

# Hemispheric Asymmetry in Categorical Versus Coordinate Visuospatial Processing Revealed by Temporary Cortical Deactivation

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## Abstract

■ Kosslyn (1987) proposed that the left hemisphere is better than the right hemisphere at categorical visuospatial processing while the right hemisphere is better than the left hemisphere at coordinate visuospatial processing. In 134 patients, one hemisphere (and then usually the other) was temporarily deactivated by intracarotid injection of sodium amobarbital. After a hemisphere was deactivated, a cognitive test battery was conducted, which included categorical and coordinate visuospatial tasks. Using this technique, the processing capabilities of the intact hemisphere could be determined, thus directly testing Kosslyn's hypothesis regarding hemispheric specialization. Specifically, if the left hemisphere does preferentially process categorical visuospatial relationships, then its deactivation should result in more

errors during categorical tasks than right hemisphere deactivation and vice versa for the right hemisphere regarding coordinate tasks. The pattern of results obtained in both categorical and coordinate tasks was consistent with Kosslyn's hypothesis when task difficulty was sufficiently high. However, when task difficulty was low, a left hemispheric processing advantage was found for both types of tasks indicating that: (1) the left hemisphere may be better at "easy" tasks regardless of the type of task and (2) the proposed hemispheric processing asymmetry may only become apparent during sufficiently demanding task conditions. These results may explain why some investigators have failed to find a significant hemispheric processing asymmetry in visuospatial categorical and coordinate tasks. ■

## INTRODUCTION

An object can be characterized by either its unique features or its location in space. The functional organization of the primate brain parallels this characterization such that object identity is preferentially processed in the ventral pathway and object location is preferentially processed by the dorsal pathway (Kohler, Kapur, Moscovitch, Winocur, & Houle, 1995; Ungerleider & Mishkin, 1982). However, there are a number of interconnections between pathways (Felleman & Van Essen, 1991), which somewhat blur the notion that there are two distinct pathways subserving the processing of object identification and location. Still, a large body of literature has shown that the primate brain is organized into two pathways extending from the earliest visual areas in posterior occipital cortex to either anterior temporal cortex or parietal cortex. These pathways have also been shown to include the primate prefrontal cortex during the executive process of working memory for either object identity or location (Courtney, Ungerleider, Keil, & Haxby, 1996; Wilson, Scalaidhe, Seama, & Goldman-Rakic, 1993); therefore, these ventral/dorsal

pathways that preferentially process object identity/location appear to extend over the entire cerebral cortex.

The previous discussion relates to the characteristics of an object presented in isolation. A realistic visual scene is composed of multiple objects and the spatial relationship between objects of interest becomes important if an action is undertaken which involves more than one object. For example, if one wanted to place a cup of coffee (Object 1) on a table (Object 2) between sips, it is important to place the coffee on top of (i.e., above) the table rather than beside the table or below the table to avoid a spill. As the preceding example illustrates, the spatial relationship between two objects can be described in a categorical fashion (e.g., above, to the left). Alternatively, the spatial relationship between two objects can be described in a coordinate fashion. For example, the cup of coffee can also be described as being 10.1 cm from the left side of the table and 5.3 cm from the front of the table. A coordinate representation of the cup of coffee (i.e., its precise location relative to the table) is important when retrieving the cup of coffee for the next sip. Thus, the spatial relationship between two objects can be described in either a categorical fashion or a coordinate fashion.

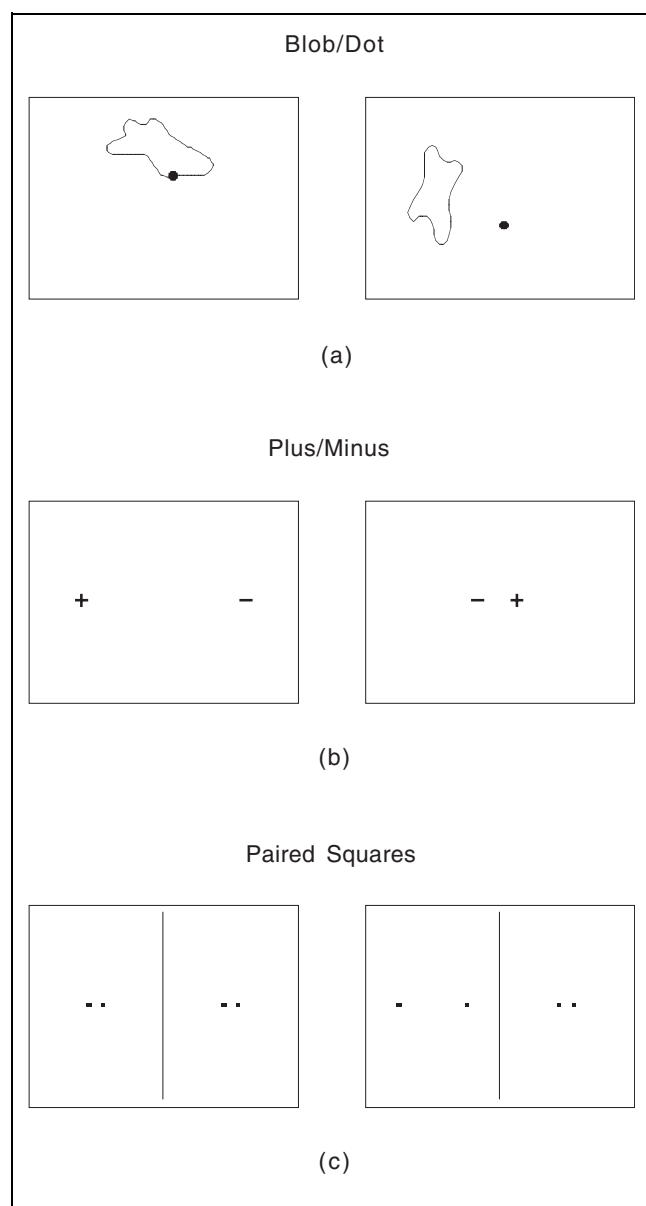
Kosslyn (1987) and Kosslyn et al. (1989) put forth the hypothesis that human cerebral hemispheres differ in

their efficacy of processing these two qualitatively different aspects of the spatial relationship between objects. Specifically, it has been proposed that the left hemisphere is better at processing categorical spatial relationships than coordinate spatial relationships, whereas the right hemisphere is better at the reverse. The underlying logic for this claim comes from the established left hemispheric advantage in language facilities (Springer & Deutsch, 1985)—an inherently categorical process—and a right hemispheric advantage during navigation (De Renzi, 1982)—an inherently coordinate-based process. Details and experimental evidence describing the hypothesis under scrutiny were presented in Kosslyn et al.'s study (1989). In the first experiment, a blob and a dot (similar to the stimuli shown in Figure 1a) were presented using a tachistoscope in either the left or right

hemifield. Presumably, presentation to one hemifield was initially processed by the contralateral hemisphere. Some of the dots were on the blob outline and others were placed a variable distance from the blob. When participants were asked to make a categorical judgment (i.e., “is the dot on or off the blob?”), reaction times were faster when the objects were presented to the left hemisphere than when the objects were presented to the right hemisphere. In contrast, when participants were asked to make a coordinate judgment (i.e., “is the dot less than or greater than 2 mm from the blob?”), reaction times were faster when the objects were presented to the right hemisphere than when the objects were presented to the left hemisphere. The same pattern of results were found using a plus and a minus as stimuli with either categorical (i.e., “Is the plus on the right?”) or coordinate judgments (i.e., “Is the plus greater than 1 inch from the minus?” see Figure 1b) and another set of stimuli.

Stratification of the data by strength of handedness showed that the asymmetry in hemispheric processing efficacy only held when subjects were strongly right-handed (Kosslyn et al., 1989). Other studies have since provided similar evidence showing that the predictions of Kosslyn's hypothesis only hold up in right-handed subjects as there are no significant differences in categorical versus coordinate hemispheric processing in left-handed subjects (Laeng & Peters, 1995; Hellige et al., 1994). Kosslyn et al. (1989) and others (Michimata, 1997; Koenig, Reiss, & Kosslyn, 1990) also conducted a block-by-block analysis that indicated that the right hemisphere only has a processing advantage during the initial block during coordinate tasks. One proposed explanation was that the left hemisphere may “learn” to categorize the coordinate spatial relationship during the first block (Kosslyn et al., 1989), thus eliminating the hemispheric processing differences in subsequent blocks. In an effort to eliminate the effect of left hemisphere categorization of the coordinate task, Banich and Federmeier (1999) varied the location of stimuli on the display screen during the coordinate task. They argued that this variation eliminated the use of the computer screen as a frame-of-reference that could be used for categorization. The results of this study showed that only when stimuli varied in screen location during the coordinate task did a trend for right hemisphere processing superiority become evident across blocks. In the present study, the paired squares stimuli (see Figure 1c) were similarly designed to resist left hemisphere categorization by forcing the subjects to make a direct metric comparison between pairs of squares for each stimulus configuration.

Kosslyn's hypothesis has been retested in a number of studies using a wide array of stimulus configurations (Banick & Federmeier, 1999; Niebauer & Christman, 1998; Bruyer, Scailquin, & Coibion, 1997; Michimata, 1997; Laeng, 1994; Sergent, 1991; Koenig et al., 1990; Servos & Peters, 1990; Hellige & Michimata, 1989;



**Figure 1.** Samples of stimuli used in the present study.

Kosslyn et al., 1989). Although some of the results from these studies did not show a significant difference between the processing efficacy of left and right hemispheres, all the results that reached significance were in line with Kosslyn's hypothesis.

Results from studies other than those of normal observers have also provided converging evidence for Kosslyn's hypothesis. Neural network simulations have shown that two separate networks perform tasks requiring categorical and coordinate processing better than a single network (Baker, Chabris, & Kosslyn, 1999; Kosslyn, Chabris, Marsolek, & Koenig, 1992). In a study using patients with focal brain lesions due to stroke, Laeng (1994) showed, as predicted by Kosslyn's hypothesis, that patients with left hemisphere strokes produced significantly more errors during categorical tasks than coordinate tasks while patients with right hemisphere strokes had significantly more errors during coordinate tasks than categorical tasks. One assumption made in this study was that a patient group's performance could be compared to a group of control subjects even though knowledge of the prelesion baseline had not been established. Although this assumption may be reasonable, it is not ideal.

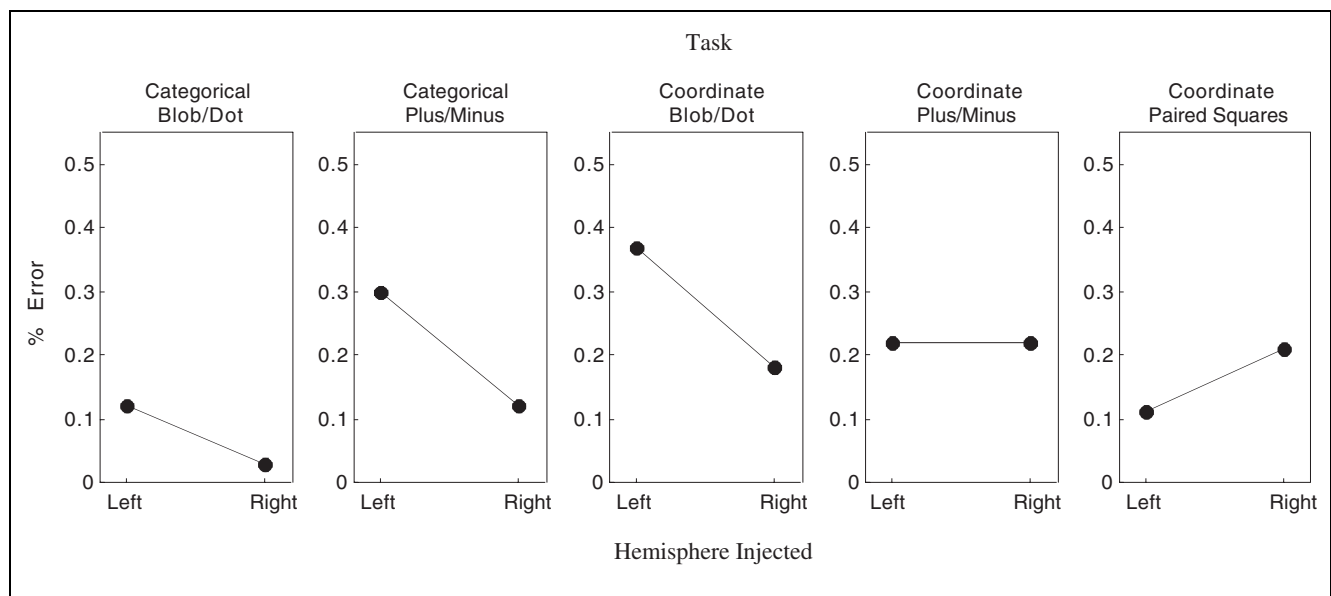
A more direct test of Kosslyn's hemispheric asymmetry hypothesis would consist of testing a group of subjects' left and right hemispheres separately while performing categorical and coordinate tasks. A procedure that temporarily deactivates a hemisphere through injection of sodium amobarbital into the ipsilateral internal carotid artery is done routinely as part of a preoperative evaluation for surgical treatment of patients with medically intractable epilepsy and tumors and has allowed us to directly test Kosslyn's hypothesis (see Methods). Because a baseline level of performance

was obtained on an individual-subject basis before hemispheric deactivation, this arrangement does not suffer from the assumption of premorbid normal function typically involved in patient studies. Moreover, any patient with a seizure or tumor focus involving the parietal lobes—which subserve the visuospatial functions under study (Laeng, 1994; De Renzi, 1982)—were removed from the analysis to ensure parietal function could be considered normal.

If the left hemisphere is better at categorical processing, patients with a deactivated left hemisphere should produce more categorical errors than patients with a deactivated right hemisphere. If the right hemisphere is better at coordinate processing, patients with a deactivated right hemisphere should produce more coordinate errors than patients with a deactivated left hemispheres. These predictions were tested using two categorical tasks and three coordinate tasks.

## RESULTS

For each task, Figure 2 shows the mean percent error for all left or right deactivated hemispheres included in the analysis. The means are connected by a line to simplify the comparison of processing efficacy between hemispheres. A negatively sloping line indicates that left hemispheres are better at a given task while a positively sloping line indicates that right hemispheres are better at a given task. Of theoretical importance, the interaction between Task  $\times$  Hemisphere is significant,  $F(4,376) = 5.09$ ,  $p < .01$ ,  $MSE = .053$ . If the asymmetry in hemispheric performance were simply due to lack of comprehension during left hemisphere deactivation, all tasks would show a negatively sloping line; however, the interaction indicates that this is not the case. Because



**Figure 2.** For each task, mean percent error of all left hemispheres is plotted on the left and mean percent error of all right hemispheres is plotted on the right.

the interaction was significant, an analysis comparing mean percent error for the left and right hemispheres was conducted for each task.

### Categorical Tasks

Deactivated left hemispheres produced more errors than deactivated right hemispheres for both categorical tasks,  $F(1,116) = 7.27, p < .01, MSE = .032$  for the blob/dot task and  $F(1,94) = 10.59, p < .01, MSE = .074$  for the plus/minus task. In support of the hypothesis being tested, these results indicate that the left hemisphere is better at these categorical tasks than the right hemisphere. These results replicate those obtained using similar stimuli and task instructions (Kosslyn et al., 1989).

### Coordinate Tasks

As expected, there was no difference in percent error for deactivated left and right hemispheres during the plus/minus coordinate task,  $F(1,52) < 1, MSE = .059$ . This result replicates previous work showing similar hemispheric processing capabilities in blocks subsequent to the initial block (Michimata, 1997; Koenig et al., 1990; Kosslyn et al., 1989)—where here, the baseline test prior to sodium amobarbital injection can be considered the initial block. Also as expected, deactivated right hemispheres made more errors than deactivated left hemispheres during the paired squares task; although this result was only marginally significant,  $F(1,73) = 2.91, p < .10, MSE = .093$ . Still, these results suggest that the right hemisphere is better than the left at this task.

Counter to Kosslyn's hypothesis, there were significantly more errors during the blob/dot coordinate task when the left hemispheres were deactivated than when the right hemispheres were deactivated indicating that the left hemisphere is better than the right hemisphere at performing this task,  $F(1,41) = 5.83, p < .05, MSE = .058$ . Although the stimuli and task instructions of this blob/dot task were very similar to those used by Kosslyn et al. (1989), there were differences. Most notably, the reference distance was 2 mm in that study, which was quite different from the reference distance of 2 in. used in the present study. Given that the stimuli used in the present study were separated by inches rather than millimeters, the tasks used in the present study may have been less difficult overall thus resulting in a failure to replicate. To determine if differences in task difficulty could explain the disparate results, an analysis was conducted by stratifying the stimuli by level of difficulty.

#### *Stratification by Difficulty*

When comparing different stimulus configurations during the dot/blob coordinate task, one would expect the task to be more difficult when the dots were near the reference distance of 2 in. Similarly, during the plus/

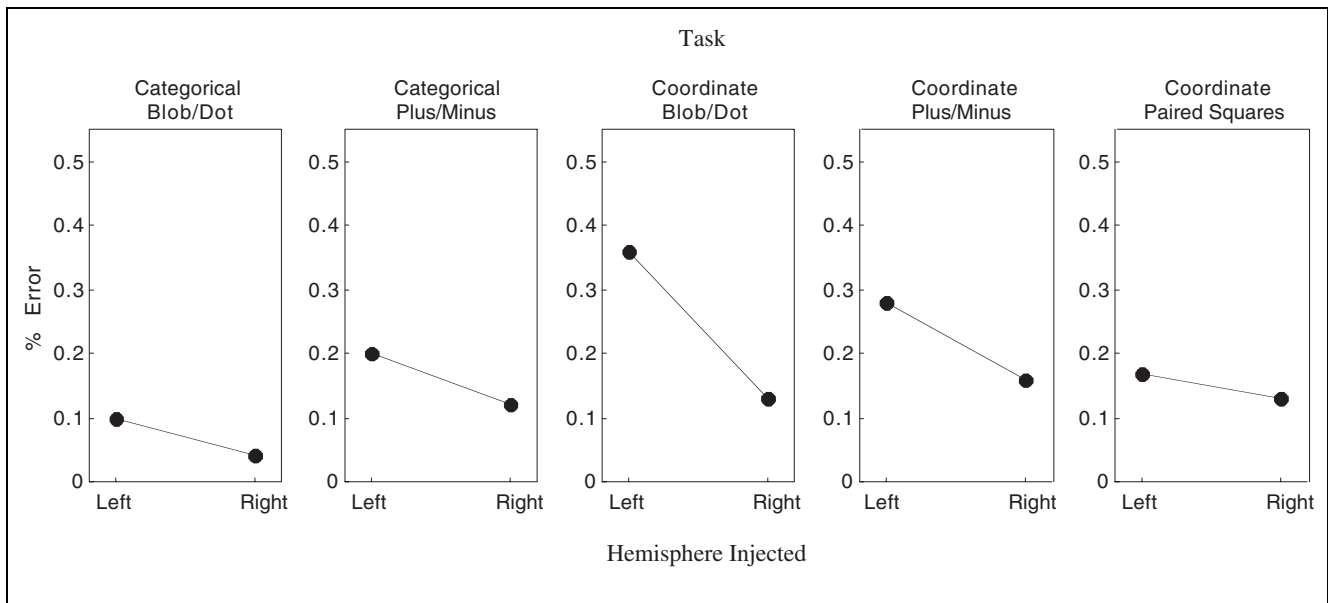
minus coordinate task, one would expect the task to be more difficult when the interstimulus distance was near the reference distance of 2 in. Separating stimulus configurations into "easy" when far from the reference distance and "difficult" when near to the reference distance has been introduced previously (Kosslyn et al., 1992). In the present study, a distance greater than 1 in. from the reference distance in either direction was arbitrarily designated as an "easy" stimulus configuration while a distance within 1 in. of the reference distance was arbitrarily designated as "difficult." For the dot/blob stimuli, stimulus configurations with dot distances less than 1 in. (see Figure 1a, left) or greater than 3 in. from the blob were "easy" while dot distances between 1 and 3 in. from the blob were "difficult" (see Figure 1a, right). For the plus/minus stimuli, interstimulus distances of less than 1 or greater than 3 in. (see Figure 1b, left) were "easy" while interstimulus distances within 1–3 in. were "difficult" (see Figure 1b, right). If the imposed stratification by difficulty is reasonable, the overall percent error given "easy" stimulus configurations should be lower than the percent error given "difficult" stimulus configurations. This was confirmed for both the dot/blob coordinate task and the plus/minus coordinate task where "easy" versus "difficult" average percent errors were .20 versus .49 and .21 versus .31, respectively.

Stratification by difficulty for the paired squares coordinate task was less clear. The two qualitatively different types of stimuli in this task were those in which the paired squares were equidistant on both sides of the page (see Figure 1c, left) and those in which the paired squares were not equidistant (see Figure 1c, right). The average percent error corresponding to the pairs that were equidistant was .14 while the pairs that were not equidistant had an average percent error of .20. Thus, the paired squares that were equidistant were empirically defined as "easy" stimuli and the nonequidistant pairs were empirically defined as "difficult" stimuli.

Unlike coordinate tasks, categorical descriptions should not depend on interstimulus distances (i.e., all categorical stimuli should have a similar level-of-difficulty). To ensure that stimulus configurations were comparable between categorical and coordinate tasks in the subsequent analysis, categorical stimuli were stratified according to the criteria used to stratify the coordinate stimuli. This ensured that stimulus attributes could be considered consistent while only task instructions differed across tasks within the "easy" or "difficult" stratification. Using all the previous criteria for defining each stimulus as "easy" or "difficult" across all tasks, a main effect of difficulty was found to be significant,  $F(1,782) = 13.50, p < .001, MSE = .098$ .

### Easy Stimulus Configurations

For each task, Figure 3 shows the mean percent error for all left or right deactivated hemispheres included



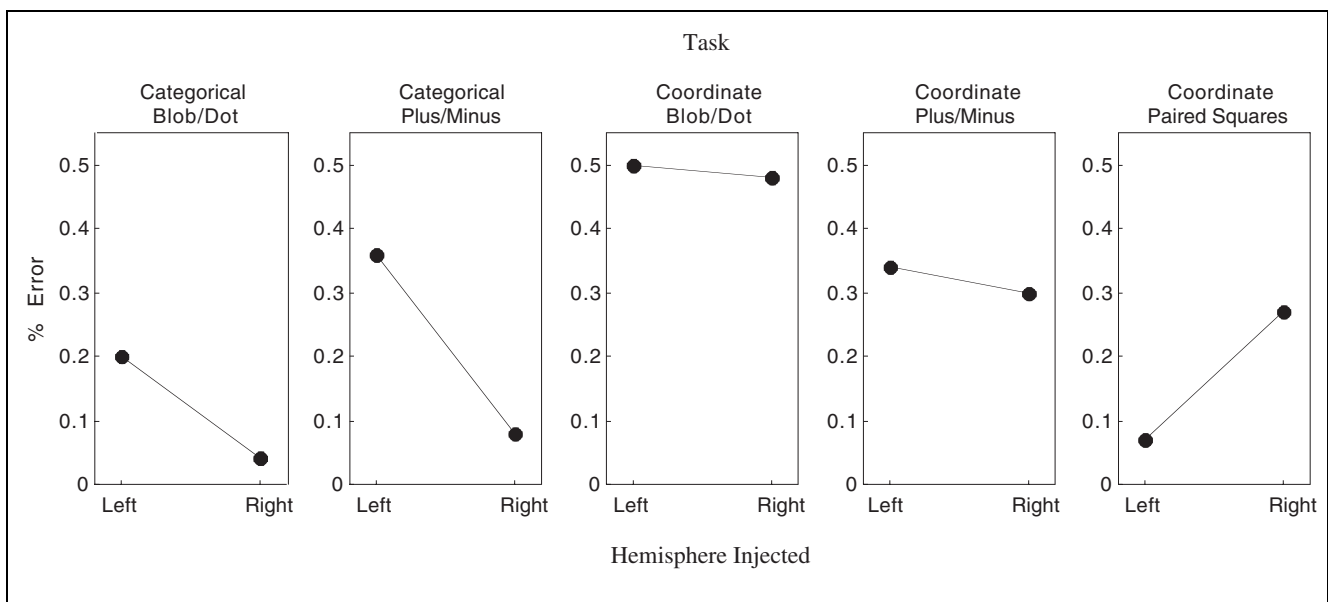
**Figure 3.** For the “easy” stimulus configurations within each task, mean percent error is plotted versus hemisphere injected.

in the analysis. The interaction between Task  $\times$  Hemisphere was not significant,  $F(4,387) = 1.51, p > .10, MSE = .063$ ; therefore, no individual task analysis was conducted. A linear trend analysis across all tasks revealed that deactivating left hemispheres resulted in significantly more errors than deactivating right hemispheres,  $F(1,395) = 9.32, p < .01, MSE = .065$ . These results indicate that the left hemisphere is better at processing “easy” stimuli than the right hemisphere—whether the task is categorical or coordinate in nature. Thus, the significant blob/dot coordinate task left hemisphere processing advantage

found in the overall analysis may have been a result of left hemispheric specialization for “easy” tasks rather than a real left hemispheric advantage for that specific task. If true, the left hemispheric advantage for that task should disappear when presented with difficult stimulus configurations.

### Difficult Stimulus Configurations

For each task, Figure 4 shows the mean percent error for all left or right deactivated hemispheres included in the analysis. The interaction between Task  $\times$  Hemisphere



**Figure 4.** For the “difficult” stimulus configurations within each task, mean percent error is plotted versus hemisphere injected.

was significant,  $F(4,385) = 5.67, p < .001, MSE = .12$ ; therefore, an analysis was conducted for each task.

### *Categorical Tasks*

For both categorical tasks, deactivating left hemispheres resulted in significantly more errors than deactivating right hemispheres,  $F(1,116) = 7.05, p < .01, MSE = .094$  for the blob/dot task and  $F(1,96) = 15.34, p < .001, MSE = .12$  for the plus/minus task. In accordance with Kosslyn's hypothesis, these results indicate a left hemispheric advantage for categorical processing.

### *Coordinate Tasks*

For both the blob/dot task and plus/minus task, errors produced following deactivations of left and right hemispheres were similar,  $F(1,41) < 1, MSE = .26$ , and  $F(1,54) < 1, MSE = .15$ , respectively. These results replicate the results of Kosslyn et al. (1989) and others (Michimata, 1997; Koenig et al., 1990) that show equality of hemispheric processing subsequent to the initial block. In the paired squares task, deactivated right hemispheres produced more errors than deactivated left hemispheres,  $F(1,78) = 8.68, p < .01, MSE = .09$ . This result indicates a right hemispheric advantage for processing stimuli in this task in line with Kosslyn's hypothesis. Thus, this task resisted left hemisphere categorization as designed.

## **DISCUSSION**

When the analysis was not stratified by task difficulty, the results replicated those of Kosslyn et al. (1989) in both categorical tasks and the coordinate plus/minus task. However, during the dot/blob coordinate task deactivation of left hemispheres resulted in significantly more errors than deactivation of right hemispheres that not only failed to replicate, but was in direct opposition to Kosslyn et al.'s results (1989). To determine if differences in task difficulty could be responsible for the disparate results, the analysis was stratified according to task difficulty. The results of this analysis indicated that the left hemisphere preferentially processes "easy" stimulus configurations. Furthermore, when "difficult" stimulus configurations were considered separately, all of Kosslyn's predictions held. Specifically, the left hemisphere was significantly better at processing categorical tasks, there was no significant hemispheric processing asymmetry in coordinate tasks using similar stimulus configurations as Kosslyn et al. (1989), and the right hemisphere was significantly better at processing the paired squares coordinate task designed to resist categorization by the left hemisphere (see Banich & Federmeier, 1999). It is important to mention that a failure to find a difference in hemispheric error rates may be accompanied by a difference

in reaction times. However, as response accuracy was stressed and response speed was not stressed during task instructions (see Methods), the analysis of error rate is expected to provide a reasonable estimate of hemispheric processing efficacy.

In the present study, task difficulty was a critical factor in the analysis. The differences in hemispheric processing capabilities became most evident when task difficulty was sufficiently high. Before the analysis was stratified by task difficulty, the blob/dot coordinate task appeared to be better processed by left hemispheres and the paired squares coordinate task showed only a marginally significant right hemispheric advantage ( $p < .10$ ). In the analysis of "difficult" stimulus configurations, the blob/dot coordinate task was shown to be processed equally well by both hemispheres and the paired squares coordinate task right hemispheric advantage was significant ( $p < .01$ ). In line with the present paired squares result, Egeth and Epstein (1972) have shown a similar hemispheric asymmetry using "same" or "different" judgments of paired letters presented in either hemifield.

Task difficulty may have had an effect in previous studies that failed to find a significant difference in hemispheric asymmetry for processing categorical versus coordinate tasks. Sergent (1991) did not find a significant hemispheric processing difference using stimuli similar to Kosslyn et al. (1989), thus failing to replicate their results in her Experiment 2. When she reduced the luminance level of the stimulus from 84 to 3  $\text{cd/m}^2$  in her Experiment 4, reaction times increased indicating the task became more difficult with reduced luminance. Of primary importance, a significant difference between hemispheric processing in support of Kosslyn's hypothesis was obtained under these more difficult task conditions. Even though she replicated Kosslyn et al. (1989) when experimental differences in stimulus luminance were eliminated, Sergent still argued that failure to reject the null hypothesis indicated that hemispheres conduct categorical and coordinate processing equally well. One cannot determine whether a hemisphere is specialized for a specific type of processing unless those processing capabilities are required for a given task. In the present analysis, the specialized processing capabilities of each hemisphere only became apparent during presentation of "difficult" stimulus configurations.

Other researchers have focused on the failure to find a significant hemispheric processing asymmetry as evidence against Kosslyn's hypothesis (Bruyer et al., 1997; Corwin & Hellige, 1994; Rybash & Hoyer, 1992; Sergent, 1991). However, numerous factors may result in failure to find a significant processing difference (e.g., insufficient statistical power, ceiling or floor effects, incorrect choice of task, and/or stimulus dimensions). Across studies, a large number of statistically significant results have been obtained in line with Kosslyn's hypothesis, thereby rejecting the null hypothesis and validating

hemispheric processing asymmetry of visuospatial categorical and coordinate processing.

## METHODS

### Participants

A total of 134 patients at Johns Hopkins Hospital with intractable seizures voluntarily underwent the intracarotid amobarbital procedure (IAP) described below to lateralize select cognitive functions as part of an evaluation for possible surgical treatment of their epilepsy. The average age at the time of testing was 30.2 years with a 10.3-year standard deviation. Although the majority of participants underwent the procedure for both hemispheres ( $n = 89$ ), many underwent the procedure for only one hemisphere, thereby producing an unequal number of hemispheres tested. Thus, a total of 100 left hemispheres and 124 right hemispheres were tested.

### Stimulus Materials

Although the cognitive test battery utilized consisted of numerous types of stimuli (e.g., objects, visually presented words, pictures—see Hart et al., 1991), only those stimuli relating to the hypothesis being tested are discussed. All relevant stimuli were printed in black ink on 8.5 × 11-in. sheets of white paper held in the landscape orientation by a neuropsychological technician. For each blob/dot stimulus set, four configurations were presented with the blob centered in the upper, lower, left, or right of side of the page (one blob in each position) and the dot placed either on the blob outline or at a variable distance toward the side of the page opposite the blob (see Figure 1a). The dot was placed on the blob in two of the four stimulus configurations. For each plus/minus stimulus set, a plus sign and minus sign were presented an equal and variable distance from the center of the page in the horizontal dimension (see Figure 1b). The plus was placed to the right of center in two of four stimulus configurations. For the paired squares task, two small squares were presented on the left side of the page an equal and variable distance from the center of the left side of the page in the horizontal dimension and two small squares were also presented on the right side of the page an equal and variable distance from the center of the right side of the page in the horizontal dimension. A thin vertical line passing through the center of the page was also presented with the pairs of squares (see Figure 1c). The distance between paired squares on the right was identical to the distance between paired squares on the left in two of four stimulus configurations. Three unique sets of stimuli were made using the above stimulus constraints, one to be used in the baseline procedure and the other two to be used for testing each hemisphere. The two stim-

ulus sets used for hemispheric testing were counter-balanced across subjects.

### Procedure

At least 1 day before the IAP was administered, each patient received a cognitive test battery developed at Johns Hopkins to test visuospatial, language, and memory function. The purpose of this session was twofold: (1) to allow the patient to gain familiarity with the tasks and (2) to obtain a baseline measure of performance for each task. Only the procedures related to the tasks in this analysis will be described. All stimuli were viewed binocularly and presented sequentially. Before the test stimuli were shown, each subject was briefly shown a piece of paper with a horizontal line 2 in. in length (positioned between a “+” and “-” sign) and instructed to remember this distance to use as a reference later in the test. The first two tasks were categorical in nature using the blob/dot stimuli followed by the plus/minus stimuli and the last three tasks were coordinate in nature using the paired squares stimuli, the blob/dot stimuli, and the plus/minus stimuli, respectively. Four stimuli were used in each task and the subject was required to make a verbal response to each query. Subjects were instructed to be as accurate as possible, with no regard to the speed of response. The categorical tasks included the questions “Is the dot on the line?” and “Is the plus sign on the right?” while the coordinate tasks included the instructions “Are the dots the same distance apart?,” “Is the dot less than two inches from the line?,” and “Are they [the plus and minus sign] less than two inches apart?”

During the IAP, one of the patient’s hemispheres was temporarily deactivated by injecting sodium amobarbital into the internal carotid artery. For each hemisphere tested during the IAP, the procedure was nearly identical to the baseline test. Because the injection induced a temporary homonymous hemianopia, stimuli were presented in the intact ipsilesional visual field. After the deactivated hemisphere regained function, most patients had the other hemisphere temporarily deactivated and a different test battery was presented. A neurologist used a two-pronged method to evaluate the dissipation of the sodium amobarbital effect: (1) strength testing of the arm contralateral to the deactivated hemisphere, which becomes flaccid upon injection (regaining 5/5 strength indicated that the effect had worn off) and (2) EEG of the ipsilateral hemisphere, which slows upon injection (0% slowing indicated the effect had dissipated). Regardless of whether all stimuli were presented, the testing was ended for that hemisphere when the anaesthetic had worn off. As the categorical and coordinate tasks were some of the last administered during the IAP procedure and the testing was frequently ended before the test battery was complete, the data available for analysis were variable.

## Statistical Analysis

Because the participant population consisted of patients, two techniques were utilized to ensure the data was acquired from subjects with “normal” visuospatial function. First, in both the group analysis and the analysis stratified by task difficulty, only subjects who performed perfectly at baseline were included in the analysis. Second, as parietal lobe dysfunction has been shown to influence categorical and coordinate visuospatial processing (Laeng, 1994; De Renzi, 1982), hemispheres with a seizure or tumor focus that included the parietal lobe were removed from the analysis (21 hemispheres removed). Using PET, Kosslyn, Thompson, Gitelman, and Alpert (1998) found both parietal and frontal lobe hemispheric asymmetry when comparing categorical versus coordinate processing. However, Laeng’s (1994) study showed that a lateralized frontal lobe lesion did not differentially affect categorical and coordinate visuospatial processing; therefore, patients with a frontal lobe foci were included in the analysis. Finally, in line with the hypothesis only applying to right-handed subjects (Laeng & Peters, 1995; Hellige et al., 1994), hemispheres corresponding to left-handed and ambidextrous subjects were removed from the analysis (33 hemispheres removed). After applying these criteria, a majority of patients were still included in the analysis.

As response accuracy was stressed and reaction time was not, only error rates were analyzed. In an effort to focus on the statistical comparisons of theoretical interest relating to the categorical versus coordinate hemispheric asymmetry hypothesis, a hierarchical approach was taken. First, the interaction between Task  $\times$  Hemisphere was computed and if this statistic was significant, the simple effects of hemispheric differences was tested for each task. The method of weighted means (Keppel & Zedeck, 1989) was used as an unequal number of left and right hemispheres were included in each analysis.

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