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Reaction time assessments of gender differences in visual-spatial performance

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This research examined gender differences in reaction time and accuracy on four visual tasks. Twenty-nine female and 29 male first-year college students responded via joysticks to video-displayed stimuli. Computer-controlled sessions consisted of trial blocks during which subjects indicated (1) a choice depending on the form of a simple stimulus, (2) which two-dimensional representation of a "folded" box was equivalent to an "unfolded" box, (3) whether test stimuli of varying rotations were the same as or different from an upright standard displayed simultaneously, and (4) whether test forms of varying dissimilarity were the same as or different from a standard. Women were more accurate but slower on the choice task; they had higher reaction times on the mental rotation and the shape-comparison tasks. These latter gender differences interacted significantly with degree of rotation and dissimilarity of the test form, suggesting the presence of gender differences in visual-spatial strategies.

Gender differences in visual-spatial abilities are well documented, with males performing more accurately on tasks involving such things as block design, disembedding figures from backgrounds, and perceptual mazes (see reviews by Burstein, Bank, & Jarvik, 1980; Harris, 1978; Maccoby & Jacklin, 1974; Sherman, 1978). Harris (1978) has concluded that such tasks have in common the requirement for static or kinetic mental imagery, but it is unclear how to account for the gender difference. The present work considers the hypothesis that men and women employ different problem-solving strategies.

Sherman (1978) introduced a strategy account. According to her "bent-twig" hypothesis, early verbal precocity in girls initiates a tendency to apply verbal solutions to visual-spatial problems; boys might find "mentally spatial" approaches more successful. Social factors reinforce these styles. Although Sherman's analysis is appealing, empirical definition and support are weak.

Current information-processing approaches suggest methods to address the notion of strategy differences. Of particular interest are studies that employ reaction time (RT). For example, verbal solutions may be more time consuming than mentally spatial approaches. Recent studies of RT during mental rotation and visual comparison tasks have suggested more specific, empirically identified distinctions among processes that may contribute to an overall RT difference. Individual differences in the way such processes are applied could lend more precision to Sherman's strategy account.

Mental rotation, requiring kinetic mental imagery and included in many tests of spatial ability, is closely associated with RT. In tasks in which comparison forms are judged the same as or different from upright standards, RT increases with the rotation of the comparison (Shepard & Metzler, 1971). Recent studies (Kail, Carter, & Pellegrino, 1979; Tapley & Bryden, 1977) have reported gender differences in mental rotation data; men had shorter overall RTs, and the slope of the RT-orientation function was flatter; that is, men's RTs depended less on the amount of rotation required. Kail et al. concluded that the gender difference lay in a rotation process, inferred from the slopes of the mental rotation functions, rather than in an encoding process or comparison process, inferred from their intercepts. The gender differences seemed to be attributable to a minority of subjects, mostly females, whose RT-orientation functions were especially steep. Kail et al. suggested that these subjects employed an analytic, feature-by-feature rotation strategy, whereas the majority applied a holistic approach.

With a task requiring static mental imagery, Cooper (1976, 1982) also identified individual, though not gender, differences in RT functions. In successive presentations of form stimuli, subjects judged whether a comparison form was the same as or different from a standard. Standard and comparison stimuli always had the same orientation, and the important variable was the similarity of the comparison to the standard form. Cooper identified two styles among her small, but highly practiced, group of subjects. Analytic processors had longer RTs overall, and RT decreased as standard and comparison forms became more dissimilar. Holistic processors had shorter RTs, which were insensitive to differences between standard and comparison forms. Although this distinction seems analogous to that made by Kail et al. (1979), there are interesting differences in the ways strategies were identified. In particular, Cooper attributed individual differences to a comparison rather than a rotation process. Additional research designed to tease apart these variables indicated that subjects who were similar with respect to speed of mental rotation differed in the time required to

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make a subsequent same-different decision (Cooper & Podgorny, 1976). Thus, although recent literature assigns similar nomenclature to visual-spatial strategies, different processes are implicated.

Despite its usefulness, RT is rarely examined in the many studies of gender differences in visual-spatial ability. The present research compared men's and women's RTs on four tasks, selected to engage differing requirements for static and kinetic mental imagery. The tasks included standard visual choice, which should demand minimal use of mental imagery, and three-dimensional mental box-folding problems, which should demand a great deal. If the gender difference is specific to processes engaged by visual-spatial demands, it should be relatively small for choice but large for the mental box folding. In addition, we used a form-comparison task to examine the strategies identified by Cooper (1978). If women perform such comparisons more analytically, their RTs should be longer than men's and should depend more on the similarity between standard and comparison forms. We also replicated conceptually previous studies of mental rotation (Kail et al., 1979; Tapley & Bryden, 1977). If a rotation process contributes to the gender difference, women should have longer RTs, and speed should be more dependent on degree of rotation.

In order to emphasize RT effects, all problems were relatively easy and administered under private, nonspeeded conditions. Instructions were intended to provide accuracy sets.

METHOD

Subjects

Thirty male and 30 female first-year undergraduates at Brown University participated. All were right-handed, and the men and women were approximately equivalent in the number of college-level math courses reported. In return for their participation, they received either money or extra credit in an introductory psychology course.

Apparatus

Stimuli appeared on a Sanyo VM4509 video monitor. An Atari 800 computer, interfaced with the monitor, presented instructions, displayed stimuli, and recorded responses entered via a Commodore joystick. The computer equipment was arranged on a set of shelves so that the keyboard and joystick were at desk level and the monitor was approximately at eye level. A separate room housed this equipment.

Stimuli

All stimulus forms were made up of black dot-matrix outlines on a white background; each dot was approximately 1 mm square. Figure 1 illustrates some of these forms. The displays were centered on the screen.

Procedure

At the start of a session, one of the two female experimenters provided a general explanation of the experiment and demonstrated the use of the joystick. These initial instructions advised the subject to try to avoid mistakes, but to work as quickly as possible; they also emphasized the importance of establishing a comfortable pace between trials and sections of the experiment. The experimenter remained in the room or booth while the subject practiced using the equipment. She then left the subject alone, and further instructions were displayed on the video monitor. The sessions lasted approximately 45 min.

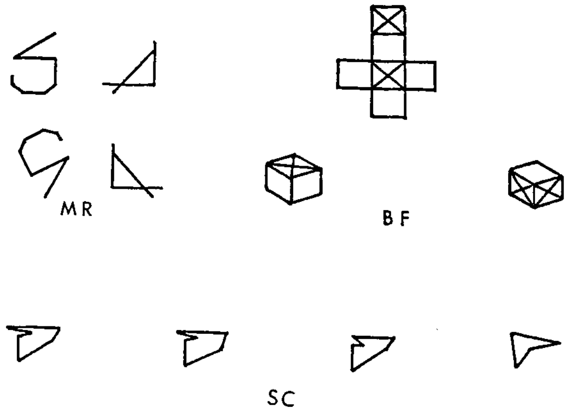

Figure 1. Examples of stimuli used in mental rotation (MR), box-folding (BF), and shape comparison (SC) tasks. The MR stimuli appeared in pairs simultaneously, the standard above the comparison; an example of a rotated comparison ("same") and a rotated reflection ("different") are shown. The box-folding (BF) stimuli appeared in triads, an unfolded standard "box" with two comparison "folded" boxes, only one of which could be assembled from the standard. The shape-comparison (SC) stimuli appeared successively, first the standard (on left), followed by one of four comparisons, the standard again ("same") or one of the three "different" forms, shown in order of increasing dissimilarity to the standard. The examples here are of intermediate complexity.

The experiment proper consisted of four parts and occurred in the same order for all subjects. For each part, the computer displayed detailed instructions and sample problems, followed by a series of practice trials with speed and accuracy feedback. The word "ready" preceded each trial, and the subject initiated the trial itself by pushing the joystick forward. A brief summary of the instructions was displayed before the experimental trials, which proceeded without feedback.

Part 1 was a study of speed and accuracy on a choice task that should involve a relatively simple decision process. Subjects discriminated between a triangle and a square, each occupying a 1.5-cm square matrix on the monitor screen. Displayed instructions followed by five practice trials informed the subjects that a correct response to the triangle was a leftward operation and to the square, a rightward operation of the joystick. There were 10 experimental trials, 5 with triangles and 5 with squares, presented in random order. Each trial was initiated by a forward action of the joystick, which produced the stimulus after a delay that had a random duration averaging 2 sec. The choice response blanked the display.

Part 2 examined mental rotation. Subjects discriminated between nonreflected and reflected images of a standard form. The standard stimuli were four letter-like characters selected from the Spatial Relations portion of Thurstone's (1958) Primary Mental Abilities Test; the forms were approximately 1.5 × 2.5 cm along the longest side. Standard and comparisons were presented simultaneously, with the standard placed above the comparison; Figure 1 provides examples. Displayed instructions followed by five sample and five practice trials informed the subjects that a rightward motion of the joystick was correct if the comparison was identical to or a rotated version of the standard form (a "same" response). The choice response blanked the stimulus display. A leftward motion was correct if the comparison form was an upright or rotated reflection of the standard ("different"). The sample and practice trials used uppercase letter stimuli. The experimental trials used the Thurstone forms, presented in their upright positions as standard stimuli. Comparison stimuli had the same shape as the associated standard and were presented either as rotations or reflections at 0°, 90°, or 150°. Each pair was presented twice, and every combination occurred equally often and in random order. Altogether, there were 48 experimental trials: each of four standard forms was paired twice with each of its six associated comparison stimuli.

Part 3 required more complex kinetic mental imagery; it used forms from the Differential Aptitude Test (DAT; Bennett, Seashore, & Wesman, 1982). The stimuli selected were similar to items 6, 8, 17, 22, 24, 28, 29, 36, 42, and 53 from the Spatial Relations Section, Form V (Bennett et al., 1982). All problems were of the box-folding variety; a standard "unfolded" box appeared above two "folded" comparison boxes located side by side, approximately 5 cm apart. An illustration appears in Figure 1. The stimuli, modified slightly to accommodate the computer's graphics capabilities, occupied up to 4.5 cm along the longest dimension (unfolded standard) or an approximately 2×2 cm matrix (folded comparisons). Displayed instructions followed by one sample and one practice problem directed the subjects to move the joystick toward the comparison form that could be constructed from the standard. The choice response blanked the display. The instructions, the examples, and the explanations of solutions were taken from the booklet that accompanied the DAT. Ten experimental problems followed.

Part 4 tested static mental imagery, using a modification of the shape comparison task described by Cooper and Podgorny (1976). There were three sets of stimulus forms, each set having a different complexity (the 6-, 8-, and 12-point conditions in Cooper & Podgorny's Figure 1). The present Figure 1 illustrates a set of intermediate complexity. Three additional sets were identical to those just described, except that they were rotated 180°. Within each set there were a standard and three comparison forms, which corresponded to probes D2, D4, and D6 in Cooper and Podgorny's Figure 1; the numbers correspond to increasing dissimilarity to the standard. All stimuli reproduced approximately the Cooper and Podgorny forms, but as outlines rather than as filled figures. They occupied a 1.5-cm matrix on the monitor screen.

A trial, initiated by the forward motion of the joystick, presented the standard form for 3 sec. After a random 1- to 2-sec delay, during which the screen was blank, either the same standard or one of the three comparison forms belonging to its set appeared. Displayed instructions directed the subjects to make a rightward motion of the joystick if the comparison form was the same (identical to) the standard and a leftward motion when the comparison was different. Eighteen practice trials included all pairs of stimuli from the first three sets; feedback following errors included displays of standards and comparisons in adjacent positions. Seventy-two experimental trials followed; 50% of these trials presented identical standard and comparison forms. The remaining trials included two presentations of each standard followed by each of the three dissimilar comparison forms from its set; thus, on half the trials, the correct response was "different." The trials occurred in quasi-random order with the constraint that no more than three "same" or three "different" trials could occur successively.

RESULTS

The data reported below describe accuracy (percent correct) and RT, the time between onset of the test stimulus and the operation of the joystick. RTs were analyzed for correct responses only. To provide an adequate basis for RT data, we dropped subjects who did not perform at least three trials correctly for every condition. By this rule, the data for 1 male and 1 female were not included in the analysis; thus *n* was equal to 29. Analyses were based on mean percent correct and median RT scores for each individual For significant gender effects, we state effect size in term of the *d* statistic recommended by Hyde (1981); this measure describes the difference between the two means i standard deviation units.

Table 1
Accuracy and Reaction Time for Simple Choice and Box-Folding Tasks

	Choice				Box Folding			
	Male		Female		Male		Female	
Measure	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
% Corr	92.4	6.3	96.9	6.0	85.5	13.8	89.0	11.
RT(sec)	.51	.10	.64	.17	9.86	4.61	9.32	3.6

Note—Data points are means of individual scores based on 10 trials pe subject. *SD* = standard deviation.

Table 1 summarizes the data for the standard choic (left column) and box-folding (right column) tasks. Thi summary compares the tasks associated with the shortes and longest overall RTs and, by that criterion, with th lowest and highest demands. Accuracy was higher o choice than on box folding, and women were more accurate on both tasks. For the choice task, this gende difference was significant [$t(56) = 2.75, p < .01$]; effect size, *d*, was .73. Women's RTs were longer tha men's on the choice task, and this gender difference wa also significant [$t(56) = 3.42, p < .01$]; *d* was .96. Th gender differences were not significant for the box-foldin task.

Figure 2 summarizes the mental rotation data. The accuracy functions (top panels) show a slight decline in accuracy with increasing rotation of the comparison form Three-way analyses of variance (ANOVAs) revealed significant effects of rotation [$F(1,112) = 14.8, p < .01$

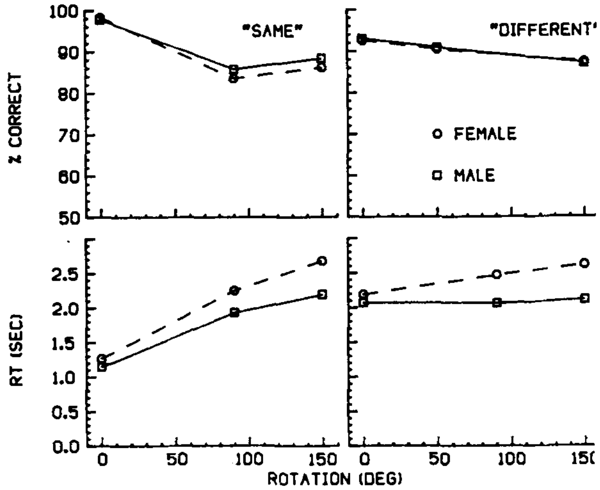

Figure 2. Mean accuracy (top) and RT (bottom) scores for femal and males on the mental rotation task. The panels on the left ref to judgments indicating that the comparison form was the same the standard; the right panels refer to judgments indicating that t comparison form was a reflection of the standard. Data points a means of individual scores based on eight trials per subject per co dition.

but no significant effect of gender or trial type ("same" vs. "different"). A significant rotation × trial type interaction [$F(2,112) = 8.4, p < .01$] reflects the lessened effect of rotation on "different" as compared with "same" responses.

The bottom panel of Figure 2 summarizes the RTs for the mental rotation task. RTs increased with rotation, and women's RTs were consistently longer than men's; d averaged over all rotations and trial types was .54. Three-way ANOVAs revealed main effects of rotation [$F(1,112) = 58.7, p < .01$], gender [$F(1,56) = 4.1, p < .05$], and trial type [$F(1,56) = 21.2, p < .01$]. There were also significant interactions between gender and rotation [$F(2,112) = 4.7, p < .01$] and between trial type and rotation [$F(2,112) = 36.6, p < .01$]. These interactions reflect the larger effect of rotation on RT for women and the more pronounced effect of rotation on "same" RTs as compared with "different" RTs.

Figure 3 describes the findings for the shape comparison task. We evaluated these data in two parts. The first comparison addressed the gender differences for the "same" response (shown as 0 on the abscissa). There was no significant difference in accuracy. However, women's RTs were longer ($d = .54$), and this difference was significant [$t(56) = 2.09, p < .05$].

The second comparison refers to the effects of dissimilarity of the comparison forms (values 1, 2, and 3 on the abscissa). Accuracy (top panel) increased as comparison stimuli became more dissimilar to the standard. The main effect of dissimilarity was significant [$F(1,56) = 63.3, p < .01$], but there were no significant effects of gender and no significant interaction. With regard to RT (bottom panel), women's responses were slower than men's (d, averaged over the three values, was .93). RT decreased as comparison form dissimilarity increased, and this effect was more pronounced for women. Two-way ANOVAs revealed significant main effects of gender [$F(1,56) = 12.4, p < .01$], of dissimilarity [$F(2,112) = 32.8, p < .01$], and the interaction between gender and dissimilarity [$F(2,112) = 4.8, p < .01$].

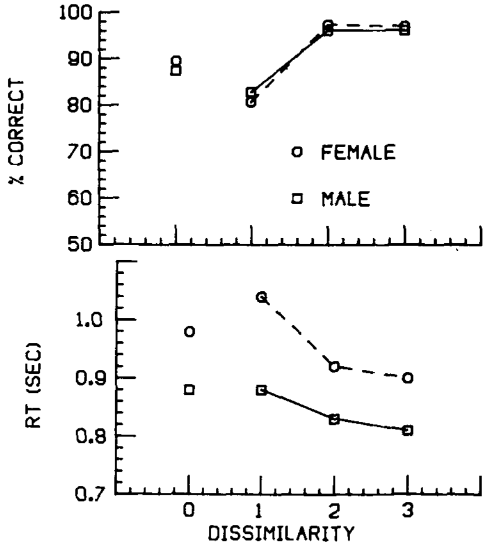

Figure 3. Mean accuracy (top) and RT (bottom) scores for females and males on the shape-comparison task. Dissimilarity refers to the difference between a standard and its associated comparison form. When this value was 0, the standard and comparison shapes were identical. Values 1, 2, and 3 correspond to the shapes D2, D4, and D6 shown in Cooper and Podgorny (1976) and are numbered in order of increasing dissimilarity. Data points are means of individual scores based on 36 trials per subject for Condition 0 ("same") and on 12 trials per subject for Conditions 1, 2, and 3 ("different").

Table 2
Correlation Coefficients (r) Describing Associations Between RT Measures

		MR-S		MR-D		BF	SC-S	SC-D	
		RT	Diff	RT	Diff	RT	RT	RT	Diff
C	F	.56*	.34	.36*	−.05	.31	.50*	.66*	.12
	M	.36	.17	.40*	.50*	.06	.38*	.49*	.16
MR-S	F		.85*	.56*	.09	.27	.67*	.56*	−.12
	M		.86*	.77*	.04	.25	.43*	.37*	.46*
Diff	F			.45*	.26	.33	.50*	.38*	.14
	M			.45*	.13	.14	.19	.15	.28
MR-D	F				.54*	.39*	.68*	.51*	−.06
	M				−.08	.37*	.50*	.41*	.35
Diff	F					.40*	.29	.17	−.15
	M					−.44*	−.20	.01	−.05
BF	F						.43*	.44*	.17
	M						.18	−.02	.07
SC-S	F							.86*	−.02
	M							.80*	.32
SC-D	F								.10
	M								.21

Note—Simple choice (C), averaged mental rotation "same" trials (MR-S), averaged mental rotation "different" trials (MR-D), box folding (BF), averaged shape comparison "same" trials (SC-S), and averaged shape comparisons "different" trials (SC-D). Measures of slope ("Diff") appear to the right of the column referring to overall RT for the associated measure. Coefficients for females (F) and males (M) are shown separately. *$p < .05$.

Table 2 shows correlation coefficients between score pairs on the various tasks. These values indicate moderately strong and significant relationships among overall RTs for choice, mental rotation, and shape comparison. Box-folding RTs were less well related to most of the others.

Associations between slopes of RT functions are of special interest, since they may involve more specific measures of strategy. Such functions include those that related RT to rotation of the comparison stimulus on the mental rotation task (Figure 2, bottom panels); for correlations, individual slopes were estimated as the difference between RT for the comparison rotated through 150° and RT for the nonrotated comparison. An additional slope measure was the relationship between RT and dissimilarity between standard and comparison forms on the shape-comparison task (Figure 3, bottom panel); for correlations, individual slopes were estimated as the difference in RT associated with "different" responses to the most and least dissimilar comparison forms. Table 2 shows the correlations between these measures and others in rows and columns labeled "Diff." As indicated there, the slope measures were not significantly related to each other; that is, within the mental rotation task, the slopes of the "same" and "different" trial-type functions were not significantly correlated, and the shape-comparison dissimilarity function failed to correlate with either mental rotation function.

Also of interest were the relationships between overall RT and slope measures. For mental rotation, slopes of "same" and "different" functions were, with one exception, significantly related to overall "same" and "different" RTs, respectively. However, in the shape-comparison task, the slope of the dissimilarity function did not correlate significantly with overall RT. A curious finding concerned relationships between box-folding RTs and slope of the "different" function for mental rotation. For both sexes, this association was significant, but it was positive for women and negative for men.

DISCUSSION

The present findings indicate that, in a variety of visual tasks, women's RTs are longer than men's. The effects occurred when accuracy differences were either absent or favored women. By psychological standards, the gender differences were of moderate to large size (Hyde, 1981). The associations among tasks (Table 2) implicate a general speed process that contributed not only to tasks requiring static (shape comparison) and kinetic (mental rotation) mental imagery, but also to decisions based on simple, physically represented forms (choice).

Of particular interest are indications of more specific strategy differences that may contribute to the visual-spatial effect. The findings from the shape comparison task suggest the classification suggested by Cooper (1976, 1982): Women's longer RTs overall and their greater dependence on standard-comparison dissimilarity conform rather closely to the pattern identified by Cooper with an "analytic" style. The pattern seen in the men's data conforms more closely, though not fully, to that associated by Cooper with a "holistic" strategy (Figure 3, bottom). However, the correlational data question the coherence of the processes associated with these styles; in the present study, the process reflected by the dissimilarity function's slope did not appear to contribute to the overall RT differences. With practice, more unitary styles could have emerged, and further research should assess the extent to which gender difference would diminish or increase.

The mental rotation data (Figure 2, bottom) indicated that women perform two-dimensional rotations more slowly, but not necessarily less accurately than men. The RT findings replicate data from other laboratories (Kail et al., 1979; Tapley & Bryden, 1977). Kail et al. attributed the gender difference to the performance of the rotation operation, since the slopes, but not the intercepts, differed for the two groups. Since men's and women's RTs were similar for the no-rotation condition, the present data are consistent with that analysis. Although Kail et al. (1979) suggested that relatively slow mental rotation indicates a feature-by-feature, analytic strategy, the work of Cooper and Podgorny (1976) suggested that mental rotation and successive shape comparison reflect separate processes. The present data are consistent with that conclusion, since the shape-comparison and mental rotation functions failed to correlate.

Comparisons between "same" and "different" decisions may also reflect visual comparison strategies, although it is not clear just how (Farell, 1985). Our mental rotation data are consistent with Kail, Stevenson, and Black's (1984), indicating that responses of "different" are less sensitive to amount of rotation, but that men and women do not differ in this contrast. Cooper's (1976, 1982) analysis suggested that holistic subjects made "same" judgments more quickly than "different" decisions. Analytic subjects showed a more complicated pattern, but "same" judgments were slower than "different" decisions when standard and comparison forms were highly dissimilar. The present data (Figure 3, bottom) do not reveal a parallel distinction between men and women, although it could have emerged with more practice.

The choice data revealed longer female RTs even in the absence of mental imagery requirements. These findings are consistent with some earlier work (e.g., Noble, Baker, & Jones, 1964). More recently, however, Landauer, Armstrong, and Digwood (1980) concluded that, in a buttonpressing task, men performed the motor component more quickly and women performed the decision component more quickly. Overall, there was no significant gender difference. Since, in the present study, women's decisions were more accurate (Table 1), it is possible that our conditions encouraged speed-accuracy tradeoffs. The range of accuracy scores precluded a quantitative analysis of such biases, but scatterplots suggested an increasing relationship between accuracy and RT for women but not for men.

The results from the box-folding task were unexpected and are not consistent with the hypothesis that strong requirements for kinetic mental imagery favor the emergence of gender differences. The very long RTs associated with this task (Table 1) indicate that it imposed especially high demands; possibly its difficulty precluded the use of fast strategies for either sex. The poor association between RT for this and most other tasks (Table 2) further suggests that mental-box folding engaged different processes. These data are not consistent with Bennett et al.'s (1982) finding of superior male accuracy. However, the DAT is typically administered in a public setting under speeded conditions; the privacy emphasized by the present arrangements and the fact that we used fewer, relatively easy trials could help to account for the discrepancy.

The present study provides some support for Sherman's (1978) strategy hypothesis, given a correspondence between "verbal" and relatively slow problem-solving styles and between "spatial" and relatively fast probelm-solving styles. However, we found that the speed difference applied to more simple decisions as well as to typical visual-spatial problems. Besides a general speed factor, more specific processes appear to contribute to the gender difference; these include, for women, slower mental rotation, slower mental comparison, and, perhaps, a bias toward accuracy. Direct and indirect effects of these differences may place females at a disadvantage on traditional speeded tests (Dwyer, 1979). Although Sherman associated strategy differences with gender differences in hemispheric specialization, our research does not bear on the relative contributions of nature and nurture.

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