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Further Exploring Processing Differences Between Geometric Shapes and Shape Words

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FURTHER EXPLORING PROCESSING DIFFERENCES BETWEEN GEOMETRIC SHAPES

AND SHAPE WORDS

by

CHELSEA V. SCORDAS

(Under direction of Lawrence Locker Jr.)

ABSTRACT

The current study sought to expand upon the research of geometric shape processing in relation to theories of domain specificity and modularity. Sturz, Edwards, and Boyer (2014) presented results for possible processing differences between geometric shapes and geometric shape words. The authors found that when processing a bi-dimensional sample (i.e., a shape word transposed inside either the same or a different picture of a shape), there was asymmetric interference. Shape words would interfere with identifying the correct shape in a delayed match-to-sample (DMTS) task but there was no such interference from geometric shapes when identifying shape words. It was concluded that geometric shapes activate a visual representation only, while shape words activate both visual and verbal representations. Sturz et al. (2014) proposed this was possible evidence in favor of an independent processing module involved in the early processing of geometric shapes. The current study further tested whether geometric shapes are processed independently from linguistics (i.e., verbal representations) by utilizing DMTS tasks along with imbedded distractor tasks (DTs). It was hypothesized that if a DT was based on visual information (i.e., nonsense shapes; adapted from Lin & Yeh, 2014), it should only affect the performance for geometric shape matching, whereas a verbal DT (i.e., strings of letters) should affect both shape and shape word matching. Results showed evidence that only the nonsense shape DTs negatively impacted performance times for geometric shapes whereas the shape words were negatively impacted by both DTs.

INDEX WORDS: Geometric processing, shape words, distractor task, domain specificity, modular processing, delayed match-to-sample, working memory, dual-task

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B.S., Georgia Southern University, 2013

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial

Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

STATESBORO, GEORGIA

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Electronic Version Approved:

July 2016

DEDICATION

To my family, both blood and friendship. I would not be where I am today without your continuous guidance and support. So, I hereby dedicate this thesis, which will have neither use nor relevance to you, in your lovely names. You all are my strength.

"The bold survive." (Ferris Bueller, 1986)

ACKNOWLEDGMENTS

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CHAPTER 1

INTRODUCTION

A great deal of study in cognition is aimed at basic processes that take place outside of awareness, including perception and memory. There are many different theories/conceptualizations that have been proposed to account for how humans and animals process information in regard to sensation, perception, memory and behavior (Craik & Lockhart, 1972; Pashler, Johnston, & Ruthruff, 2001; Peverly, 2006; Quiroga, 2016; Shiffrin & Schneider, 1977). As perception and memory processes in cognition interrelate, an organism's behavioral outputs originate from goals (aware and/or unaware) and how these goals are influenced by outside stimuli (direct and/or indirect). One way an organism elects to process certain stimuli over others is the allocation of attentional resources, either outside of awareness or voluntarily (e.g., through sensation and perception; Pashler et al., 2001). For example, evolutionary psychology research predicts that this allocation of attention to act upon certain problems over others stems from the natural selection of these problem-solving skills in order to overcome certain reproductive obstacles (i.e., avoiding predators or finding mates; Duchaine, Cosmides, & Tooby, 2001).

Natural selection has helped species solve for these types of adaptive problems faced by their ancestors. These adaptive problems are a possible explanation as to why humans now have organized and specialized systems in their computational architecture devoted to problem-solving (i.e., facial recognition and attending to certain facial expressions for emotion to assess for danger; see for review, Duchaine, et al., 2001). These systems are based on filter-like mechanisms that attend to outside stimuli that are unique or devote attention only to certain aspects of our environment while ignoring others (Corradi-Dell'Acqua, Fink, & Weidner, 2015).

These filter-like perceptual mechanisms are referred to as top-down and bottom-up attentional control. Top-down attentional control is usually within the organism's awareness and includes the use of preexisting knowledge and/or intentional current goals. Bottom–up processing is based on information from our surroundings that uniquely stand out from other stimuli in our environment (commonly outside of the organisms' conscious awareness; Corradi-Dell'Acqua, Fink, & Weidner, 2015; Sobel, Gerrie, Poole, & Kane, 2007). Whether or not a visual stimulus uniquely stands out is determined by the saliency (i.e., its notability in the environment) of the stimulus (e.g., a salient sensory feature of a red ball would be the color red; Sobel et al., 2007; c.f., Treisman & Gelande, 1980). In some cases, these salient features detected by bottom-up filters interrupt allocation of attention to the task at hand and this requires that top-down filters must actively ignore them, utilizing attentional resources in the process. This is crucial since there are a limited amount of processing resources available for use at any given time (Baddeley & Hitch, 1974; Corradi-Dell'Acqua et al., 2015). These two processes (bottom-up and top-down) interact to form our selective visual attention and work together in such a way that top-down mechanisms are essential in our ability to control and focus said attention (Corradi-Dell'Acqua et al., 2015; Quiroga, 2016; Yang, Chiu, & Yeh, 2012). This selective visual attention, for example, facilitates our ability to ignore vivid distractors in our environment that activate bottom-up mechanisms (Sobel et al., 2007).

Selective attention is a primary component through which perceptual information is transferred into working memory (Archibald, Levee, & Olino, 2015; Boucart & Humphreys, 1994; Doeller, King, & Burgess, 2008; Olivers, Peters, Houtkamp, & Roelfsema, 2011; Patt et al., 2014; Sandry, Schwark, & MacDonald, 2014; Schneider, Einhauser, & Horstmann, 2015; Serences, Schwarzbach, Courtney, Golay, & Yantis, 2004; Sobel et al., 2007; Williams, Pouget,

Boucher, & Woodman, 2013). For example, visuospatial attentional resources are required when locating individual features of an object, which are then bound together with the object's representations in working memory (Johnson, Hollingworth, & Luck, 2008; c.f., Baddeley, Allen, & Hitch, 2011; Treisman & Gelande, 1980). It is also said that spatial attention not only helps filter out potentially distracting information but also actively facilitates visual working memory maintenance of certain object properties (Williams et al., 2013). With that being said, these different types of perceptual stimuli are processed differently or together depending on which system(s) in the cognitive architecture are responsible for them (c.f., Cheng & Newcombe, 2005). That is, there are multiple domains (e.g., visual and verbal modalities) that have their own processing systems within cognitive processing (Cosmides & Tooby, 1994; Craik & Lockhart, 1972; Klein, Cosmides, Tooby, & Chance, 2002).

According to Klein et al.'s (2002) review of the evolution of memory, cognitive architecture is divided into five functional memory systems. Each system is responsible for the application, retrieval, and manipulation of different kinds of functions and/or information. The majority of these systems are known to have specific subsystems for certain skill sets or domains (Klein et al., 2002). Working memory, for example, is a system of cognition that is responsible for taking attended information and either maintaining it temporarily (necessary for comprehension and other higher order thinking skills) and/or transferring it to long-term memory (Baddeley & Hitch, 1974).

Working memory is a foundational concept in all information processing systems, regardless of modality and therefore it is important to discuss its involvement throughout cognition. In a recent version of a working memory model, Baddeley (2000) describes a multicomponent system with four components. The first component in this model of working

memory is a main central executive component that houses the majority of cognitive resources (i.e., attentional control discussed earlier). The central executive actively devotes the limited amount of cognitive resources to maintaining/working on perceptual stimuli within working memory. Also, Baddeley and others (e.g., Archibald, 2013) describe this central executive mechanism as a part of processing that can be utilized as a global tool (i.e., it can manipulate multiple classes of information). Additionally, according to Sobel et al. (2007), the central executive component would presumably be associated with top-down mechanisms. For example, during a memory task people consciously attend (through top-down processing according to Sobel et al., 2007) to certain stimuli to recall later on, while ignoring other irrelevant details (of bottom-up stimuli according to Corradi-Dell'Acqua et al., 2015; Pashler et al., 2001).

Two lower-level local (i.e., specific to certain domains unlike the central executive that is unspecific to domains it can process) subsystem processors that assist the central executive component of Baddeley's working memory model are the phonological loop and the visuospatial sketchpad (Baddeley & Hitch, 1974; Baddeley, 2000; Baddeley, 2002; Baddeley et al., 2011). The phonological loop is used during the maintaining (i.e., temporary storage) of verbal and auditory (e.g., directly audible or sub-vocally; Baddeley & Andrade, 2000; Baddeley, 2002) information. A major function of this subsystem is the retention of sequential information (e.g., a sequence of letters that is to be immediately recalled in that order; Baddeley, 2000). This component of working memory is also heavily involved in certain aspects of language (e.g., translating thoughts to verbal codes, lexical knowledge; Archibald, 2013; Archibald et al., 2015). The visuospatial sketchpad subsystem, on the other hand, maintains visual and spatial information (Baddeley, 2002; Olivers et al., 2011; Schneider et al., 2015). For example, a function of this subsystem is to facilitate the vividness of memory representations (e.g., its image

within working memory) of visual sensory information by "image-enhancement" (e.g., taking a representation of a certain experience and combining it with generic information of that experience to make it more vivid; Baddeley & Andrade, 2000, pg. 141).

These working memory subsystem components are strict in that they are devoted to their own specific domain and depending on if the action demanding working memory processing is simple enough, these subsystems can actually solve and produce an output on their own (Baddeley & Hitch, 1974). However, similar to what has been described above, the central executive mechanism can globally use its higher-order problem-solving skills to produce a final output on its own or with minimal help from its subsystems. Also, one should note that a fourth component was added called the episodic buffer (Baddeley, 2000). This buffer can hold and pool various types of information (i.e., output from different domains, semantics/context of perceptual stimuli and/or reference knowledge from long-term memory) together with the information that is actively being retained in working memory for easier recall (Baddeley, 2000; Baddeley et al., 2011).

These concepts of working memory are comprised of several components involving specific types of information (i.e., phonological and visual) that can also work in parallel with the multi-dimensional episodic buffer that processes information from various sources (e.g., takes the visuospatial sketchpad's collective feature information and maintains it as one visual object along with other episodic information; Baddeley, 2000; Baddeley et al., 2011). Similarly, Craik and Lockhart (1972) claimed that when a stimulus has been recognized within a specific domain, different associations may be triggered that relate to it. This concept is said to bias everyday experiences or working memory tasks specific to that domain (Schneider et al., 2015; c.f., Lin & Yeh, 2014). For example, it is presumed that since selective attention is based on

visual perception of various stimuli in the environment, spatial aspects (e.g., locations of objects within space) and the descriptive language used to describe spatial aspects (e.g., above, below, etc.) both have an effect on processing and perception. Additionally, visuospatial memory and its cognitive capacities (e.g., the ability to maintain information) are also seen to play a role in at least some cases of language comprehension (Baddeley, 2002).

Given the somewhat complex inner workings of working memory, a major aim of research has sought to assess the specific components dedicated to processing different types of information and examine the extent to which these systems are specialized. A common way to assess the inner workings of these components of working memory is by having participants complete more than one memory task at the same time, referred to as a dual-task/secondary task. Each of these tasks usually involves different parts of the system (i.e., different domains). For example, Baddeley and Andrade (2000) conducted several experiments to test whether or not mental representations of domain-specific stimuli (i.e., auditory and visual) would be affected by concurrent domain-specific dual-tasks in working memory. In the study, participants would be given an image (e.g., shapes or pictures cut from magazines) or an audio clip (e.g., a number of musical notes in varying patterns or a 10 word sentence describing random scenarios) and then asked to replicate that image or audio clip in their minds and hold it in memory (their mental image of the image, descriptions or sounds). Following this, they rated the vividness (i.e., how closely their mental representation compared to the original stimuli; visually or phonetically vivid in one's mind) of their mental representation on a scale of 0 (i.e., no image at all) to 10 (i.e., very close to the original stimuli; clear and vivid image or audio). After providing the ratings, participants matched the visual or audio stimuli to a secondary visual or audio message (i.e., participants respond either yes it matched the original stimulus or no it did not match).

Participants were assigned to one of three concurrent task conditions (i.e., control [no concurrent task], a spatial tapping task, or a counting out-loud task). Baddeley and Andrade (2000) were interested in determining if perceived vividness (e.g., of a visual image) decreased if given a dual-task in the same domain (e.g., the spatial tapping was predicted to affect the vividness of a visual image since they are both processed in the visual domain). Among their results, the authors found that if the dual-task was in the same domain as the stimulus (e.g., spatially tapping a pattern with one's fingers while maintaining a mental representation of an image in working memory), the stimulus' representation (i.e., its image within working memory) was rated as less vivid. However, if the dual-tasks were not within the same domain, then the representation of the image was not affected in terms of vividness (Baddeley & Andrade, 2000). As discussed above, working memory tasks can be utilized to explore processing differences between visual and verbal domains, these concepts are relevant to the current study and the procedures used to determine what aspects of working memory are utilized. Specifically, the yes or no matching task in Baddeley and Andrade (2000) was adapted as the distractor tasks in the current study as one of the dual-tasks to selectively investigate processing of different kinds of information. The stimuli used within this task are discussed later on in this chapter.

In summary, there is evidence suggestive of both domain-general and domain-specific processing related to working memory (Duchaine et al., 2001; Lin & Yeh, 2014). These ideas of working memory and top-down/bottom-up mechanisms are used when explaining the main conceptual framework of information processing as a whole. Two major views of information processing are content general systems (domain-general) and as discussed above, and content specific systems (domain- specific; Duchaine et al., 2001). Content general systems compute and manipulate information from all domains of input and solve problems (in any given cognitive

task) in a universal fashion (i.e., globally; Archibald, 2013; Duchaine et al., 2001). In other words, it is the notion that the mind is comprised of general/holistic sets of processing/reasoning abilities that apply to all types of cognitive processes (e.g., concepts similar to the notion of the central executive and episodic buffer components of Baddeley's working memory model). Content specific systems, on the other hand, are more restricted in terms of the domain to which it can be applied. That is, the mind is categorized into many specialized systems dedicated to certain domains (Duchaine et al, 2001; c.f., Cosmides & Tooby, 1994). Craik and Lockhart (1972) claim that attention is the mental sensor that reads out and transfers information into their domain-specific codes and depending on which response needs to take place, different sets of retrieval/processing "search engines" across domain-specific memory systems activate. These systems are domain-specific such that the appropriate dimensions of information must be input a certain way in order to fit the specialized skills that a specific domain pathway needs in order to process it (Klein et al., 2002).

This idea of domain specificity is even used in terms of the attentional resources allocated to domain-specific subsystems (e.g., visual-spatial or phonological) in memory discussed above in Baddeley's working memory model (Lin & Yeh, 2014). Again, these factors that impact the allocation of attentional resources are crucial to how we remember and processes information (see for review, Awh & Jonides 2001; c.f., Archibald et al., 2015). This is important, especially in the context of how working memory combats against distractions (Baddeley & Andrade, 2000; Lin & Yeh, 2014; c.f., Sobel et al., 2007). Traditionally, there has been a prevalent idea that working memory's attentional control is domain-general, meaning that the effect of memory load distractibility (i.e., how well a bottom-up distractor diverts attention from the task at hand; Lin & Yeh, 2014) impacts multiple domains at once (Duchaine et al., 2001). Even though this

has been the main idea behind attentional control in the past, there has been more recent evidence in support of not only a domain-specific type of memory load (c.f., Baddeley & Andrade, 2000; Baddeley et al., 2011) but domain-specific effects of attentional control (i.e., an effect of distractibility for a specific domain only; Kelley & Lavie, 2011; Lin & Yeh, 2014). In order to further test these ideas, Lin and Yeh (2014) used a dual-task procedure similar to Baddeley and Andrade (2000). Lin and Yeh examined the yes or no memory matching task described above using nonsense shapes for visual stimuli and numbers (presented visually and auditory) for verbal stimuli. The procedure also utilized a concurrent flanker task (i.e., a letter categorization task that had a distractor letter in the periphery of this task on the computer screen). This task was used to distract attention from the verbal stimuli matching task. Again, the goal was to assess the effect of the distractor task's distractibility. An additional goal was to examine the relationship between the distractor in relation to either domain-general or domain-specific attentional control in working memory (e.g., how well participants ignored the letter distractor in the flanker task). The study found that increased distractibility of the letter flanker was dependent on the distractor items (letters) being held/processed in the same content domain as the primary task (i.e., the verbal number-matching task was affected more so than the visual matching tasks). These effects are similar to the domain-specific effects of vividness reported by Baddeley and Andrade (2000). Lin and Yeh (2014) added that distractibility was also affected by the number of items being held within the same domain (e.g., low load being one object versus a high load of four objects). Further, it is how closely stimuli are to how they were encoded (in visual and verbal means) in working memory (in this case under high working memory load) that impairs the effectiveness against distractors and impacts the communication between memory and selective attention (i.e., top-down attention controlling against bottom-up distractors; Lin &

Yeh, 2014). As noted, this supports what was found by Baddeley and Andrade (2000) that disruption (from the task at hand towards a secondary task) comes from how close or how different one task is from another (e.g., sharing the verbal or visual domain).

With that being said, many researchers agree that we have domain-specific processors that manipulate specific types of informational inputs (Baddeley & Andrade, 2000; Craik & Lockhart, 1972; Lin & Yeh, 2014). This idea of domain specificity uses overlapping content specialized processors which people use during forming assumptions, inferences and other reasoning skills in everyday problem-solving application (e.g., face recognition, socialization; c.f., Duchaine et al., 2001; Grusec & Davidov, 2010). Commonly in evolutionary research, the specialization of cognitive systems benefits to reduce the allocation of mental resources needed by having subsystems relative to certain skills and/or domains (Klein et al., 2002). Further, domain-specific cognitive abilities are even narrowed to certain aspects of the environment that affect their functioning (e.g., visual-object matching performance differs according to particular information such as luminance, form, color, size, and orientation of an object that are specific to vision; Boucart & Humphreys, 1994; c.f., domain-specific attentional control of distractors in Lin & Yeh, 2014). However, some of these domain-specific mechanisms are proposed to be specific to a given type of perception (e.g., visual or auditory) and encode perceptual information automatically, without the involvement of conscious, or any other cognitive processes (Fodor, 1983, 1985; c.f., Duchaine et al., 2001). For example, in a book review of David Marr's "Vision: a Computational Investigation into the Human Representation and Processing of Visual Information, Rolls (2011) cited evidence that the early visual detection of objects possesses coherent coordination of atomic visual units (i.e., modules responsible for detecting edges, surface texture, etc.). That is, the act of "seeing" is dependent on these visual modules working in

tandem and transforming perceptions into visual representations (in this case, mental representation of shape, size, and motion; Rolls, 2011). These visual-spatial modules are important in the visual domain of working memory by producing outputs that aid in the maintenance of objects within the visual field (Williams et al., 2013).

The ideas behind this extreme approach to domain-specific mechanisms are utilized in Fodor's (1983) *modularity* of the mind (c.f., Coltheart, 2011; Fodor, 1985; Frankish, 2011). According to Coltheart (1999), modular processing systems are composed of domain-specific subsystems, which are "informationally encapsulated". Coltheart interprets Fodor's definition of "Informationally encapsulated" to mean a module cannot access episodic information (i.e., experiences, beliefs, etc.; pg. 117). Modules primarily process bottom-up driven functions that are a mandatory (automatic) occurrence. In other words, modules process certain information with specialized efficacy. For example, evolutionarily speaking, object recognition does not access a person's entire knowledgebase or it would take too much time in a situation in which speed of recognizing a predator is crucial. Domain specificity refers to the notion that a domain of processing is unable to receive information from other classes of domains (e.g., a domain-specific visual subsystem can not receive information from phonological audio unless there is a dimensional buffer; Coltheart, 1999; pg. 119). Modular processing systems propose specific aspects of perception and cognition utilize encapsulated mental units (i.e., modules) responsible for certain processing functions (Coltheart, 2011; Fodor, 1985). That is, the evolutionary gains of having a domain-specific categorized mind (e.g., Duchaine et al., 2001; Cosmides & Tooby, 1994) lead to the development of "modules" devoted only to one specific function of information (e.g., aspects of object recognition; Coltheart, 1999; 2011). Again, the early processing in these units is mostly automatic and not influenced by an individual's experiences, education, or

language (Cheng, 1986, Chiandetti & Vallortigara, 2008; Spelke, Lee, Izard, 2010). This means that modules pass on their output without any influence from other domains (i.e., processing within the module is independent of other information). This should not be confused with the idea that these modules do not work with other units at all, but rather that functions within a module are independent (Cheng & Newcombe, 2005; Coltheart, 1999, 2011; Fodor, 1983). In sum, it is assumed that some domain-specific subsystems are encapsulated within modules that are typically utilized during the early and simple automatic stages of processing (Coltheart, 1999).

Concepts of modular processing have been explored extensively in studies of spatial navigation and orientation (Cheng, 1986; Hermer & Spelke, 1996; Huttenlocher & Lourenco, 2007; Lourenco & Cabrera, 2015; Spelke et al., 2010; Vickery, Sussman, & Jiang, 2010). Specifically, past studies have shown evidence that there is a module involved in perceptions of navigating one's surroundings specific to the processing of its geometric shape (see for review, Cheng & Newcombe, 2005; c.f., Spelke et al., 2010). This was first proposed by using a reorientation task. That is, rats were found to spatially reorient themselves after having been disoriented (e.g., by being removed from the enclosure and then replaced in a different direction) in a rectangular enclosure to find a target (where food was hidden) by using geometric properties to reorient within their surroundings (Cheng, 1986). It was concluded that this was a purely geometric process since rats made a crucial error when trying to find the goal location. Rats were trained and experimented upon in the same rectangular container that had corners with distinguishing featural properties (i.e., unique color or patterns associated with each corner of the enclosure) but the rats failed to use these features when reorienting to navigate to the target. That is, they would make the crucial error of searching for the goal in the correct goal area as well as

the rotationally equivalent corner equally (despite the unique features at each corner; Cheng, 1986). It is assumed that if features were used to facilitate reorientation of the enclosure to find the goal location, they would use these unique features to relocate the correct position after being disoriented. That did not occur which lead Cheng (1986) to believe that rats simply use geometry to reorient and find a goal location. Cheng (1986) claims this is due to a geometric module specific to the coding of certain qualities in the environment, in this case, the geometric shape (e.g., properties of boundaries within a space). The processing of these geometric properties is assumed to involve an automatic module that is independent of other information (i.e., language or symbolic thought since features unique to the corners were not utilized) in rats. This failure seen in rats (i.e., an inability to integrate features within the geometry of their surroundings to help reorient towards a goal location) lead researchers to question whether these types of errors can also be found in humans or if it is unique to rats possibly without symbolic integration abilities (Hermer & Spelke, 1996; Hermer-Vazquez, Spelke, & Katsnelson, 1999; c.f., Lourenco & Cabrera, 2015).

Hermer and Spelke (1996) conducted a reorientation task similar to Cheng (1986) with children. The study found that children made the same reorientation mistake by checking goal location of an enclosure that was geometrically equivalent to the correct location equally as often. Children were said to use geometrical cues such as the length of walls in the enclosure to navigate the area. Hermer and Spelke conducted several experiments to test this phenomenon and were also able to rule out possible human errors by also testing the detection and memory of features. Further, Hermer-Vazquez et al. (1999) questioned if superior language abilities of adults (compared to children) would be related to reorientation. These authors found that adults reorient themselves better and use unique features to locate a goal. That is, adults did not make

the reorientation error seen in children or rats and Hermer-Vazquez et al. (1999) proposed that the unique use of language was responsible for this difference. Adults tend to only use geometric cues to locate the goal when concurrently blocking language via a concurrent verbal shadowing task (e.g., verbally shadowing a recorded message) was used during a reorientation task. This suggests that language plays a unique role in spatial navigation, but when language is interfered with, simple geometry of the environment guides navigation (Hermer-Vazquez et al., 1999). These findings have been interpreted as providing support for a module responsible for core geometry of one's environment independent of linguistic or symbolic thought since it was active in the absence of symbolic thought (see for review, Spelke et al., 2010). Caffò, Picucci, Di Masi, and Bosco (2011) replicated these results with adults in a virtual environment. They utilized the same reorientation task used in Hermer-Vazquez et al. (1999), which involved a virtual enclosure with varying wall colors (i.e., conditions varied in that some virtual enclosures had all white walls devoid of features and some with one uniquely colored wall as a feature). The study added cognitive load specific to verbal and visual components of working memory via concurrent articulatory suppression and/or spatial tapping tasks to each enclosure condition. They found that when in an enclosure with features (i.e., a colored wall), reorientation performance was decreased by both of these concurrent tasks and proposed that reorientation tasks engage visuospatial working memory and to a lesser extent verbal aspects of working memory. Spatial tapping was seen to inhibit performance more so since spatial aspects would primarily be used within a reorientation task but due to adults' unique ability to use language (c.f., Hermer-Vazquez et al., 2011), articulatory suppression still had a debilitating effect on performance (Caffò et al., 2011). This makes sense since visual modules are said to work together outputting and manipulating stimuli in the context of processing mechanisms that transform perceptions

into visual representations (Rolls, 2011). Caffò and colleagues (2011) added to these ideas by proposing that these types of processes not only include mechanisms in visual working memory but also to a certain extent verbal (particular to adults; c.f., Hermer-Vazquez et al., 1999) working memory in adults. Spatial navigation data collected on adults performing reorientation tasks discussed above illustrates the challenges aimed at providing strong support for the notion of a module dedicated to processing of geometry or geometric shapes. This is due to the fact that under most task conditions, adults use language.

Furthermore, there is debate concerning the extent to which functions in human cognition are truly modular (e.g., Lourenco & Cabrera, 2015; c.f., Huttenlocher & Lourenco, 2007) as well as the nature of their involvement in other information processing (e.g., the integration of features and geometric information; Cheng & Newcombe, 2005; c.f., Spelke et al., 2010) in general. Cheng and Newcombe (2005) reviewed research that suggests there are three different ideas of how modular components and featural information are possibly integrated within information pathways. The first idea is referred to as the impenetrable module. During reorientation tasks, only geometric information affects decisions or actions, and if the featural information is involved at all, it is processed through a different view-based pathway. The second view is that of modular-memorial subsystems where features and geometry are represented independently in subsystems (Cheng & Newcombe, 2005). This means that orientation primarily uses geometry but some features may also be integrated (i.e., by means of cross communicating between subsystems within the module) in the decision or action only if the features are physically close to the target in this relocation task. Cheng and Newcombe's (2005) review concludes by stating that some modular systems are modular at input only. This means that geometric shape information is indeed incorporated with featural information but integrated

after the automatic module manipulates its geometric inputs and produces and output to pass on in memory in a "central integration system" (Cheng & Newcombe, 2005; pg. 15-17). This integration system is comparable to Baddeley's (2000) episodic buffer in which different types of information in working memory can be integrated within the system. All three of these views provide an example of how module integration in task processing can be very complex and vary in many different ways. These theories discussed here specifically present evidence of how information is integrated during reorientation task (Cheng & Newcombe, 2005; see for review, Cheng, 1986; c.f., Hermer & Spelke, 1996).

The notion of domain differences (i.e., information processing differences) in spatial navigation research has relied heavily on the idea that there is a geometric module that aids people in reorientation and navigation (Cheng, 1986; Cheng & Newcombe, 2005; Doeller & Burgess, 2008; Hermer & Spelke, 1996). However, it is important to provide support and converging evidence for theories of modular processing of geometric information outside of reorientation task studies (e.g., Sturz, Edwards & Boyer, 2014; Edwards, Boyer, Bell, & Sturz, 2016). For example, is geometric information used independently (i.e., in a module on its own) only in reorientation studies, or can one see evidence of this type of modularity in other cognitive tasks involving visual/spatial memory? Is there further means or paradigms that can be utilized to isolate language from geometric processing (c.f., Caffò et al., 2011; Hermer-Vazquez et al., 1999)? To what extent does working memory load (Kelley & Lavie, 2010; Lin & Yeh, 2014) or domain-specific attentional distractors (Lin & Yeh, 2014) affect geometric shape processing outside of reorientation tasks? These are the questions the current study aimed to further explore.

CHAPTER 2

USING THE DELAYED MATCH-TO-SAMPLE TASK TO EXPLORE SELECTIVE DOMAINS

As noted above, in separating language from visual stimuli in the investigation of modularity is challenging as performance for adults in tasks such as spatial orientation is a function of multiple processing domains (c.f., Caffò et al., 2011; Cheng & Newcombe, 2005; Hermer-Vazquez et al., 1999; Sturz et al., 2014; Ratliff & Newcombe, 2008a, 2008b). Dual-task paradigms have been utilized to this end (e.g., Baddeley & Andrade, 2000; Caffò et al., 2011; Lin & Yeh, 2014). More recently, researchers have utilized variations of the delayed-match-to-sample task (DMTS) as a means by which to separately assess responding on the basis of visual characteristics versus verbal or linguistic (Sturz, Green, Locker, & Boyer, 2013; Sturz et al., 2014; Yang et al., 2012). A delayed match-to-sample (DMTS) is a common memory task that consists of multiple trials presenting a stimulus (referred to as the *sample,* most commonly a perceptual stimulus), which is to be maintained in memory during a short delay until two stimuli (referred to as *targets*) are presented, one of which matches the sample. Participants are asked to select the appropriate target as rapidly as possible without compromising accuracy.

Sturz et al. (2013), for example, used the DMTS procedure to isolate the source of interference in the processing of Stroop-like stimuli (i.e., a color word such as "red" in an incongruent font color such as blue or yellow). Specifically, utilizing the DMTS task to examine whether semantic competition (i.e., slowed responding to incongruent stimuli due to conflicting semantic codes) or response competition (i.e., slowed responding due to competing response options) could account for the pattern of responding to Stroop stimuli (color words written in congruent or incongruent colored ink). Sturz et al. (2013) used samples that consisted of color

words. These word samples were presented for a predetermined amount of time (in this case for

1 second) either in congruent color font (e.g., "blue" written in blue font), incongruent color font

(e.g., "blue" written in green font), or neutral font (e.g., "blue" written in black font). The unique

aspect of using the DMTS task was its ability to investigate responding to a certain dimension or

domain (either linguistic or visual) by utilizing color and word targets (Sturz et al., 2013). That

is, after the presentation of a sample, participants would match the sample to targets on a specific

dimension (word to correct color word or font color to a corresponding color patch). Another

unique aspect of utilizing the DMTS task was the use of related and unrelated foil targets. For

example, an incongruent sample word "green" written in blue font, followed by two targets such

as words "green" (the correct response) and "blue" (i.e., related foil incorrect response). This is

an example of a related target foil, as the foil "blue" corresponded to the incongruent aspect of

the dimensions in the sample (since "green" was written in blue font). Alternatively, an unrelated

foil would not match a dimension of the sample (See Figure 1 for a depiction of this DMTS task;

Sturz et al., 2013). Sturz et al. (2013) interpreted their findings as providing evidence in favor of

semantic competition. Compared to baseline trials (trials in which color words were presented in

black font) and congruent trials (a color word presented in the same font color, such as the word

red in red font), response times were slower for incongruent trials (color words in incongruent

font) irrespective of relatedness of the foil. This slowed reaction time was attributed to

suppression of the irrelevant semantic content in order to make a response (Sturz et al., 2013).
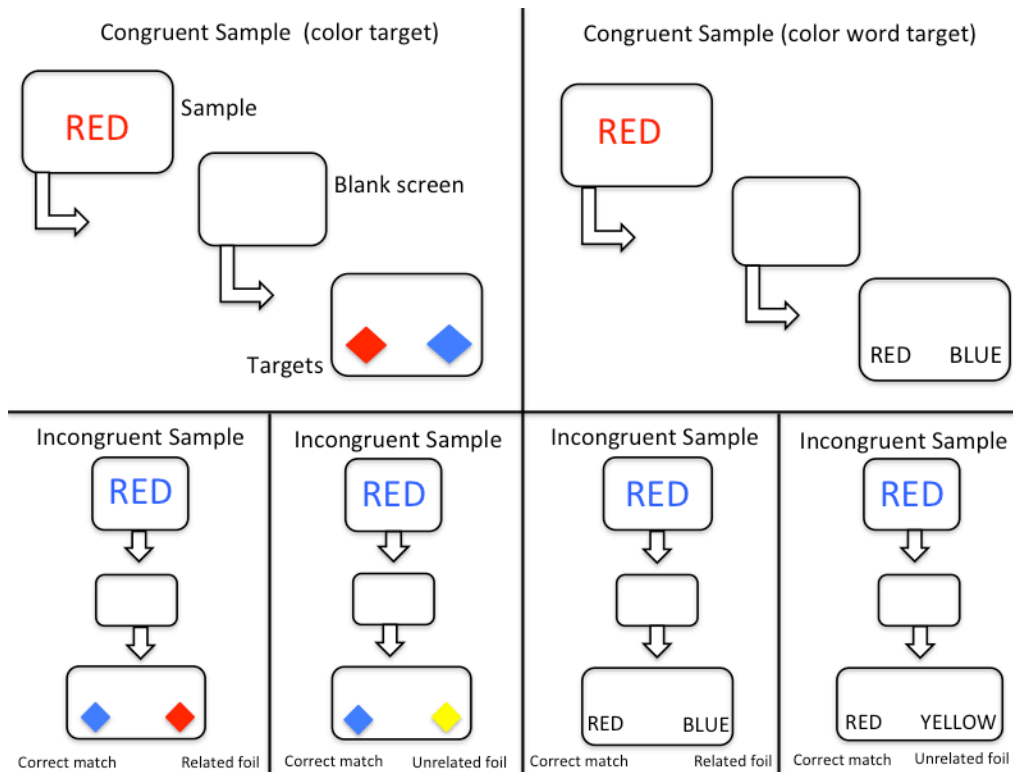
Figure 1. Stroop stimuli used in a DMTS task from Sturz, Green, Locker, and Boyer (2013). Examples of samples and targets are shown respectively for each type of trial type. Adapted from Sturz, Green, Locker, and Boyer (2013).

CHAPTER 3

ASYMMETRICAL INTERFERENCE AND VISUAL AND LANGUAGE DOMAIN

DIFFERENCES

Sturz and colleagues (2014) were able to extend the use of the DMTS task to directly address and explore the issue of examining separately the verbal and visual dimensions of geometric shapes and words. Sturz et al. (2014) provided support in favor of the notion that there is a separate module devoted to the processing of geometric shapes. The samples used in the DMTS task were geometric shapes (i.e., circle, square, and triangle) and geometric shape words (i.e., the words, "circle", "square" and "triangle"). Trials included a congruent sample condition in which a shape word was transcribed in the corresponding geometric figure (e.g., the word "circle" written at the center of a circle shape) and an incongruent sample condition in which a shape word was transcribed in an incongruent figure (e.g., the word "circle" written inside a triangle shape). These samples were to be matched to their correct targets of either geometric shapes or geometric shape words. Both these targets, like in Sturz et al. (2013), had related or unrelated foil target conditions. For example, if the sample was a triangle with the word "circle" in the center, a related foil for two shape targets would be a triangle and a circle shape (or an unrelated foil would be a square shape). This was the same for geometric shape word targets as well. For example, if a triangle with the word "circle" inside it was presented, then the two word targets would be "triangle" and "circle" (or an unrelated word foil would be "square"; see figure 2; Sturz et al., 2014). In summary, Sturz et al.'s (2014) study presented all participants with trials comprised of all four trial types. Notably, Sturz et al. (2014) found that incongruent sample/related word foils caused interference for matching geometric shape targets, but not word targets. The performance was worse in both accuracy and response times for shape targets in this

condition due to interference from the shape word in this condition's sample, but shape word

targets did not show the same interference from a related shape foil (Sturz et al., 2014). It was

proposed that this finding provided evidence in favor of modularity since the pattern was

asymmetrical. That is, the interference was not seen for geometric shape words, only shapes (i.e.,

the shape sample dimension did not interfere with the shape word targets, but the word sample

dimension did interfere with matching the geometric shape targets; Sturz et al., 2014).
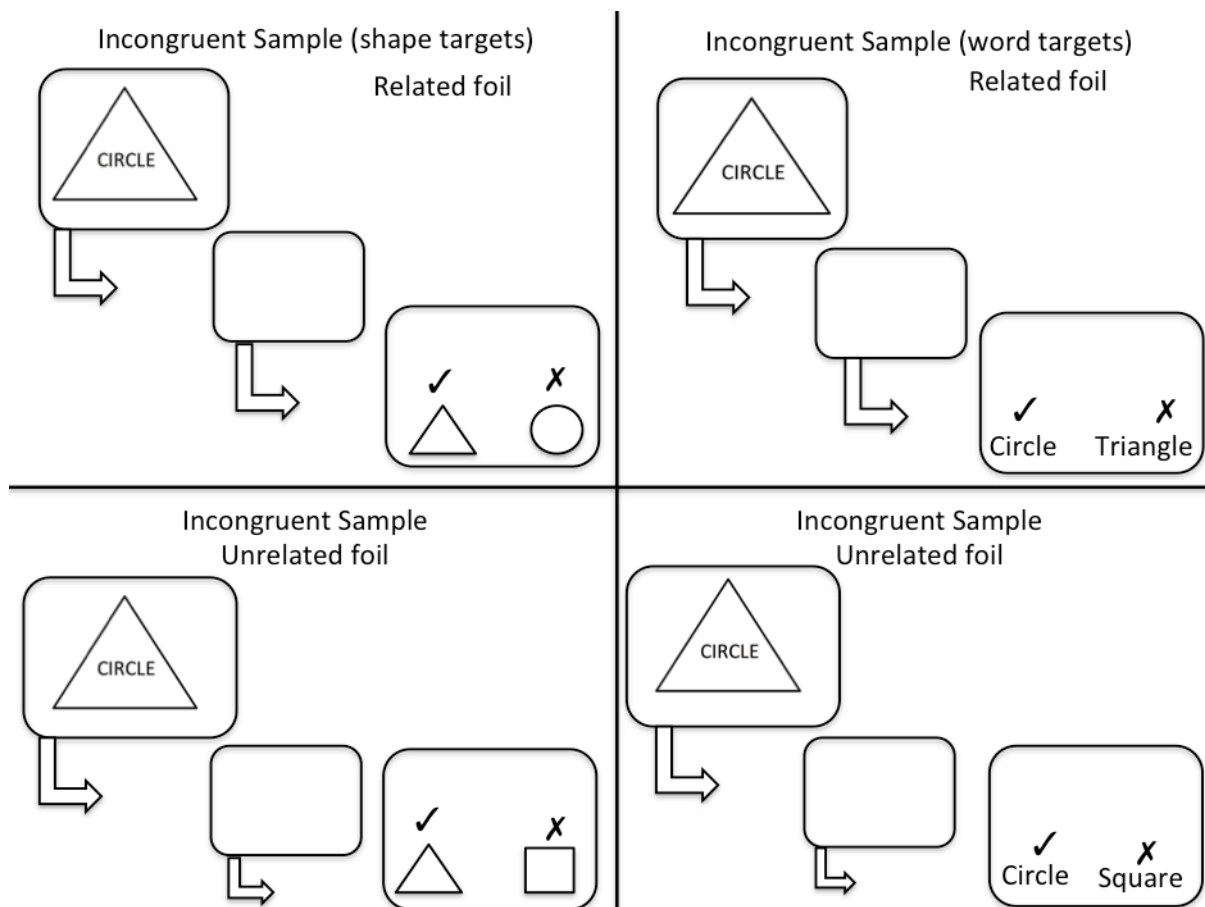

Figure 2. Shape stimuli for incongruent experimental trials from Sturz, Edwards, and Boyer (2014). Related and unrelated foils, one with shape targets and the other with word targets in a DMTS task used in Sturz et al. (2014). Adapted from Sturz, Edwards, and Boyer (2014).

Sturz et al. (2014) argued that this provided evidence for modularity of geometric shape processing in that presumably the word "circle" activates both its linguistic and spatial representation in the mind. Consequently, this led to interference on trials that involved choosing the correct shape targets (as the competing foil activated a representation in the same domain). This interference is asymmetrical, however, since the circle shape presumably did not activate its corresponding linguistic representation it and therefore, did not interfere with the matching of shape word targets, as there would be no competing information the language domain. To summarize, Sturz et al. (2014) concluded that in the context of their task, processing of geometric shapes alone does not involve semantics or linguistic representations as evidenced by the asymmetrical pattern of interference for shapes and words.

The findings reported by Sturz et al. (2014) were replicated and extended by Edwards and colleagues (2016). Edwards et al. (2016) extended this research by conducting an experiment that required semantic processing of *both* shapes and shape words. They did so by including conditions in which participants matched shape sample dimensions to word targets and word sample dimensions to shape targets. In this case, a symmetrical pattern was found such that both shape and shape word dimensions exhibited interference effects. This was attributed to the task demands requiring activation of both spatial and linguistic representations of shapes in conditions in which they would be matched to words. However, when geometric shapes were not matched to shape words and therefore not requiring activation of semantic information, the symmetrical interference was not found and an asymmetrical pattern of interference was observed similar to that reported by Sturz et al. (2014; Edwards et al., 2016). Therefore, in a DMTS procedure, it seems that a geometric shape is processed as a shape independent of

linguistic meaning unless conditions specifically require additional linguistic information as a

basis of responding (Edwards et al., 2016).

CHAPTER 4

PURPOSE OF STUDY

The goal of the present study is to provide further support in favor of a geometric module through examination of working memory processing of geometric shapes and shape words. Specifically, the current study examined shape and word processing within the context of a DMTS procedure (i.e., sample, retention interval, a response on targets adapted from Sturz et al., 2014) by adding a dual-task component. Using a concurrent operations approach, two different distractor tasks were imbedded in the DMTS procedure that placed a load on visual and verbal working memory components (the two distractor tasks were adapted from Baddeley & Andrade, 2000; Lin & Yeh, 2014). The purpose of imbedding these tasks within a DMTS paradigm was to selectively interfere with processing of geometric shapes versus words. Specifically, the DMTS procedure was adapted from Sturz et al. (2014) in order to display two types of trials to participants: baseline trials and DMTS trials with the imbedded verbal or visual distractor tasks.

One purpose of this approach was to examine matching of uni-dimensional samples (i.e., shapes and words separately) rather than bi-dimensional samples utilized by Sturz et al. (2014). In this approach, interference was manipulated by means of the imbedded distractor task. Examining uni-dimensional samples may be of benefit in order to assess processing of words and shapes without the potential for dimensional conflict. For example, Sturz et al. (2013) found that when presented incongruent Stroop stimuli (i.e., bi-dimensional color word written in a different color font) in a DMTS procedure, participants took longer to suppress the irrelevant dimension of the sample regardless of whether foils were related or unrelated to the other dimension (c.f., Kalanthroff, Avnit, Henik, Davelaar, & Usher, 2015; MacLeod & MacDonald, 2000). Given the potential for dimensional or task conflict when processing bi-dimensional stimulus, the current

study allowed for an examination of geometric shape processing in a DMTS format while removing the potential for such conflict. Rather selective verbal or geometric interference could be examined via the distractor tasks providing converging evidence concerning the processing of geometric shapes.

To this end, we utilized two differing distractor tasks that have been shown to selectively interfere with the visual or verbal dimensions (domains) in working memory (Lin & Yeh, 2014). The current study utilized the nonsense objects and letter stimuli from Lin and Yeh (2014) within a yes or no matching task (similar to the matching task described in Baddeley & Andrade, 2000) to serve as the distractor tasks. The study's distractor task is comprised of a stimulus (i.e., one nonsense shape or a string of three letters) shortly followed by a target (matching or not matching the previous stimulus) and participants must respond to whether the sample and target matched. This was to investigate whether geometric shapes are processed in a visually automatic module that operates outside of linguistics relative to shape words, which presumably are processed within the terms of geometric and language representations (Sturz et al., 2014). One distractor task was utilized to interfere with the performance of the visuospatial subsystem (i.e., 12 different nonsense shapes; see figure 3) and another to inhibit the phonological subsystem (i.e., a series of three letters representing consonants; e.g., FPT, VQX, etc.) of the multicomponent working memory model (Baddeley & Hitch, 1974; distractor tasks adapted from the stimuli used in Lin & Yeh, 2014). Consequently, depending on which representations were activated during a given DTMS trial, interference was predicted to be a function of the type of concurrent distractor task (i.e., matching the language or shape dimensions) rather than dimensional conflict at the level of the sample. When shape and word dimensions are presented in samples independently in a DMTS task, these specified distractor tasks are predicted to hinder

the specified processing of geometric shape or shape word relative to the distractor task. To summarize, this methodology was utilized to provide converging evidence of domain-specific or modular processing of geometric shapes via a working memory dual-task method.
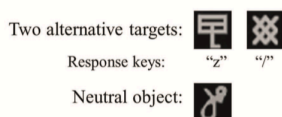

Figure 3. The nonsense shapes used in Lin and Yeh (2014). The stimuli used for the visual stimuli in Lin and Yeh (2014) and also used in the current study to serve as the visual distractor stimuli. Adapted from Lin and Yeh (2014).

It is expected that inhibition or interference of geometric shapes and shape words will be a function of the type of distractor, based on the evidence presented in studies by Sturz and colleagues (2014; c.f., Edwards et al., 2016). If shapes are processed via a dedicated module within a visual information pathway, then it would be predicted that a concurrent distractor task that impacts visual processing (i.e., the nonsense shape distractor task noted above) in working memory would interfere with the matching of shapes, but not words. This prediction is based on the idea that when a secondary task is processed in the same domain as a given sample, then it should take more time and be more difficult to suppress the distractibility of that concurrent distractor task due to depleted resources (i.e., a load placed on the visual-spatial component of working memory; Baddeley & Hitch, 1974; Baddeley & Andrade, 2000; Caffò et al., 2011; Lin & Yeh, 2014). Furthermore, if shape processing is modular processing a distractor load should

only have an influence if it maps to that visual domain within the informationally encapsulated module.

Alternatively, if the processing of shape word involves activation of both linguistic and geometric information, then either visual-based or language-based distractors are expected to interfere with word matching. Critically, this is due to both visuospatial aspects of working memory and phonological language having a connection with processing in spatially relevant tasks (Archibald, 2013; Archibald et al., 2015; Baddeley, 2002; Caffò et al., 2011; Olivers et al., 2011; Schneider et al., 2015). Since the DMTS task stimuli being used in the current study (i.e., geometric shapes and geometric shape words) have been related back to the geometric concepts that are inherently innate within a geometric module (key factors in reorientation and spatial navigation studies; Spelke et al., 2011), it is expected that these shape words have a tie to visuospatial representations as well as linguistic representations (Baddeley, 2002; Cheng & Newcombe, 2005; Edwards et al., 2016; Olivers et al., 2011; Spelke et al., 2010; Sturz et al., 2014). In summary, it is predicted that by reading a shape word, activation of semantic knowledge of that word includes a visual depiction of that shape word. This can bias selection of a certain working memory process over the other (visuospatial sketchpad or phonological loop) and therefore distractor tasks should affect both systems due to their respective representations while being maintained in memory (see for review, Craik & Lockhart, 1972).

The current research hypothesizes that the letter matching distractor task would not have an effect on the shape targets in the DMTS task, whereas nonsense shapes are expected to have an effect on both shape and possibly shape word targets. In other words, it is expected (if the modular processing concerning geometric shapes is supported) that in shape matching trials, geometric shapes would be selectively affected by visual (i.e., nonsense shapes), but not verbal

(i.e., letter patterns). Alternatively, based on the findings by Sturz and colleagues (2014; Edwards et al., 2016) it is also expected that in shape word, word targets would be affected by both the letter and nonsense shape distractor tasks as words activate both geometric image and linguistic representations (Edwards et al., 2016; Sturz et al., 2014).

To summarize, the aim of the current study is to conceptually replicate the findings of Sturz et al. (2014) by using a DMTS procedure with a dual-task paradigm. The current study attempts to provide converging evidence supporting Sturz et al.'s (2014) finding concerning differences in processing of words and shapes. If the current results support their findings, it would be expected that, as shape words should activate both a spatial (visual) and a verbal representation within working memory, both types of distractors should slow processing times and reduce accuracy for word targets. Alternatively, if geometric shapes do not activate verbal representations of shape words (Edwards et al., 2016; Sturz et al., 2014), then only the nonsense shape distractor task would be expected to affect processing of geometric shapes. Importantly, the letter distractor would not be expected to have an effect.

CHAPTER 5

METHOD

Participants

Participants in the current study consisted of 27 Georgia Southern University students recruited from psychology classes by the online SONA system. Participants were18 years of age or older and had normal or corrected-to-normal vision. Participants received credit towards the fulfillment of a course requirement or extra credit in exchange for their participation.

Stimulus and Apparatus

The current study used a delayed match-to-sample procedure comprised of several trials types. The trials included either one of the following tasks alone or of two of these tasks combined. Tasks include two different distractor tasks (DTs) and two different delayed match-to-samples tasks (DMTS; see figure 4 for examples of each of the individual-task types). DMTS task stimuli included either geometric shape samples and targets (i.e., a triangle, circle, and square) or shape word samples and targets (i.e., the word "triangle", "circle" and "square"; adapted from Sturz et al., 2014). DT stimuli included either counterbalanced strings of three different letter consonants (e.g., VHK, QTC, etc.) or one of twelve different nonsense shapes (see figure 3 for images of nonsense shapes; adapted from Lin & Yeh, 2014). All stimuli were presented on computers with 22' flat-screen LCD monitors and responses were made by pressing designated buttons on the keyboard. Responses for DMTS tasks were made by pressing the "C" key for the targets on the left and the "M" key for the targets on the right. For DTs, participants pressed the spacebar to indicate a match or made no response (i.e., no spacebar press) for a non-

match. The experiment utilized the E-Prime software (Psychology Software Tools, Inc.,

www.pstnet.com).

Procedure

Participants, upon entry of the lab, were seated at their designated computers and were asked to read and sign the informed consent placed next to their keyboards. After this, they were told to read through the instruction slides on their own on the computer screen and then pause at the end of these instructions before moving on to the training trials of the DMTS measure. The experimenter would briefly explain the instructions again then asked participants to move on to the training trials. Participants were told to respond to all the trials as quickly and as accurately as possible. If participants did not understand the tasks presented in the training trials fully (e.g., via excessive errors, non-responses or indicating confusion concerning the procedure to the experimenter), the experimenter would rerun another set of training trials. However, if the participant indicated a good understanding of the task, they proceeded to the experimental trials. Following these training trials, participants were presented with a break screen for which they were allowed to take time to rest before pressing the spacebar to initiate the experimental trials. This break screen would appear periodically after each trial block (after the training trial block and after each of the 16 experimental trial blocks) to reduce fatigue. Both training trials and experimental trials consisted of either baseline trials (one DT or one DMTS) or combined trials (one DMTS with one DT). Below is a description of each trial and task type followed by a description of the entire procedure.

Baseline trials. There are four different types of baseline trials: nonsense shape DTs, letter DTs, shape to shape targets DMTS and shape word to shape targets DMTS. For DMTS baseline trials, participants first saw a fixation-cross presented in the middle center of their

computer screen for .5 seconds, then a blank screen followed for 1 second. Following the blank screen, a sample was presented in the middle of the screen for 1 second. This sample stimulus was either a geometric shape (a circle, a triangle or a square; see figure 4A for shape baseline DMTS example) or a shape word (the words: "circle", "triangle", or "square"; see figure 4B for a shape word baseline DMTS example). A second blank screen occurred after the sample for 5 seconds until two targets (either two shapes or two words; one matching the previous sample and a foil) appeared at the bottom of the screen. Participants had 1.5 seconds to recall and match one of the presented targets to the previously shown sample. Participants responded to these targets by pressing the "C" key on their keyboard for the bottom left target or the "M" key for the bottom right target. After either responding or after 1.5 seconds, participants were presented with a feedback slide for .5 seconds (i.e., a check for correct or an "X" for incorrect or "NO RESPONSE" after 1.5 seconds), which was then followed by the next fixation-cross indicating the start of the next trial.

For DT baseline trials, the trial begins with same fixation-cross presented for .5 seconds. However, this fixation-cross is immediately followed by a DT sample in the center of the screen. This was either a nonsense shape (one of the 12 nonsense objects adapted from Lin & Yeh, 2014; see figure 4C for a nonsense shape baseline DT example) or one string of three random letter consonants (see figure 4D for a letter baseline DT example). This stimulus would remain on the screen for one second and was followed by a blank screen for 2.5 seconds. Participants would then be shown one target to match to the previous DT sample (i.e., either a second nonsense shape or the second string of letters). Participants had 1.5 seconds to make a response to this secondary stimulus. Responses were made by pressing the spacebar if the two matched or not to press anything if it did not match. After responding, participants were presented a feedback slide

(i.e., a check for correct or an "X" for incorrect) for .5 seconds. The next trial was signaled to start after the feedback slide by another fixation-cross in the center of the screen (procedures adapted from Baddeley & Andrade, 2000; Lin & Yeh, 2014; Sturz et al., 2014). It should be noted that the timing of these baseline trials matched the timing of their presentation within combined trials to keep presentation time consistent throughout.
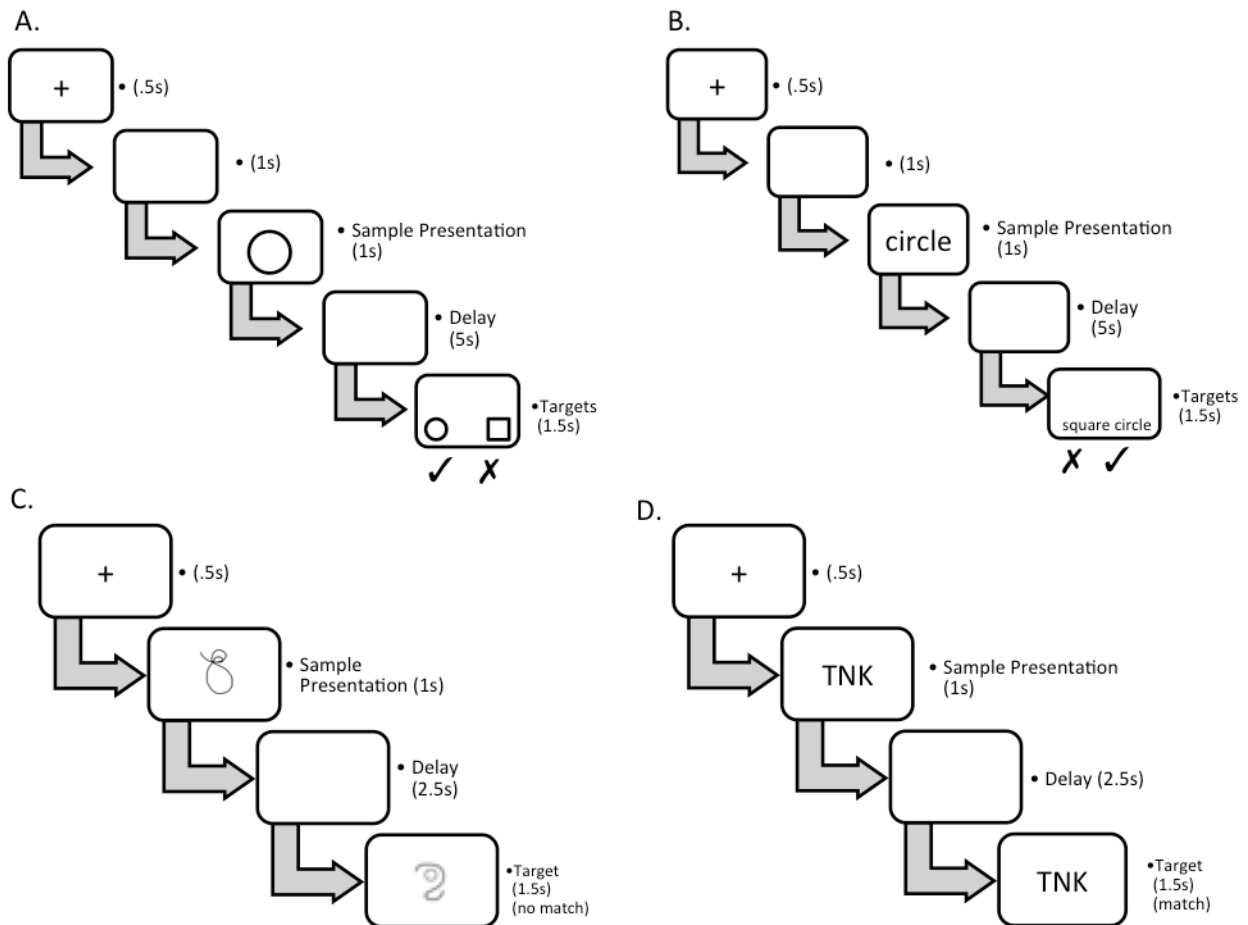

Figure 4. Examples of the current study's DMTS procedure for baseline trials. A. Depicts an example of a shape DMTS task baseline trial; B. Depicts an example of a word DMTS task baseline trial; C. Depicts an example of a nonsense shape DT baseline trial; D. Depicts an example of a letter DT baseline trial.

Combined trials. There are four different combinations of combined trials: Shape DTMS with nonsense shape DT, shape DMTS with letter DT, shape word DMTS with nonsense shape DT and shape word DMTS with letter DT. Combined trials (i.e., trials including one DMTS task with a DT in one trial) first consisted of a .5 second fixation-cross immediately followed by a sample. In all combined trials, the first sample presented was always a DT sample (i.e., either a nonsense shape or a string letters) shown in the middle center of the screen for 1 second. Following the DT sample was a DMTS sample (i.e., a shape or shape word) presented at the same location for 1 second. After a 1.5 second blank screen, a secondary DT target appeared for 1.5 seconds. Here participants determined whether this target was either the same or different from the DT sample they were shown before. If the stimulus was the same participants pressed the spacebar and if it was different participants were to not respond (there were an equal number of match and no-match responses), After responding, or after 1.5 seconds, participants were shown a feedback screen for .5 seconds (a check for correct or an "X" for wrong). Following another 1.5 second blank screen, two DMTS targets would appear at the bottom of the screen (either two shapes or two shape words). One target corresponded to the DMTS sample that they saw from earlier and the other was a foil. These targets were presented for 1.5 seconds and participants were asked to select the correct target that matched the preceding shape or shape word sample (pressing the corresponding "C" or "M" keys on their keyboard to make a match choice) as rapidly and accurately as possible. Again, after a response or a lack of a response (after 1.5 seconds), participants received a feedback screen (a check for correct; an "X" for incorrect; or "NO RESPONSE") for .5 seconds until proceeding to the next trial (see figure 5A and B for examples of combined trials).
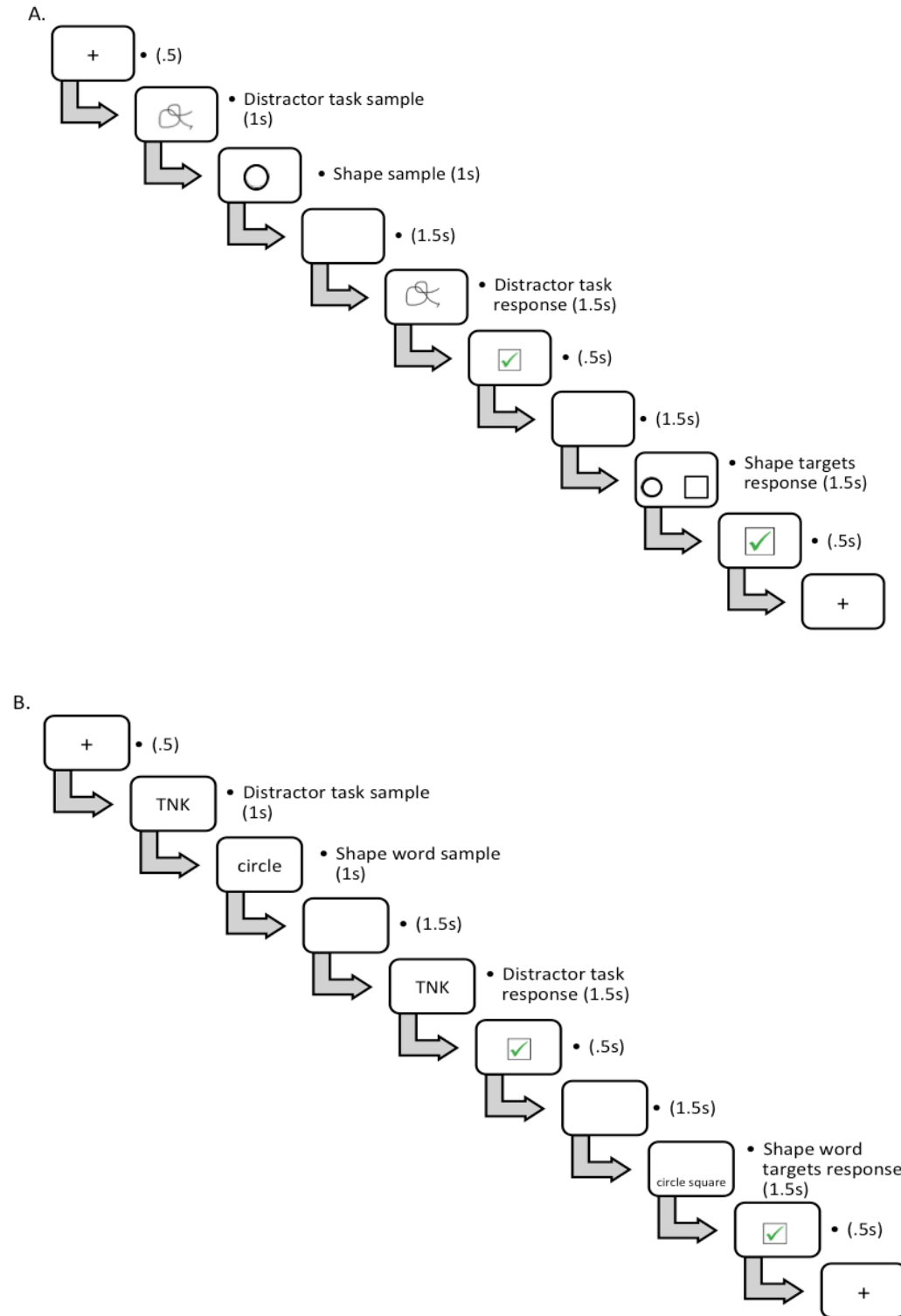
Figure 5. Two examples of combined trials in the DMTS procedure. A. Example trial of a shape DMTS task with a nonsense shape DT imbedded. B. Example trial of a shape word DMTS task with a letter DT imbedded.

In summary, each participant was presented a randomized order of baseline trials (i.e., trials that involve one task; either one DT or one DMTS task) and combined trials (i.e., trials that consist of a set of each of the two task types; one DMTS task with an imbedded DT). As noted, baseline trials were comprised of either one distractor task or one delayed match-to-sample task. In DMTS baseline trials, participants were asked to simply match a shape or shape word sample to one of two targets (Figure 4 A & B; c.f., Sturz et al., 2013; Sturz et al., 2014; Edwards et al., 2016). Baseline trials for DTs involved participants indicating whether two visual nonsense shapes or a set of letters matched or did not match (Figure 4 C & D; c.f., Baddeley & Andrade, 2000; Lin & Yeh, 2014). Combined trials interpolated the distractor tasks within the DMTS tasks with the distractor task samples and targets presented before the DMTS samples and targets (Figure 5).

The entire experimental procedure consisted of multiple trials (208 trials per participant; 16 training trials and 192 experimental trials) with 8 different trial types (shape to shape DMTS baseline/ shape word to shape word DMTS baseline/ letter to letter DT baseline/ nonsense shape to nonsense shape DT baseline/ shape to shape DMTS with nonsense shape DT/ shape to shape DMTS with letter DT/ shape word to shape word DMTS with nonsense shape DT/ shape word to shape word DMTS with letter DT). The experimental trials consisted of 16 blocks of 12 randomized trials for each participant (i.e., both baseline types [distractors and DMTS] and all combinations of DMTS with imbedded distractors). Each participant served as their own controls by completing all the different task types comprising both the training trials and the experimental trials. Participants' reactions times (RTs) and accuracy were recorded for each trial to assess for interference effects of DT type (i.e., letter DT and nonsense shape DT) on DMTS type (i.e., geometric shape DMTS and shape word DMTS) compared to DMTS baseline (i.e., geometric

shape DMTS task presented on its own or shape word DMTS presented on its own). Responses to the DT task as well as the primary DMTS task were recorded to assess for possible interference effects at the time of the distractor response as well as response to the DMTS targets. The only RTs unable to be recorded were the no-match responses for DT tasks as these non-matches were indicated by not pressing anything while matches (i.e., spacebar presses) could be recorded.

As noted, the inclusion of the baselines for DTs (i.e., letter and nonsense match or non-match tasks on their own) was to assess if there would be backwards masking or interference (i.e., distracting effects) by the DMTS stimuli that were presented after the DT stimuli in combined trials (i.e., whether a shape or word sample might interfere with DT performance). However, the primary goal of the current study is to focus on the effects of the differing DTs on the performance of the differing DMTS tasks when compared to baseline. However, the inclusion of both baseline types allowed for examination of possible interference effects for DT trials as well as DMTS trials.

Data analysis

Data from 27 participants was collected. One participant was excluded from all analyses on the basis of excessively high error rate within the procedure (33% errors). Accuracy for this participant fell three standard deviations below the overall mean accuracy of the sample (0.95). Therefore analysis was based on data from 26 participants. Reactions times (RTs) in milliseconds and accuracy in proportion correct for DMTS trials (i.e., baseline DMTS shape/shape word trials and each of the combined trials) were analyzed utilizing 2 (Target Type: Geometric shape vs. Shape word) x 3 (Trial Type: Letter DT, Nonsense shape DT and DMTS Baseline) repeated-measures factorial analyses of variance (ANOVAs). Analysis for RTs was

based on correct responses and did not include trials for which participants made incorrect responses to the preceding DT task or made no response to the DMTS targets. For accuracy analysis, all DMTS responses were included except trials in which participants did not respond to the DMTS targets or made incorrect responses to the DTs.

In order to assess whether the shape or word sample had any influence on matching on the distractor task, DT reaction times and accuracy rates were analyzed using 2 (Target Type: Letters vs. Nonsense shapes) X 3 (Trial Type: Shape DMTS, Word DMTS, and DT Baseline) repeated-measures factorial ANOVAs. This analyzed RTs of correct DMTS responses and correct matching DT trials only (since reaction times were only recorded when a DT was a match in which the spacebar was pressed). For accuracy, proportion correct was collected and analyzed for DT spacebar presses (correct and incorrect matching DT trials only) and correct DMTS trials. The purpose of this analysis was to assess whether any patterns analogous to the DMTS task would be observed in the DT tasks. It was hypothesized that samples from the DMTS tasks (i.e., geometric shapes or geometric shape words) might interfere with performance on nonsense shape distractors or letter distractors. As the shape or word sample is interpolated between the to-be-matched distractor patterns, this analysis explored whether the DMTS samples have any effect on the ability to perform the DT tasks. Data will be maintained for a minimum of 7 years after completing the study per Board of Regents Policy.

CHAPTER 6

RESULTS

Delayed match-to-sample Analysis

Response times. Response times (RTs) for shape and shape word DMTS baselines and combined DMTS Trial Types (shape with letter DT/ shape with nonsense shape DT/ word with letter DT/ word with nonsense shape DT) were analyzed. DT baselines, tasks with non-responses, incorrect trials of both DMTS baseline and combined trials and the combined trials in which participants got either of the DTs wrong were excluded from analysis (1503/4992; 30%). There was a main effect of Target Type $F(1, 25) = 69.17$, $p = .00$, $\eta_p^2 = 0.74$ such that on average, geometric shape DMTS trials ($M = 531.99$, $SEM = 11.30$) were responded to more rapidly than shape word DMTS tasks ($M = 617.10$, $SEM = 10.37$). There was also a main effect of Trial Type, $F(2, 50) = 10.62$, $p = .00$, $\eta_p^2 = 0.30$. LSD post hoc tests revealed that, on average, baseline DMTS trials ($M = 554.40$, $SEM = 13.87$) were responded to faster than both DMTS trials with either letter DTs ($M = 586.59$, $SEM = 14.52$) and nonsense shape DTs ($M = 582.65$, $SEM = 14.95$) included (ps < .05). There were no differences between the combined DMTS Trial Type conditions ($p = .50$). These results were, however, qualified by a significant Target Type x Trial Type interaction $F(2, 50) = 3.71$, $p = .03$, $\eta_p^2 = 0.13$.

In order to further examine the source of the interaction, one-way repeated-measures ANOVAs were performed to examine Trial Type differences at each level of Target Type. That is, Trial Type differences (DMTS Baseline vs. DMTS with nonsense shape DTs vs. DMTS with letter DTs) were examined separately for DMTS shape targets and word targets. For shape DMTS targets, there was a simple main effect of Trial Type $F(2, 50) = 4.23$, $p = .02$, $\eta_p^2 = 0.15$.

LSD post hoc comparisons revealed that compared to shape DMTS baseline trials ($M = 517.30$, $SEM = 19.08$), shape DMTS trials with nonsense shape DTs were responded to more slowly ($M = 544.82$, $SEM = 21.47$; $p = .01$). There was no significant difference ($p = .10$) between shape DMTS baseline and shape DMTS trials with letter DTs ($M = 533.85$, $SEM = 18.40$). Furthermore, there was no difference ($p = .25$) between shape DMTS conditions with shape DT and letter DT Trial Types.

For shape word DMTS targets, there was a simple main effect of Trial Type $F(2, 50) = 10.63$, $p = .00$, $\eta_p^2 = 0.30$. LSD post hoc tests revealed that shape word DMTS Trial Types were all significantly different from each other. Word DMTS baseline trials were faster ($M = 591.50$, $SEM = 17.61$), compared to both word DMTS combined trials with letter DTs and nonsense shape DTs ($ps < .05$). Further, word trials with letter DTs were responded to more slowly ($M = 639.32$, $SEM = 17.30$) than word trials with nonsense shape DTs ($M = 620.48$, $SEM = 18.36$; $ps < .05$). Figure 6 shows a graph of mean RTs (in ms) plotted by Target Type for each Trial Type.
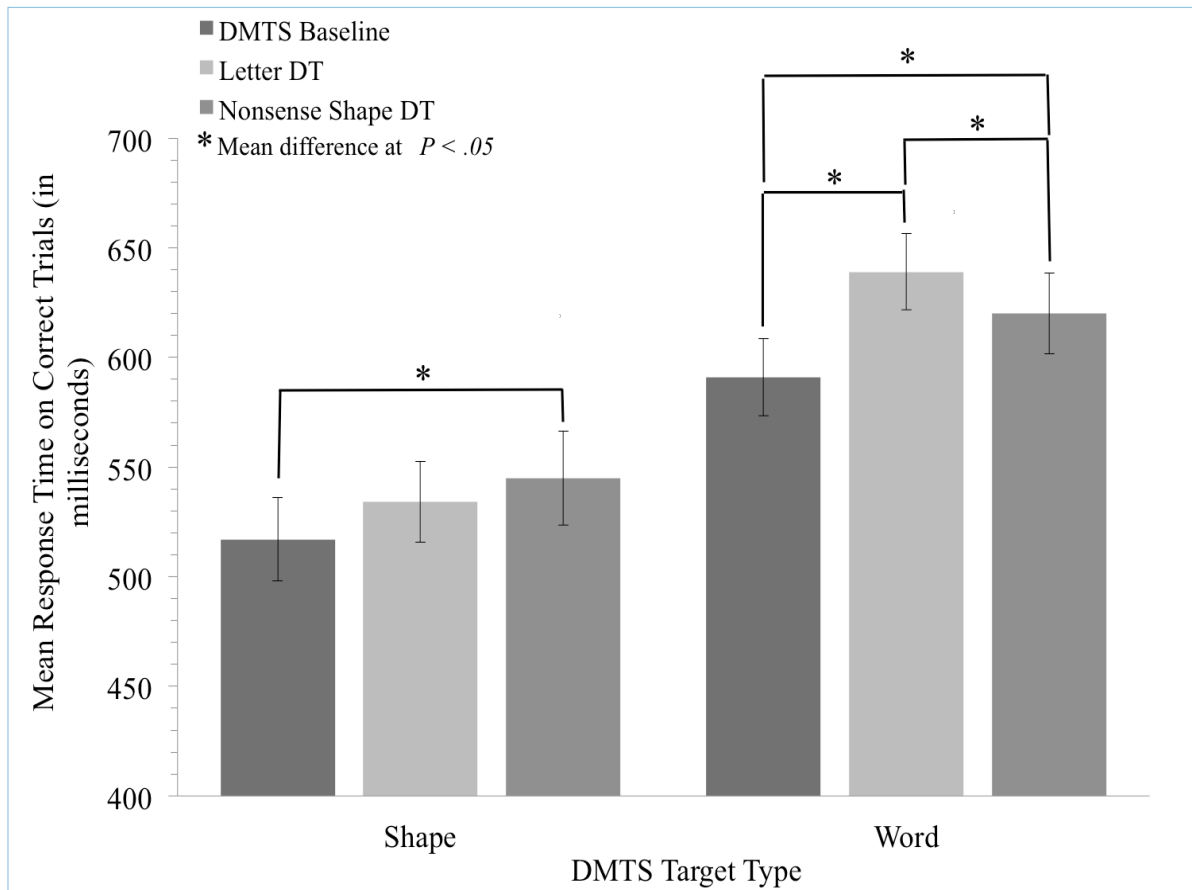
Figure 6. Results for shape and shape word DMTS targets (RTs). Mean reaction times (in milliseconds) on the DMTS task trials for each of the experimental conditions. Error bars represent SEMs for each condition. Bolded lines brackets represent differences significant at a 0.05 level.

Accuracy. Average accuracy for the shape/shape word DMTS baselines and combined

DMTS Trial Types (shape with letter DT/ shape with nonsense shape DT/ word with letter DT/

word with nonsense shape DT) were analyzed. This analysis examined the average proportion

correct for each participant, eliminating DT baselines, DMTS combined trials in which

participants got DTs wrong and DMTS trials in which participants failed to make a response

(1368/4992; 27%). There was a significant main effect of Trial Type, $F(2, 50) = 7.23$, $p = .00$, η_p^2

$= 0.22$, such that DMTS baseline trials ($M = .98$, $SEM = .01$) were the most accurate overall

compared to either of the combined DMTS Trial Types (DMTS with letter DTs and DMTS with nonsense shape DTs; *ps* < .05). However, there was a nonsignificant difference between the combined DMTS trials with letter DTs (*M* = .95, *SEM* = .01) and DMTS with nonsense shape DTs (*M* = .955, *SEM* = .010; *p* = .86). There was no main effect of Target Type, $F(1, 25) = .96$, *p* = .34 and no interaction effect $F(2, 50) = .33$, *p* = .72. Figure 7 shows a graph for mean proportion correct plotted by Target Type for each Trial Type.
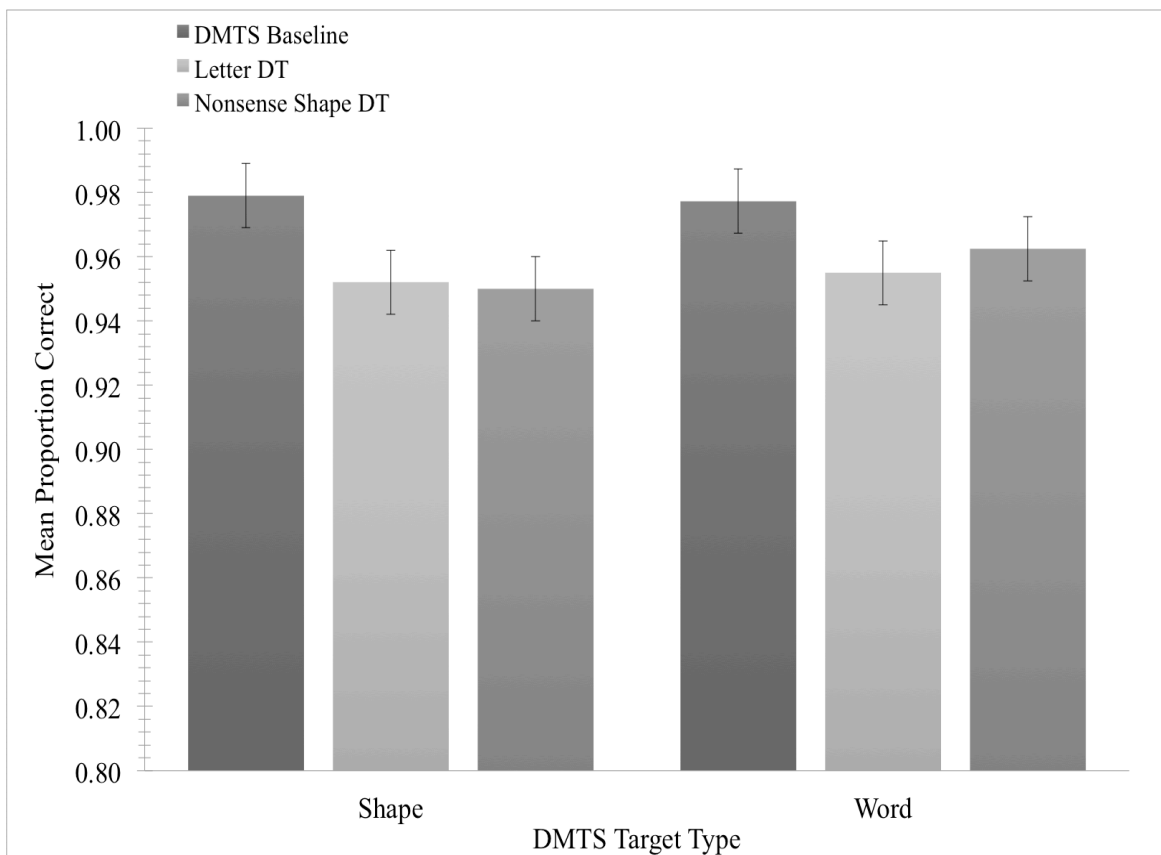

Figure 7. Results for shape and shape word DMTS targets (Accuracy). Average proportion correct of the DMTS task trials for each of the experimental conditions. Error bars represent SEMs for each condition.

Distractor Task analysis

An additional analysis was conducted for the distractor task responses. As noted, RTs and accuracy were analyzed to test for whether or not there are any reverse interference effects of the DMTS samples on DT performance. This used the same analyses as the DMTS analysis above with, two separate 2 (DT Type: letter and nonsense shape) X 3 (Trial Type: baseline, shape DMTS, word DMTS) repeated-measures ANOVAs for RTs and accuracy.

Reaction times. Reaction times for DT matches (i.e., space bar presses) in the letter/nonsense shape DT baselines and combined DMTS Trial Types (shape with letter DT/ shape with nonsense shape DT/ word with letter DT/ word with nonsense shape DT) were analyzed. We eliminated DMTS baselines trials, non-response and incorrect DT baselines and combined DMTS trials in which participants got shape and shape DMTS tasks wrong or did not respond (3240/4992; 65%). There were no main effects of DT Target $F(1, 25) = 3.29$, $p = .08$ or Trial Type $F(2, 50) = .36$, $p = .70$ reaction time differences. There also was no significant interference effect $F(2, 50) = .37$, $p = .70$ (see table 1 for descriptives).

Table 1.

Results for nonsense shape and letter DTs (RTs).

	DT Baseline	Shape DMTS	Word DMTS
Distractor Type	*M* (*SEM*)	*M* (*SEM*)	*M* (*SEM*)
Nonsense Shape	559.30 (19.68)	563.74 (25.51)	555.18 (23.41)
Letter	566.84 (22.33)	586.66 (23.10)	578.67 (18.07)

Accuracy. Average proportion correct for matching DTs (i.e., space bar presses) in the letter/nonsense shape DT baselines and combined DMTS trials (shape with letter DT/ shape with nonsense shape DT/ word with letter DT/ word with nonsense shape DT) were analyzed. DMTS baselines, incorrect or non-response DMTS combined trials and DTs with no response were eliminated from analysis (3182/4992; 64 %). There were no main effects of DT Target $F(1, 25) = 2.99$, $p = .10$ or Trial Type $F(2, 50) = .54$, $p = .59$ accuracy. There also was no significant interaction $F(2,50) = .76$, $p = .47$ (see Table 2 for descriptives).

Table 2.

Results for nonsense shape and letter DTs (Accuracy).

	DT Baseline	Shape DMTS	Word DMTS
Distractor Type	*M* (*SEM*)	*M* (*SEM*)	*M* (*SEM*)
Nonsense Shape	.97 (.01)	.97 (.01)	.95 (.02)
Letter	.97 (.01)	.98 (.01)	.98 (.01)

CHAPTER 7

DISCUSSION

The results from the current study support the evidence reported by Sturz et al. (2014). Specifically, this study provides some indirect evidence in favor of a geometric module and active visual representations involved in geometric shape processing. Further, the findings of this study suggest that both visual and verbal representations are actively involved in shape word processing based off the patterns of DT interference. Although DMTS Target Types (geometric shape and shape word) did not significantly differ in accuracy, there was a clear pattern in reaction time averages such that responding to geometric shape targets was faster overall compared to responding to shape word targets. Additionally, baseline trials for both DMTS Target Types in general were responded to more rapidly than any of the other Trial Types (DMTS tasks with letter DT, and with nonsense shape DT). However, the critical finding was an interaction effect of Trial Type and Target Type in the reaction time data.

The interaction analyses revealed that compared to shape DMTS baseline, shape target reaction times were significantly slower only when concurrently paired with a visual distractor (i.e., the nonsense shape DT). However, there was no significant difference between combined shape DMTS trials with the letter distractor and the other trials (i.e., the nonsense shape DT trials and shape baseline). These results present evidence in favor of Sturz et al. (2014) in terms of shape visual representations being activated during geometric processing and they can only weakly be associated with the concepts of geometric modular processing. In other words, the post hoc analysis of shape targets revealed no difference between combined shape DMTS tasks with nonsense shape DTs and shape DMTS tasks with letter DTs but the nonsense shape DT did differ significantly from shape baseline. This pattern presents some support for visual specificity

in regard to shape processing but the nonsignificant effects between the two combined shape DMTS conditions does not provide clear evidence that nonsense shape DTs interfere selectively with processing of shape targets.

Alternatively, shape word DMTS interaction analysis revealed that compared to shape word DMTS baseline, both distractor types significantly slowed responses to shape word targets. Further, there was a significant difference between the combined shape word DMTS tasks with letter DTs and word DMTS tasks with nonsense shape DTs. That is, letter DTs slowed responding to word targets significantly more compared to nonsense shape DTs. In particular, these post hoc reaction time analyses for shape word DMTS trials do provide converging evidence in favor of the findings of Sturz et al. (2014) in regard to both the word and its corresponding shape representation are activated in this task. Specifically, the author's interpretations of these results suggest that geometric shape words are being processed more generally with activated representations in both verbal and visual working memory domains was supported. However, this effect was of a greater magnitude for the distractor in the same domain as the target, which also supports some evidence of domain specificity.

Craik and Lockhart (1972), explain that within cognitive processing, preliminary stages (beginning of processing) deal with simple sensory features (e.g., lines, brightness, pitch) whereas later stages handle things like pattern recognition (c.f., Baddeley, 2000) or comparing novel representations to stored knowledge (c.f., Baddeley, 2000; Baddeley & Andrade, 2000; Baddeley et al., 2011). The current study follows these ideas and presents evidence that geometric shapes seem to be processed faster overall and processed more primarily on the basis of possibly early sensory/visual information whereas geometric words are more slowly processed involving both visual and verbal representations possibly involved in both early/later stages of

visual and symbolic information, respectively. The current study found that compared to baseline, reaction times for shape targets were significantly slower with a nonsense shape DT, but not with a letter DT. As noted, this study provides some evidence in favor of the modularity suggestions (i.e., of a possible independent geometric module that works outside of language to process geometric shapes) made by Sturz, et al. (2014), although not conclusive given that the only difference observed was compared to baseline. To summarize, the current study proposes converging evidence in line with those of Sturz et al. (2014) providing support indirectly for a modular system of geometry (i.e., possibly encapsulated under some conditions) along with more direct support for domain-specific views (i.e., processing of geometric shapes does not appear to be domain-general).

Further, the results do not provide strong evidence in favor of modularity, but taken together with the findings reported by Sturz et al. (2014), the results do support their suggestions that the processing of geometric shape activates only visual information. The current study's findings also support that geometric words activate multiple representations including mechanisms implicating semantics, geometry, and linguistic information in processing. One alternative explanation of why greater interference effects for letter DTs were found compared to a smaller effect for nonsense shapes on DMTS word targets is differences in memory load (i.e., the amount of data being maintained within working memory; Lin & Yeh, 2014). The number of objects (samples) did vary by DT type in that a letter DT was composed of three letters to maintain in memory whereas a nonsense shape DT was one object. According to Lin and Yeh (2014), distractor task distractibility (i.e., how well a distractor interferes with the task at hand) is affected by memory load differences especially within the same working memory domain (i.e., visual, verbal, etc.; Lin & Yeh, 2014). Additionally, the finding that DMTS shape word targets

were influenced by both types of distractors supports prior findings in past literature showing

words represent spatial concepts (Doeller & Burgess, 2008; Doeller et al., 2008; Williams et al.,

2013) and activate both a visual and verbal representations in the DMTS procedure upon

recognition (Baddeley, 2000, 2000; Baddeley & Andrade, 2000; Caffò et al., 2011; Craik &

Lockhart, 1972; Lin & Yeh, 2014; Sandry et al., 2014; Sturz et al., 2014).

Finally, in regard to the analyses of DMTS samples on DTs, there were no significant

differences between DT Target Types and no differences between any of the Trial Types. This

suggests that there were no reverse effects of the DMTS sample stimuli on distractor task stimuli.

This may be due to the fact that distractor tasks were responded to first in any of the combined

trials within the DMTS paradigm. When responding to DTs, we speculate that there was no

substantial depletion of working memory resources. Alternatively, another possible reason may

be the relative simplicity of the DTs. Samples did not interfere with the DTs, as the task was a

simple yes or no matching task. That is, the DTs may have simply been easy enough such that an

intervening stimulus would not have affected responding. Lastly, we suggest that effects were

observed in the DMTS targets, as by that point in processing, cognitive resources within their

specific domains may have been depleted sufficiently due to having completed the DT and

retaining the sample stimulus in memory. This suggests that the load placed upon the system by

the DTs were sufficient to affect reaction time in relation to DMTS targets. Further, the effect of

a concurrent task in this context may depend upon the serial position within the sequence.

Limitations and Future Research

Considering the fact that accuracy analyses did not show the same differences as our

reaction time data, there is the need for further explanation as to why this might be. One possible

explanation is the structure of the task in the present study. Dual-task procedures, particularly

choice-response tasks similar to that utilized here (e.g., choosing between the two targets in the

DMTS task), commonly show what is called a psychological refractory period (PRP) effect

(Ruthruff, Pashler, & Klaassen, 2001). This effect predicts slowing for one if not both tasks in

concurrent-task paradigms, especially if the time between tasks is as short as it is in the present

paradigm (5 to 9.5 seconds per trial). The PRP effect can even persist after multiple

manipulations of order, time delay, varying the difficulty of the dual-tasks and the type of task

manipulated (Ruthruff et al., 2001). Ruthruff and colleagues found that response selection for a

variety of different tasks ranging in difficulty and in task type will worsen regardless of whether

the tasks share the same processing systems (i.e., input to output systems; differencing domains).

This could explain why accuracy in the current study's combined trials (i.e., the combined DMTS

tasks with DT trials) are at ceiling. Additionally, the effects discussed above could conceptually

be eliminated with practice over time (Ruthruff et al., 2001). This may also account for ceiling

effects particularly for the baseline accuracy (i.e., after a certain amount of time and after a

certain amount of trials, distractor tasks will hit ceiling accuracy and will not show any

substantial differences in terms of a pattern of effects). However, in past studies that have tested

the PRP effect, researchers told participants that speed of a certain task is particularly important,

therefore biasing participants (consciously and even unconsciously) to prioritize one task over

the other in a dual-task procedure (Ruthruff et al., 2001). This was not the case in the current

study since participants were instructed to respond as quickly and accurately as possible to

everything as to not bias a certain task over the other. Although there was no reason for

participants to place priority of one task over others, it is still important for future research to

continue to manipulate these current tasks and procedures in various orders to further explain

performance differences.

Further, all the stimuli in the current study were presented visually in the DMTS procedure. This could have had some implications to the current study's results, which future research could benefit to examine. Specifically, the fact that all stimuli were presented visually could have had an effect on the shape word DMTS task results in general (i.e., distractor task effects to words). For example, the fact that the stimuli for shape words were visually presented on a computer screen is a possible explanation as to why the visual distractor affected words. According to Olivers et al. (2011), visually displayed words could supersede verbal processing, affecting visual memory and visual attention simply due to being displayed as a visual stimulus (i.e., instead of interference from an activated visual representation of the shape tied to the shape word being responsible; see for review, Schneider et al., 2015). Given these possibilities, the current study could benefit by adapting the verbal stimulus to another modality. Future research could replace the visual words with an audio clip speaking the shape word or possibly replace the letter distractor task with an audio version of the letter strings. This could help tease apart these possible domain effects and determine if the same kinds of patterns observed in the current study are similar in a paradigm in which an audio DT effect is utilized (e.g., since phonological information is processed within the same subsystem as verbal information, would audio stimuli replicate the same results shown in the current study?).

In summary, the current study showed that response times in a DMTS procedure are influenced by the nature of the distractor tasks that are imbedded. Specifically, these results showed some indirect evidence in favor towards a geometric module for shapes, while also supporting findings that show evidence of different patterns of activation for words versus shapes (e.g., Sturz et al., 2014; Edwards et al., 2016). Further, the current study also supports a multi-component, domain-specific working memory system (visual and verbal; Baddeley, 2000,

2002; Baddeley & Andrade, 2000; Craik & Lockhart, 1972; Lin & Yeh, 2014; Sandry et al., 2014). However, these results suggest that processing of geometric shapes under certain conditions are more domain-specific than words, presumably as function of the types of information activated at the time of processing.

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