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BRIEF COMMUNICATIONS

Effects of Auditory and Visual Interference on Auditory–Visual Delayed Matching to Sample in Monkeys (*Macaca fascicularis*)

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Two monkeys were trained on an auditory–visual (AV) delayed matching-to-sample (DMS) task with auditory cues serving as sample stimuli and visual cues serving as comparison stimuli. To determine whether the monkeys were remembering auditory or visual information during the delay period, auditory and visual interference were presented following the sample stimulus. Auditory interference had little effect on AV DMS performance. In contrast, visual interference severely impaired AV DMS performance, indicating that the monkeys were remembering visual information during the delay period. This finding may reflect a predisposition of monkeys toward remembering information via their dominant visual modality.

The information that animals remember when a delay is imposed between two events is an issue of considerable interest in comparative cognition. Take for example a delayed matching-to-sample (DMS) task in which an auditory sample stimulus (A1 or A2) is followed by a delay period, which is then followed by two visual comparison stimuli (V1 and V2). Correct responding requires that the animal choose V1 when A1 appears as the sample and V2 when A2 appears as the sample. Animals may solve this task by remembering aspects of either the auditory sample stimuli or visual comparison stimuli during the delay period, that is, they may engage in either *retrospective* or *prospective* processing (Honig & Thompson, 1982).

Although early studies of DMS behavior advocated the view that animals engaged in retrospective processing (D'Amato, 1973; Roberts & Grant, 1976), subsequent studies indicated that animals were capable of prospective processing as well (Gaffan, 1977; Roitblat, 1980). It is now recognized that adoption of retrospective or prospective processing is not an all-or-none phenomenon and is influenced by a number of factors such as memory load (Cook, Brown, & Riley, 1985), stimulus discriminability (Urcuioli & Zentall, 1986), and sample-comparison contingencies (Honig & Thompson, 1982).

Another factor that may influence processing strategy is stimulus modality. This issue surfaced indirectly in an experiment by Kraemer and Roberts (1984), who attempted to probe auditory memory in pigeons using an auditory–visual (AV) DMS task in which auditory cues served as sample stimuli and visual cues served as comparison stimuli. The fact that AV DMS performance was impaired by visual and not auditory interference, however, suggests that the pigeons were remembering visual rather than auditory information during the delay period (Herman & Forestell, 1985).

A number of studies have shown that animals display superior retention when information is processed through their dominant sensory modality. For example, visual retention is superior to auditory retention in monkeys (Colombo & D'Amato, 1986), with the reverse holding true for rats (Wallace, Steinert, Scobie, & Spear, 1980) and dolphins (Forestell & Herman, 1988; Herman, 1980; but see Herman, Hovancik, Gory, & Bradshaw, 1989, for evidence of equivalence of auditory and visual retention in dolphins). Although no study has accurately compared retention across different modalities in the pigeon, the fact that a large amount of the pigeon brain is dedicated to processing visual information suggests that vision is a dominant sense in this species (Hodos & Karten, 1974).

The evidence for modality preferences across a number of species raises the possibility that the pigeons in the Kraemer and Roberts (1984) study adopted a processing strategy that allowed for retention in their preferred visual modality. To the extent that animals choose to retain information via their dominant modality, one would predict that the visually dominant monkey would also display prospective processing when confronted with an AV DMS task. This did not appear to be the case, however, in a study by D'Amato and Salmon (1984), who argued that the absence of any effect of visual interference on AV DMS performance supported the view that the monkeys were using retrospective processing and remembering auditory information during the delay period. Unfortunately, the effects of auditory interference on AV DMS behavior were equivocal, making the case for retrospective processing tenuous.

Part of the problem may have been that the type of auditory interference used by D'Amato and Salmon (1984), monkey vocalizations, has been shown for unknown reasons to have very little effect on auditory memory (Colombo & D'Amato,

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1986). The purpose of this study was, therefore, to reexamine the effects of visual and auditory interference on AV DMS performance in monkeys using a form of auditory interference, music, that has been shown to impair auditory memory (Colombo & D'Amato, 1986). Contrary to our expectations, we noted that visual interference severely disrupted AV DMS performance whereas auditory interference had little effect. This finding suggests that the monkeys were remembering visual information during the delay period and raises the possibility that stimulus modality may indeed have a role in directing the type of processing strategy that animals adopt.

Method

Subjects

Two naive male monkeys (*Macaca fascicularis*) from the California Regional Primate Center, weighing 2.6 kg (OS) and 3.3 kg (FE) at the start of the study, served as subjects. Each monkey was housed individually and maintained on an ad libitum diet of Purina Monkey Chow supplemented with fresh fruit. Access to water was restricted to a 1 hr period approximately 2 hr following an experimental session.

Apparatus and Stimuli

All training and testing was conducted while the monkey sat in a primate chair housed inside a sound-attenuating chamber. Situated 57 cm in front of the monkey was an opaque panel. Attached to the front of the chair was a lever that served as the response mechanism. Cranberry juice (0.4 ml), delivered directly to the monkey's mouth by means of a metal spigot, served as reward.

The auditory stimuli consisted of a pulsating (3 cps) high-frequency tone and a burst of white noise that were generated by a Commodore 64 computer. The stimuli, which registered 75–80 dB as measured on the C-scale (slow-setting) of a sound level meter (Model 886, Simpson Electric, Elgin, IL), were presented via a speaker situated 40 cm above the monkey's head.

The visual stimuli consisted of a colored picture of a monkey face and a white four-lobed pattern and were backprojected at the center of the screen by means of an in-line stimulus projector (Model 80-0052-1886-A, Industrial Electronic Engineers, Van Nuys, CA). The luminances of the monkey face and four-lobed pattern were 6.2 eV and 4.1 eV, respectively, as measured by a Soligor digital spot sensor meter (Model 401, Tokyo).

Three types of interference were used. Visual interference consisted of illuminating the chamber houselight, a condition that has been shown to reliably impair visual sample stimuli and visual comparison stimuli (VV) DMS performance in monkeys (Worsham & D'Amato, 1973). Auditory interference consisted of classical music recorded onto a tape and delivered via a speaker situated on the right side of the chamber. The auditory interference was identical to that used in a previous study (Colombo & D'Amato, 1986) and ranged in intensity between 65–80 dB. To reduce habituation to the auditory interference, different portions of the tape were presented on different trials. Combined interference consisted of both visual and auditory interference presented simultaneously.

DMS Procedure

Both monkeys were trained to perform an AV DMS task with two auditory stimuli (A1 and A2) serving as sample stimuli and two visual stimuli (V1 and V2) serving as comparison stimuli. The sequence of events on a typical DMS trial was as follows. At the end of a 10-s intertrial interval (ITI), an auditory stimulus was presented and was played until the monkey pressed the lever, at which time the sample stimulus was extinguished and a variable delay period was initiated. At the end of the delay period, a visual comparison stimulus was presented for 3 s. On matching trials (A1–V1 and A2–V2), a correct response required pressing the lever during the presentation of the visual stimulus. Such responses resulted in termination of the visual stimulus, delivery of reward, and entry into the ITI. On nonmatching trials (A1–V2 and A2–V1), the correct response required withholding responses to the lever during the presentation of the visual stimulus. Such correct responses resulted in termination of the visual stimulus and entry into the ITI, but they were not rewarded.[1] Pressing on nonmatching trials and withholding presses on matching trials, both defined as incorrect responses, resulted in a 60-s time-out period. The time-out was followed by the ITI.

All sessions consisted of three blocks of 48 trials, with an equal number of matching and nonmatching trials quasi-randomly intermixed on a daily basis with the restriction that no more than four matching or four nonmatching trials appear in succession.

Training Procedure

The training procedure was similar to that adopted by D'Amato and Colombo (1985). Training consisted of three phases. In Phase 1, the monkeys were exposed for two sessions to the AV DMS task with only matching trials (A1–V1 and A2–V2). In Phase 2, the monkeys were trained with a subset of three of the four sample/comparison configurations. Training continued through three cycles with a different subset of the three sample/comparison configurations in each cycle. Monkey OS received training with both nonmatching pairs (A1–V2 and A2–V1) and only one matching pair, which in cycles 1, 2, and 3 was A1–V1, A2–V2, and A1–V1, respectively. Monkey FE, on the other hand, received training with both matching pairs (A1–V1 and A2–V2) and only one nonmatching pair, which in cycles 1, 2, and 3 was A1–V2, A2–V1, and A1–V2, respectively. In all cases, there were an equal number of matching and nonmatching trials. The criterion for advancing from one cycle to the next for monkey OS was one block with 19/24 correct matching trials and 8/12 correct on each of the nonmatching trials. For monkey FE, the criterion was one block with 19/24 correct nonmatching trials and 8/12 correct on each of the matching trials.

Finally, in Phase 3, the monkeys were trained with all four sample/comparison configurations. Once this task was learned, the delay interval, which had been set at 0.0 s throughout acquisition, was increased to 0.5 s, then to 1.0 s, and then to 9.0 s in 1.0-s increments. The criterion for advancing through the different delays was an average of at least 80% correct on each of the four trial types across three sessions. All training was conducted with the chamber houselight off.

Interference Test

Once the monkeys learned the AV DMS task with a 9-s delay, interference testing was initiated. The DMS procedure was identical to that described earlier, except that there were two delay periods, 3 s and 9 s, and four delay-interval conditions: control (houselight off, music off), visual interference (houselight on, music off), auditory interference (houselight off, music on), and combined auditory and visual interference (houselight on, music on). To reduce interactions with the sample and comparison stimuli, the interference did not begin until 1 s of the delay period had elapsed and terminated 1 s prior to the

[1] We found in many previous attempts with symmetrical reward (rewarding for correct presses *and* correct omissions) that monkeys tend to adopt a strategy of not pressing on any trial.

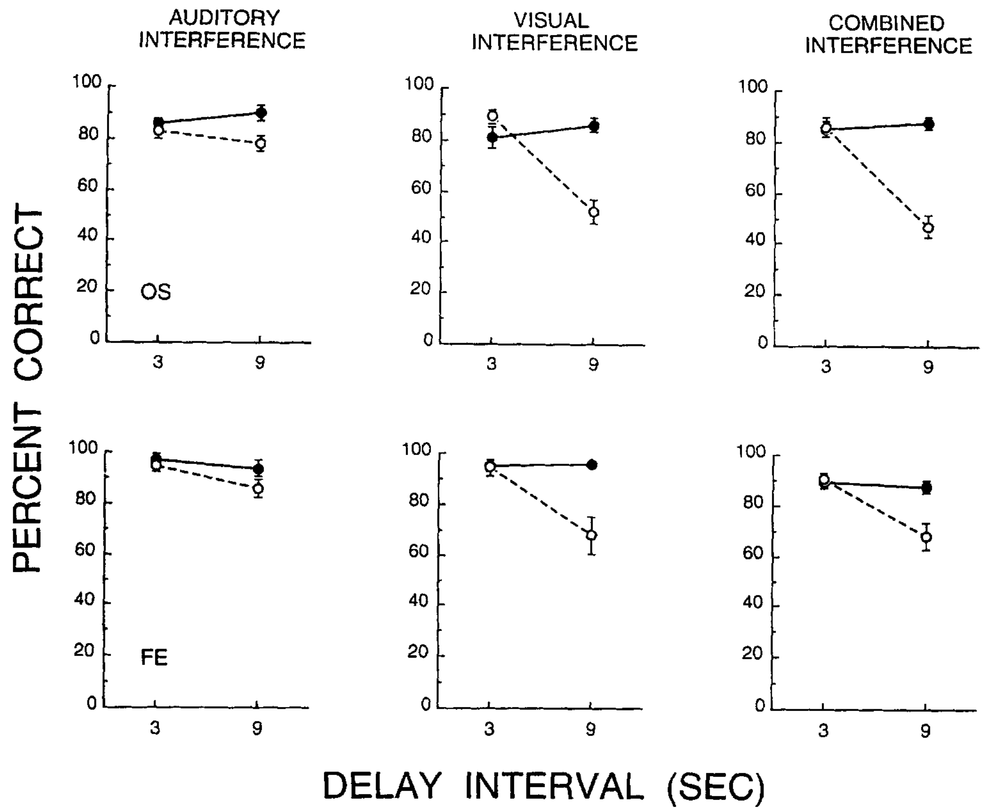

Figure 1. The effects of auditory, visual, and combined interference on auditory–visual delayed matching-to-sample performance in Monkeys OS and FE. The control gradients are indicated by solid lines, and the interference gradients are indicated by dashed lines. Each data point is based on 128 trials.

end of the delay period. Effectively, the first second and the last second of the delay period were similar to the control condition.

Each session consisted of 96 trials. The first 32 trials served as warm-up trials and consisted of an equal number of quasi-randomly intermixed 3-s and 9-s delay control trials. The next 64 trials consisted of 32 control and 32 interference trials quasi-randomly intermixed with 16 3-s control trials, 16 9-s control trials, 16 3-s interference trials, and 16 9-s interference trials. The three interference conditions were manipulated as between-sessions variables.

The monkeys were tested for 30 sessions, 10 for each interference condition quasi-randomly intermixed, with the first 2 sessions in each interference condition used to introduce the subject to the interfering stimuli and, therefore, not included in the data analysis.

Results

The effects of auditory, visual, and combined interference on AV DMS performance for both monkeys are shown in Figure 1. Of the three forms of interference, it is clear from the figure that visual and combined interference resulted in the greatest impairments in AV DMS performance.

To determine which type of interference impaired AV DMS performance, a two-way analysis of variance (ANOVA) with delay (3 s and 9 s) and delay condition (control and interference) as factors was applied to each monkey's auditory, visual, and combined interference data. A significant delay-condition effect would indicate that the interference affected overall AV DMS performance, that is, affected performance equally at both the short and long delay periods. A significant Delay-Condition × Delay interaction effect, on the other hand, would indicate that the interference affected the rate of forgetting, that is, the slope of the interference gradient would be different from the slope of the control gradient. For monkey OS, auditory interference, $F(1, 28) = 7.37$, $p < .05$, visual interference, $F(1, 28) = 12.73$, $p < .01$, and combined interference, $F(1, 28) = 31.89$, $p < .01$, all impaired overall AV DMS performance; however, only visual interference, $F(1, 28) = 32.83$, $p < .01$, and combined interference, $F(1, 28) = 34.44$, $p < .01$, but not auditory interference ($p = .13$), resulted in faster rates of forgetting on the AV DMS task.

For monkey FE, only visual and combined interference resulted in both overall impairments, $F(1, 28) = 11.62$, $p < .01$, and, $F(1, 28) = 7.42$, $p < .05$, respectively, and faster rates of forgetting, $F(1, 28) = 10.39$, $p < .01$, and, $F(1, 28) = 10.23$, $p < .01$, respectively, on the AV DMS task. Auditory interference did not affect either aspect of AV DMS performance (overall, $p = .10$; rate of forgetting, $p = .36$).

There was also no indication that combining auditory and visual interference impaired AV DMS performance more than visual interference alone. A two-way ANOVA with delay (3 s and 9 s) and interference type (visual and combined) revealed no difference between the two interference gradients for either monkey OS ($p = .29$) or monkey FE ($p = .70$), suggesting that the impairments observed with combined interference were due mostly, if not completely, to the visual interference.

Discussion

For both monkeys, AV DMS performance was substantially more impaired with visual rather than auditory interference. It seems unlikely that these results are due to the auditory interference being simply less disruptive than the visual interference. The reason is that the exact same auditory interference used in this experiment has been shown in a previous experiment to severely impair auditory sample stimuli and auditory comparison stimuli (AA) DMS performance, whereas the same visual interference used in this experiment had no effect on AA DMS performance (Colombo & D'Amato, 1986).

The results of this experiment suggest that the monkeys were remembering visual information during the delay period. Whether this visual information represents the physical characteristics of the comparison stimuli, or whether the visual information represents a visual code unrelated to the physical characteristics of the comparison stimuli, remains unclear (see Colombo & Gross, 1994, for further discussion of this point). Nevertheless, converting the auditory sample stimuli to some visual trace might reflect, as pointed out earlier, the monkeys' predisposition to remember information via their dominant visual modality.

An alternative possibility is that the contingencies of the successive DMS task used in this experiment were such that it favored the use of prospective processing irrespective of sensory modality. This possibility may be tested by training monkeys on a procedurally identical VA DMS task in which visual cues serve as the sample stimuli and auditory cues serve as the comparison stimuli. If indeed stimulus modality is a factor affecting processing strategy, then we would again expect visual and not auditory interference to impair performance. On the other hand, if the contingencies of the task merely favor prospective processing, then auditory and not visual interference ought to impair performance.

Finally, Herman and Forestell (1985) have suggested that under certain conditions the delay code may take the form of an amodal representation and become stripped of the modality of the sample and comparison stimulus. This might explain why the AV DMS performance of the monkeys in the D'Amato and Salmon (1984) study, which were quite sophisticated with respect to DMS behavior, was not affected by visual interference. Thus, future studies should aim towards unraveling not only the weights that animals assign to the variables that affect retrospective and prospective processing but also the conditions under which modality information is discarded in favor of a more "general" code.

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