one speaker behind the right side, through another speaker behind the left side, and through a third speaker located directly behind the subject. Three Radio Shack 2.5-in. round speakers were mounted 73 in. above the floor, one on the wall on the subject's right side, one on the left wall, and one on the wall behind the subject. A straight-line distance of 88 in. separated subjects from the left and right speakers; the third speaker was located 155 in. directly behind them. The decibel level of the interfering tone measured at the subject's location was maintained at 80 dB across interference levels. The interfering tone(s) were presented simultaneously with the onset and offset of the stimulus digits, which were presented at a rate of two per second as in the first experiment. All other details of the experimental procedure were identical to those of Experiment 1.

Results and Discussion

The major goal of Experiment 2 was to investigate whether we could affect auditory or visual recall, or both, by systematically varying the quantity of same-modality interference. The number of digits that were correctly recalled at each serial position for each of the three auditory interference levels are shown in the left panel of Figure 3, and in the right panel, recall for the three visual interference levels is represented. We found strong auditory mid-list, preterminal, and recency effects but weak visual effects, if any. Furthermore, it was clear that visual recency was not affected by interference.

As expected, there was a main effect of serial position, $F(7, 294) = 56.9, p < .0001, MS_e = 51.89$, but recall at each serial position did not depend on the level of interference, $F(7, 294) < 1.15, p < .0001, MS_e = 51.89$. However, serial position recall did interact with modality of presentation, $F(7, 294) = 39.02, p < .0001, MS_e = 51.89$.

Analyses of recency effects. An analysis of just the seventh and eighth positions indicated a main effect of modality, $F(1, 42) = 10.12, p < .0028, MS_e = 253.26$; a main effect of serial position, $F(1, 42) = 130.14, p < .0001, MS_e = 31.97$; Modality × Serial Position interaction, $F(1, 42) = 54.24, p < .0001, MS_e = 31.97$. There were no other significant effects. These findings indicate that recall at the eighth serial position was dependent on whether the stimuli were presented auditorily or visually, but was not dependent on interference, $F < 1, MS_e = 31.97$.

Comparisons between recall at the seventh and eighth positions confirmed that there was an effect of modality across all levels of interference. The magnitude of the increase in auditory recall (ignoring interference level) at the eighth versus seventh position ($M = 21.70$) was greater than the increase in visual recall at the eighth versus seventh position ($M = 4.67$), $F(1, 22) = 99.66, p < .0001, MS_e = 31.97$. These results agree with those from Experiment 1 showing greater auditory than visual recency effects regardless of the level of interference.

There was a small visual recency enhancement when visual interference was moderate, and also when interference was maximal, but not when interference was minimal. In the visual condition with maximal interference, recall at the eighth position ($M = 30.125$) was greater than that at the seventh ($M = 24.125$), $F(1, 14) = 7.88, p < .025, MS_e = 31.97$; in the visual condition with moderate interference, recall at the eighth position ($M = 35.13$) was greater than that at the seventh ($M = 29.75$), $F(1, 14) = 6.33, p < .025, MS_e = 31.97$. However, comparisons of differences in visual recency across interference level, regardless of statistical significance, found that the visual recency effect was not differentially affected by the level of visual interference, $F < 1.6, MS_e = 31.97$.

Moreover, although auditory recency effects were strong, they were found regardless of interference level. The left panel of Figure 3 shows a large increase in recall at the eighth position versus recall at the seventh position. With minimal interference, the eighth position auditory mean recall (51.0) was greater than that of the seventh (28.88), $F(1, 14) = 107.12, p < .0001, MS_e = 31.97$; with moderate interference, the eighth position mean recall

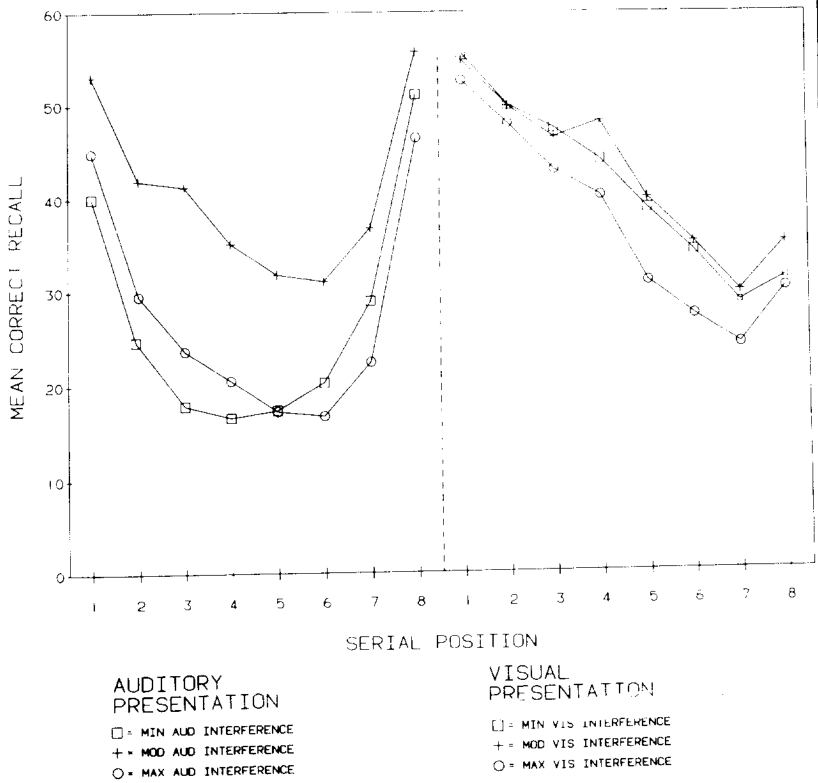

FIGURE 3. Left panel: Mean correct recall of auditorily presented digits as a function of quantity of auditory interference. Right panel: Mean correct recall of visually presented digits as a function of quantity of visual interference.

(55.63) was greater than that of the seventh (36.75), $F(1, 14) = 77.96$, $p < .0001$, $MS_e = 31.97$; with maximal interference, eighth position recall (46.38) was also greater than that of the seventh (22.38), $F(1, 14) = 126.04$, $p < .0002$, $MS_e = 31.97$. However, other comparisons of the effect of interference on auditory recency were not significant.

Mid-list and preterminal analyses. Although the overall interaction between interference level and serial position was not significant, a significant interaction between auditory interference and auditory serial position recall was found, $F(7, 22) = 32.45$, $p < .0007$, $MS_e = 43.92$. Furthermore, recall in mid-list and preterminal positions was consistently affected by level of auditory interference. Tukey's HSD pairwise comparisons showed that recall was significantly greater in the moderate than in the minimal level of auditory interference at Positions 1 through 7, and also that recall was significantly greater in the moderate than in the maximal level of interference at Positions 2 through 7. Thus, mid-list and preterminal auditory recall was affected by auditory interference as in Experiment 1, and mid-list and preterminal recall was consistently greater with moderate than with minimal or maximal interference. Also, the reduced preterminal recall resulted in the greater reduction of auditory recency when interference was at a moderate than at a maximal level, $F(1, 14) = 5.75, p < .05. MS_e = 31.97$.

On the other hand, mid-list and preterminal visual recall was not consistently affected by visual interference. Although maximal interference tended to lower visual recall at Positions 4 through 7, this difference was significant only at Positions 5 and 6.

The results of Experiments 1 and 2 agreed in that immediate serial recall of auditorily presented, but not of visually presented, familiar stimuli was consistently affected by the amount of same-modality interference (minimal, moderate, maximal, or no interference). The level of auditory interference consistently affected mid-list, preterminal, and terminal auditory recall. Although auditory recency was determined as much by preterminal as by terminal recall, auditory recency effects were strong. On the other hand, mid-list and preterminal recall of visual items was not affected by level of visual interference. Visual recency effects were also, in general, independent of interference level. Although small visual recency effects were found in the absence of visual interference, these effects were also found with moderate and maximal interference. Furthermore, the systematic introduction of varied amounts of interference into the controlled visual environment did not eliminate these small effects of visual recency. In fact, the only nonsignificant effect of visual recency occurred with minimal interference. Auditory recency effects were consistently greater than visual recency effects across all conditions in both experiments.

General Discussion

The purpose of these experiments was to test the effects of background interference on the immediate serial recall of auditory and visual information. Typically, past research using the immediate, serial-recall task found similar recall of beginning and mid-list items whether the information was presented auditorily or visually. However, items at the end of the list were consistently recalled better when heard than when seen. To this end, the focus of the present research was initially on enhancing the weak visual recency effect usually found in immediate memory tasks and on decreasing the robust effects of auditory recency. The explanation was that recency does not generally occur in the immediate recall of visually presented items because extra-experimental or ambient visual information overwrites the modality-dependent features of the visually presented stimuli to be remembered (Nairne, 1988), or because the encoding of these features into STM is easily disrupted (Penney, 1989). On the other hand, auditory recency occurs because the encoding of auditory information is not easily disrupted, and extra-experimental, salient auditory interference is not typically present during the presentation and recall of auditory stimuli.

In one condition of Experiment 1, all visual interference was eliminated and small effects of visual recency were found, but the magnitude of these effects was no different than that found when subjects performed the same immediate memory task under conditions typically used for this paradigm (i.e., without the hood blocking other stimuli in the ambient visual field). Eliminating visual interference did not result in increasing visual recency. Furthermore, the introduction of background auditory interference did not result in decreasing auditory recency. The presence of auditory distractions did, however, have an unexpected effect on recall: Mid-list and preterminal recall of auditorily presented information was better with auditory interference than without it. The recency effect was measured by the difference in preterminal and terminal list recall (as typically defined); therefore, the existence and the magnitude of recency effects had to depend equally on the recall of preterminal and terminal list items.

In Experiment 2, we wanted to know if systematic increases in the amount of auditory interference would lead to increased mid-list and preterminal recall of auditory information. Our results replicated Experiment 1 only when the level of auditory interference was moderate; when minimal or maximal levels of auditory interference were present, mid-list and preterminal recall was decreased. Recency recall was not as affected by the amount of interference as were beginning, mid-list, and preterminal recall (see Figure 3). Thus, if arousal was lower when remembering auditory items with a background of minimal auditory interference, or higher during recall with maximal interference, it did not affect recency. This suggested that an auditory sensory memory was not disturbed and was able to facilitate STM recall of the terminal item.

In Experiment 2, we also investigated whether visual recency would diminish and disappear as interference was systematically increased in the masked environment. In fact, the findings suggested the reverse. Recency effects did not disappear as the amount of interference in the hooded visual environment increased; instead, recency disappeared as interference decreased. Small effects of visual recency were found when interference was maximal (three outlined figures) and moderate (two outlined figures), but visual recency did not occur at the lowest level of interference (one outlined figure).

The consistent demonstration of only weak, if any, visual recency but strong auditory recency effects in the immediate, serial-recall tasks used in these experiments did not necessarily support Nairne's (1988) visual interference explanation of recency and modality effects. At least, simply eliminating visual interference did not generate any more visual recency superiority than what is usually found in these tasks. Furthermore, the small visual recency effects that were found did not disappear in some consistent manner when the quantity of interfering visual information was varied.

On the other hand, these findings lend support to theories suggesting that processing of recent auditory information is superior to that of recent visual information. In the immediate-memory tasks used in these studies, information was available for the recent recall of auditorily presented digits that was not available for the recall of visually presented digits. Possibly, the recent auditory memory representations were stored in a Precategorical Acoustic Storage (PAS) and then used as an extra source of information in the recall of end-of-list items (Crowder & Morton, 1969). According to the PAS model, subjects integrate the relatively long-lasting traces of items in PAS with representations held in STM. However, because visual information was considered to last for only 250 ms, these traces would not be available long enough to produce better end-of-list recall. Thus, the model assumes that recent recall of visual items is based on only one source of information (i.e., STM traces) and that auditory items have two sources of information (i.e., STM and PAS memory traces) available for recent recall.

Superior processing of recent auditory versus recent visual information is also an assumption central to the temporal coding theory, first developed by Glenberg & Swanson (1986). However, in this theory, recency and modality effects are explained by a more general retrieval process, rather than by a specific sensory process. Glenberg et al. (1987) argued that one part of the memory trace of each stimulus item defines that item's time of presentation. To the extent that the time of presentation is coded in fine detail, recall of end-of-list items will be facilitated because these items are most distinct. And, temporal coding was considered more accurate (i.e., it had more distinctive features) for auditory than for visual events. In either case, whether a general retrieval or a specific sensory process is posited, superior processing of auditory information is basic to the explanation of recency and modality effects such as those found in these studies.

However, theories based on auditory superiority do not necessarily explain the lack of visual recency effects. Glenberg (in press) has suggested that the recall of dynamically changing visual stimuli may exhibit recency effects similar to those found with auditory stimuli. Kallman and Cameron (1989) found enhanced recency with moving but not with stationary visual stimuli, so Glenberg investigated whether dynamic stimulus change may be the crucial dimension underlying recency.

In his second experiment, in which he specifically tested a phonological recoding explanation of dynamic visual recency, his subjects suppressed articulation while viewing a rectangle that appeared to move in one of four possible directions (up, down, left, and right) on a computer screen. The four directions were digitized and used as spoken stimuli in the auditory condition. The subjects' scores on the preterminal item were partialed from their performance on the list items, yielding residual measures of recency. These residual scores—namely, recall beyond what can be predicted from the preterminal position—were correlated (r = .43) in the auditory and moving box conditions. Because these correlations (i.e., r = .40 an .43) were essentially replicated in the other two studies he reported, Glenberg (in press) argued some similarity in the processing of recent auditory and dynamically presented visual information. These results suggest that finding a recency effect does not depend on temporal discrimination; the coding of time of presentation simply becomes more accurate for moving than for static events.

Visual recency would be more likely, therefore, with moving than with static visual stimuli. The question is, then, whether a finding of dynamic visual recency would be due to more accurate temporal coding (Glenberg, in press) or to an increased probability of encoding the more distinctive, dynamic, modality-dependent features (Nairne, 1990). Thus, the presence of modality-dependent features in a memory trace may predict whether recency will occur in an immediate, serial-recall task.

However, the theory that items at the end of a visually presented list are overwritten by ambient, visual interference in the performance of immediate, serial-recall tasks was not supported by these data. Recency and modality effects found here suggest that superior auditory versus visual processing of recent information may occur. Auditory recency may be due to the availability of modality-dependent features or to more accurate temporal encoding, but a mechanism is still needed to explain differences between the recent recall of auditory and visual information. Positing separate auditory and visual sensory stores through which auditory and visual information is processed over different durations is still a viable theoretical explanation of recency and modality effects found in immediate memory tasks.

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