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Choice Criterion Effects in the Radial-Arm Maze: Maze-Arm Incline and Brightness

MICHAEL F. BROWN AND KATARZYNA B. LESNIAK-KARPIAK

Villanova University

Male rats were tested in a radial-arm maze in which the maze-arms differed in terms of surface brightness (black vs white) and incline (flat vs inclined such that the end of the arm was elevated). Errors were more likely to black arms than to white arms and to flat arms than to inclined arms. Application of signal detection theory to the go/no-go decisions made regarding individual maze-arms indicated that these effects were due, at least in large part, to differences in the choice criterion applied to maze-arms. These results increase the range of variables that have been shown to affect choice accuracy in the radial-arm maze by influencing a choice criterion. They suggest that more caution should be applied in attributing effects on spatial performance to memory processes. © 1993 Academic Press, Inc.

The radial-arm maze task is often characterized as measuring properties of spatial *memory* (e.g., Olton, 1978). Although it seems quite clear that memory structures and processes critically determine performance, relatively little experimental and theoretical attention has been devoted to other determinants of radial-arm maze performance. Recent work from our laboratory (Brown, 1990; Brown & Huggins, in press; Brown, Wheeler, & Riley, 1989) has explored choice criterion effects as one such factor. In this context, choice criterion effects refer to differences in the tendency or bias to visit maze-arms that are independent of memory for previous arm visits.

Brown (1990) found that maze-arms that were shorter than those normally used in the radial-arm maze produce low levels of choice accuracy. He suggested and provided initial evidence that this effect was due not to an effect of maze-arm length on memory ability, but rather to a difference in the choice criterion applied to long and short maze-arms. That

This research was supported by national Institute of Mental Health Grant MH45004.
Correspondence and reprint requests should be addressed to Michael F. Brown, Department of Psychology, Villanova University, Villanova, PA 19085. Electronic mail: brownmf@vuvaxcom.bitnet.

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is, rats apply a relatively lax choice criterion to shorter maze-arms and are therefore more likely to revisit them.

Support for this explanation of the effect of maze-arm length on choice accuracy was recently provided by Brown and Huggins (in press). This evidence came in the form of detailed measures of the behavior of rats in the central arena of the maze as they chose from among the 12 arms of the maze. Specifically, the *microchoices* of rats were measured. Microchoices are instances of visual orientation toward maze-arms that result either in an arm visit (macrochoice) or in rejection of the arm. Brown (1992, in press) has developed a theory of spatial choice in the radial maze that includes the proposal that independent go/no-go decisions are made regarding individual maze-arms, and that microchoices are the behavioral expression of these decisions. Given this, microchoices can be analyzed using the logic of signal detection theory (SDT; Macmillan & Creelman, 1991). If the target of a microchoice is an unvisited (baited) maze-arm, then a visit constitutes a *hit* and a rejection constitutes a *miss*. A visit and rejection when the target of a microchoice is a previously visited (unbaited) arm constitutes a *false alarm* and *correct rejection*, respectively. These microchoice outcomes can be used to determine discriminability (d'; i.e., the ability of rats to discriminate baited and unbaited arms, presumably on the basis of memory) and choice criterion (β, i.e., the tendency of the rat to visit as opposed to reject the arm independently of the correct response). Thus, the logic of SDT can be used to separate effects resulting from differences in the accuracy of memory (d') from effects resulting from (nonmemorial) criterion effects. As explained by Banks (1970):

> The application of SDT to memory depends on conceiving of a memory trace as a signal that the subject must detect in order to perform in a retention task. Given this conception of memory performance, it is reasonable to assume that percentage correct scores may be biased indicators of retention—just as thresholds may be biased indicators of sensory performance—and, in addition, that SDT techniques should be used where possible to separate the truly retention-based aspects of memory performance from the decision aspects. (p. 82).

In Brown and Huggins' (in press) experiment, a 12-arm maze with 6 standard length (long) arms and 6 short arms was used. Using the analysis outlined above, it was determined that there is no difference in rats' ability to discriminate baited and unbaited arms as a function of arm length. However, a more lax choice criterion is applied to short arms than to long arms. This supports the idea that lower levels of choice accuracy resulting from the use of short maze-arms are a function of a choice criterion difference rather than a difference in memory ability.

The results presented below extend the list of variables that affect choice accuracy in the radial-arm maze by affecting the choice criterion applied to maze-arms. The two variables examined are the brightness of the maze-arm surface (black versus white) and incline of the maze-arm (flat versus angled upward from the central arena). The results show that both of these variables produce a marked effect on choice accuracy (i.e., the probability of revisiting the maze-arm) and that both do so, at least in large part, by modulating the choice criterion applied to maze-arms. Thus, these results point out the generality of the view that choice criterion effects are important for understanding spatial performance.

EXPERIMENT 1

The first experiment was intended to further elucidate the effect of maze-arm length on the choice criterion applied to maze-arms. A number of differences between short and long maze-arms can be identified (Brown & Huggins, in press). Visits to standard length (long) maze-arm require more effort, time, and possibly fear (if it is assumed that elevated maze-arms elicit fear) than do visits to short maze-arms. Perhaps one or more of these factors can account for the relatively strict choice criterion that is applied to long maze-arms. One variable that might affect the level of effort, time, and fear associated with maze-arms is the vertical tilt of maze-arms. With the exception of the recent experiment of Grobéty and Schenk (1992), radial-arm mazes have flat surfaces. However, it is possible to incline the maze-arms by hinging them at the junction of the central arena and the maze-arm such that rats must travel "uphill" to the end of the arm (and "downhill" back to the central arena). When Grobéty and Schenk used an 8-arm maze with arms that had a variety of such inclines, they found a small enhancement of choice accuracy relative to a standard maze. It is possible that this difference was produced by the same mechanism as the effect of maze-arm length; i.e., by a difference in the choice criterion applied to arms as a function of vertical incline. In other words, the effects of arm length and arm incline may be mediated by the same underlying process.

In order to explore the possibility that arm incline affects a choice criterion, we examined performance in a 16-arm maze that had arms equal in length to the short maze-arms used by Brown (1990) and Brown and Huggins (in press). Eight of the arms were flat (as in a standard radial-arm maze) and eight of them were inclined. Importantly, we followed the lead of these earlier experiments in providing an additional cue as to the status of individual maze-arms. In the earlier experiments using short and long maze-arms, the short arms were painted white and the long arms were painted black. The brightness difference was intended to provide a means for discriminating short and long arms as it is unknown whether arm length can be directly discriminated from the central arena. It is well known that rats "prefer" black to white surfaces and thus the assignment of white to short arms was designed to work against the predicted (and obtained) result that a more lax choice criterion would be applied to short arms. In order to conform to the logic and procedure of these earlier experiments, inclined arms were painted black and flat arms were painted white in the present experiment. Thus, any evidence for lower levels of choice accuracy to flat arms than to inclined arms would be obtained *despite* the assumed preference for black arms.

Method

Subjects. The subjects were 16 male Sprague–Dawley rats, obtained as weanlings from Harlan–Sprague–Dawley, Inc. They were experimentally naive and approximately 4 months old at the beginning of this experiment. Their diet was restricted to 13 g of Purina Rat Chow daily for approximately 2 weeks prior to the introduction to the experimental procedures and throughout the experiment. They were housed in groups of four, and were transported daily between the colony and laboratory. Individual rats were identified by tail marks. Experimental sessions were conducted during the dark phase of a 12:12 light:dark cycle.

Apparatus. The apparatus was a 16-arm radial maze constructed of 1.5-cm-thick plywood. The circular central arena of the maze was 60 cm in diameter. The arms were 10 cm wide and 40 cm in length. Holes (approximately 1 cm in diameter and 1 cm deep) were centered 2.5 cm from the end of each arm, and served as the food cups. If the 16 arms are considered to be numbered consecutively in a clockwise fashion, then arm numbers 1, 2, 3, 6, 8, 10, 11, and 15 were painted black, whereas the remaining arms (as well as the central arena) were painted white. Black fiberglass screening material was attached to the surface of each black arm, to increase traction when the arms were inclined. A wooden wall was attached to one edge of each arm to prevent the rats from jumping from arm to arm without returning to the central arena. These walls extended for 19 cm from the central arena at a height of 11 cm, and an additional 18 cm at a height of 5 cm. Maze-arms were attached to the central arena with a hinge which allowed them to be inclined such that the end of the arm was elevated.

The maze was elevated 57 cm above the floor of the experimental room. The room was 4.4 × 3.1 m, and contained a number of salient extramaze stimuli. It was illuminated by two fluorescent tubes. A convex mirror was located above the maze and was used in recording behavior using a videocamera.

Pretraining procedure. During the first 3 days of exposure to the experimental apparatus, rats were placed in the apparatus in groups of four (cagemates). Forty-five-milligram sucrose pellets (BioServe, Inc.) were located in the food cups, on the arms of the maze, and in the central arena. Rats were left in the apparatus until all the pellets were consumed. All maze-arms were flat during this phase.

No incline training. Beginning on Day 4, rats were trained individually in a free choice procedure for one session per day. Prior to each session, two pellets were placed in each food cup. All maze-arms were flat during this phase. The rat was placed in the central arena, and allowed to choose arms until all 16 arms had been visited, 31 choices had been made, or 12 min had elapsed. A choice was defined as the rat's nose crossing the plane defined by the end of the taller section of wall along the edge of the arm (i.e., 19 cm from the central arena). The experimenter recorded the sequence of arms chosen. The rats were trained in this free choice procedure until 30 successful sessions were completed (i.e., all 16 arms were visited within 12 min).

Half-height incline training. The 8 black maze-arms were inclined such that the end of the maze-arm was 8 cm above the surface of the central arena (incline pitch = 11.5°). The rats were trained under these conditions using the same procedure described above until 20 successful sessions had been completed.

Testing. The 8 black maze-arms were inclined such that the end of the maze-arm was 16 cm above the surface of the central arena (incline pitch = 23.6°). The rats were tested under these conditions using the same procedure described above for 20 sessions.

Results and Discussion

For reasons that are explained below, only 12 rats were tested during the test phase of Experiment 1. During this test, there were three instances of a rat not completing the maze within the required 12 min and 2 instances of a rat not completing the maze within the required 31 choices. Not counting these sessions, the maze was completed in a mean (over rats) of 18.7 choices.

In contrast to our expectation, errors during the test phase were more likely to occur to inclined maze arms than to flat maze-arms. Figure 1 shows the probability of one or more revisits to short and long maze-arms as a function of the ordinal position of the initial visit to that arm. It is important to note that inclusion of the ordinal position of initial visits controls for effects that might be due to a tendency to visit one arm type earlier or later in the choice sequence. A repeated-measures Analysis of Variance (ANOVA; Initial Choice Number X Arm Length) revealed that arms initially visited earlier in the choice sequence were more likely to be revisited ($F(14, 154) = 10.8$, $p < .001$). The more critical result is the confirmation that inclined (black) arms were more likely to be revisited than flat (white) arms $F(1, 11) = 27.4$, $p < .001$). The effects of these two variables did not interact ($F(14, 154) < 1$).

One obvious explanation for the unexpected pattern of results is the confounding of arm incline and arm brightness included in the experimental design. As indicated above, this confound was included to conform

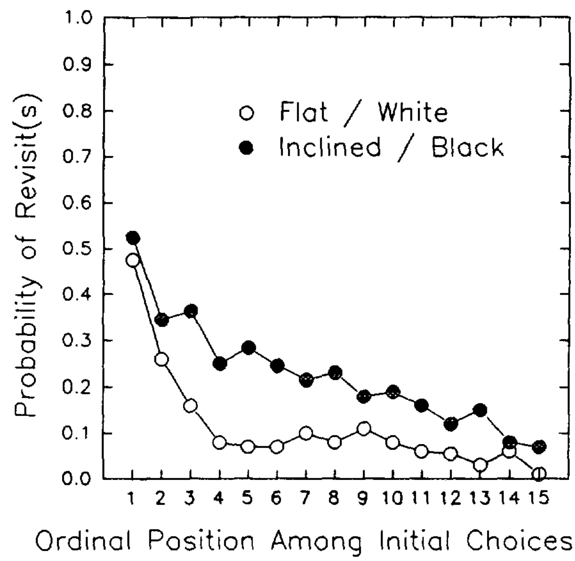

FIG. 1. The probability of one or more revisits to maze-arms as a function of the ordinal position of the initial choice to the arm during the Test Phase of Experiment 1. Values for flat (white) and inclined (black) maze-arms are shown separately.

to the earlier procedure of Brown (1990; Experiment 3) and Brown and Huggins (in press), who found more revisits to short arms than to long arms despite the fact that the long arms were black and the short arms were white. Thus, it appears that the effect of arm length in the earlier experiments was large enough to overcome any effect of arm brightness. However, assuming that arm incline does produce the effect predicted above, perhaps its effect is not strong enough to overcome an effect of arm brightness.

In order to explore this possibility, data from the last 15 sessions of the "no-incline" training phase of the present experiment were examined. During this phase, all 16 maze-arms were flat, but 8 were black and the remaining 8 were white. Figure 2 shows these data, analyzed in the same manner as the data from the test phase. An ANOVA confirmed that arms chosen earlier in the choice sequence were more likely to be revisited ($F(14, 210) = 17.0$, $p < .001$), and that black arms were more likely to be revisited than white arms ($F(1, 15) = 28.4$, $p < .001$). A reliable interaction between the effects of these variables was also found ($F(14, 210) = 1.9$, $p < .05$).

Four rats that were being trained in the "half-height inclined training" phase when the importance of the confound between incline and brightness became clear were not tested in Experiment 1, but were placed directly

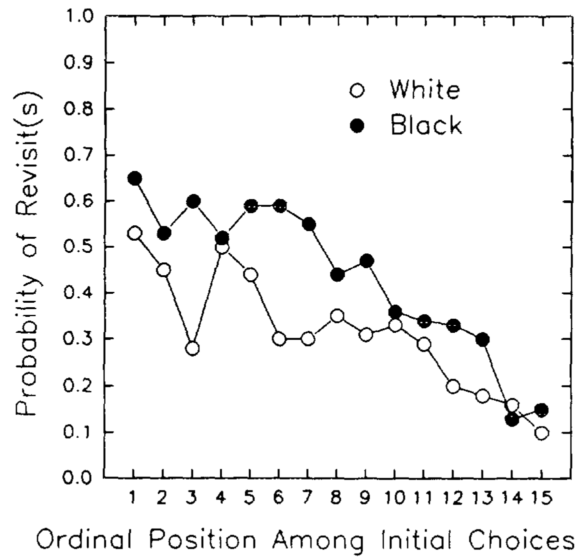

FIG. 2. The probability of one or more revisits to maze-arms as a function of the ordinal position of the initial choice to the arm during the no-incline training phase of Experiment 1. Values for white and black maze-arms are shown separately.

into Experiment 2 following the completion of half-height inclined training.

The present results show that the provision of arm surface brightness as a cue to the incline of a maze-arm has effects on performance of its own. This means that in order to understand the effect of arm incline, it must be manipulated independently of arm brightness. The results also raise the question of the nature of the effect of arm brightness. Just as in the case of arm length and arm incline, any effect of arm brightness on choice accuracy might be due to an influence on the ability of rats to discriminate visited and unvisited maze-arms or to a choice criterion effect. Experiment 2 examines these issues. It should also be noted that the results of the present experiment suggest that the effects of arm length reported by Brown (1990; Experiment 3) and Brown and Huggins (in press) may be larger than estimated given the effect of arm brightness reported here.

EXPERIMENT 2

Experiment 2 was designed to unconfound the effect of arm incline and arm brightness by manipulating them in a factorial manner. The maze was modified such that there were four arms each of four types: flat black, flat white, inclined black, and inclined white. The rats were tested in two phases, the first being a standard free choice procedure in which all 16 maze-arms were freely available. The second phase was a forced-choice procedure in which 8 maze-arms (2 of each type) were randomly selected, and access to only one at a time was allowed. Subsequently, the rat completed the maze by selecting from among the 16 arms until all arms had been visited. This forced-choice procedure controls for the possibility that certain arm types tend to be visited early in the choice sequence, and that such order effects contribute to any differences in errors to the different arm types. In both phases, the free choices were videotaped, and microchoices were coded from these videotapes. Microchoice outcomes were used to determine d' and β for the four types of maze-arms.

Method

Subjects. The subjects were the same 16 rats that participated in Experiment 1, maintained in the same manner.

Apparatus. The apparatus used in Experiment 1 was modified in several ways. The spatial locations of the flat and inclined arms remained the same as in the earlier experiment. However, four flat arms were changed from white to black in brightness and four inclined arms were changed from black to white. If the 16 arms are considered to be numbered consecutively in a clockwise fashion, then arm numbers 4, 5, 9, and 14 were flat and black, arm numbers 7, 12, 13, and 16 were flat and white, arm numbers 1, 3, 8, and 10 were inclined and black, and arm numbers 2, 6, 11, and 15 were inclined and white. The textured surface located on the inclined arms during Experiment 1 was not present during Experiment 2. A 18-cm-tall × 10-cm-wide metal panel was located at the entrance to each arm. Each panel had a 7.8-cm-diameter hole which allowed access to the maze arm. The hole could be covered with a metal door, which slid in a vertical track and was controlled by the experimenter using a string and pulley system. This allowed access to maze arms to be individually controlled.

Free-choice phase. Sessions during the free-choice phase of the experiment were identical to those during the test phase of Experiment 1, except for the properties of the maze described above. The doors to all 16 arms were open throughout this phase of the experiment. Twenty-five sessions were conducted.

Sessions were videotaped via the mirror above the apparatus. The camera's field of view did not include the food cups at the ends of the maze-arms. Thus, the coder could not see whether the food cup was baited. A microchoice was defined as "clear orientation toward the end of an arm that was accompanied either by a discernable stop in the motion of the rat or by a macrochoice." Results presented below are based on the coded data provided by the primary coder, who was naive regarding the specific theoretical predictions being tested. A second coder coded the first 10 sessions of the present experiment, in order to allow interrater reliability to be established.

Forced-choice phase. The rats were then tested using a forced-choice procedure. A randomly ordered sequence of 8 maze-arms, 2 of each type, was chosen for each session. The rat was placed in the central arena with the doors to all 16 maze arms closed. After approximately 5 s, the door to the first arm in the sequence was opened. While the rat visited that arm, the door to the second arm was opened. Thereafter, as the rat visited each arm in the sequence, the door to the previous arm was closed and the door to the next arm was opened. Following its return to the center after the eighth choice, the rat was removed from the maze and placed in a holding cage, distinct from the home cages in size and construction. The rat was kept in this cage while the experimenter opened the arms to all 16 maze-arms (approximately 20 s).

After this interruption, the rat was returned to the central arena. All maze-arm doors were open and only the eight unvisited arms were baited. The rat was allowed to make choices until all baited arms were visited or until 5 min elapsed without a choice. The behavior of the rat was videotaped during these free choices. Rats completing the experiment continued this procedure until 15 sessions were completed.

Results and Discussion

Free-choice phase. Initial data analysis indicated that there was little or no carryover effect from the brightness status of the arms during Experiment 1. That is, results for arms that had been changed in brightness relative to Experiment 1 did not differ systematically from arms that had not changed in brightness. Therefore, this factor is not included in the data analyses presented below.

Figure 3 shows the mean number of errors per session to arms of the four types. An ANOVA showed that more revisits occurred to black arms than to white arms ($F(1, 15) = 9.1$, $p < .01$), and that more revisits occurred to flat arms than to inclined arms ($F(1, 15) = 9.0$, $p < .01$). The effects of these variables did not interact ($F(1, 15) < 1$).).

Interrater reliability of coded microchoices was calculated only for those microchoices resulting in rejection of the maze-arm, because there is no ambiguity in microchoices resulting in arm visits (macrochoices). As in earlier experiments in which microchoices were measured (Brown, 1992; Brown & Huggins, in press), interrater reliability was high. Of the arm rejections coded by the primary coder, a mean (over rats) of 94.2% were also coded by the secondary coder. One rat produced a very small number of arm rejections (a total of 2). Data from this rat were not included in the microchoice analysis and this rat did not participate in the forced-choice phase of the experiment.

Figure 4 shows the microchoice data from the free-choice phase. The

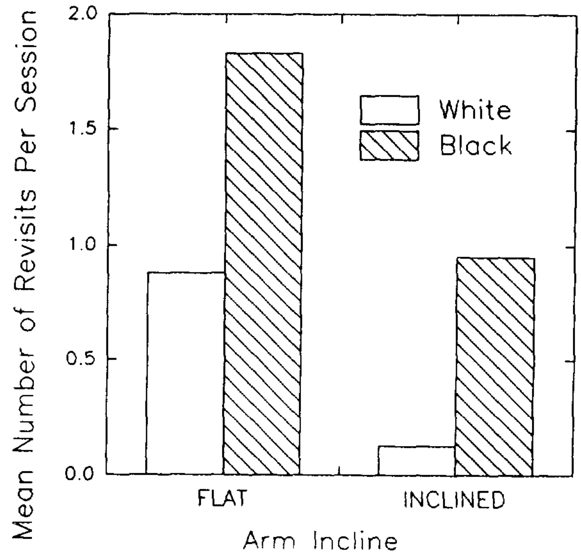

FIG. 3. The mean number of errors per session during the free-choice phase of Experiment 2 as a function of the brightness and incline of maze-arms.

top panel shows the mean hit rate and correct rejection rate for the four arm types. These data are best interpreted by converting them to d' and log β, the standard measures of discriminability and bias, respectively (e.g., Macmillan & Creelman, 1991). The middle panel shows d' as a function of arm incline and arm brightness. An ANOVA revealed that baited and unbaited arms were better discriminated when the arms were flat than when they were inclined ($F(1, 14) = 7.8, p < .05$). Discrimination was also better when the arms were black than when they were white ($F(1, 14) = 4.8, p < .05$). There was also a significant interaction between these effects ($F(1, 14) = 5.4$, $p < .05$). The bottom panel shows the results in terms of log β. Higher values indicate a tendency to reject arms (rather than visit them), while lower values indicate a tendency to accept (visit) arms. Rats rejected white arms at higher levels than those of black arms ($F(1, 14) = 30.0$, $p < .001$) and rejected inclined arms at higher levels than those of flat arms ($F(1, 14) = 38.3$, $p < .001$). These effects did not interact ($F(1, 14) = 1.3$).

These results make it clear that the differences in choice accuracy to the various arm types were not a result of differences in the ability of rats to discriminate visited and unvisited arms as a function of arm brightness or arm incline. In fact, the small but reliable differences in d' were in opposition to the choice accuracy results. Rats revisited black arms more often than white arms and flat arms more often than inclined arms.

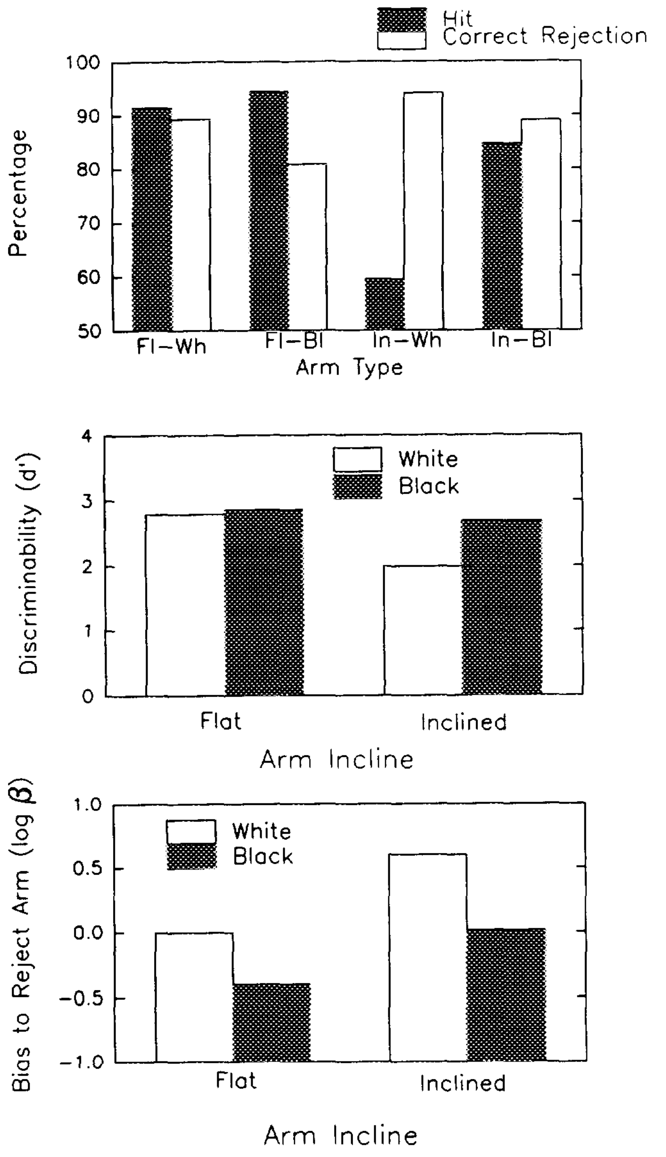

FIG. 4. Microchoice outcome data from the free-choice phase of Experiment 2. Top: Mean hit rate and correct rejection rate as a function of arm type. Middle: Mean values of d' as a function of the brightness and incline of maze-arms. Bottom: Mean values of log β as a function of the brightness and incline of maze-arms. (Note: Fl, flat; In, inclined; Wh, white; Bl, black).

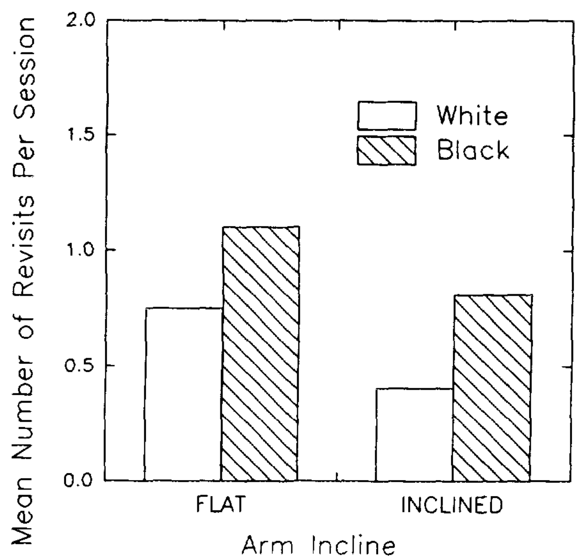

FIG. 5. The mean number of errors per session during the forced-choice phase of Experiment 2 as a function of the brightness and incline of maze-arms.

However, the microchoice analysis shows that discrimination ability was somewhat higher for black arms than for white arms, and for flat arms than for inclined arms. Thus, the explanation for the choice accuracy results is to be found in the relatively strict choice criterion applied to white and inclined arms, and not to a difference in the ability of rats to discriminate previously visited arms and unvisited arms as a function of arm type.

Forced-choice phase. The performance of seven rats was greatly disrupted by the introduction of the forced-choice procedure. These rats "timed-out" (i.e., 5 or more minutes elapsed without a choice) repeatedly. A number of techniques were unsuccessfully used in an attempt to train these rats in the forced-choice procedure; however, all seven were eventually dropped from the experiment. The data presented below represent the remaining eight subjects.

Data from the forced-choice phase were analyzed in the same manner as data from the free-choice phase, except that microchoices were measured only for the free choices made following the first eight (forced) choices. Figure 5 shows the mean number of errors per session to arms of the four types. An ANOVA showed that more revisits occurred to black arms than to white arms ($F(1, 7) = 31.3, p < .001$) and that more revisits occurred to flat arms than to inclined arms ($F(1, 7) = 7.6, p < .05$). The effects of these variables did not interact ($F(1, 7) < 1$).

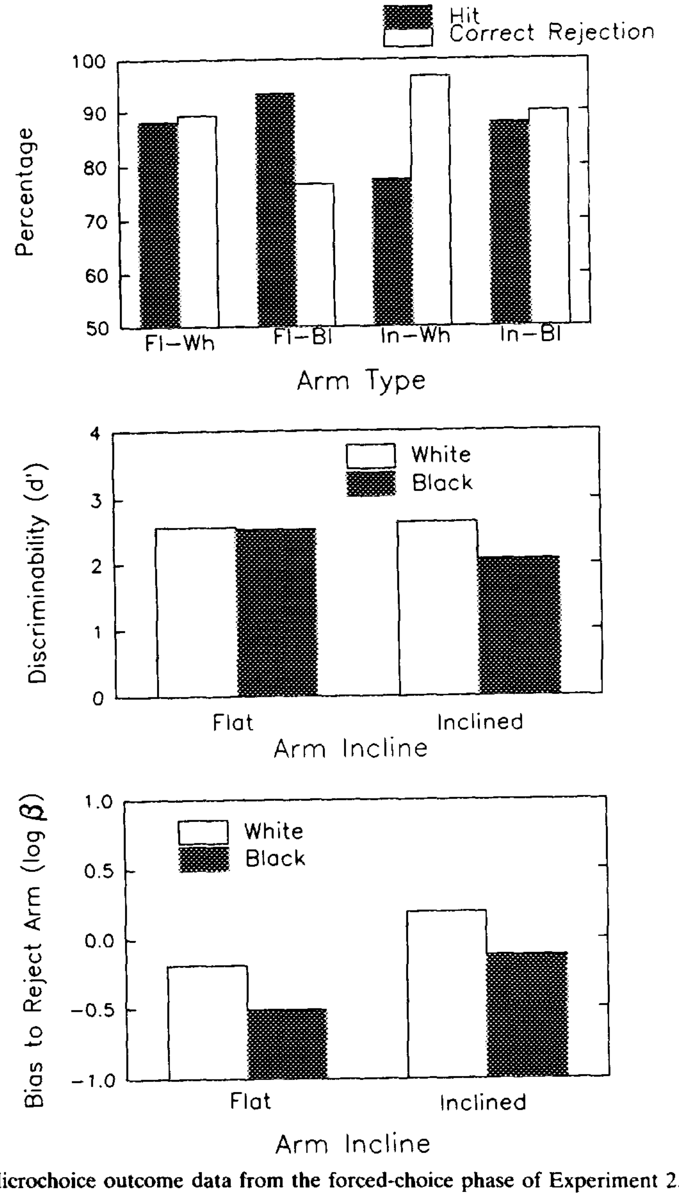

FIG. 6. Microchoice outcome data from the forced-choice phase of Experiment 2. Top: Mean hit rate and correct rejection rate as a function of arm type. Middle: Mean values of d' as a function of the brightness and incline of maze-arms. Bottom: Mean values of log β as a function of the brightness and incline of maze-arms. (Note: Fl, = flat; In, inclined; Wh, white; Bl, black).

Figure 6 shows the microchoice data from the forced-choice phase in a manner that is identical to the corresponding data from the free-choice phase. In terms of d', there was no effect of arm incline ($F(1, 7) = 2.6$). White arms produced higher levels of d' than black arms ($F(1, 7) = 15.0$, $p < .01$). There was no significant interaction between the effects of these variables ($F(1, 7) = 3.5$). In terms of log β, white arms appeared to result in a higher level of arm rejections than did black arms; however, this effect did not quite reach the accepted threshold of statistical reliability ($F(1, 7) = 5.44$, $p = .052$). Inclined arms resulted in a higher level of arm rejections than did flat arms ($F(1, 7) = 7.4$, $p < .05$). The effects of these two variables did not interact ($F(1, 7) < 1$).

The forced-choice procedure allows any effects of the order in which arms are initially visited to be controlled. That is, in the free-choice procedure, rats are free to visit some classes of arms earlier in the choice sequence than other classes of arms, and this order may influence choice accuracy. In the forced-choice procedure, the first eight choices are randomized with respect to the arm types. Unfortunately, the forced-choice procedure resulted in relatively high attrition of rats from the experiment, thereby decreasing both the statistical power of the experimental design and our ability to compare results from the two phases.

However, the results of the forced-choice phase are largely in agreement with those of the free-choice phase. More errors occurred to black arms than to white arms and more errors occurred to flat arms than to inclined arms. These effects are apparently independent, in that there was no evidence of an interaction between them. Perhaps the most puzzling result in this report is that, in direct opposition to the results from the free-choice phase, discrimination ability in the forced-choice phase was better for white arms than for black arms. The explanation for this is unclear. Although the effect of arm brightness on log β was not quite significant, it was in the same direction as the significant result found in the free-choice phase. Thus, we conclude that white maze-arms do consistently result in a stricter choice criterion than black maze-arms. Given the inconsistent effect of arm brightness on d', we further conclude that this choice criterion difference provides at least a large portion of the explanation for the effect of brightness on choice accuracy.

The results of the forced-choice phase with respect to the effects of maze-arm incline were also largely in agreement with those of the free-choice phase. Unlike the results of the free-choice phase, there was no reliable effect of arm incline on d'. However, in agreement with the results of the free-choice phase, a stricter choice criterion was applied to inclined arms than to flat arms. Thus, taken as a whole, these results indicate that choice criterion effects provide at least part of the explanation for the effect of both maze-arm brightness and incline on choice accuracy.

GENERAL DISCUSSION

The present results show that maze-arm length is not unique in affecting choice accuracy in the radial-arm maze by modification of the choice criterion applied to arms. Maze arm brightness and incline also affect choice accuracy, and do so at least in large part by modification of the choice criterion. It is important to emphasize that differences in choice accuracy that were a function of differences in the ability of rats to discriminate visited and unvisited maze-arms would be indicated by corresponding differences in d'. With the exception of the effect of arm brightness in the forced-choice phase of Experiment 2, no evidence for this was obtained. Thus, under the present conditions, choice accuracy differences appear to be primarily accounted for by choice criterion differences. It should be kept in mind that the effects reported here were found in a maze with short arms. Because of the relatively large number of errors made in mazes with short arms, this may have provided a more sensitive context in which to measure the effects of these variables. Whether these effects of brightness and incline would be found in a maze with standard length arms remains to be determined.

The precise aspects of brightness and incline that produce the effect on choice criterion also remain to be determined. In the case of inclined maze-arms, additional effort, time to reinforcement, and fear may correspond to arm visits, just as has been suggested to be the case for long maze-arms relative to short ones (Brown & Huggins, in press). Any of these factors might be expected to produce a relatively strict choice criterion. In the case of arm brightness, rats' well-known "preference" for dark areas is presumably related to the choice criterion effect found in the present experiments. This preference may itself be based on fear.

The effects of maze-arm incline and brightness may be similar in some respects to several previously reported effects. Batson, Best, Phillips, Patel, and Gilleland (1986) showed that maze-arms that contained reinforcers that had been devalued by pairing them with lithium-induced illness came to be visited later in the choice sequence. Furthermore, a maze-arm that contained a preferred reinforcer (chocolate milk) came to be visited earlier in the choice sequence when the rats were both food- and water-deprived. Melcer and Timberlake (1985) also reported that rats would avoid maze-arms that consistently contained saccharin, when saccharin had been paired with injections of lithium. Dallal and Meck (1990) reported that sets of consistently located maze-arms baited with different reinforcers resulted in arms within a set being visited in sequence. That is, visits to arms baited with a particular reinforcer tended to be followed by visits to arms baited with the same reinforcer. Dallal and Meck attributed this effect to an active memory "chunking" process. However, at least part of the effects reported in all three of these previous studies might be characterized as due to choice criterion effects. That is, a relatively strict or lax choice criterion may be applied to maze-arms as a function of the hedonic value of the reinforcer located on the arm. This hypothesized difference in choice criterion is one way of understanding the process that leads to the avoidance of particular maze-arms.

The radial-arm maze has become a standard paradigm not only for the study of basic cognitive processes underlying spatial performance, but also in behavioral pharmacology (e.g., Olton, 1987), functional neuroanatomy (e.g., Kesner, 1986), behavioral endocrinology (e.g., Williams, Barnett, & Meck, 1990), and other areas of psychobiology. There is often a tendency to attribute the effects of the variables studied to working memory processes, with little consideration of the possibility that cognitive processes other than memory might play an important role. Some controversies in the literature might be resolved by consideration of the role of choice criterion effects. For example, it has been reported that scopolamine adversely affects radial-arm maze performance (Eckerman, Gordon, Edwards, MacPhail, & Gage, 1980; Watts, Stevens, & Robinson, 1981). However, it has also been argued that scopolamine's effects do not indicate a memory effect per se, but rather indicate a "performance effect" (Godding, Rush, & Beatty, 1982; see Beatty & Rush, 1983, for a similar analysis of the effects of *d*-amphetamine). Choice criterion effects provide one specific hypothesis about the nature of such nonmemorial effects on spatial performance. In fact, Eckerman et al. provide data which encourage the possibility that scopolamine affects a choice criterion. In addition to the standard measure of choice, they measured "abbreviated arm entrances" in which rats broke the plane of the arm entrance but did not enter the arm. This behavior is similar to the "microchoices" measured in our laboratory. Eckerman et al. found that scopolamine reduced the rate at which these abbreviated arm entrances occurred, which can be interpreted as indicating a relatively lax choice criterion (fewer arm rejections).

Perhaps the most important implication of the present results is that effects of variables on spatial performance in the radial-arm maze should not be attributed to memory ability without converging evidence that it is memory rather than some other cognitive process that underlies the effect. The present results together with those of Brown and Huggins (in press) and Brown et al. (1989) indicate that the effects of a number of variables on spatial performance are mediated not by working memory quality, but rather by differences in the choice criterion applied to maze-arms. More precise determination of the mechanisms of spatial performance will require that this be kept in mind.

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