Isolated Processing of Geometric Shapes and Their Corresponding Shape Words: Evidence From a Delayed Match-to-Sample Task

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Some theorists propose a domain-specific cognitive system dedicated to processing geometric information, but existence of this system remains debatable because of challenges in isolating geometric from linguistic and semantic processing. Recently, Sturz, Edwards, and Boyer (2014) developed a delayed match-to-sample task that presented a sample of a shape, shape word, or bidimensional stimulus composed of a shape and shape word. After a delay, participants identified the sample shape or the sample word by selecting between 2 shapes or 2 shape words. An asymmetrical pattern of interference emerged such that increased response times (RTs) and errors occurred in matching shape targets but not word targets. This was interpreted as shape words activating a semantic and spatial representation of shapes, but shapes only activating a spatial representation. The present experiments attempted to replicate and extend these results by manipulating figure-ground relations to contrast the original condition with an alternative to address an explanation based upon sample shape saliency (Experiment 1), by confirming the effectiveness of the saliency manipulation (Experiment 2), and by explicitly testing the assumption that shapes did not activate a semantic representation by reversing the sample-to-target matching criteria (Experiment 3). Experiment 1 replicated the asymmetrical pattern of results for both conditions, and Experiment 2 confirmed the saliency manipulation, which together undermine a pure saliency explanation. Experiment 3 produced a symmetrical pattern of results and suggests that the reversed matching criteria forced shapes to be processed in both a spatial and semantic fashion. These results provide support for a cognitive system dedicated to processing geometric information isolated from linguistic and semantic processing.

Keywords: geometric processing, semantic processing, delayed-match-to-sample

With the integration of evolutionary theory into contemporary psychological theory, the conception of cognition has synthesized a domain-general view (i.e., the mind is composed of a few general systems that process all domains of input) with that of a domain-specific view (i.e., the mind is composed of numerous systems dedicated to processing specific inputs; Barrett & Kurzban, 2006; Cosmides & Tooby, 1994a, 1994b; Duchaine, Cosmides, & Tooby, 2001). Given the operation of natural and sexual selection, individuals capable of solving specific adaptive problems related to survival and reproduction were more likely to pass their genes on to future generations. In the presence of various distinct problems, evolution would favor some domain-specific processes to solve these specific adaptive problems (Coltheart, 1999; Confer et al., 2010).

One extreme domain-specific account suggests that some aspects of cognition are composed of modules dedicated to solving specific adaptive problems (Fodor, 1985). These modules are proposed to be encapsulated such that they process narrow and specific inputs that are isolated from other cognitive processes, automatically and without conscious involvement. For example, in the classic Müller-Lyer illusion, two lines, one with arrow-heads pointed inward the other with arrow-heads pointed outward, appear to differ in length despite their objective equivalence. This illusion persists even after learning the lines are identical in length suggesting it occurs automatically and independent of conscious awareness, which has been argued consistent with modular processing (Fodor, 1985).

Some theorists hypothesize that geometric information is perceived and represented domain-specifically (Spelke, Lee, & Izard, 2010). Numerous studies provide evidence for the use of geometry in reestablishing orientation by means of the overall shape of an environment (i.e., global geometry; Cheng, 1986; Cheng & Newcombe, 2005; Hermer-Vazquez, Spelke, & Katsnelson, 1999). Specifically, when human and nonhuman animal participants are trained to search for and locate a target object in one corner of a rectangular environment, if they are then disoriented they search for the object at the correct and geometrically opposite (i.e., rotationally equivalent) corners at similar rates (see, Cheng, Huttenlocher, & Newcombe, 2013). This error persists even when a unique landmark disambiguates the correct and rotationally equivalent corners, which has been interpreted as indicating that the
overall shape of the environment and landmarks are processed independently during reorientation (see also, Cheng, 1986; Gallistel, 1990).

In modified reorientation paradigms, children also make the rotational error in environments with and without unique features (Cheng, 1986; Cheng et al., 2013; Hermer & Spelke, 1994). Adults show some success in using unique features to disambiguate the correct from the rotationally equivalent corner (i.e., they do not appear to make the rotational error in the presence of unique features); however, verbal shadowing tasks appear to disrupt the use of the unique features and result in rotational errors (Hermer-Vazquez, Spelke, & Katsnelson, 1999). Such results appear to provide evidence that language interferes with the use of landmark information but not the use of geometric information. As a result, some have suggested that language is required to combine the isolated information processed by geometric systems with that of landmark information (Hermer-Vazquez et al., 1999; cf., Ratliff & Newcombe, 2008).

The pervasive use of geometry in reorientation has led to the hypothesis that euclidean geometry is one of many domains of core knowledge that predates both linguistic and symbolic cognition (Dehaene, Izard, Pica, & Spelke, 2006; Lee & Spelke, 2010a, 2010b; Spelke, Lee, & Izard, 2010). For example, using a two-dimensional discrimination task, Dehaene et al. (2006), found that the Mundurukú, an indigenous tribe in the Amazon who had few words for geometry and arithmetic, appeared to comprehend basic concepts of euclidean geometry. Mundurukú adults and children viewed arrays of images that demonstrated a basic euclidean concept (e.g., parallel lines, right angles), which included one image that violated the concept (e.g., a curved line in an array depicting the concept of a straight line). Both Mundurukú children and adults could identify the violation, which was interpreted as providing support for the notion that basic euclidean geometry predates linguistic and symbolic thought and does not require spatial language or formal education.

Despite past research supporting the independent processing of geometric information, isolating this processing from the potential influence of linguistic and semantic processing in normal functioning adults has remained difficult because semantic memory and semantic processing are often necessarily and spontaneously involved in laboratory tests of object recognition and identification (Collins & Quillian, 1969; Hermer-Vazquez et al., 1999; cf., Ratliff & Newcombe, 2008). Essentially, semantic processing appears to activate representations associated with viewed objects. Therefore, it is quite a challenge to obtain evidence for the isolation of geometric processing, and to do so a task must provide evidence for the activation of a spatial representation independent of other representations.

One potential way to investigate the isolation of geometric and semantic processing would be to embed spatial stimuli into a visual task that has provided evidence for semantic competition (i.e., interference resulting from two different sources of semantic information). Recently, Sturz, Edwards, and Boyer (2014) investigated the isolation of geometric from semantic processing using a delayed match-to-sample (DMTS) task. In a DMTS task, a sample stimulus (e.g., a word or shape) is presented for a brief time, followed by a delay, and then a pair of targets appears. The participants’ task is to select the target that corresponds to (i.e., matches) the previously presented sample. It is important that this paradigm allows presenting word and shape samples either independently or bidimensionally (i.e., a shape word embedded within a shape), and probing word and shape targets independently by presenting either two word targets or two shape targets (see Figure 1). As important, the paradigm utilized by Sturz et al. (2014) prevented participants from knowing which dimension of the bidimensional sample would later need to be recalled because the appearance of word or shape targets indicated which dimension to recall.

Given that shapes are hypothesized to be perceived and represented by a domain-specific process dedicated to geometric information, Sturz et al. (2014) predicted that in the DMTS task, shape processing would be isolated from semantic processing, and, as a result, a shape word would activate a spatial representation of the shape, but a shape would not necessarily activate a semantic representation of a shape word. The results showed that RTs were slower in the presence of a bidimensional and incongruent sample (e.g., “square” surrounded by a circle), but only when the targets were shapes. When the targets were words, RTs did not differ whether the sample had been a shape word or a congruent and incongruent bidimensional sample word within a shape. Participants were also less accurate on trials where they had viewed an incongruent bidimensional sample (e.g., square surrounded by a circle) followed by the presentation of shape targets with a foil shape that was related with the shape word (i.e., the targets were a circle and a square). More important, this decrement in accuracy was limited only to trials where shape targets were probed, and did not apply to trials where shape words were probed. This asymmetrical pattern was interpreted as suggesting that a shape word activated a spatial representation of a shape that interfered with processing the shape, but a shape did not activate a semantic representation, and, hence, did not interfere with processing the shape word. In other words, suppression of the irrelevant spatial representation activated by shape words increased response times (RTs), but shapes did not require suppression of an irrelevant sample dimension because they did not activate a semantic representation.

Although this interpretation explains the reported asymmetrical pattern of interference, the bidimensional sample did not permit combining the shape and shape word into one distinct unified object. As a result, the observed asymmetrical interference pattern (words interfering with shapes, but shapes not interfering with words) obtained by Sturz et al. (2014) could have been because of the shape word being relatively more salient than the shape. If the shape was relatively less perceptually salient than the shape word, then it may have been more weakly encoded than the shape word, and, therefore, less likely to interfere with the shape word than the shape word was to interfere with it. It is important to note, however, that performance on trials with shape and word targets were significantly above chance levels, indicating that participants were encoding both dimensions. However, it seems reasonable that if words were relatively more salient than shapes, then this may have contributed to the obtained asymmetrical effects.

The present experiments had two main purposes. First, we attempted to directly test the possibility that differential saliency of the shape stimuli compared with word stimuli contributed to the asymmetrical interference effect observed by Sturz et al. (2014). We propose that altering the figure-ground relations of the word and shape stimuli (i.e., using filled vs. unfilled shapes and shape words) may modify the relative saliency of the shape and shape
word stimuli, which we used to probe this alternative saliency explanation in Experiment 1. In instances of bidimensional filled sample stimuli, the shapes were black filled with words presented in white font, giving the percept of the shape as being in the foreground with a shape word cutout (see Figure 2). In Experiment 2, we tested whether the saliency manipulation utilized in Experiment 1 was effective by investigating the speed of processing during matching while manipulating the fill type (i.e., unfilled vs. filled) of the sample, match, and foil in the DMTS paradigm. Second, we more explicitly tested the hypothesis that a shape word activates a spatial representation of a shape but a shape does not activate a semantic representation of the shape word (Experiment 3). Specifically, we required semantic-level processing of both shape and shape word stimuli by modifying the matching paradigm such that shapes were required to be matched to shape words and shape words were required to be matched to shapes. In short,
matching opposing dimensions should require that both shapes and shape words are processed semantically.

**Experiment 1**

The purpose of Experiment 1 was to directly test a differential saliency explanation of the asymmetrical pattern of interference obtained by Sturz et al. (2014) by manipulating the relative saliency of shapes and/or shape words by utilizing knowledge of figure-ground perception. In an Unfilled condition, the shapes were basic line drawings (see Figure 1) and were a direct replication of the stimuli used by Sturz et al. (2014). In a Filled condition, all shapes were black filled (see Figure 2). In instances of bidimensional filled sample stimuli, the shapes were black filled with words presented in white font. Reversing the figure-ground relations in the bidimensional stimuli was intended to increase the

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**Figure 2.** Sample Trial Types and trial structures for the Delayed Match-to-Sample task for the Filled Condition of Experiment 1. One sample Baseline/Training trial is illustrated for Shape Targets (a) and Word Targets (b), and one sample Congruent, Incongruent-Unrelated Foil, and Incongruent–Related Foil trial is illustrated for Shape Targets (c) and Word Targets (d). For illustrative purposes, all correct matches are shown as the left target even though correct target and foil target locations were balanced (see text for details). See the online article for the color version of this figure.
relative saliency of shapes and/or decrease the relative saliency of words (i.e., figure versus ground, respectively; see Figure 2). If the relatively greater saliency of the sample word compared with the sample shape contributed to the asymmetrical pattern of interference found by Sturz et al. (2014), then participants in the Unfilled condition should replicate the asymmetrical pattern of interference whereas those in the Filled condition should not produce an asymmetrical pattern of interference. In contrast, if sample shape word was not of greater saliency compared with the sample shape, or if it was and this did not actually contribute to the obtained asymmetrical interference, then both Unfilled and Filled conditions should produce a similar asymmetrical pattern of interference as found by Sturz et al. (2014).

Method

Participants. Sixty-four undergraduates at Georgia Southern University (32 men, 32 women) served as participants. Participants had normal or corrected-to-normal vision and received extra class credit or participated as part of a course requirement.

Apparatus. We constructed and implemented a delayed match-to-sample task (see Figures 1 and 2) on a personal computer with a 22-inch flat-screen liquid crystal display (LCD) monitor (1,680 × 1,050 pixels). Responses occurred via the “c” (left target) and “m” (right target) keys on a standard keyboard. Experimental events were controlled and recorded using E-Prime (Psychology Software Tools, Inc., www.pstnet.com).

Stimuli. There were two stimulus types: Shapes (Figures 1 and 2 a/c) and Shape Words (Figures 1 and 2 b/d). Shape stimuli were circles, squares, and triangles each presented in a 5 pixel width black outline measuring 312 pixels in diameter (circle), 312 pixels in height and width (square), and 440 pixels in base width and 312 pixels in height (triangle) subtending 7.3° visual angle horizontally and vertically (circle and square) and 10.3° horizontally and 7.3° vertically (triangle). Shape stimuli for the Unfilled condition consisted of a black outline filled with white (see Figure 1) whereas shape stimuli for the Filled condition consisted of a black outline filled with black (see Figure 2).

Shape word stimuli were “circle,” “square,” and “triangle” presented in bold 40 point Courier New font and were 187 (circle and square) and 250 (triangle) pixels in width, subtending 4.4° (circle and square), and 5.9° (triangle) visual angle horizontally, and 34 (circle and square) or 44 (triangle) pixels in height, subtending 0.8° or 1.0° visual angle vertically. When presented in isolation (i.e., not part of a bidimensional sample), shape word stimuli for both the Unfilled and Filled conditions were displayed in black font over a white background. When presented as bidimensional stimuli, shape word stimuli for the Unfilled condition were displayed in black (see Figures 1 and 2) whereas shape word stimuli for the Filled condition were displayed in white (see Figure 2). Samples were presented in the horizontal center of the screen 25% down from its top edge. Targets were presented on opposite sides of the screen, 50% of screen width apart, and 25% up from its bottom edge. All stimuli appeared on a white background.

Procedure. We provided participants with instructions that they would complete a memory test in which one of several shapes and words would appear on the screen, would disappear, and then either a pair of shapes or words would appear. Instructions also informed them that their task would be to select the shape that matched the sample shape if shape target pairs appeared or select the word that matched the sample word if word target pairs appeared. Like Sturz et al. (2014), when the sample was a bidimensional stimulus, participants did not know whether they would need to recall the sample shape or shape word until the targets appeared, and, therefore, it was crucial that they remember both dimensions of the sample stimulus to successfully complete the task.

The experimental protocol consisted of 120 total trials for each participant composed of 24 Training Trials and 96 Testing Trials. All trials presented samples for 1 s, followed by a 5 s blank screen retention interval delay, followed by target stimuli for 1.5 s. A response to the correct target (i.e., match) resulted in the presentation of a green check mark; a response to the incorrect target (i.e., foil) resulted in the presentation of a red “X,” and failure to respond during the 1.5 s target presentation produced a “No Response” statement. Feedback was presented for 1 s and served as the intertrial interval (ITI).

Before the start of the experiment, participants were randomly assigned to one of two Fill Type conditions (see Figures 1 and 2): Unfilled (shape stimuli filled white with shape word stimuli in black font; see Figure 1) or Filled (shape stimuli filled black with shape word stimuli in white font; see Figure 2). This resulted in 32 participants (16 men and 16 women) in the Unfilled condition and 32 participants (16 men and 16 women) in the Filled condition.

Training. To familiarize participants with the task, we provided them with 24 training trials composed of two 12-trial blocks. One block included 12 unique shape training trials in which participants matched a sample shape to its corresponding shape target (Figure 1a), and the other block included 12 unique word training trials in which participants matched a sample word to its corresponding word target (Figure 1b). We balanced for gender and counterbalanced the training blocks order of presentation.

Testing. Testing consisted of 96 trials composed of 12 eight-trial blocks. Each trial block was composed of two trials of each of four trial types (see Figure 1): Baseline (Training), Congruent (sample shape with corresponding shape word), Incongruent–Unrelated Foil (sample shape with noncorresponding shape word and a foil unrelated to the irrelevant sample dimension), and Incongruent–Related Foil (sample shape with noncorresponding shape word and a foil related to the irrelevant sample dimension). Baseline trials were identical to Training trials. For all trial types, when shape targets were presented (e.g., circle and square), the corresponding sample shape was the correct response. When word targets were presented (e.g., “circle” and “square”), the corresponding sample word was the correct response.

We presented one trial with shape targets and one trial with word targets for each trial type within each block in randomized sequences. The left/right location of the correct target (i.e., match) and foil were counterbalanced, which resulted in each unique combination of each trial type being presented once, without replacement, for a total of 96 trials during Testing (24 Baseline trials, 24 Congruent trials, 24 Incongruent–Unrelated Foil trials, and 24 Incongruent–Related Foil trials). Feedback was identical to Training.
Results

Response times. RTs were analyzed after removing both incorrect trials and trials in which participants failed to make a response (583/6144; 9.49%). Figure 3 shows the mean RTs (in milliseconds) plotted by Target Type for each Trial Type for the Unfilled Condition (a) and Filled Condition (b). A three-way mixed measures analysis of variance (ANOVA) was conducted on RTs with Fill Type (unfilled, filled), Target Type (shape, word), and Trial Type (Baseline, Congruent, Incongruent–Unrelated Foil, Incongruent–Related Foil) as factors and revealed a main effect of Target Type F(1, 62) = 26.52, p < .001, η² = .30, and a main effect of Trial Type F(3, 186) = 32.71, p < .001, η² = .35. These results were qualified by a significant Target Type × Trial Type interaction, F(3, 186) = 23.34, p < .001, η² = .27. None of the other factors or interactions were significant (ps > .3). Given the lack of effects or interactions with Fill Type, data were collapsed across Unfilled (M = 561.45, 95% confidence interval [CI] = 13.02) and Filled (M = 570.60, 95% CI = 13.91) conditions.

![Figure 3](image_url)

Figure 3. Mean response time on correct trials during Testing (in milliseconds) plotted by Target Type for each Trial Type for the Unfilled Condition (a) and the Filled Condition (b) of Experiment 1. Error bars represent 95% confidence intervals of the means.

To isolate the source of the Target Type × Trial Type interaction, we conducted two separate one-way repeated measures ANOVAs on RTs for Shape Targets and Word Targets with Trial Type (Baseline, Congruent, Incongruent–Unrelated Foil, Incongruent–Related Foil) as a factor. To control the family wise error rate, the alpha levels were reduced to p = .025 for each comparison (Keppel, 1991). For Shape Targets, there was a main effect of Trial Type, F(3, 189) = 38.41, p < .001, η² = .38. Fisher’s Least Significant Difference (LSD) post hoc tests revealed that Baseline and Congruent trials were significantly different from each other (p < .001), and both of these trial types were significantly faster than Incongruent–Unrelated Foil and Incongruent–Related Foil trials (ps < .001). Incongruent–Unrelated Foil and Incongruent–Related Foil trials were not significantly different from each other (p = .81). For Word Targets, the effect of Trial Type was not significant, F(3, 189) = 2.82, p = .04, η² = .04.

Proportion correct. We eliminated trials in which participants failed to respond (64/6144; 1.04%). Figure 4 shows the mean proportion correct plotted by Target Type for each Trial Type for the Unfilled Condition (a) and Filled Condition (b). A three-way mixed measures ANOVA on proportion correct with Fill Type (unfilled, filled), Target Type (shape, word), and Trial Type (Baseline, Congruent, Incongruent–Unrelated Foil, Incongruent–Related Foil) as factors revealed a main effect of Target Type F(1, 62) = 7.36, p < .01, η² = .11, and a main effect of Trial Type F(3, 186) = 23.84, p < .001, η² = .28. These main effects were qualified by a significant Target Type × Trial Type interaction, F(3, 186) = 16.71, p < .001, η² = .21. None of the other factors or interactions were significant (ps > .2). Given the lack of effects or interactions with Fill Type, data were collapsed across Unfilled (M = .92, 95% CI = .01) and Filled (M = .91, 95% CI = .01) conditions.

To isolate the source of the Target Type × Trial Type interaction, we conducted two separate one-way repeated measures ANOVAs on proportion correct for Shape Targets and Word Targets with Trial Type (Baseline, Congruent, Incongruent–Unrelated Foil, Incongruent–Related Foil) as a factor. To control the family wise error rate, the alpha levels were reduced to p = .025 for each comparison (Keppel, 1991). For Shape Targets, there was a main effect of Trial Type, F(3, 189) = 32.68, p < .001, η² = .34. LSD Post hoc tests revealed that Baseline, Congruent, and Incongruent–Unrelated Foil trials were not significantly different from each other (ps > .17), but all three trial types were significantly more accurate than Incongruent–Related Foil trials (ps < .001). For Word Targets, the effect of Trial Type was not significant, F(3, 189) = .43, p = .73. All mean proportions correct for each Trial Type and each Target Type were significantly greater than chance (0.5), one-sample t tests, ts(63) > 17.18, ps < .001.

Discussion

In the current DMTS task, participants took longer to make a correct decision between two shape targets following the presentations of an incongruent bidimensional sample (i.e., Incongruent–Unrelated Foil and Incongruent–Related Foil trials) compared to following a congruent or a uni-dimensional sample (i.e., Congruent and Baseline trials). No reaction time (RT) differences emerged, regardless of congruency of the sample or number of
Second, modifying the shape and word perceptual characteristics did not appear to influence this asymmetrical pattern of interference. Thus, the present findings are consistent with those obtained by Sturz et al. (2014) and the interpretation that words interfered with the identification of the correct sample word. This suggests that the sample shape dimension did not activate a semantic and spatial representation associated with the shape word needed to be suppressed to identify the correct match. Given that this additional spatial representation activated by the sample word dimension would also produce an additional potential match with the irrelevant sample word dimension, any difficulty in suppressing this irrelevant sample dimension would result in a decrement in accuracy in the presence of a related foil (i.e., Incongruent–Related Foil trials). In contrast, a lack of interference in the presence of word targets indicates that the sample shape dimension did not activate a semantic representation. As a result, there would be no semantic representation in need of suppression and no additional semantic representation as a potential match with the irrelevant sample dimension.

Although this experiment provides evidence to undermine a differential saliency explanation of the asymmetrical pattern of interference, our manipulation was based upon purely theoretical grounds of the effect of figure-ground relations between the shape and the shape word. For simplicity, we have described this as a manipulation of the fill type of the shape (e.g., filled vs. unfilled), but this manipulation also affected the way in which the shape words were presented (i.e., from the figure to the ground, relative to the unfilled and filled shapes, respectively). Furthermore, this introduced a potential imbalance in the stimuli; specifically, in the Filled Condition, the font color of the shape words embedded in filled shapes changed from sample presentation to match and foil presentation (i.e., from white in sample to black for matches and foils). As a result, it remains unclear to what extent a change in font color of the word stimulus may have influenced the relative saliency of the word dimension in bidimensional stimuli, which may have potentially undermined the attempt to manipulate saliency through figure-ground reversals.

**Experiment 2**

The purposes of Experiment 2 were to directly assess which manipulations of shape and shape word fill type (i.e., filled and unfilled shape and shape word stimuli) produce differences in saliency in a DMTS task, as well as to investigate the potential influence of changing stimulus characteristics from sample presentation to match and foil presentation. Specifically, we manipulated the fill type (black outline with black fill or black outline with white fill) of both the shape and shape word stimuli under the...
Training/Baseline conditions presented during Experiment 1. Given that a DMTS task has three components: sample, match, and foil, we manipulated the extent to which samples, matches, and foils were filled or unfilled for both shape and shape word stimuli. We utilized the relative speed of matching shapes to shapes and words to words (identical to Training/Baseline trials of Experiment 1) under these various sample, match, and foil fill conditions as indicative of relative saliency. Specifically, we then interpreted faster (correct) responses as indicative of greater saliency. More important, this approach also allowed us to determine the extent to which changes in fill type from sample presentation to the presentation of matches and foils potentially influenced performance in Experiment 1.

Method

Participants. Thirty-six undergraduate students at Georgia Southern University (14 men, 22 women), different from those who participated in Experiment 1, served as participants. Participants had normal or corrected-to-normal vision and received extra class credit or participated as part of a course requirement.

Apparatus. The apparatus was identical to that used in Experiment 1.

Stimuli. As with Experiment 1, there were two stimulus types: shapes (circle, square, and triangle) and shape words (circle, square, and triangle). Identical to Experiment 1, shape stimuli were further subdivided into Unfilled and Filled types. Unfilled Shape stimuli consisted of a black outline filled with white (see Figure 5) whereas Filled Shape stimuli consisted of a black outline filled with black (see Figure 5). Similarly, word stimuli were also further subdivided into Unfilled and Filled. Unfilled Shape Word stimuli consisted of a black outline filled with white over a white background. Filled Shape Word stimuli consisted of a black outline filled with black over a white background (see Figure 5). All other stimulus dimensions were identical to those of the uni-dimensional stimuli used in Training/Baseline trials of Experiment 1.

Procedure. Similar to Experiment 1, we provided participants with instructions that they would complete a memory test in which one of several shapes or words would appear on the screen, would disappear, and then either a pair of shapes or words would appear. Instructions also informed them that their task would be to select the shape that matched the sample shape if shape target pairs appeared or select the word that matched the sample word if word target pairs appeared.

Using only the Training/Baseline trial structure of Experiment 1, the experimental design was 2 (Shape Sample, Word Sample) x 2 (Sample Filled, Sample Unfilled) x 2 (Match Filled, Match Unfilled) x 2 (Foil Filled, Foil Unfilled) with all factors manipulated within-subjects. Given that a DMTS task has three components: sample, match, and foil, the manipulation of unfilled and filled samples, matches, and foils resulted in eight unique trials types for both shape and word stimuli (see Figure 5). Three shape samples (circle, square, or triangle) or three word samples (circle, square, or triangle), there were 12 unique combinations of sample type, left/right match location, left/right foil location, and foil. This also means that the left/right location of the correct target (i.e., match) and foil were counterbalanced. Combined with the eight unique trial types this resulted in 96 total shape trials (matching shapes to shapes) and 96 total word trials (matching word to word). This resulted in 192 total trials for each participant. Stimuli timing and feedback were identical to Experiment 1.

Results

Response times. RTs were analyzed after removing both incorrect trials and trials in which participants failed to make a response (550/6912; 7.96%). Table 1 shows the mean RTs (in milliseconds) and 95% CIs for both Shape and Word Samples separated by the Sample Fill Type (Filled, Unfilled) for each of the Match Fill Type (Filled, Unfilled) and Foil Fill Type (Filled, Unfilled) combinations.

A four-way repeated measures ANOVA was conducted on response time with Sample Type (Shapes, Words), Sample Fill Type (Filled, Unfilled), Match Fill Type (Filled, Unfilled), and Foil Fill Type (Filled, Unfilled) as factors and revealed a main effect of Sample Type, $F(1, 35) = 153.61, p < .001, \eta_p^2 = .81$. These results were qualified by significant Sample Type x Match Fill Type, $F(1, 35) = 5.36, p < .05, \eta_p^2 = .13$, Sample Type x Foil Fill Type $F(1, 35) = 7.78, p < .01, \eta_p^2 = .18$, and Sample Type x Sample Fill Type x Match Fill Type, $F(1, 35) = 5.84, p < .05, \eta_p^2 = .14$, interactions. None of the other factors or interactions were significant ($ps > .05$).

To isolate the source of the Sample Type x Sample Fill Type x Match Fill Type and Sample Fill Type x Foil Fill Type interactions, we conducted two separate three-way repeated measures ANOVAs for Shape Samples and Word Samples with Sample Fill Type (Filled, Unfilled), Match Fill Type (Filled, Unfilled), and Foil Fill Type (Filled, Unfilled) as factors. For Shape Samples there were significant Sample Fill Type x Match Fill Type, $F(1, 35) = 5.01, p < .05, \eta_p^2 = .13$ and Sample Fill Type x Foil Fill Type, $F(1, 35) = 9.97, p < .01, \eta_p^2 = .22$, interactions. None of the

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Figure 5. Examples of Filled (a/b) and Unfilled (c/d) Shape (a/c) and Word (b/d) stimuli for the Delayed Match-to-Sample (DMTS) task of Experiment 2. Note that Experiment 2 only utilized the Training/Baseline trial structure of Experiment 1. Also note that given that a DMTS task has three components: sample, match, and foil, all possible combination of unfilled and filled samples, matches, and foils for both shape and word stimuli were presented to participants (see text for details).
other factors or interactions were significant ($ps > .4$). To further isolate the source of the interactions for Shape Samples, we conducted two separate two-way repeated measures ANOVAs for Filled and Unfilled Shape Samples with Match Fill Type (Filled, Unfilled) and Foil Fill Type (Filled, Unfilled) as factors. For Filled Shape Samples, there was a main effect of Match Fill Type, $F(1, 35) = 8.55, p < .01, \eta^2_p = .19$, and a main effect of Foil Fill Type, $F(1, 35) = 9.22, p < .01, \eta^2_p = .21$. The Match Fill Type × Foil Fill Type interaction was not significant, $F(1, 35) = 0.5, p = .48$. In short, for Filled Sample Shapes, participants were faster if the Foil was Filled compared with when it was Filled ($M = 480.46, 95\% CI = 40.53$) compared with when it was Filled ($M = 496.12, 95\% CI = 37.36$), and participants were faster if the Foil was Unfilled ($M = 480.31, 95\% CI = 38.28$) compared with when it was Filled ($M = 499.66, 95\% CI = 39.79$). For Unfilled Shape Samples, there were no significant main effects or interactions ($ps > .1$). For Shape samples, these results suggest that there was no clear increase in saliency of Filled compared with Unfilled Shape samples, though there appeared to be variability in processing speed as a function of whether the Sample and Match, Sample and Foil, and Match and Foil were congruent in their fill type (i.e., whether they matched in terms of being filled or unfilled).

More important, for Word samples, there was only a main effect of Sample Fill, $F(1, 35) = 5.66, p < .05, \eta^2_p = .14$. Participants were faster to respond to Filled Samples ($M = 551.57, 95\% CI = 40.58$) compared with Unfilled Samples ($M = 564.62, 95\% CI = 38.35$). This suggests that filled sample words were more salient than unfilled sample words regardless of Match Fill Type or Foil Fill Type. As important, the Sample-Match, Sample-Foil, and Match-Foil congruency did not appear to impact speed of processing.

**Propportion correct.** We eliminated trials in which participants failed to respond (96/6912; 1.39%). Table 2 shows the mean proportion correct and 95% CIs for both Shape and Word Samples separated by the Sample Fill Type (Filled, Unfilled) for each of the Match Fill Type (Filled, Unfilled) and Foil Fill Type (Filled, Unfilled) combinations. A four-way repeated ANOVA was conducted on proportion correct with Sample Type (Shapes, Words), Sample Fill Type (Filled, Unfilled), Match Fill Type (Filled, Unfilled), and Foil Fill Type (Filled, Unfilled) as factors and revealed a main effect of Sample Type, $F(1, 35) = 5.89, p < .05, \eta^2_p = .14$. This result was qualified by a significant Sample Fill Type × Match Fill Type × Sample Fill Type × Foil Fill Type interaction, $F(1, 35) = 8.33, p < .01, \eta^2_p = .19$, and Sample Type × Sample Fill Type × Foil Fill Type interaction, $F(1, 35) = 6.05, p < .05, \eta^2_p = .15$. None of the other factors or interactions were significant ($ps > .07$).

To isolate the source of the Sample Type × Sample Fill Type × Foil Fill Type and Sample Fill Type × Foil Fill Type interactions, we conducted two separate three-way repeated measures ANOVAs for Shape Samples and Word Samples with Sample Fill Type (Filled, Unfilled), Match Fill Type (Filled, Unfilled), and Foil Fill Type (Filled, Unfilled) as factors. For Shape Samples there was a significant Sample Fill Type × Foil Fill Type interaction, $F(1, 35) = 10.39, p < .01, \eta^2_p = .23$. None of the other factors or interactions were significant ($ps > .2$). To further isolate the source of the interaction for Shape samples, we conducted two separate two-way repeated measures ANOVAs for Filled and Unfilled Shape Samples with Match Fill Type (Filled, Unfilled) and Foil Fill Type (Filled, Unfilled) as factors. For Filled Shape Samples, there was a main effect of Foil Fill Type, $F(1, 35) = 4.35, p < .05, \eta^2_p = .11$. Neither the effect of Match Fill Type nor the Match Fill Type × Foil Fill Type interaction was significant ($ps > .7$). In short, for Filled Sample Shapes, participants were more accurate if the Foil was Unfilled ($M = 0.96, 95\% CI = 0.02$) compared with when it was Filled ($M = 0.94, 95\% CI = 0.02$). For Unfilled Sample Shapes, there was also a main effect of Foil Fill Type, $F(1, 35) = 7.50, p < .05, \eta^2_p = .18$. Neither the effect of Match Fill Type nor the Match Fill Type × Foil Fill Type interaction was significant ($ps > .2$). In short, for Unfilled Sample Shapes, participants were more accurate if the Foil was Filled ($M = 0.96, 95\% CI = 0.02$) compared with when it was Unfilled ($M = 0.92, 95\% CI = 0.04$). Consistent with the RT data reported above, these results for Shape Samples suggest that there was no clear increase in saliency of Filled compared with Unfilled Shape samples, despite evidence for an effect on accuracy of Sample and Match, Sample and Foil, and Match and Foil congruency with respect to their fill type (i.e., whether they matched in terms of being filled or unfilled).

For Word samples, there was a significant Sample Fill Type × Match Fill Type interaction, $F(1, 35) = 4.3, p < .05, \eta^2_p = .11$. To isolate the source of the interaction for Word Samples, we conducted two separate two-way repeated measures ANOVAs for

### Table 1
**Response Times (in Milliseconds) and 95% Confidence Interval (in Parentheses) for Sample Fill Type, Match Fill Type, and Foil Fill Type for Shape (Top) and Word (Bottom) Samples of Experiment 2**

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Filled samples</th>
<th>Unfilled samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match fill type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Match filled</td>
<td>510.19 (42.37)</td>
<td>479.83 (41.02)</td>
</tr>
<tr>
<td>Match unfilled</td>
<td>480.04 (35.43)</td>
<td>493.40 (40.91)</td>
</tr>
<tr>
<td>Match unfilled</td>
<td>489.14 (39.98)</td>
<td>483.15 (40.50)</td>
</tr>
<tr>
<td>Match unfilled</td>
<td>471.78 (44.95)</td>
<td>499.01 (44.06)</td>
</tr>
</tbody>
</table>

To isolate the source of the Sample Type × Sample Fill Type × Foil Fill Type and Sample Fill Type × Foil Fill Type interactions, we conducted two separate three-way repeated measures ANOVAs for Shape Samples and Word Samples with Sample Fill Type (Filled, Unfilled), Match Fill Type (Filled, Unfilled), and Foil Fill Type (Filled, Unfilled) as factors. For Shape Samples there was a significant Sample Fill Type × Foil Fill Type interaction, $F(1, 35) = 10.39, p < .01, \eta^2_p = .23$. None of the other factors or interactions were significant ($ps > .2$). To further isolate the source of the interaction for Shape samples, we conducted two separate two-way repeated measures ANOVAs for Filled and Unfilled Shape Samples with Match Fill Type (Filled, Unfilled) and Foil Fill Type (Filled, Unfilled) as factors. For Filled Shape Samples, there was a main effect of Foil Fill Type, $F(1, 35) = 4.35, p < .05, \eta^2_p = .11$. Neither the effect of Match Fill Type nor the Match Fill Type × Foil Fill Type interaction was significant ($ps > .7$). In short, for Filled Sample Shapes, participants were more accurate if the Foil was Unfilled ($M = 0.96, 95\% CI = 0.02$) compared with when it was Filled ($M = 0.94, 95\% CI = 0.02$). For Unfilled Sample Shapes, there was also a main effect of Foil Fill Type, $F(1, 35) = 7.50, p < .05, \eta^2_p = .18$. Neither the effect of Match Fill Type nor the Match Fill Type × Foil Fill Type interaction was significant ($ps > .2$). In short, for Unfilled Sample Shapes, participants were more accurate if the Foil was Filled ($M = 0.96, 95\% CI = 0.02$) compared with when it was Unfilled ($M = 0.92, 95\% CI = 0.04$). Consistent with the RT data reported above, these results for Shape Samples suggest that there was no clear increase in saliency of Filled compared with Unfilled Shape samples, despite evidence for an effect on accuracy of Sample and Match, Sample and Foil, and Match and Foil congruency with respect to their fill type (i.e., whether they matched in terms of being filled or unfilled).

For Word samples, there was a significant Sample Fill Type × Match Fill Type interaction, $F(1, 35) = 4.3, p < .05, \eta^2_p = .11$. To isolate the source of the interaction for Word Samples, we conducted two separate two-way repeated measures ANOVAs for

### Table 2
**Proportion Correct and 95% Confidence Interval (in Parentheses) for Sample Fill Type, Match Fill Type, and Foil Fill Type for Shape (Top) and Word (Bottom) Samples of Experiment 2**

<table>
<thead>
<tr>
<th>Sample Type</th>
<th>Filled samples</th>
<th>Unfilled samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Match fill type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Match filled</td>
<td>.94 (.03)</td>
<td>.95 (.03)</td>
</tr>
<tr>
<td>Match unfilled</td>
<td>.96 (.03)</td>
<td>.92 (.04)</td>
</tr>
<tr>
<td>Match unfilled</td>
<td>.94 (.03)</td>
<td>.96 (.02)</td>
</tr>
<tr>
<td>Match unfilled</td>
<td>.96 (.02)</td>
<td>.92 (.04)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Word samples</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Match filled</td>
<td>.93 (.02)</td>
<td>.94 (.03)</td>
</tr>
<tr>
<td>Match unfilled</td>
<td>.91 (.03)</td>
<td>.93 (.03)</td>
</tr>
<tr>
<td>Match unfilled</td>
<td>.92 (.02)</td>
<td>.91 (.03)</td>
</tr>
<tr>
<td>Match unfilled</td>
<td>.94 (.03)</td>
<td>.92 (.04)</td>
</tr>
</tbody>
</table>
Discussion

The purpose of Experiment 2 was to assess whether, and if so, which manipulations of the fill type of shapes or shape words produced differences in saliency in a DMTS task to provide converging evidence that our manipulation of figure-ground relations in Experiment 1 altered the relative saliency of shapes and/or shape words. Despite the complexity of the results from Experiment 2, the most robust result appears to be that Filled Word samples were processed faster than Unfilled Word samples. We interpret this relative speed of processing as indicative of Filled Word samples being more salient than Unfilled Word samples. Furthermore, the extent to which the Match and Foil Fill Type were consistent with the Sample Fill Type did not appear to influence performance for Unfilled Word samples.

These results are important for two primary reasons. First, these results provide converging evidence that the figure-ground manipulation utilized in Experiment 1 (i.e., bidimensional stimuli with unfilled shapes and filled words or filled shapes and unfilled words) were effective in reducing the relative saliency of the word stimuli. In short, the results of Experiment 2 indicate that the unfilled words were less perceptually salient than the filled words. By extension, this suggests that despite the reduction in relative perceptual saliency of the word stimuli in Experiment 1, the asymmetrical pattern of interference was still obtained. As a result, Experiment 2 provides converging evidence to undermine a differential saliency explanation of the asymmetrical pattern of interference obtained in Experiment 1. Second, the results of Experiment 2 indicate that changes in Match Fill Type and Foil Fill Type did not appear to influence speed of processing of Unfilled Word samples. In the Filled Condition of Experiment 1, word samples changed font colors from sample presentation to match and foil presentations (i.e., white to black), and the results of Experiment 2 suggest that this change in font color did not influence the perception of the word dimension in bidimensional stimuli of the Filled condition.

It is worth noting that we explicitly acknowledge that the results of Experiment 2 do not conclusively rule out an explanation based upon differential saliency of shapes relative to shape words in accounting for the asymmetrical pattern of interference obtained in Experiment 1 and in Sturz et al. (2014) and Experiment 1. Specifically, the results of Experiment 2 do not support the conclusion that the saliency manipulation used in Experiment 1 was effective at increasing shape saliency. Although the results of Experiment 2 indicate that outlined words (i.e., white words on a white background that are outlined rather than filled) are less salient than filled words (i.e., black words on a white background), this manipulation was not identical to that used in Experiment 1. In Experiment 1, word stimuli were presented in white, but they were not outlined in black against a white background; instead word stimuli were presented on an entirely black background (i.e., the filled shape). Given this difference, we acknowledge that we cannot definitively conclude that our manipulation of fill type utilized in Experiment 1 necessarily reduced the saliency of word stimuli relative to shape stimuli (or increased the saliency of shape stimuli relative to word stimuli). As such, a saliency explanation appears to remain a viable alternative. This possibility notwithstanding, we believe that such a proposition is difficult to reconcile with the fact that multiple iterations of the DMTS task continue to produce results in which shapes have been found to be processed faster as well as more accurately than words.

Experiment 3

Given that the results of Experiment 1 are consistent with those obtained by Sturz et al. (2014) and can be interpreted in the same fashion, and Experiment 2 supported the theoretically based proposal that modifying the figure-ground relations of the shape and word would affect their relative saliency, Experiment 3 attempted to further test the core Sturz et al. (2014) and Experiment 1 finding of asymmetrical performance with shape and word stimuli. The primary aim of this study is to explicitly test the hypothesis that it is possible to force semantic processing with all stimuli. Specifically, in Experiment 3, the matching criteria were reversed such that participants were required to match a shape to its corresponding shape word and a shape word to its corresponding shape (see Figure 6). The logic is that reversing the matching criteria should require a shape to be semantically processed as well as require a shape word to be spatially processed (though the results of Experiment 1 and Sturz et al., 2014, suggest that shape words activate spatial representations). To match a shape to its corresponding shape word, the shape should require additional processing to activate its corresponding semantic representation and identify the correct match. In contrast, matching a shape word to its corresponding shape should not require any additional processing, because the asymmetrical pattern of interference reported in Experiment 1 and in Sturz et al. (2014) suggests that a shape word spontaneously activates a spatial representation of the shape. As a result, both dimensions should be semantically processed and result in a symmetrical, as opposed to an asymmetrical, pattern of interference. In addition, this proposed extra processing required to activate a semantic representation of the corresponding shape word after viewing a shape should result in longer RTs for word targets (i.e., matching shapes to shape words) than shape targets (i.e., matching shape words to shapes).

Method

Participants. Sixty-four undergraduate students at Georgia Southern University (32 men, 32 women), different from those
who participated in Experiments 1 and 2, served as participants. Participants had normal or corrected-to-normal vision and received extra class credit or participated as part of a course requirement.

**Apparatus and stimuli.** The apparatus and stimuli were identical to those used in Experiment 1.

**Procedure.** The design and procedure for Experiment 3 were identical to Experiment 1 with the exception that the matching criteria were reversed. Specifically, participants were required to match a shape to its corresponding shape word and match a shape word to its corresponding shape (refer to Figures 6 and 7).

Similar to Experiment 1, we provided participants with instructions that they would complete a memory test in which one of several shapes and words would appear on the screen, would disappear, and then either a pair of shapes or words would appear. Instructions also informed them that their task would be to select the shape that matched the sample word (if shape pairs) or select
the word that matched the sample shape (if word pairs). Again, when viewing a bidimensional stimulus, participants did not know whether they would subsequently be required to recall the sample shape or shape word until they saw the shape word or shape targets, respectively, and, therefore, it was crucial that they be able to recall both the sample shape and shape word, at least until the presentation of the match and foil targets.

Identical to Experiment 1, before the start of the experiment, participants were randomly assigned to one of two conditions (refer to Figures 6 and 7): Unfilled (shape stimuli filled white with shape word stimuli in black font; Figure 6) or Filled (shape stimuli filled black with shape word stimuli in white font; Figure 7). This resulted in 32 participants (16 men and 16 women) in the Unfilled condition and 32 participants (16 men and 16 women) in the Filled condition.

Training. Similar to Experiment 1, we provided participants with 24 training trials composed of two 12-trial blocks. However, for Experiment 3, one block included 12 unique shape training
trials in which participants matched a sample shape to its corresponding shape word target, and the other block included 12 unique word training trials in which participants matched a sample word to its corresponding shape target. We balanced for gender and counterbalanced the training blocks order of presentation.

**Testing.** Testing was identical to Experiment 1 with the exception that when shape targets were presented (e.g., circle and square), that which matched the corresponding sample word was the correct response, and when words targets were presented (e.g., “circle” and “square”), the corresponding sample shape was the correct response.

**Results**

**Response times.** RTs were analyzed after the removal of both incorrect trials and trials in which participants failed to make a response (1068/6144; 17.38%). A three-way mixed measures ANOVA was conducted on RTs with Fill Type (Unfilled, Filled), Target Type (Shape, Word), and Trial Type (Baseline, Congruent, Incongruent–Unrelated Foil, Incongruent–Related Foil) as factors and revealed a main effect of Target Type \( F(1, 60) = 120.56, p < .001, \eta^2_g = .67 \), and a main effect of Trial Type \( F(3, 180) = 157.60, p < .001, \eta^2_g = .72 \). None of the other factors or interactions were significant \((ps > .15)\). Figure 8 shows the mean RTs (in milliseconds) plotted by Target Type for each Trial Type for the Unfilled Condition (a) and the Filled Condition (b). Given the lack of effects or interactions with Fill Type, data were collapsed across Unfilled \((M = 665.41, 95\% CI = 20.25)\) and Filled \((M = 670.861, 95\% CI = 18.81)\) conditions.

Overall, participants responded to Shape Targets \((M = 616.09, 95\% CI = 28.01)\) significantly faster than Word Targets \((M = 717.54, 95\% CI = 22.97)\). Pairwise comparisons on the Trial Type factor revealed that Baseline \((M = 576.73, 95\% CI = 21.84)\) and Congruent \((M = 587.42, 95\% CI = 21.87)\) trials were not significantly different from each other \((p = .09)\), but both of these trials types were significantly faster than Incongruent–Unrelated Foil \((M = 770.51, 95\% CI = 28.82)\) and Incongruent–Related Foil \((M = 732.60, 95\% CI = 35.31)\) trials \((ps < .005)\). Incongruent–Related Foil trials were significantly faster than Incongruent–Unrelated Foil trials \((p < .01)\).

**Proportion correct.** We eliminated trials in which participants failed to respond \((133/6144; 2.16\%)\). Figure 9 shows the mean proportion correct plotted by Target Type for each Trial Type for the Unfilled Condition (a) and Filled Condition (b). A three-way mixed measures ANOVA on proportion correct with Fill Type (Unfilled, Filled), Target Type (Shape, Word), and Trial Type (Baseline, Congruent, Incongruent–Unrelated Foil, Incongruent–Related Foil) as factors revealed a main effect of Target Type \( F(1, 62) = 10.00, p < .01, \eta^2_g = .14 \), and a main effect of Trial Type \( F(3, 186) = 236.32, p < .001, \eta^2_g = .79 \). These main effects were qualified by a significant Target Type \( \times \) Trial Type interaction, \( F(3, 186) = 3.51, p < .05, \eta^2_g = .05 \). No other factors or interactions were significant \((ps > .18)\). Given the lack of effects or interactions with Fill Type, data were collapsed across Unfilled \((M = .84, 95\% CI = .03)\) and Filled \((M = .85, 95\% CI = .02)\) conditions.

To isolate the source of the Target Type \( \times \) Trial Type interaction, two separate one-way repeated measures ANOVAs were conducted on proportion correct for Shape Targets and Word Targets with Trial Type (Baseline, Congruent, Incongruent–Unrelated Foil, Incongruent–Related Foil) as a factor and revealed a main effect of Trial Type for Shape Targets, \( F(3, 189) = 119.07, p < .001, \eta^2_g = .65 \), and a main effect of Trial Type for Word Targets, \( F(3, 189) = 114.00, p < .001, \eta^2_g = .64 \). These results indicate that the source of the Target Type \( \times \) Trial Type interaction was different from what was observed in Experiment 1. Specifically, this interaction was not because of an asymmetry in shape and word targets.

Instead, the Target Type \( \times \) Trial Type interaction was driven by differences in Shape Targets and Word Targets between specific conditions.
Discussion

Overall, participants took longer to make a correct decision when presented with an incongruent bidimensional sample (i.e., Incongruent–Unrelated Foil and Incongruent–Related Foil trials) compared with Baseline and Congruent trials. Furthermore, participants took longer to match a shape to its corresponding shape word compared with matching a shape word to its corresponding shape. Additionally, accuracy decreased for both Target Types when the foil was related to the irrelevant sample dimension (Incongruent–Related Foil trials). Finally, RTs and accuracy did not differ between the Unfilled and Filled conditions, nor did this interact with any other factors.

These results are important for three primary reasons. First, unlike Experiment 1, the results of Experiment 3 produced a symmetrical pattern of interference across shape and shape word target stimuli. In short, reversing the matching criteria, such that participants were required to match a sample shape to its corresponding shape word and match a sample shape word to its corresponding shape, appeared to result in interference for both shapes and shape words. Such a result is consistent with the interpretation that suppression of an irrelevant sample dimension was required for both Target Types. Specifically, to identify the correct shape target match, participants were required to activate a geometric representation of the sample shape word and suppress the irrelevant geometric representation activated by the sample shape dimension, and, likewise, identification of the correct shape word target match required activation of a semantic representation of the sample shape and suppression of the irrelevant semantic representation activated by the sample shape word dimension. We suggest that this required pattern of suppression is what produced longer RTs in the sample shape conditions. Symmetrical interference is also supported by the decrease in accuracy for both Shape Targets and Word Targets during Incongruent–Related Foil trials compared with Baseline and Congruent trials. We suggest that any inability or difficulty in suppressing the irrelevant sample dimension would result in increased error rates because of the presence of a potential match.

Second, the differences in RTs between Shape Targets and Word Targets suggest an additional process is involved in the perception and representation of a sample shape in the reverse matching task. We suggest that forcing sample shapes to be processed in a semantic fashion resulted in additional processing that would not otherwise be engaged. The difference in the speed between matching a sample shape to its corresponding shape word compared with matching a sample shape word to its corresponding shape is consistent with the interpretation that sample shapes do not automatically activate a corresponding semantic representation, but sample words spontaneously activated both a corresponding semantic and spatial representation. In short, the results of Experiment 3 suggest that sample shapes were processed in a semantic fashion only after initial automatic spatial processing, but sample words activated both a semantic and spatial representation.

Third, these results again undermine the suggestion that the asymmetrical pattern of interference obtained in Experiment 1 and reported by Sturz et al. (2014) was because of a difference in relative perceptual saliency between shapes and words. Although null effects must be interpreted with caution, these results appear to undermine an alternative explanation that the pattern of interference reported in Sturz et al. (2014) and replicated in Experiment 1 was because of differential relative saliency of the shape and shape word samples. In short, Experiment 3 provides converging evidence to undermine this alternative interpretation.
Presumably, in the present experiment, both sample dimensions activated both semantic and spatial representations, and in each case, one of these representations needed to be suppressed to identify the correct target. The presence of an extra and related representation presumably resulted in the decrement in accuracy seen in the Incongruent-Related Foil trials. The symmetrical pattern of interference suggests that both shape and word samples activated both semantic and spatial representations. As a result, there was an irrelevant representation in need of suppression for both sample shape and sample shape words.

**General Discussion**

Collectively, these results are important for three reasons. First, these results appear to undermine an alternative explanation for the asymmetrical pattern of interference between geometric shapes and their corresponding shape words because of differences in relative stimulus saliency. Shape words were arguably more salient than the shapes used in previous research (i.e., Sturz et al., 2014), which may have resulted in weaker relative encoding of shapes than words and produced the observed asymmetrical pattern of interference. However, a manipulation of the figure-ground relation of the shape and word in the present study still produced an asymmetrical pattern of interference. Although null effects must be interpreted with caution, a lack of differences between the Unfilled and Filled conditions for either Experiment 1 or 3, coupled with the confirmation from Experiment 2 that this manipulation effectively reduced the relative saliency of words, at least provides converging evidence to undermine an interpretation that the obtained asymmetrical pattern of interference resulted from a difference in saliency between shapes and shape words.

As previously mentioned, we acknowledge that the current results do not conclusively rule out an explanation based upon differential saliency of shapes relative to shape words in accounting for the obtained asymmetrical pattern of interference of Sturz et al. (2014) and Experiment 1. Given the subtle differences between the figure and ground manipulations used in Experiments 1 and 3 compared with Experiment 2, we cannot definitively conclude that our manipulation of fill type reduced the saliency of word stimuli relative to shape stimuli or increased the saliency of shape stimuli relative to word stimuli. In short, the explanation that the observed asymmetry may be because of differential relative shape and shape word perceptual saliency remains feasible; however, such an explanation seems difficult to reconcile with the numerous replications of the finding that shapes are processed faster and more accurately than words in the context of the adopted DMTS task.

Second, the current study supports the proposal that the asymmetrical pattern of interference resulted from shapes not automatically activating a semantic representation. Experiment 1 provides a direct replication of Sturz et al. (2014), in that semantic interference appeared to occur only for shape targets, while no differences emerged in any of the trial types for word targets. These findings suggested that words activated the necessary semantic representation to correctly identify the word target and also provided a spatial representation that interfered with choosing the correct shape target. The lack of differences between trial types for word targets was interpreted as shapes not activating the appropriate semantic representation to interfere with choosing a word target. This core assumption was directly tested in Experiment 3. Reversing the matching criteria produced a symmetrical pattern of interference. The elimination of an overall difference in the pattern of interference between shape and word targets suggests that both shapes and shape words were activating both a semantic and a spatial representation when the task required responding across the opposite dimension.

It is worth noting that we have interpreted the current results within the context of semantic competition to be consistent with prior interference/competition research (e.g., Sturz et al., 2013, 2014; for a review, see MacLeod, 1991, 1992); however, we acknowledge there is evidence to suggest that words can be processed at a lexical level that may be distinct from semantic processing (e.g., Bormann & Weiller, 2012; see also, Borowsky & Besner, 2006). As a result, our results do not preclude the possibility that shapes and shape words were processed in a semantic fashion. Although it may be unclear to what extent (if any) shapes and shape words were processed in a semantic fashion, it seems clear that shapes were not processed in a lexical fashion. To the extent that shapes and shape words activated semantic representations, any semantic activation by shapes was not sufficient to interfere with word matching. Rather, our results indicate that in the case of shapes, participants were responding primarily on the basis of spatial representations.

As an aside, response competition (i.e., relative speed of processing, also known as “horse-race” models), appear to be unable to explain the current results (for a review, see MacLeod, 1991, 1992). Specifically, evidence from multiple iterations of the DMTS task have shown that shape processing is faster than word processing (i.e., performance on Baseline/Training trials). As a result, any information from shape stimuli should always arrive faster to a decision process than that from word stimuli regardless of trial type. In short, this faster processing of shapes would actually predict the exact opposite pattern of the results (i.e., shapes should interfere with word matching, but words should not interfere with shape matching).

Third, and most generally, the current studies provide additional support for the conception of domain-specific processing of geometric information. The asymmetrical pattern of interference obtained in Experiment 1 indicates that shapes were processed by a system different from that which processes semantic information. The lack of interference from shapes in matching shape words to shape words, suggests that the processing of the geometric shapes was isolated from semantic information. Only after requiring geometric shapes to be processed in a semantic fashion (by reversing the matching criteria in Experiment 3) did a symmetrical pattern of interference emerge. This evidence for a symmetrical pattern of interference in Experiment 3 indicates that both shapes and shape words were activating both a semantic and a spatial representation. That matching a sample shape to its corresponding shape word took longer than matching a sample shape word to its corresponding shape suggests that the activation of additional semantic representations was necessary after initial automatic activation of spatial representations with perceptions of the shape stimulus. Though we are unable to test certain assumptions of a pure modular account (Fodor, 1985), the reported results appear consistent with some of the characteristics of a cognitive system that is proposed to be dedicated to processing geometric information; specifically, the findings are consistent with the assumptions of isolated processing and automaticity.

Overall, the present results are consistent with past research that has suggested the existence of a domain-specific geometric information process and support the hypothesis that euclidean geometry is one of many domains of core knowledge that is separable from and predates...
linguistic and symbolic cognition (Dehaene et al., 2006; Lee & Spelke, 2010a, 2010b; Spelke, Lee, & Izard, 2010). More important, the current DMTS tasks appear to provide evidence for the activation of a spatial representation independent of other representations (Experiment 1), and only when shapes are forced to be processed semantically, are they processed in a semantic fashion after initial automatic spatial processing (Experiment 3). As a result, it appears that perceiving a shape only automatically activates a corresponding spatial representation. Isolation is seen in the sense that a spatial representation was immune to interference by its corresponding shape word. Future research could continue to utilize the present task to determine the extent to which there is also isolated neurological activation to provide converging evidence for the isolation of geometric processing and illuminate the biological underpinnings of such cognitive processes.

References


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