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Using a Delayed Match-to-Samples Task to Investigate the Isolated Processing of Geometric Shapes and Their Corresponding Shape Words

Joshua E. Edwards

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USING A DELAYED MATCH-TO-SAMPLES TASK TO INVESTIGATE THE ISOLATED

PROCESSING OF GEOMETRIC SHAPES AND THEIR CORRESPONDING SHAPE

WORDS

by

JOSHUA EDWARDS

(Under the Direction of Bradley R. Sturz, Ph.D.)

ABSTRACT

Evidence suggests an isolated system dedicated to processing geometric information (Spelke, Lee, & Izard, 2010), but isolating geometric processing from semantic processing has remained difficult. Recently, Sturz, Edwards, and Boyer (2014) utilized a delayed match-to-sample (DMTS) task to present participants with a sample composed of a shape, shape word, or a bi-dimensional stimulus composed of a shape and a shape word. After a delay, participants were required to identify the sample shape or the sample word by selecting between two shapes or two shape words. Results suggested that sample shapes did not interfere with selecting a correct match in the presence of two shape words, but a sample shape word interfered with selecting a correct match in the presence of two shapes. Interference took the form of increased reaction times and increased errors in the presence of selecting between two shapes but not two words. Results were interpreted as suggesting that shapes do not activate a semantic representation of shape words, but shape words activate semantic and spatial representations of shapes. The present experiments attempted to replicate and extend these results. Experiment 1 included a condition that was identical to the original condition (Unfilled) and one condition in which the shapes were filled (Filled) to address a potential explanation based upon sample shape saliency. As predicted Experiment 1 replicated the asymmetrical results for both Filled and Unfilled

conditions and undermine an explanation based upon saliency. Experiment 2 tested the assumption that shapes do not activate a semantic representation by reversing the matching criteria such that a sample shape word needed to be matched to its corresponding shape whereas a sample shape needed to be matched to its corresponding shape word. Such a reversal should require the semantic processing of shapes and result in increased reaction time and decreased accuracy. As predicted Experiment 2 produced a symmetrical pattern of results and indicated that word targets took a significantly longer time to match compared to shape targets. Collectively, results support an isolated system dedicated to processing geometric information by suggesting that both shapes and shape-words are automatically processed by two different psychological systems.

KEYWORDS: Modularity, Domain Specificity, Geometry, Semantics, Suppression, Delayed Match-to-Sample Task

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JOSHUA EDWARDS

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Major Professor: Bradley R. Sturz
Committee: Ty W. Boyer
Lawrence Locker, Jr.

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DEDICATION

This manuscript is dedicated to my parents, Ben and Theresa Edwards, without whom I could have never gotten this far. Their love and support made me into the great individual I am today.

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I would like to acknowledge my mentor without whom I could not have produced my thesis. Dr. Sturz patiently guided me through both the process of conducting and writing my thesis with both expertise and understanding. Also, I would like to acknowledge the research assistants who assisted with data collection and scholarly feedback: Candyce Asby, Travis Baker, Allison Dyches, Destiny Brooks, and Chelsea Scordas.

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CHAPTER ONE

INTRODUCTION

With the integration of evolutionary theory into modern psychology, the conception of the mind has changed from that of a domain-general view (i.e., the mind is composed of a few general systems that process all domains of input) to that of a domain-specific view (i.e., the mind is composed of numerous systems dedicated to processing specific inputs) [Cosmides & Tooby, 1994; Barrett & Kurzban, 2006]. 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, it is proposed that evolution would favor domain-specific processes to solve specific adaptive problems (Cosmides & Tooby, 1994; Barrett & Kurzban, 2006). For example, the immune and visual systems appear to have evolved to solve two distinct adaptive problems (defense against foreign microorganisms and predator detection, respectively).

Fodor (1985) proposed a view of domain specificity called *modularity of the mind*. Modularity is the concept that the human mind is composed of several modules each dedicated to a specific function. The modules are proposed to be encapsulated such that they process specific inputs isolated from other processes (Fodor, 1985; Cosmides & Tooby, 1994; Barrett & Kurzban, 2006). Most modular processes are suggested to occur automatically and without conscious involvement such that they could be considered reflexive. For example, in the classic Müller-Lyer illusion (Figure 1), the lines appear to differ in length despite their objective equivalence (Fodor, 1985; Ciccarelli & Meyer, 2006). Despite learning the lines are identical in length, the illusion persists; it occurs automatically and without conscious awareness.
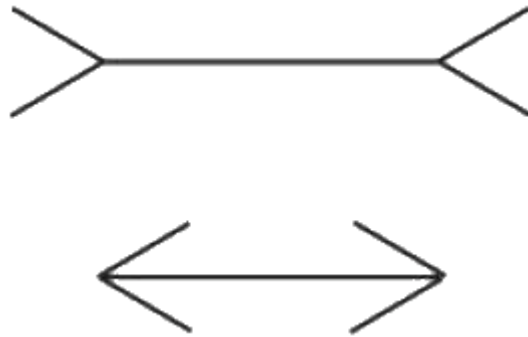
Figure 1. **Müller-Lyer illusion**

This and other illusions have been used as evidence to suggest that isolated mechanisms process information without influence from other mechanisms (e.g., higher level knowledge or processing).

One hypothesized perceptual module relates to the processing of geometric information (Spelke, Lee, & Izard, 2010). Numerous human and non-human animal studies provide evidence for the use of geometry in re-establishing orientation by means of the overall shape of an environment (global geometry) [Cheng, 1986; Hermer-Vazquez, Spelke, & Katsnelson, 1999; Cheng, & Newcombe, 2005]. The recurring evidence in support of the use of geometry for reorientation is that both human and non-human animals make rotational errors in rectangular enclosures (Cheng, Huttenlocher, & Newcombe, 2013; Cheng, & Newcombe, 2005). A rotational error refers to the error made in selecting the rotational equivalent location of a symmetrical environment (i.e. the opposite of the correct corner).

Rats were trained in a rectangular environment to respond to a specific corner containing food that was specified by unique features (landmark color, texture, and smell; Cheng, 1986). After several training trials, the rats were removed, disorientated, and placed back into the same environment. Despite the presence of unique features in each corner, rats searched at the correct

corner and the rotational equivalent corner to the same extent. This rotational error was interpreted as providing evidence that the overall shape of the environmental was processed separately from features during reorientation (see also, Gallistel, 1990).

In a modified reorientation paradigm, children (from 18 months to 4 years of age) made the same error of choosing the rotational equivalent corner as often as the correct corner in environments with and without unique features (Hermer & Spelke, 1994; Hermer, Spelke, & Katsnelson, 1999; Cheng, & Newcombe, 2005; Lee, Shusterman, & Spelke, 2006; Cheng, Huttenlocher, & Newcombe, 2013). Although adults appear able to use unique features to locate the correct corner (i.e., do not appear to make the rotational error in the presence of unique features), verbal shadowing tasks that disrupt the use of language result in the use of only the overall geometry of the environment (Hermer-Vazquez, Spelke & Katsnelson, 1999). Such results appear to provide evidence that language interferes with landmark navigation but not global navigation. As a result, some have suggested that language is required to combine the isolated information processed by feature and geometric systems (Hermer-Vazquez et al., 1999; c.f., 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, 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 Euclidean geometry. The researchers showed Mundurukú adults and children 45 slides consisting of six images with each slide demonstrating a basic Euclidean concept (e.g., parallel lines, right angles). One image on each slide violated the concept (e.g., a curved line on the slide

depicting the concept of a straight line). When asked to identify the "weird" or "ugly" image both Mundurukú children and adults performed significantly above chance in identifying the violation. Such results provide support for the notion that basic Euclidean geometry predates linguistic and symbolic cognition and does not appear to require spatial language or formal education.

Despite past research supporting the independent processing of geometric information, isolating the processing of geometric information from the potential influence of linguistic and semantic processing has remained a difficult task (Hermer-Vazquez et al., 1999; c.f., Ratliff & Newcombe, 2008). Separating the processing of geometric information from that of semantic and linguistic processing in normal human adults has been difficult because semantic memory and semantic processing appear to be major sources of object identification (Collins & Quillian, 1969). Specifically, semantic processing appears to activate or prime all other associated information related to an object. For instance the object "chair," can activate the overall shape of a chair (spatial representation), the meaning of a chair (semantic representation), the function of a chair (functional representation), and even the anatomical parts of the human body used to sit in a chair. To obtain evidence for the isolation of geometric processing, a task must be capable of providing evidence that a geometric shape activates a geometric representation but the geometric shape does not activate a semantic representation. In short, a task must provide evidence for the activation of a spatial representation independent of other representations.

CHAPTER TWO

DELAYED MATCH-TO-SAMPLES TASK AND SEMANTIC COMPETITION

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). Given that an isolated module dedicated to processing geometric information is suggested to only provide a spatial representation of geometric information, then spatial stimuli should not activate a semantic representation (i.e. the shape word). As a result, semantic competition should not take place when a geometric stimulus is presented along with stimuli that will activate a semantic representation, because an irrelevant semantic representation will not be activated by the shape.

Historically, researchers have often used the Stroop task (1935) to investigate interference. Specifically, Stroop (1935) found that response times to name the font color of a color word written in an incongruent font color (i.e. the word "red" written in blue ink) were longer than response times to name the font color of a color word written in a congruent font color. Unfortunately, such interference effects have been explained via both semantic competition and response competition (Sturz et al., 2013). Semantic competition suggests that the interference results from irrelevant semantic representations that are activated by the color word and the font color (Luo, 1999, see for review, MacLeod, 1991, 1992). In contrast, response competition suggests that the interference results from competing response options that are related to both the word and the color dimensions (Besner et al., 1997; see for review, MacLeod, 1991, 1992).

Recently, Sturz, Green, Locker, and Boyer (2013) modified a Stroop task using a delayed match-to-sample (DMTS) paradigm to test semantic versus response competition explanations of the Stroop interference effect. In the DMTS task, a stimulus (e.g., a word or colors), known as the sample, was presented for a brief time followed by a delay. After the delay, a pair of targets was presented and with the possible exception of baseline trials, whether the targets consisted of color patches or color words was not known until the targets appeared. Participants selected the target that corresponded to (i.e., matched) the previously presented sample. Sturz et al. (2013) manipulated the congruency of the sample and the relatedness of the incorrect target (foil) by presenting four trial types derived from all possible combinations of three color words and three color patches (red, yellow, and blue). Specifically, Baseline trials presented a sample consisting only of a color patch or the word of a color written in black font with targets of the respective dimension (i.e., color targets or word targets). On congruent trials, the sample consisted of a color word written in the same color of the word (i.e., the word "red" written in red font). Incongruent trials consisted of a color word written in colors different from the color word (i.e. the word "red" written in blue font). The Incongruent trials were separated on the basis of the relatedness of the foil to the irrelevant sample dimension. Incongruent-Unrelated Foil trials consisted of an incongruent bi-dimensional sample (i.e., the word "blue" written in red font) with targets that would be composed of the correct match (i.e., the word "blue" or the color red) and a foil that was unrelated to the irrelevant sample dimension (i.e., the word "yellow" or the color yellow). Incongruent-Related Foil trials also consisted of an incongruent bi-dimensional sample (i.e., the word "blue" written in red font) with targets composed of the correct match (i.e., the word "blue" or the color red), but the foil was related to the irrelevant sample dimension (i.e., the word "red" or the color blue).

Sturz et al. (2013) suggested three potential outcomes based upon predictions derived from semantic competition, response competition, and the combination of both semantic and response competition. According to semantic competition, the interference in the Stroop task originated from the need to suppress the semantic representation related to the irrelevant sample dimension. As a result, suppression of the semantic content would have occurred in both Incongruent trial conditions causing an increase in response times (RTs) for both color targets and word targets as compared to Baseline and Congruent trials due to the extra processing required to suppress the irrelevant dimension. In contrast, response competition suggests that the interference in the Stroop task originated from the need to suppress the irrelevant response option. Suppression of an irrelevant response option would have occurred only in the presence of a related target. As a result, suppression would have only occurred in the Incongruent-Related trials resulting in an increase in RTs. Finally, if both semantic and response competition were operating, participants would have needed to suppress an irrelevant sample dimension and an irrelevant response option during Incongruent-Related Foil trials. As a result, RTs would have increased in both Incongruent trials for color and color words. However, Incongruent-Related trials should have the longest RTs.

Interference was measured by the response times (RTs) on correct trials. For both target types (colors and color words) RTs were significantly longer in the Incongruent-Unrelated Foil and Incongruent–Related Foil trials compared to Baseline and Congruent trials (Figure 2).
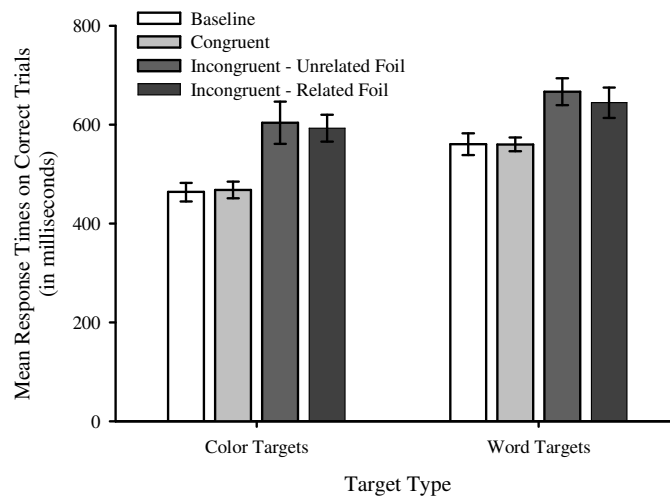
Figure 2. Results from Sturz, Green, Locker, & Boyer (2014). Mean RTs on correct trials plotted by target type and trial type. Baseline and Congruent conditions were significantly different than both incongruent trials for both target types. Reproduced from Sturz, Green, Locker, and Boyer (2013).

Sturz, et al., (2013) interpreted the results as evidence for semantic competition. The key finding of the research was the increased RTs for both of the Incongruent trials compared to Baseline and Congruent trials regardless of the relatedness of the foil. The increased RTs in both Incongruent trials were interpreted as the suppression of the semantic representation activated by the irrelevant sample dimension. The researchers suggested that both dimensions activated a semantic representation (both word and color activated a semantic representation), and the suppression of the irrelevant dimension increased RTs for both Incongruent conditions. Response competition appeared unable to explain the results because RTs increased for both Incongruent trials. Importantly, RTs for the Incongruent-Related Foil trials were not significantly different from the Incongruent-Unrelated Foil trials.

CHAPTER THREE

ASYMMETRICAL PATTERN OF INTERFERENCE OF SHAPES AND SHAPE WORDS

Using the Sturz et al. (2013) paradigm that provided evidence for semantic competition, Sturz, Edwards, and Boyer (2014) investigated the isolation of semantic and geometric processing. Given that shapes are hypothesized to be processed by a domain-specific module dedicated to processing geometric information, shape processing should be isolated from semantic processing. As a result, a shape word should activate a spatial representation of the shape, but a shape should not automatically activate a semantic representation of a shape word. In short, shapes should not interfere with the identification of a shape word, but shape words should interfere with the identification of shapes.

In the context of the DMTS task, Sturz et al. (2014) presented bi-dimensional samples composed of an outline of a shape (circle, square, or triangle) and a respective shape word ("circle", "square", or "triangle"). The sample consisted of a black outline of a shape and a shape word written in black font. After a delay, shape targets (two shapes) or word targets (two shape words) were randomly presented to measure the extent of interference. Analyses were based on RTs of correct responses and proportion of correct responses.

Sturz et al. (2014) found that when given an incongruent sample (e.g., "square" surrounded by a circle), RTs were slower compared to both baseline and congruent trials but only for shape targets. RTs for word targets showed no significant differences across trial types (Figure 3). A significant difference for mean proportion correct was found with Incongruent-Related Foil trials but only for shape targets. In contrast to the symmetrical pattern of interference found in Sturz, et al., (2013), Sturz et al. (2014) found an asymmetrical pattern of interference (i.e., effects only for shape targets as opposed to both words and colors).
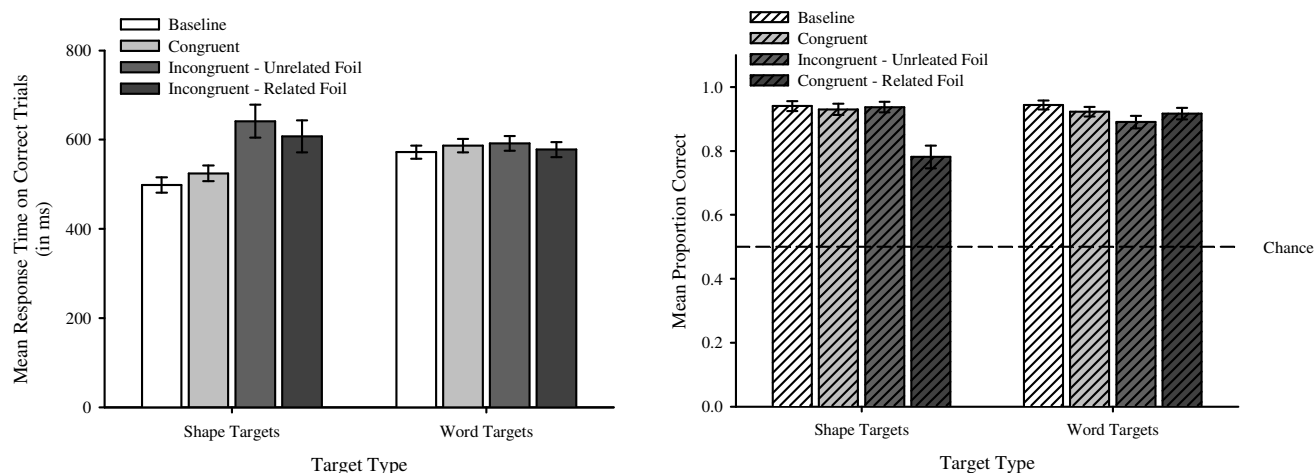
Figure 3. Results from Sturz, Edwards & Boyer (2014). *Left*. Mean RTs on correct trials plotted by target type and trial type. Baseline and Congruent conditions were significantly different than both incongruent conditions for Shape Targets, but Word Targets did not significantly differ from each other across trial type. *Right*. Mean proportion of correct responses plotted by target type and trial type. Participants made more errors on shape targets then word targets only for Incongruent-Related Foil trials. Reproduced from Sturz, Edwards, and Boyer (2014).

This asymmetrical pattern of interference was interpreted as suggesting that a shape word activated a spatial representation of a shape, but a shape did not activate a semantic representation of a shape word. In short, shapes did not activate semantic content (e.g., linguistic information) to interfere with the semantic representation of shape words, but shape words did activate a spatial representation of the shape and interfered with the spatial representation of the shape targets. Within the context of suppression, suppression of the irrelevant spatial representation activated by a shape word, increased RTs. Given that shapes did not activate a semantic representation, no suppression of an irrelevant sample dimension was required.

Figure 4 outlines the processes that were suggested to occur in each condition of the spatial Stroop task for each target type in the Sturz, et al., (2014) paradigm. Baseline trials (Figure 4a) illustrate the basic underlying interpretation by Sturz, et al., (2014) that shapes did not activate a semantic representation (i.e., shape words), but shape words did activate a spatial representation (i.e., the shape). As shown, it is not until the Incongruent trials that a
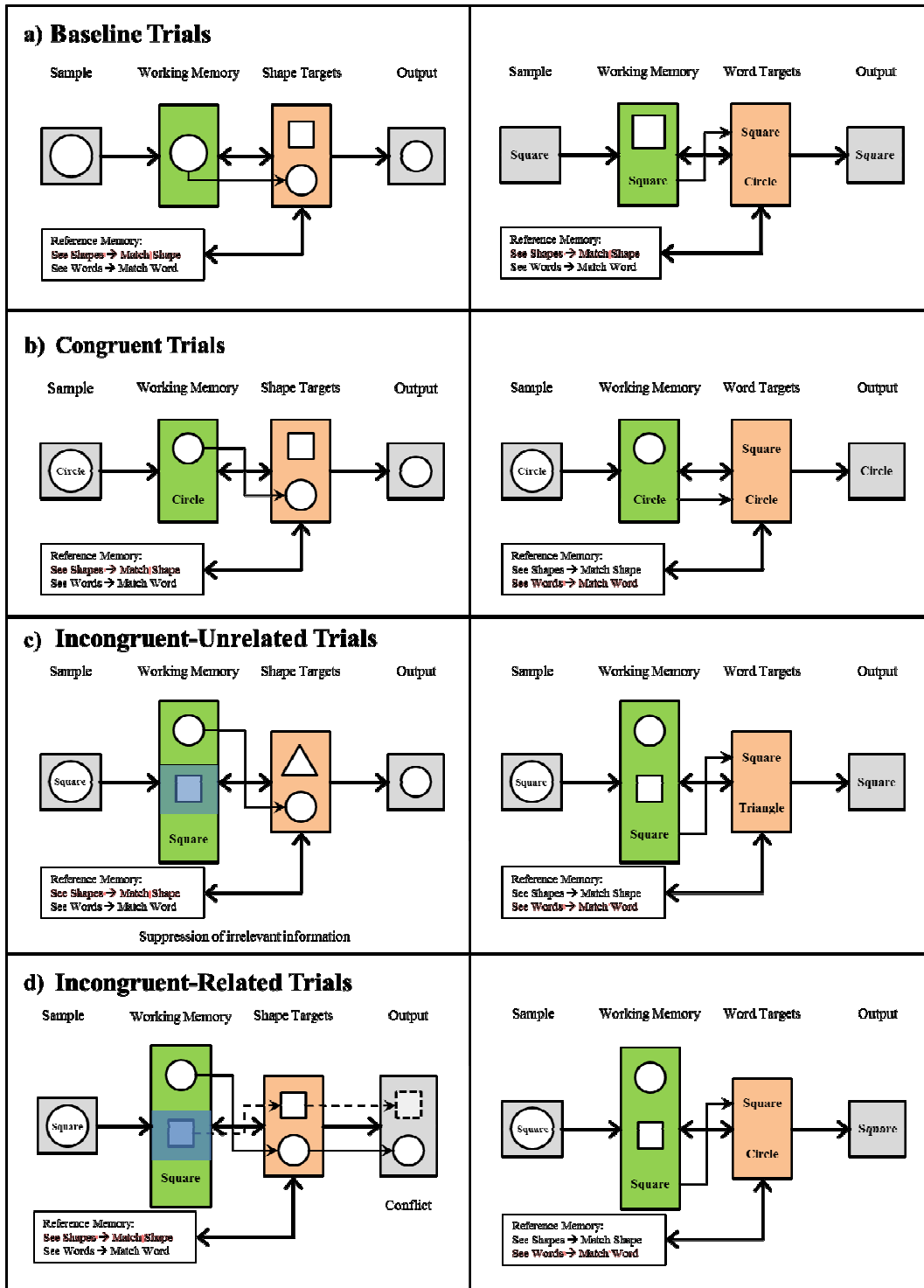
Figure 4. Illustration of the hypothesized processing of shapes and shape words. The results for Sturz, et al., (2014) suggest that shapes do not activate a semantic representation of a shape word but shape words activate both a semantic representation of a shape word and a spatial representation of a shape.

noticeable difference emerged among the target types. In the Incongruent-Unrelated trials (Figure 4c) the shape "square" would have needed to be suppressed in order to select the correct shape (i.e., circle). In contrast, for word targets, a shape word was not activated by the irrelevant sample dimension and as a result did not require suppression of an irrelevant dimension to make the correct choice. This asymmetry is also observed in the Incongruent-Related trials in which the sample only activated one shape word. The Incongruent-Related trials (Figure 4d) illustrate the process by which conflict is hypothesized to have taken place in the spatial Stroop task for shape targets. The spatial representation activated by the shape word conflicted with the foil, causing the foil to appear correct upon recollection of the bi-dimension sample.

The interpretation drawn by Sturz et al. (2014) was that shapes did not activate the semantic representation of the shape word. This interpretation is fundamental to explaining their obtained asymmetrical pattern of interference. However, it is possible that the shape stimuli used by Sturz et al. (2014) were not as salient as the word stimuli. From a Gestalt theoretical perspective, a shape outline could be considered a "ground" whereas the shape word could be considered "figure." As figure would draw more attention than ground, it may have been relatively easier to ignore sample shapes compared to sample words, thus producing an asymmetrical pattern of interference. Although performance accuracy on shape and word targets were significantly above chance levels, it seems reasonable that the relatively greater salience of words compared to shapes may have been responsible for the obtained asymmetrical effects.

The purpose of the present experiments is to test not only the possibility that saliency of the shape stimuli may have contributed to the asymmetrical interference effect observed by Sturz et al. (2014), but also to test the interpretation that shape words activate a spatial representations of shapes whereas shapes did not activate a semantic representation of the shape

word. The first objective was reached by increasing the relative saliency of the sample shapes compared to sample words. Specifically, using knowledge of figure-ground relations, shape stimuli were made more salient by filling in the shape outlines (black filled shape with a word written in white). Using this figure-ground reversal, filling in the shape should make the shape stimulus appear more figure and the word stimulus appear more ground. If saliency of shape stimuli were responsible for producing the asymmetric pattern of results, filling in the shapes should increase the shape saliency and produce a symmetrical pattern of interference. The second objective was reached by encouraging semantic-level processing of both shape and shape words by modifying the matching paradigm such that shapes were required to be matched to shape words and shape words matched to shapes. In order to make a correct decision when matching shapes to shape words, the semantic representation must be obtained. Assuming that shapes do not automatically activate a semantic representation, shapes should require additional semantic processing to obtain the correct shape words. In short, matching opposing dimensions should require that shapes are processed semantically to obtain the necessary representation to make a correct decision.

CHAPTER FOUR

EXPERIMENT 1

Unlike a traditional Stroop task, the shape and shape word DMTS task was unable to combine the bi-dimensional sample into one distinct object. This difference could have resulted in one dimension being perceived as more salient than another. As a result, it was possible that the asymmetrical interference pattern (words interfering with shapes but shapes not interfering with words) obtained by Sturz et al. (2014) could have been the result of the shape word being more salient than the shape. Specifically, the shape could have been weakly encoded relative to the shape word. As a result, shapes could have failed to activate the necessary semantic representation resulting in the asymmetrical pattern found by Sturz et al. (2014). The purpose of Experiment 1 was to explicitly test such a possibility by presenting two conditions: 1) an Unfilled condition which was a direct replication of the stimuli used by Sturz et al. (2014) and 2) a Filled condition in which all shapes were filled in black. If the relatively greater saliency of the sample word compared to the sample shape was responsible for 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 produce a symmetrical pattern of interference. In contrast, if sample shape words were not of greater saliency compared to the sample shape or the relatively greater saliency of the sample shape words compared to the sample shapes was not responsible for the obtained asymmetrical interference, both Unfilled and Filled conditions should produce a similar asymmetrical pattern of interference as found by Sturz et al. (2014).

METHOD

Participants

Sixty-four undergraduate students (32 males; 32 females) were recruited through the SONA system at Georgia Southern University. As per the guidelines by Cohen (1992), 64 participants were used because it provided appropriate power for a study of this design. Participants received class credit for participation.

Apparatus

Both conditions were conducted on a computer with a 22-inch flat-screen liquid crystal display (LCD) monitor (1,680 x 1,050 pixels). Responses were made via the "c" (left target) and "m" (right target) keys on a standard keyboard. The experiment was created and recorded using E-Prime (Psychology Software Tools, Inc., www.pstnet.com).

Stimuli

Stimuli consisted of shapes and shape words (see Figure 5 & 6). Shape stimuli consisted of 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). Word stimuli consisted of the shape words "circle," "square," and "triangle" printed in black 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. Bi-dimensional stimuli for the Unfilled condition

consisted of a shape word printed inside of a shape outline (see Figure 5). For the Filled

condition all shapes were filled black and shape words were white when in a bi-dimensional

stimulus (see Figure 6). All stimuli appeared on a white background.

Procedure

Participants were randomly assigned to one of two conditions. For both Unfilled and

Filled conditions participants matched shapes to shapes and shape words to shape words.

Instructions were given (both written and oral) at the start of the study after participants signed

the informed consent form. Oral instructions were "to pay close attention to what you will be

matching." For all participants, a sample appeared on screen for 1s followed by a blank screen

delay of 5s. After the delay, a pair of targets appeared for 1.5 s. A response to the correct target

resulted in the presentation of a green check mark, while a response to the incorrect target

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 second, and

served as the inter-trial interval (ITI). The first 24 trials were training trials composed of the

baseline trials in two blocks of 12 trials. One block consisted of all shape samples and the other

block consisted of all word samples. The blocks were counterbalanced in terms of the order of

presentation. Testing consisted of 96 trials composed of 12 blocks each containing eight trials.

Each trial block was composed of two trials each of the four Trial Types: Baseline (one

dimensional sample followed by targets of the same dimension), Congruent (sample shape with

corresponding shape word), Incongruent-Unrelated Foil (bi-dimensional sample consisting of a

shape with a non-corresponding shape word and a foil unrelated to the irrelevant sample

dimension), and Incongruent-Related Foil (bi-dimensional sample consisting of a shape with a

non-corresponding shape word and a foil related to the irrelevant sample dimension). Refer to figures 5 and 6 for an illustration of the procedure for both the Unfilled and Filled conditions. The location of the correct target and the foil were counterbalanced, which resulted in 96 unique combinations of each trial type (24 Baseline trials, 24 Congruent trials, 24 Incongruent-Unrelated Foil trials, and 24 Incongruent-Related Foil trials). Feedback was identical to Training. All measures were recorded automatically by the E-prime software (Psychology Software Tools, Inc., www.pstnet.com).

Figure 5. Unfilled Design. 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. Reproduced from Sturz, Edwards, & Boyer (2014).
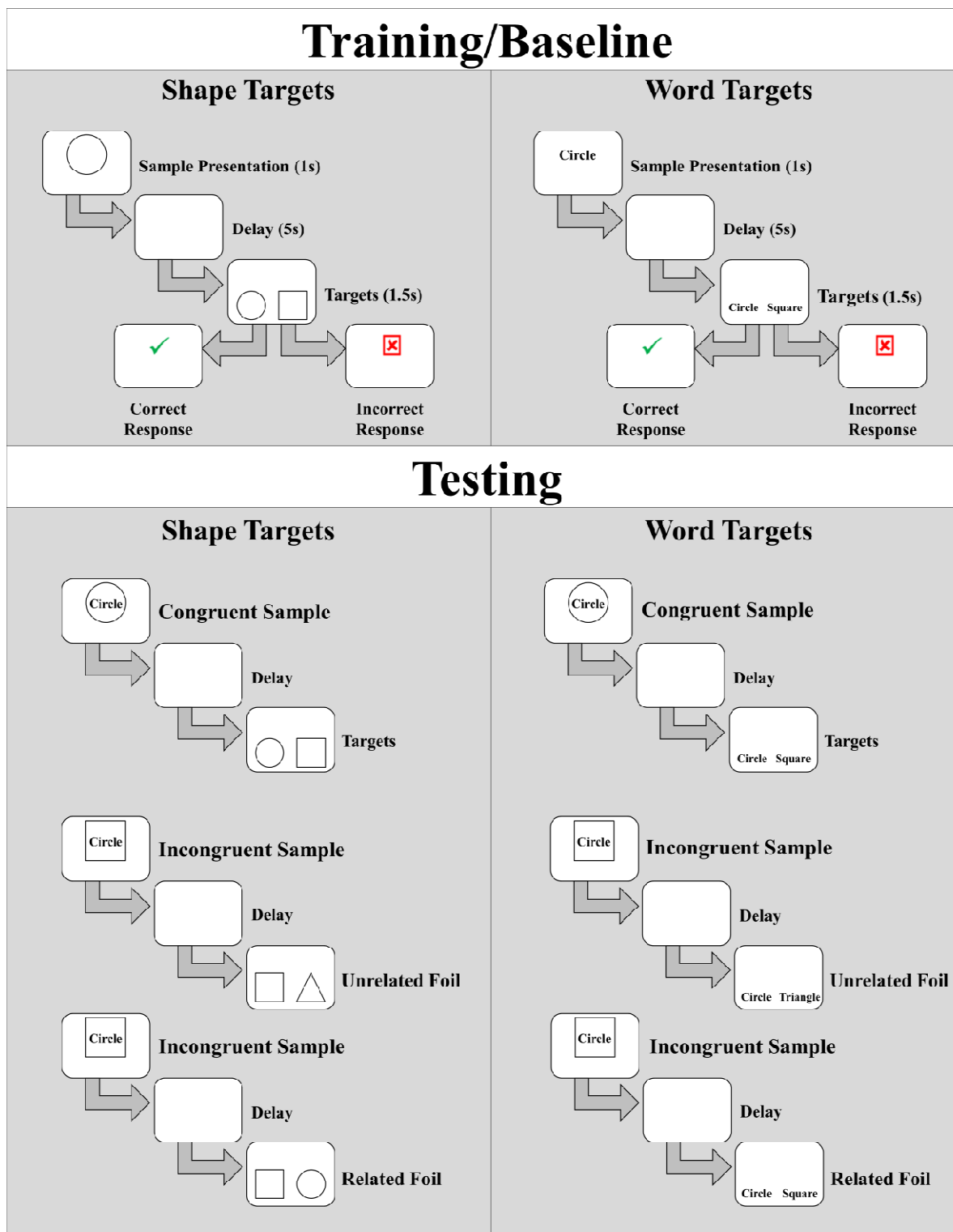
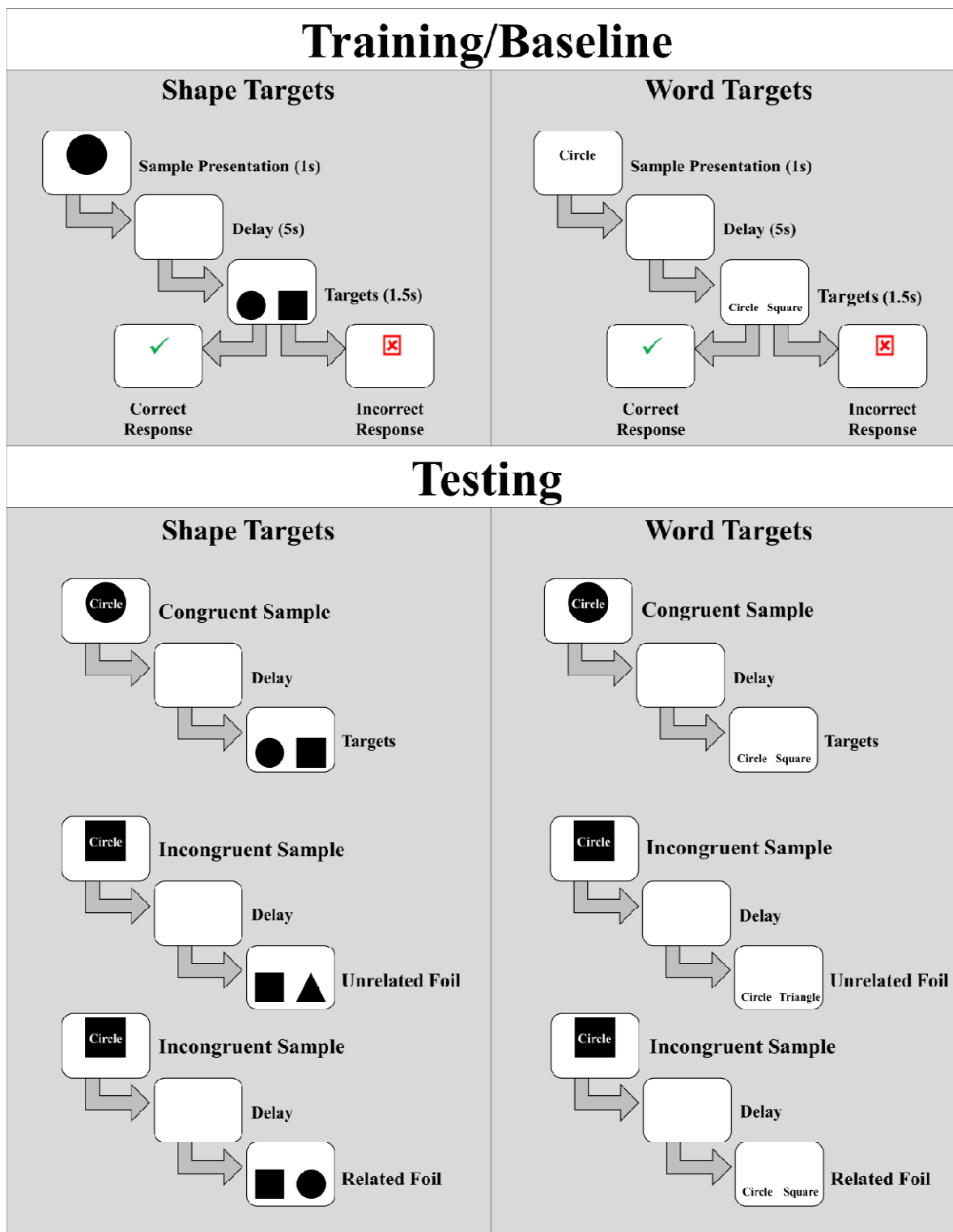**Figure 6. Filled Design.** One sample Baseline/Training trial is illustrated for Shape Targets (a) and Word Targets (b), and one sample Congruent, Incongruent – Unrelated Foil, and Incongruent – Related Foil trial is illustrated for Shape Targets (c) and Word Targets (d). For illustrative purposes, all correct matches are shown as the left target even though correct target and foil target locations were be balanced.

CHAPTER FIVE

EXPERIMENT 1 RESULTS

Response times. Response times from correct trials only were analyzed. This resulted in

the removal of incorrect or no response trials (583/6144; 9.49%). A Condition (Unfilled and

Filled) x Target Type (Shapes and Shape words) x Trial Type (Baseline, Congruent,

Incongruent-Unrelated Foil, and Incongruent-Related Foil) mixed analysis of variance

(ANOVA) was conducted on RTs and revealed a main effect of Target Type $F(1, 62) = 26.52$,

$p < .001$, $\eta_p^2 = .30$, and Trial Type $F(3,186) = 32.71$, $p < .001$, $\eta_p^2 = .35$. These results were

qualified by a significant Target Type x Trial Type interaction, $F(3, 186) = 23.34$, $p < .001$,

$\eta_p^2 = .27$. No significant effects were found for Target Type x Condition ($p = .73$), Trial Type x

Condition ($p = .73$), or Target Type x Trial Type x Condition ($p = .33$). Given the lack of effects

or interaction with Condition, data were collapsed across the Condition factor (Unfilled,

$M = 561.45$, 95% *C.I.* = 13.02; Filled, $M = 570.60$, 95% *C.I.* = 13.91). Figure 7 shows the mean

RTs (in milliseconds) plotted by Target Type for each Trial Type collapsed across Condition.

Two separate one-way repeated measures ANOVAs were conducted on RTs for Shape

Targets and Word Targets with Trial Type (Baseline, Congruent, Incongruent-Unrelated, and

Incongruent-Related) as a factor to identify the source of the Target Type x Trial Type

interaction. To control for family-wise error rates, the alpha level was set at .025 for the two

comparisons (Keppel, 1991). For Shape Targets, there was a main effect of Trial Type,

$F(3, 189) = 38.41$, $p < .001$, $\eta_p^2 = .38$. Fisher's Least Significant Differences (LSD) post hoc

tests revealed that Baseline and Congruent trials were significantly different from each other

($p < .001$), and both of these trials 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, $F(3, 189) = 2.82$, $p = .04$.
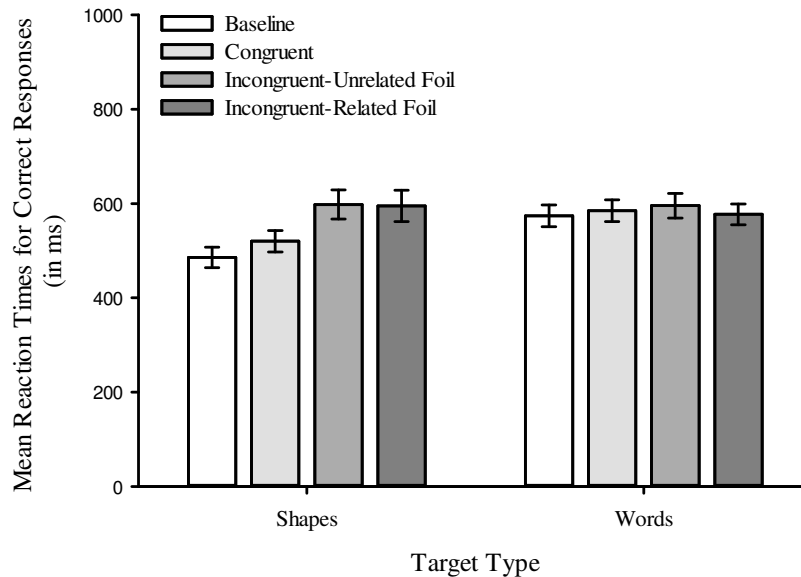

Figure 7. Experiment 1 Results (RTs). Mean RTs on correct trials plotted by Target Type for each Trial Type collapsed across Condition. Error bars represent 95% confidence intervals.

Proportion correct. Trials in which participants did not respond were eliminated (64/6144; 1.04%). A Condition (Unfilled and Filled) x Target Type (Shapes and Shape words) x Trial Type (Baseline, Congruent, Incongruent-Unrelated Foil, and Incongruent-Related Foil) mixed ANOVA was conducted on proportion correct and revealed a main effect of Target Type $F(1, 62) = 7.36$, $p < .01$, $\eta_p^2 = .11$, and Trial Type $F(3, 186) = 23.84$, $p < .001$, $\eta_p^2 = .28$. These main effects were qualified by a significant Target Type x Trial Type interaction $F(3, 186) = 16.71$, $p < .001$, $\eta_p^2 = .21$. No significant main effect was found for Target Type x Condition ($p = .21$), Trial Type x Condition ($p = .43$), or Target Type x Trial Type x Condition ($p = .43$). Given the lack of effects or interaction with Condition (Unfilled, $M = .92$,

95% *C.I.* = .01; Filled, *M* = .91, 95% *C.I.* = .01), the data were collapsed across the Condition factor. Figure 8 shows the mean proportion correct plotted by Target Type for each Trial Type collapsed across Condition.

Two separate one-way repeated measures ANOVAs were conducted on proportions correct for Shape Targets and Word Targets with Trial Type (Baseline, Congruent, Incongruent-Unrelated, and Incongruent-Related) as a factor to identify the source of the Target Type x Trial Type interaction. To control for family-wise error rates, the alpha level was set at .025 for the two comparisons (Keppel, 1991). For Shape Targets, there was a main effect of Trial Type, $F(3, 189) = 32.68$, $p < .001$, $\eta_p{}^2 = .34$. 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 of these trial types were significantly more accurate than Incongruent-Related Foil trials $(ps < .001)$. For Word Targets, the effect of Trial Type was not significant, $F(3, 189) = .43$, $p = .73$. Eight individual one-sample *t*-tests were conducted to analyze performance compared to chance (.5) for each Trail Type separated by Target Type. Data were collapsed across Condition with adjusted alpha levels of .006 for the eight comparisons (Keppel, 1991). All mean proportions correct were significantly greater than chance, $ts(63) > 17.18$, $ps < .001$.
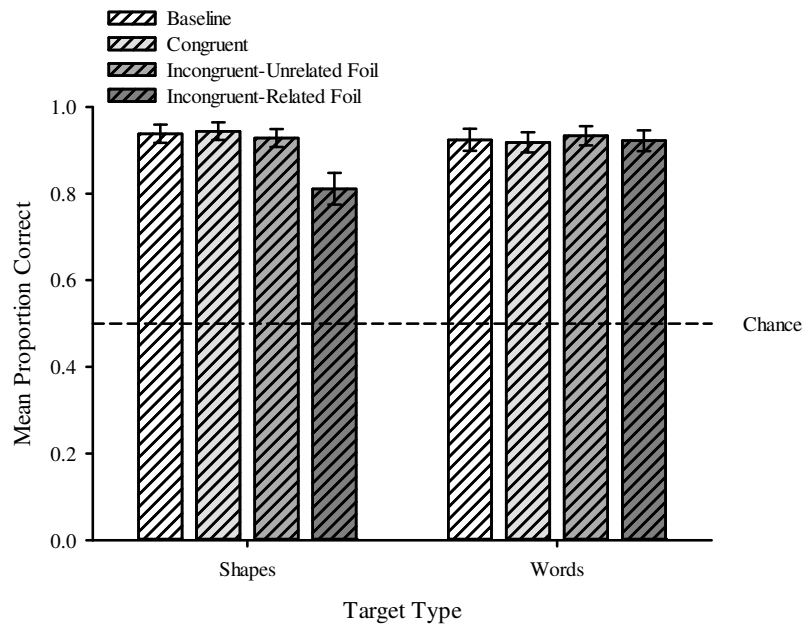
Figure 8. Experiment 1 Results (Accuracy). Mean proportion correct plotted by Target Type and Trial Type collapsed across Condition. Dashed line represents chance (0.5) performance. Error bars represent 95% confidence intervals.

CHAPTER SIX

EXPERIMENT 1 DISCUSSION

In the current DMTS task, participants took longer to make a correct decision between two shapes following the presentations of an incongruent bi-dimensional sample (i.e. Incongruent-Unrelated and Incongruent-Related Foil trials) compared to following a congruent or uni-dimensional sample (i.e., Congruent and Baseline trials). However, regardless of congruency of the sample or number of dimensions, no differences emerged in RTs for correct decisions between two shape words. Analysis of accuracy revealed a decrement in performance when choosing the correct target for shape targets but not word targets in trials in which 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.

These results are important for two primary reasons. First, these results revealed an asymmetrical pattern of interference. This finding supports the notion that a sample word interferes with the identification of the correct sample shape but a sample shape does not interfere with the identification of the correct sample word. This suggests that words activated both semantic and spatial representations whereas shapes only activated spatial representations (Sturz, et al., 2014). Second, filling in the shapes such that they were presented in black containing shape words printed in white did not appear to influence obtaining this asymmetrical pattern of interference. This suggests that the asymmetrical pattern of interference may not have been due to a difference in saliency between shapes and words assuming that filling in the shape increased the saliency of the shape. As a result, the present findings appear consistent with those obtained by Sturz et al. (2014) and are consistent with the interpretation that words interfered with matching shapes, but shapes did not interfere with matching words. This asymmetry is

attributed to words activating spatial representations of the shape, but shapes not activating semantic representation.

The interference obtained with shape targets indicates that the sample word dimension activated a semantic and spatial representation. In the presence of shape targets, the spatial representation needed to be suppressed in order to identify the correct match. Given that this additional spatial representation activated by the sample word dimension would also provide an additional potential match with the irrelevant sample 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.

Given that the results are consistent with those obtained by Sturz et al. (2014) and appear to be capable of being interpreted in the same fashion, Experiment 2 attempted to test the core assumption of the interpretation through an attempt to force semantic processing with all stimuli. Specifically, in Experiment 2, the matching criteria were reversed such that participants were required to match a sample shape to its corresponding shape word and a sample shape word to its corresponding shape. The logic is that reversing the matching criteria should require shapes to be semantically processed. To match a shape to a shape word, shapes must undergo additional semantic processing in order to make a correct match. In contrast, to match a shape word to a shape should not require any additional processing because the asymmetrical pattern of interference suggests that shapes words activate a spatial representation. 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 extra processing required of shapes to activate a semantic representation should result in longer RTs for word targets (i.e., matching shapes to shape words) compared to shape targets (i.e., matching shape words to shapes).

CHAPTER SEVEN

EXPERIMENT 2

The core assumption from Sturz et al., (2014) was that shapes did not activate the semantic representation necessary to interfere with choosing the correct shape word target. However, shape words activated both the semantic and spatial representation and interfered with the choosing of the correct shape target. Experiment 2 tested this core assumption by reversing the matching criteria. Participants were required to match opposing dimensions (i.e. match shape words to shapes, and shapes to shape words). Matching opposing dimension should require the activation of the semantic representation of the shape in a sample in order to make a correct decision. This should force shapes to undergo semantic processing to obtain the relevant representation if shapes are truly processed by an isolated modular system dedicated to the processing of geometric information. Under these conditions, a symmetrical pattern of interference (as opposed to an asymmetrical pattern of interference) should be obtained because suppression and semantic competition should occur for both target types. In addition, this extra processing required of shapes to active a semantic representation should result in longer RTs for word targets (i.e., matching shapes to shape words) compared to shape targets (i.e., matching shape words to shapes). A Filled Condition was also implemented to further test a potential explanation based upon sample shape saliency. As with Experiment 1, if saliency of the sample shape were responsible for the obtained asymmetrical pattern of interference obtained by Sturz et al. (2014), then difference should emerge between Unfilled and Filled Conditions. In contrast, if sample shape saliency was not responsible for the obtained asymmetrical interference, both Unfilled and Filled conditions should exhibit the predicted symmetrical pattern of interference.

METHOD

Participants

Sixty-four undergraduate students (32 males; 32 females) different from those who participated in Experiment 1 were recruited through the SONA system at Georgia Southern University. As per the guidelines by Cohen (1992), 64 participants were used because it provided appropriate power for a study of this design. Participants received class credit for participation.

Apparatus

The apparatus was identical to Experiment 1.

Stimuli and Procedure

For Experiment 2, participants had to match shapes to shape words and shape words to shapes (see Figure 8 and 9). The stimuli and procedure of Experiment 2 were otherwise identical to Experiment 1.

Figure 9. Unfilled Revers Matching Design. 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 counterbalanced.
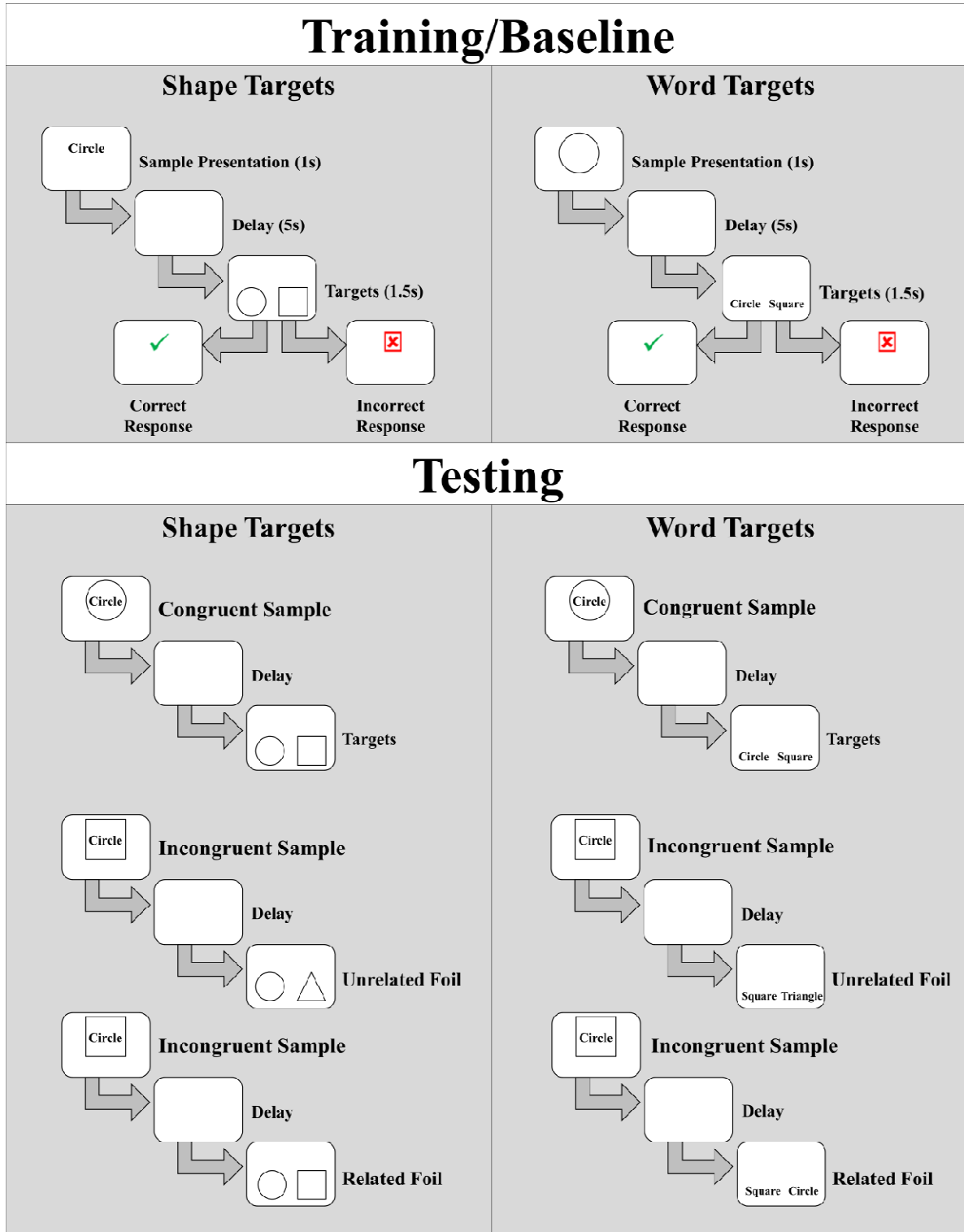
Figure 10. Filled Reverse Matching Design. One sample Baseline/Training trial is illustrated for Shape Targets (a) and Word Targets (b), and one sample Congruent, Incongruent-Unrelated Foil, and Incongruent-Related Foil trial is illustrated for Shape Targets (c) and Word Targets (d). For illustrative purposes, all correct matches are shown as the left target even though correct target and foil target locations were counterbalanced.
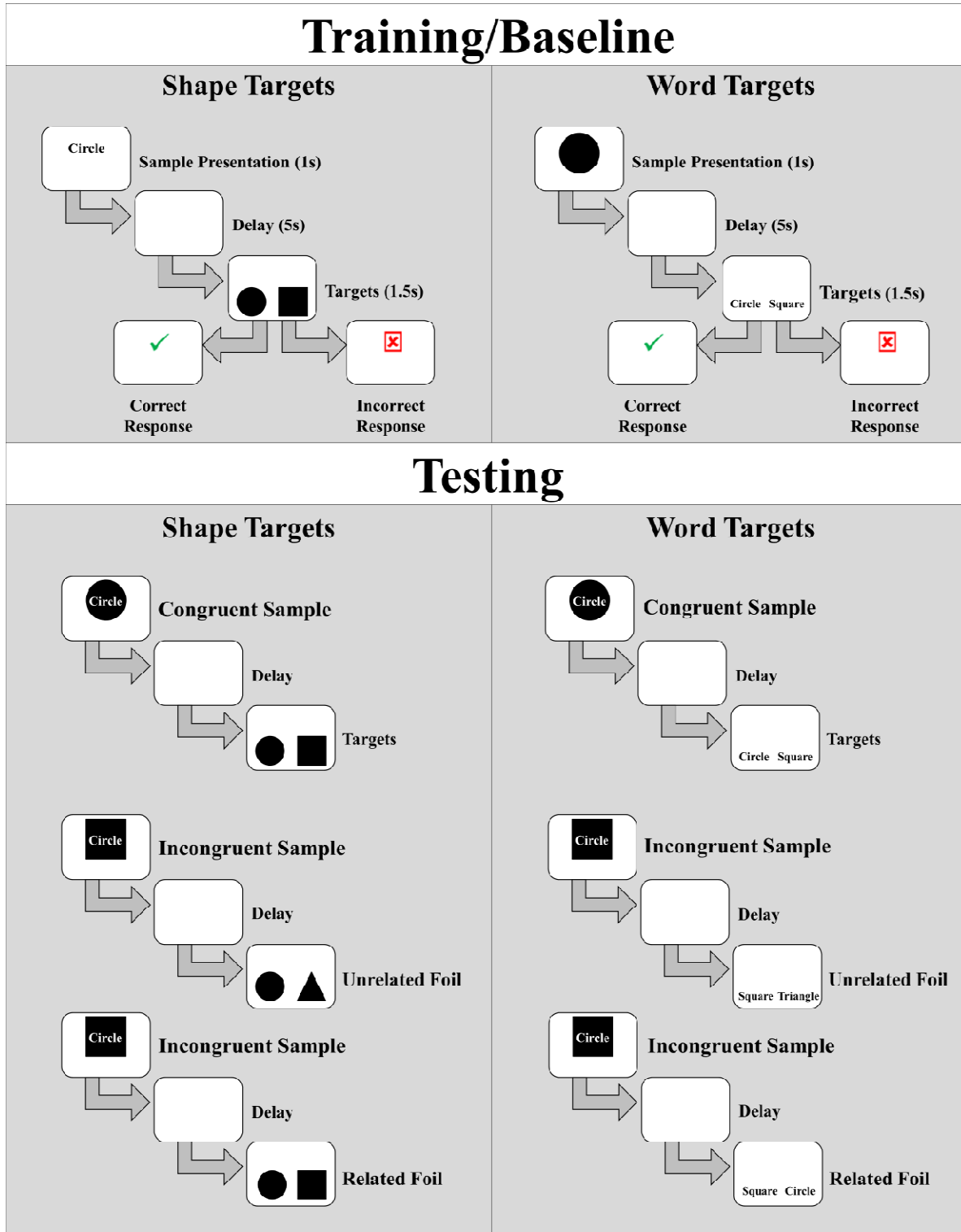
CHAPTER EIGHT

EXPERIMENT 2 RESULTS

Response times. Response times from correct trials only were analyzed. This resulted in the removal of incorrect or no response trials (1068/6144; 17.38%). A Condition (Unfilled and Filled) x Target Type (Shapes and Shape words) x Trial Type (Baseline, Congruent, Incongruent-Unrelated Foil, and Incongruent-Related Foil) mixed ANOVA was conducted on RTs[1] and revealed a main effect of Target Type $F(1, 60) = 120.56$, $p < .001$, $\eta_p^2 = .67$, and Trial Type $F(3, 180) = 157.60$, $p < .001$, $\eta_p^2 = .72$, No significant Target Type x Trial Type interaction effect was found, $F(3, 180) = 1.77$, $p = .16$. Additionally, no significant effects were found for Target Type x Condition ($p = .39$), Trial Type x Condition ($p = .45$), or Target Type x Trial Type x Condition ($p = .90$). Given the lack of effects or interaction with Condition (Unfilled, $M = 665.41$, 95% *C.I.* $= 20.25$; Filled, $M = 670.861$, 95% *C.I.* $= 18.81$), data were collapsed across the Condition factor. Figure 11 shows the mean RTs (in milliseconds) plotted by Target Type for each Trial Type collapsed across Condition.

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[1] One participant did not make any correct responses during Incongruent-Related trials for shape targets and another participant did make any correct responses during Incongruent-Related trials for word targets. The data for these participants could not be used in the main analysis of response times.

Overall, matching shape words to shape targets ($M = 616.09$, 95% *C.I.* = 28.01) was significantly faster than matching shapes to shape word Targets ($M = 717.54$, 95% *C.I.* = 22.97). LSD post hoc on the Trial Type factor revealed that Baseline ($M = 576.73$, 95% *C.I.* = 21.84) and Congruent ($M = 587.42$, 95% *C.I.* = 21.87) trials were not significantly different from each other ($p = .09$), but both of these trial types were significantly faster than Incongruent-Unrelated ($M = 770.51$, 95% *C.I.* = 28.82) and Incongruent-Related ($M = 732.60$, 95% *C.I.* = 35.31) Foil trials (*ps* < .005). Incongruent-Related Foil trials were significantly faster than Incongruent-Unrelated Foil trials ($p < .01$).
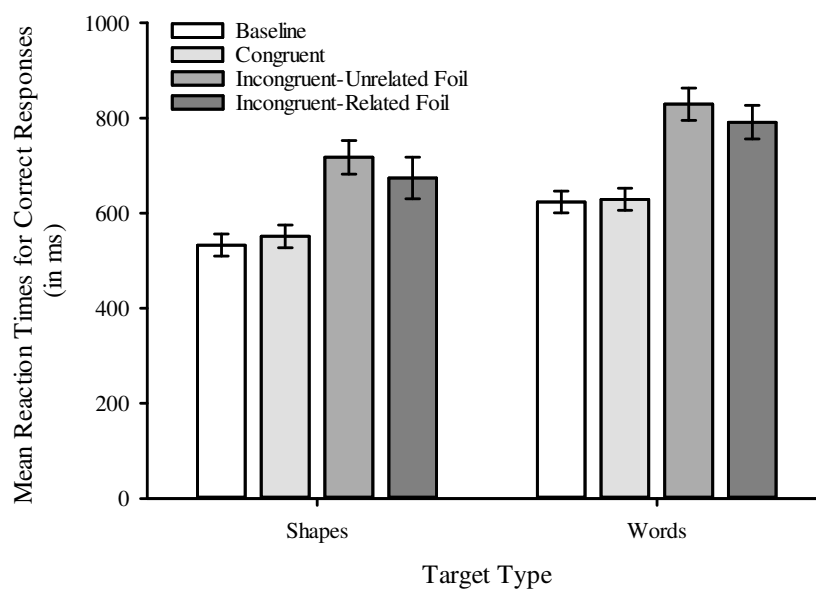
Figure 11. Experiment 2 Results (RTs). Mean RTs on correct trials plotted by Target Type for each Trial Type collapsed across Condition. Errors bars represent 95% confidence intervals.

Proportion correct. Trials in which participants did not respond were eliminated (133/6144; 2.16%). A Condition (Unfilled and Filled) x Target Type (Shapes and Shape words) x Trial Type (Baseline, Congruent, Incongruent-Unrelated Foil, and Incongruent-Related Foil) mixed ANOVA was conducted on proportion correct and revealed a main effect of Target Type,

$F(1, 62) = 10.00, p < .01, \eta_p^2 = .14$, and Trial Type, $F(3, 186) = 236.32, p < .001, \eta_p^2 = .79$.

These main effects were qualified by a significant Target Type x Trial Type interaction

$F(3, 186) = 3.51, p < .05, \eta_p^2 = .05$. No significant effect was found for Target Type x

Condition ($p = .76$), Trial Type x Condition ($p = .19$), or Target Type x Trial Type x Condition

($p = .30$). Given the lack of effects or interactions with Condition (Unfilled, $M = .84$,

95% *C.I.* = .03; Filled, $M = .85$, 95% *C.I.* = .02), data were collapsed across the Condition factor.

Figure 12 shows the mean proportion correct plotted by Target Type for each Trial Type

collapsed across Condition. Unlike Experiment 1, the source of the Target Type x Trial Type

interaction was not a result of differences across Trial Type for Shape Targets but not Word

Targets. This was confirmed by two separate one-way repeated measures ANOVAs that were

conducted on proportion correct for Shape Targets and Word Targets with Trial Type (Baseline,

Congruent, Incongruent-Unrelated, and Incongruent-Related) which revealed a main effect of

Trial Type for Shape Targets, $F(3, 189) = 119.07, p < .001, \eta_p^2 = .65$, and a main effect of Trial

Type for Word Targets, $F(3, 189) = 114.00, p < .001, \eta_p^2 = .64$. To control for family-wise

error rates, the alpha level was adjusted to .025 for the two comparisons (Keppel, 1991).

Instead, the Target Type x Trial Type interaction was driven by differences in Shape

Targets and Word Targets for some trial types but not others. This was confirmed with four

separate related samples *t*-tests comparing mean proportions correct for Shape Targets and Word

Targets for Baseline, Congruent, Incongruent-Unrelated, and Incongruent-Related trials with. To

control for family-wise error rates, the alpha level was adjusted to .0125 for the four comparisons

(Keppel, 1991). A significant difference was found for only Incongruent-Unrelated Foil trials,

$t(63) = 5.41, p < .001$. More errors were made in the Incongruent-Unrelated Foil condition for

Word Targets than Shape Targets. All other trial types were not significantly different from each

other (*ps* > .27). Eight individual one-sample *t*-tests were conducted to analyze performance

compared to chance (.5) for each Trial Type separated by Target Type. Data were collapsed

across Condition with adjusted alpha levels of .006 for the eight comparisons (Keppel, 1991).

All other mean proportions correct were significantly greater than chance, $ts(63) > 4.47$, $ps \leq$
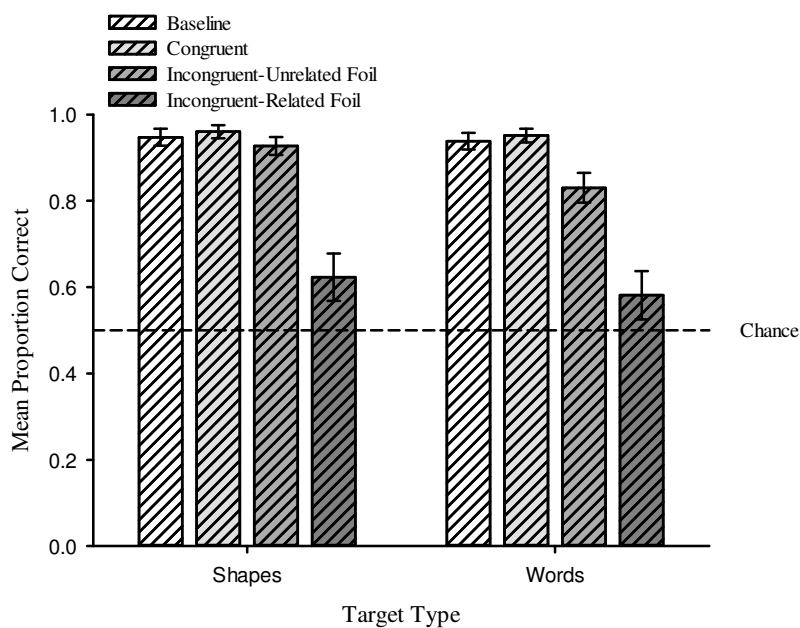
.006.

Figure 12. Experiment 2 Mean Results (Accuracy). Mean proportions correct plotted by Target Type for each Trial Type collapsed across Condition. Dashed line represents chance (0.5) performance. Error bars represent 95% confidence intervals.

CHAPTER NINE

EXPERIMENT 2 DISCUSSION

Overall, participants took longer to match shapes to shape words compared to matching

shape words to shapes. Participants also took longer to make a correct decision when presented

with an incongruent bi-dimensional sample (i.e. Incongruent-Unrelated and Incongruent-Related

Foil trials) compared to a congruent or uni-dimensional sample (i.e., Congruent and Baseline

trials).   Also, Incongruent-Unrelated trials were slower than Incongruent-Related trials.

Analysis of accuracy revealed significant decreases in choosing the correct target when the foil

was not related to the irrelevant sample dimension (Incongruent-Unrelated Foil trials) for word

targets compared to shape targets. Additionally, accuracy decreased for both Target Types when

the foil was related to the irrelevant sample dimension (Incongruent-Related Foil trials). In

addition, RTs and accuracy did not differ between the Unfilled and Filled conditions.

These results are important for three primary reasons. First, these results produced a

symmetrical pattern of interference. In short, reversing the matching paradigm appeared to result

in both words and shapes in the sample to interfere with making a correct decision for both shape

targets and word targets. This is consistent with the suppression of an irrelevant sample

dimension for both Target Types (Sturz et al., 2013). In order to make a correct match, the

irrelevant sample dimension, regardless of relatedness, needed to be suppressed. This

suppression results in longer RTs. Interference is also supported by the decrease in accuracy for

choosing the correct target when an incongruent bi-dimensional sample was followed by a pair

of targets in which the foil was related to sample (Incongruent-Related Foil trials) for both shape

and word targets compared to a uni-dimensional or a congruent bi-dimensional sample (Baseline

and Congruent trials). The presence of a related irrelevant sample dimension appeared to disrupt

the decision making process (Sturz et al. 2013).

Second, the current findings suggest an additional process for shape targets. Forcing sample shapes to be processed in a semantic fashion appeared to require additional processing time. The difference in the speed between matching shape samples to word targets compared to matching word samples to shape targets supports the assumptions that shapes do not automatically activate the semantic representation, but words do activate both semantic and spatial representations. The results of Experiment 2 suggest that sample shapes were processed in a semantic fashion only after being processed automatically by an isolated geometric module (Figure 13a-d). In contrast, word samples appear to only require semantic processing to activate the spatial representation.

Third, the present findings provide evidence that the saliency of shapes did not affect the pattern of interference. Filling in the shapes did not cause any observed changes in RT's or accuracy.

Presumably, if both sample dimensions activated a semantic and spatial representation and in each case, one of these representations needed to be suppressed in order to identify the correct target, the presence of an extra and related representation may have resulted in a decrement in accuracy seen in the Incongruent-Related Foil trials.
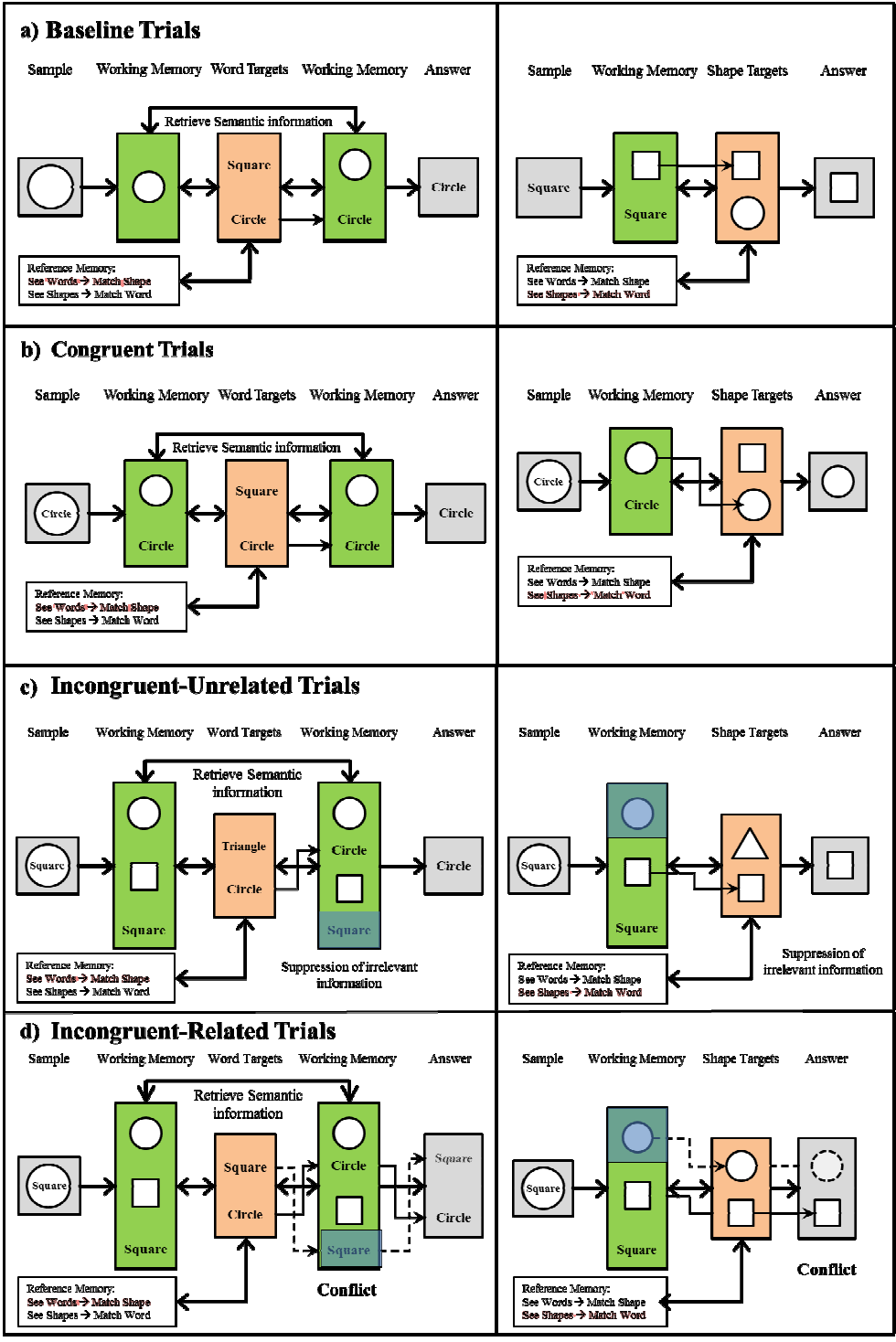
Figure 8. Reverse Matching Illustration. The graphic above illustrates the conceptual mental process by which a sample dimension is matched with the opposing dimension.

CHAPTER TEN

GENERAL DISCUSSION

In Experiment 1, participants took longer to make a correct choice between two shapes when presented with an incongruent bi-dimensional sample compared to a congruent or uni-dimensional sample. No differences emerged in RTs for correct decisions between two shape words. Furthermore, choosing the correct target for shape targets but not word targets when the foil was related to the irrelevant sample dimension resulted in more errors. Together, the results from Experiment 1 produce an asymmetrical pattern of interference. In addition RTs or accuracy did not differ when the shapes were filled in black (Filled) or an unfilled outline (Unfilled).

In Experiment 2, participants had to match shapes to shape words and shape words to shapes. In this new matching paradigm, participants took longer to choose between shape targets than shape word targets. Trials in which the foil was related to the sample were significantly more prone to errors for both target types. In contrast to Experiment 1, the results from Experiment 2 produced a symmetrical pattern of interference. Similar to Experiment 1, no difference emerged between unfilled shape outlines and black ink filled shapes for either RTs or accuracy.

The results of Experiment 1 and 2 are important for three reasons. First, the results appear to undermine an explanation for the asymmetrical pattern of interference between shapes and shape words based upon differences in saliency for shape targets and word targets. Given that shapes could have been encoded weakly relative to word targets because the shape words were more salient than the shape, an inability to activate the semantic representation of shape words could have produced the asymmetrical pattern of results. However, increasing the saliency

of the sample shape resulted in an asymmetrical pattern of interference. Although it is possible that filling in the shape did not affect saliency, the lack of differences between the Unfilled and Filled conditions for either Experiment 1 or 2 suggest that greater saliency of the sample shape word relative to the sample shape was not responsible for the obtained asymmetrical pattern of interference.

Second, the current study supports the initial assumption 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 trials 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 2. Reversing the matching requirement (i.e. shapes to shape words and shape words to shapes) 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.

Third, the current studies provide additional support for the conception of an isolated module dedicated to processing geometric information. The asymmetrical pattern of interference obtained in Experiment 1 indicates that shapes were processed by a different system then semantic information. The lack of interference from shapes in matching shape words to shape words, suggest that the two processes are isolated from each other. The symmetrical pattern of

interference obtained in Experiment 2 indicates that both shapes and shape words were being processed in a semantic fashion. Given that both dimensions now required both a semantic and spatial representation, the longer RTs found from matching the sample shape to a word target compared to matching a sample word to a shape target suggests additional processing of shape targets. Importantly, the results of these studies provide evidence that geometric information is processed by a module that is isolated from semantic information.

A primary characteristic for a perceptual module is automaticity (Fodor, 1985). Taking this characteristic into account, the significant difference in overall reaction times of matching shape word targets to a shape in a sample as compared to matching a shape to a shape word in a sample may be explained as shapes being automatically processed by an isolated geometric module first and then subsequently forced through semantic processing. The difference in RTs between shape targets and word targets may also suggests the lack of conscious involvement. It could be conceived that participants knowing that they were to match shapes to shape words, would consciously obtain all possible representations during the five second delay. However, participants in Experiment 2 still took longer to match shapes to shape words despite knowing the matching requirements, suggesting a lack of conscious involvement or control. It appears that shapes are automatically processed through the isolated geometric module before processing for the semantic information can begin.

Overall, the results from the current studies are consistent with the past research regarding the existence of an isolated modular process for geometric information. Importantly, the current DMTS tasks appear to provide evidence for the activation of a spatial representation independent of other representations (Experiment1), and only when shapes are forced to be processed semantically, do they undergo semantic processing to activate a semantic

representation (Experiment 2). As a result it appears that, consistent with a module dedicated to processing geometric information, shapes automatically activate only a spatial representation of shapes. Isolation is seen in the sense that the spatial representation was immune from interference by shape words. Future research could 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 isolated cognitive processing.

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