2015

Mental Rotation: Can Familiarity Alleviate the Effects of Complex Backgrounds?

Anthony Selkowitz
University of Central Florida

MENTAL ROTATION: CAN FAMILIARITY ALLEVIATE THE EFFECTS OF COMPLEX BACKGROUNDS?

by

ANTHONY SELKOWITZ
B.S. University of Central Florida, 2009
M.A. University of Central Florida 2013

A dissertation submitted in partial fulfillment of the requirements
for the degree of Doctor of Philosophy
in the Department of Psychology
in the College of Science
at the University of Central Florida
Orlando, Florida

Fall Term
2015

Major Professor: Valerie Sims

ABSTRACT

This dissertation investigated the effects of complex backgrounds on mental rotation. Stimulus familiarity and background familiarity were manipulated. It systematically explored how familiarizing participants to objects and complex backgrounds affects their performance on a mental rotation task involving complex backgrounds. This study had 113 participants recruited through the UCF Psychology SONA system. Participants were familiarized with a stimulus in a task where they were told to distinguish the stimulus from 3 other stimuli. A similar procedure was used to familiarize the backgrounds. The research design was a 2 stimulus familiarity (Familiarized with the Target Stimulus, not familiarized with the Target Stimulus) by 2 background familiarity (Familiarized with Target Background, not familiarized with Target Background 1) by 2 stimulus response condition (Target Stimulus, Non-Target Stimulus) by 3 background response condition (Target Background, Non-Target Background, Blank Background) by 12 degree of rotation (0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330) mixed design. The study utilized target stimulus and target background familiarity conditions as the between-subjects variables. Background, stimulus, and degree of rotation were within-subjects variables. The participants' performance was measured using reaction time and percent of errors. Reaction time was computed using only the correct responses. After the familiarization task, participants engaged in a mental rotation task featuring stimuli and backgrounds that were present or not present in the familiarization task. A 2 (stimulus familiarization condition) by 2 (background familiarization condition) by 2 (stimulus response condition) by 3 (background response condition) by 12 (degree of rotation) mixed ANOVA was computed utilizing reaction time and percent of errors. Results suggest that familiarity with the Target Background had the largest effect on improving performance across response conditions. The results also suggest that familiarity with both the Target Stimulus and Target Background promoted inefficient mental rotation strategies which resulted in no significant differences between participants familiarized with neither the Target Stimulus nor the Target Background. Theoretical conclusions are drawn about stimulus familiarity and background familiarity. Future studies should investigate the effects of long term familiarity practice on mental rotation and complex backgrounds.

ACKNOWLEDGMENTS

First and foremost I would like to thank my advisor, Dr. Valerie Sims. Her insight and guidance has been invaluable on my journey through graduate school and my dissertation. I would not be where I am today if it were not for her. Second I would like to thank my committee, Dr. Matthew Chin, Dr. Florian Jentsch, and Dr. Mason Cash. Their advice and challenges have made this document and project something I can be proud of. I would also like to thank ACAT members, past and present, my interactions with them have always challenged me to think differently. This might be strange, but I would like to thank R Programming, CRAN repository, and RStudio. Without my use of this statistical and data processing software I would not have been able to process my data as quickly and error free in order to defend my dissertation in a reasonable timeframe. Lastly, I would like to thank my fiancé, Torie. Her patience throughout this process has been innumerable.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE: INTRODUCTION

Statement of the Problem

Shepard and Metzler (1971) demonstrated that humans have the cognitive ability to rotate representations of objects in their mind—a capability known as mental rotation. In mental rotation studies, it was found that as the angular disparity between two objects increases, the amount of time required to make same/different judgments and errors increase. The corresponding increase between angular disparity and reaction time led to the analogy that a person performing mental rotation mirrors the act of physical rotation. When performing mental rotation, it is theorized that one must undergo the same intervening steps that one would perform when physically rotating an object. In order to describe the relationship between mental imagery and perception, it was proposed that mental imagery has a 'functional' relationship with the physical world (Finke, 1985). This 'functional' relationship is known as the functional theory of mental imagery. The functional theory describes the physical act of manipulating an object as an analogue to the processes that a human undergoes to mentally manipulate an object. In using the physical world as an analogue for mental rotation, it is important to note that one would rarely rotate an object outside of a context or environment. With regard to the functional theory of mental imagery, it is theorized that the environment or background would have an effect on mental rotation. The study investigated if background familiarity, stimulus familiarity, or both background familiarity and stimulus familiarity play a role in mental rotation.

Explanations for the Effects of Backgrounds on Mental Rotation

Distinguishing the relationship between object, background, and mental rotation is critical. Previous research has shown that when an object to be mentally rotated is presented upon a complex, non-realistic background, the amount of time to mentally rotate an object increases (Heil and Rolke, 2002; Jolicoeur and Cavanagh, 1992). The primary focus of this dissertation is to investigate why mental rotation is more difficult, (i.e. an increase in reaction time to rotate the object) when an object is presented against a complex background. One explanation for the increase in mental rotation difficulty when an object is presented upon a background is presented below.

Explanation

Including a background in the mental rotation task makes it more difficult to distinguish the mental rotation object from objects in the background.

Previous research has shown that when including more objects in an environment, it becomes more difficult to locate an object in that environment (Wolfe, 1998). This increased difficulty is known as increased set size or the set size effect. The set size effect describes the relationship between the amount of time to find an object and the number of other objects in that display. The reason a background would increase the difficulty, vis á vis the set size effect, is because including a background may make it more difficult to locate a object in a mental rotation task in relation to the background. This difficulty could be explained using the model of local clutter as studied in Beck, Lohrenz, and Trafton (2010); who investigated the effects of global and local clutter in a visual search task. Global clutter was defined as the clutter in the overall image. Local clutter was defined as clutter located primarily around the target object in the visual search task. Beck, Lohrenz, and Trafton manipulated levels of local clutter, either high or low local clutter. It was shown that participants' reaction times were significantly higher when there were high levels of local clutter around the target. This finding indicates that when the local area around an object has increased clutter, it is more difficult to distinguish that object from the others around it. The implications for mental rotation and backgrounds could be that increasing local set size around the object to be rotated may be making it more difficult to distinguish between vital portions of the object needed to rotate it and the background. This would increase the time needed to rotate the object and errors made during mental rotation.

One possible way to reduce the effects of complex backgrounds on mental rotation stems from the visual search domain. In a study by Wang, Cavanagh, and Green (1994), it was shown that by increasing familiarity with the distractors (read: background) in a visual search task, it reduced the amount of time needed to locate objects in that environment. Wang, Cavanagh, and Green tested this by presenting participants with a visual search task with every combination of familiar target, unfamiliar target, familiar distractor, and unfamiliar distractor see Figure 1 below. It was shown that when the distractors were familiar in a visual search task, the reaction time to find the unfamiliar target was reduced.

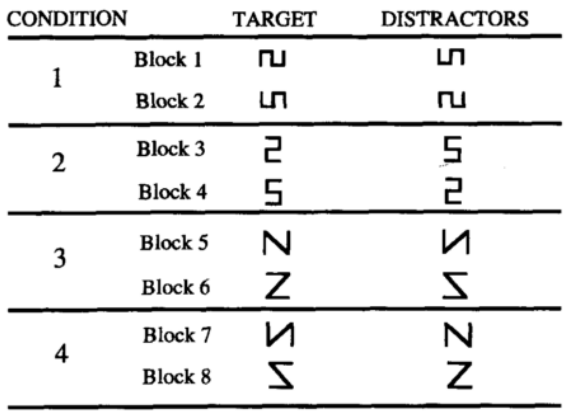


Figure 1 Familiarity Conditions

The above figure illustrates all of the possible conditions from Wang, Cavanagh, and Green (1994). The first column indicates the condition of the visual search task. Condition 1 was one in which participants were unfamiliar with both the target and distractors in the search task. Condition 2, participants were familiar with both target and distractors in the visual search task. Condition 3 included familiar targets among unfamiliar distractors. Condition 4 featured unfamiliar targets among familiar distractors.

This is applicable to the current study because by increasing the familiarity of the background in whichan object is rotated, it may reduce the theorized effects of local clutter on the mental rotation task.

Another possible way to reduce the difficulty in mental rotation and complex backgrounds is to increase the familiarity with the object. This solution stems from the literature on figure-ground distinction. Studies (Peterson and Gibson, 1994) have shown that familiarity can predict figure-ground discrimination. By increasing familiarity with the object to be rotated, it may reduce the mental rotation difficulty encountered when presenting an object in a complex background. Familiarity with the object could increase its distinctiveness from the background, making it easier to locate the object from the portions of the background during mental rotation.

The present study investigated the relationship between a background and an object during mental rotation. It does so by familiarizing subjects with an object, a background, both object and background, or neither. By studying object-background familiarity, it attempts to determine how an object being mentally rotated interacts with a background. The study attempts to isolate the effects outlined above by familiarizing subjects with the target stimulus, the target background, both the target stimulus and target background, or a control condition in which neither the target stimulus nor the target background was made familiar. The effects of the familiarity conditions were measured by comparing performance across conditions on six response conditions. The six response conditions featured the Target Stimulus and non-Target Stimulus. It also included the Target Background, Non-Target Background and a control background that is blank. By comparing the interactions between stimuli and backgrounds familiarized or not familiarized during training, the proposed study will attempt to identify the effects of a complex background on the mental rotation task.

CHAPTER TWO: LITERATURE REVIEW

The following sections are an overview of the mental rotation task in a task analysis and a cognitive task analysis. The task analysis section covers the design of the mental rotation task. The cognitive task analysis reviews the cognitive processes that are theorized to occur during mental rotation. The next section discusses the visual factors that were controlled for when introducing a background to the mental rotation paradigm. The visual factors, discussed, stem from the figure-ground assignment and visual search/clutter domains. Next, the relevant literature in encoding (perception) and mental rotation will be reviewed. The encoding (perception) section reviews the studies that investigated how perceptual processing is theorized to occur during the mental rotation task. Following the section on how objects are perceptually encoded, the process by which objects are trained and stored in mental rotation will be discussed.

Mental Rotation Task Analysis

The theoretical framework for mental rotation is presented below in a task analysis of a typical mental rotation procedure. There are many different variants of the mental rotation task, so only the relevant and most widely used methodology and paradigms will be discussed.

The paradigm discussed typically presents the stimuli upon a computer screen. The subject is given a keyboard to indicate their response during the task. The order of actions and presentation of the stimuli is reviewed below. Prior to the presentation of the mental rotation stimulus, typically there is a brief presentation of a focus stimulus in the center of the screen. The focus stimulus is presented to ensure that the subject’s gaze is drawn to the center of the screen. The focus stimulus is typically a star or a circle that the subject is instructed to look at between mental rotation trials. The focus stimulus can be presented briefly for ~50ms-100ms or until the subject presses a button to advance to the next screen. This focus stimulus is presented between every mental rotation stimulus.

Next, the subject would see two objects on the screen. The object on the left hand side of the screen is the comparison object. The object on the right hand side is compared to the object on the left. The object on the right is presented rotated, or mirrored and then rotated, to any degree between 1 and 359. The subject's task is to examine the object on the right and compare it to the object on the left. The subject must decide whether the object on the right is a mirrored or not mirrored when compared to the object on the left. Once a decision has been made, the subject presses a response key, and the inter-trial screen containing the dot is presented. The stimuli in typical mental rotation studies are usually composed of two objects presented against a uniform background that is usually white or black. The mental rotation stimulus can be a figure composed of blocks, similar to the stimuli that Shepard and Metzlar (1971) used in their original study. It also can be an ambiguous multi-sided polygon, typically created using the method outlined in Attneave and Arnoult (1956). The mental rotation object can be line drawings of real world figures (Tarr, 2014). In the above section, the physical aspects of the mental rotation task as presented to subjects were examined. Accordingly, the following section examines the cognitive processes that a subject is theorized to undergo during a mental rotation task.

Mental Rotation Cognitive Task Analysis

Cognitive scientists (Mumaw, Pellegrino, Kail, & Carter, 1984; Cooper, & Shepard, 1973) theorize that the cognitive processes that the subject undergoes during mental rotation occur in four sequential stages. The first stage is encoding, also known as perceptual encoding, of the stimulus. During perceptual encoding, the subject mentally recreates a representation of the stimulus and holds that recreation in working memory (Baddley, 2000). The subject also encodes the stimulus' orientation and identity during encoding. The second stage is rotation. During rotation, the subject mentally rotates the object. The third stage is the comparison stage. During this stage, the subject compares his or her rotated mental representation of the object to the comparison object. This rotated mental representation is held in working memory (Baddley, 2000) while the comparison is being made. The final stage in mental rotation is the response stage. In the response stage, the subject indicates if the rotated object is a mirrored or non-mirrored version of the comparison object. The previous section reviewed the theorized cognitive principles and tasks that the participant undergoes during a mental rotation task. The following section reviews the visual principles that must be accounted for when adding another variable, figure-background discrimination, to the mental rotation task.

Visual principles

Including a background in the mental rotation task adds many visual variables that one must take into consideration. The following sections on figure-ground segregation and background composition will discuss the visual principles that should be taken into consideration when redesigning the mental rotation task. The section on figure-ground/depth segregation will discuss the geometric properties that determine the relationship between an object and a background. These principles aid in determining which objects should be considered a figure in front of a background and which should be considered a portion of a background. These principles are primarily concerned with the geometric properties of a figure that aid in distinguishing it from a background. This is in contrast to the section concerning background composition. The background composition section reviews the principles concerning the organization and color composition of a background. Organization refers to how a background is organized and how that would influence the mental rotation task. Color composition introduces the visual principles of saliency and color density and their relationship to background composition in the mental rotation task. The first topic to be discussed is figure-ground segregation.

Figure-Ground Segregation

The following section reviews the principles concerning figure-ground segregation. Figure-ground segregation is the process of identifying a figure from a background. This principle is related to the proposed experiment because during mental rotation, the object to be rotated is to be perceived as a figure and the background is to be perceived as a ground.

The current experiment investigates if increasing figure-ground distinction through object familiarity reduces the effects of background complexity on mental rotation. One of the research questions is whether mental rotation task performance in a complex environment is improved if the object is familiar. In order to effectively study the effects of familiarity on figure-ground perception in mental rotation, the other figure-ground principles must be taken into account. The basic principles of figure-ground perception will be discussed in the following section.

There have been many cues identified by vision scientists (Fowlkes, Martin, & Malik, 2007; Peterson & Gibson, 1993; Vecera, Vogel, & Woodman, 2002) that humans use for figure-ground segregation. In the proposed experiment, some of the figure-ground cues are controlled for and others are manipulated as independent variables. Familiarity will be manipulated as an independent variable. Other cues have been controlled for to establish a clear figure-ground relationship between the mental rotation object and the background. The cues controlled for in the current study are: symmetry, convexity, size, and lower region.

The first principle to be discussed is familiarity. Familiarity aids in figure ground discrimination, because the portion, of an image, that is recognized as familiar is more likely to be assigned the cue of figure and the unfamiliar portion is more likely to be assigned the cue of ground (Peterson & Gibson, 1994). The principle of familiarity is manipulated in the proposed study by using figures that are unfamiliar to the subjects and increasing familiarity through interaction with the stimuli. Please see figure 2 below for an example of familiarity in figure-ground assignment.

Figure 2 Familiarity

The above figure illustrates how familiarity contributes to figure-ground assignment. Familiarity contributes to the dark region being assigned as the figure in the upright image. In the inverted image, familiarity is reduced and this makes it more likely that the lighter region will be assigned as the figure. (Peterson and Gibson; 1994).

The second principle to be controlled is symmetry. In figure-ground segregation a more symmetrical object is seen as the figure and the area surrounding it is seen as the ground. The principle can be seen in figure 3 below. The principle of symmetry is controlled for because the mental rotation task requires a mirrored/not-mirrored decision. If a figure is symmetrical, then making a mirrored/not-mirrored decision is not possible because the figure cannot be discriminated from its mirrored version. A figure that is symmetrical is indistinguishable from its mirrored version.

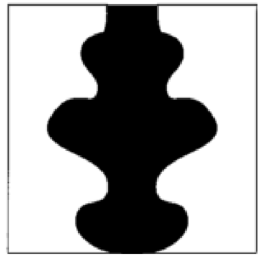


Figure 3 Symmetry

The above figure (from Vecera, Vogel, & Woodman, 2002) illustrates the principle of symmetry. Note that the object would be indistinguishable from a mirrored version of the object.

The fourth principle, to be controlled, is convexity. Convexity describes the probability that a line connecting two points in a shaded region can lie completely within that region. This principle would suggest that when an object has many smaller (concave) parts that intersect with an area that is perceived as larger (convex), the object with larger (convex) portions is perceived as the figure and the smaller (concave) area is perceived as the ground. The figure, when following the principle of convexity, often appears to pop out against a background; please see figure 4. below. With regard to mental rotation—in order to establish a figure-ground relationship, between a stimulus and a background, one must ensure that there are multiple areas of convex regions on the stimulus overlapping areas of concave regions created by the background.

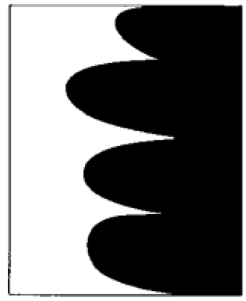


Figure 4 Convexity

The above figure (from Vecera, Vogel, & Woodman, 2002) illustrates the principle of convexity. In the figure, the darker area appears to be a figure on a white background. This is because the darker figure has many convex areas on a background with areas of concave angles.

The next principle is size. Size refers to the area that the figure occupies in comparison to the area of the background in the same image. In an image, the object that is typically assigned as the figure occupies a smaller area than the object that is seen as the ground. In regard to mental rotation, this should be taken into consideration when including a background with a stimulus, because one does not want any objects in the background that could be of comparable size to the stimulus to be rotated. An example of the figure-ground principle of size is shown below in figure 5.

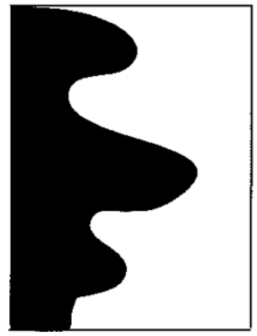


Figure 5.Size

The above figure (from Vecera, Vogel, and Woodman, 2002) illustrates the figure-ground perception concept of size. In the above figure, the dark portion on the left is perceived as the figure because it occupies a smaller area. The light portion on the right is perceived as the ground because it is larger than the darker area.

The last principle is lower region. Lower region refers to where the center of mass for the figure lies in relation to the center of mass for the ground. If the center of mass for the figure lies below the center of mass for the ground it is often perceived of as the figure (Vecera, Vogel, & Woodman, 2002). This is important for mental rotation because when taking the other figure-ground cues into account, one must ensure that the center of mass for the object is below the center of mass for a portion of the background. An example of the principle of lower region is presented below in figure 6.

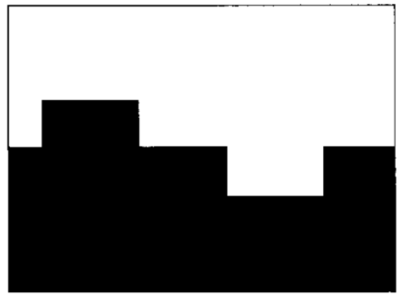


Figure 6 Lower Region

In the above figure (from Vecera, Vogel, and Woodman, 2002), the principle of lower region is illustrated. In the figure, the darker area is perceived as the figure, and the lighter area is perceived as the ground.

Recent studies of figure-ground perception have empirically tested the concepts of convexity, size, and lower region in complex real-world scenes. A study by Fowlkes, Martin, and Malik (2007) tested the principles of convexity, size, and lower region through the development of a computational model that predicted figure-ground assignment. The computational model analyzed local figure ground cues at the edges of an object that is considered to be the figure in front of a background. They first had subjects go through a set of 200 images to assign figure ground labels. They then compared their computational predictions to the assignments made by the human operators. It was shown that multiple figure ground association cues (convexity, size, and lower region) could be used by a computational model to predict figure-ground assignment. In the study, three different cues were measured simultaneously to predict figure-ground assignment. This principle of taking multiple cues into account when studying figure-ground association is important for mental rotation because when considering an image as a whole, no single cue can be said to entirely predict figure-ground assignment.

In conclusion, it is important to remember that no single cue denotes figure and ground. It is a combination of the factors, outlined here, that contributes to figure-ground perception. In addition to figure-ground cues, there are background composition factors from the visual search domain to consider. The contrast between figure-ground assignment cues and visual search cues is that visual search cues account for the color contrasts and overall organization of a background. Figure-ground assignment cues are used to control the shape of an object and its position relative to the background. The following section will discuss the principles that contribute to how background composition is controlled for in the current study.

Background composition

There is relevant research on visual processing that stems from the clutter and visual search domains. When discussing adding a background to the mental rotation task, it is important to note all of the visual factors that should be taken into account and controlled.

The first factor discussed is how the objects in a background are positioned. The positioning of the elements is an important factor to take into account when considering a background in the mental rotation task. Biederman, Glass, and Stacy (1973) examined how an incoherent background would affect visual search by having subjects perform visual search in scenes that were either "jumbled" (incoherent) or had a coherent pattern. Examples are presented below.

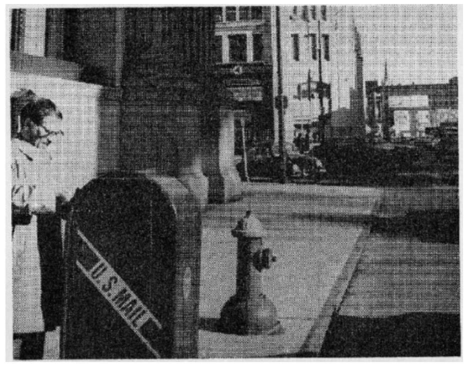


Figure 7 Coherent Scene

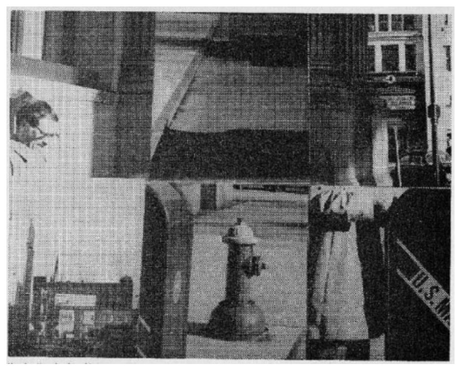


Figure 8 Jumbled Scene

In the above figures, “jumbled” was operationalized by taking a complete scene and dividing it into 10 equal pieces. After the scene was divided, the pieces were randomly arranged to form an incoherent scene. Subjects had to say whether or not an object was located in the scene. In the “jumbled” and coherent scenes, the object was either “possible” to be in the scene or “impossible” to be in the scene. In the “possible” condition, an example could be a mug presented in a kitchen scene. In the “impossible” condition, an example could be a fire hydrant presented in a kitchen scene. It was shown that when figures were arranged in a highly predictable fashion, it was easier to find the target using visual search. The visual search reaction times for the coherent scenes were significantly lower than the reaction times for the "jumbled" scenes. The finding that visual search in an organized background is easier is important to consider. If a background is highly complex and disorganized, it might make the mental rotation task more difficult. It would be more difficult because a lack of background organization would make it harder to locate the object in the background. Conversely, if a background were highly complex though organized in a predictable fashion, such as a grid system, then it would be easier to distinguish the mental rotation object from the background. In addition to the arrangement of the items, it is important to take into account the color and saliency of the items when discussing backgrounds and mental rotation. It is important because, the color density and saliency of the background determine how easy it is to distinguish the object from the background. The following section will discuss the impact of color density and saliency in background composition on the mental rotation task.

There are two different factors that contribute to how color interacts with the visibility of an object against a background and other objects in its environment (Lohrenz, Trafton, Beck, & Gendron, 2009).). Since the current study is investigated whether the background is encoded during the mental rotation task, saliency and color density must be controlled for in the design of the stimuli.

The first controlled factor to be discussed is saliency. Saliency is the perceptual quality of an object to be easily distinguished from objects around it and the area it is presented against (Itti & Koch, 2000). For example, a highly salient object could be a black object presented against a white background surrounded by other white objects, or a white object presented against a black background surrounded by black objects. In both of the previous scenarios, the object presented against a background would have high saliency. In a low saliency condition, the object presented against a background would be a similar color to the background, making it more difficult to distinguish.

The second controlled factor is color density. Color density is based on how distributed similarly colored objects are in an image. For instance, if many objects of differing colors are grouped together in an image, then it is said that the image has low color density. An image with high color density would have objects of similar colors grouped together. An example is presented below (Figure 9. from Lohrenz, Trafton, Beck, & Gendron 2009) illustrating both color density and saliency.

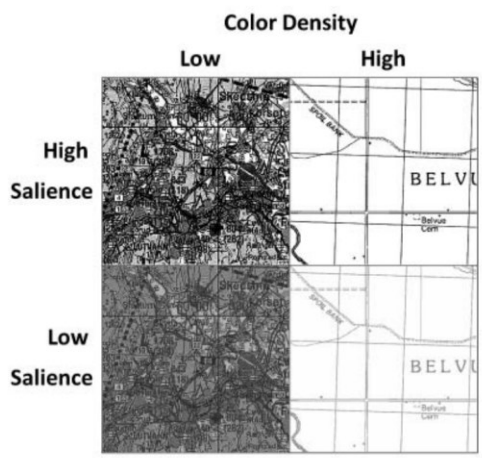


Figure 9.Color Density

The above figure (From Lohrenz, Trafton, Beck, & Gendron 2009) is an illustration of different scenarios in which color density and saliency affect ratings of clutter. The section in the top left corner is a scenario in which there is the highest rating of clutter (High salience with low color density). The section in the lower right corner has the lowest rating of clutter (High color density with low salience).

Color density relates to mental rotation and backgrounds because presenting an object, that has a similar color to the background, in an area of low color density would make it more difficult to distinguish from the noise in the environment. If one were to present an object in a high color density background, in which the object is a different color than the background, it would make it easier to distinguish from the background.

Color density and saliency were empirically tested in how they relate to clutter using a model called the Color-Cluster Clutter Model (C3 model) developed by Lohrenz, Trafton, Beck, and Gendron (2009). The C3 model was developed to predict the amount of clutter in an image based on the color density and saliency of the objects in the image. Lohrenz, Trafton, Beck, and Gendron (2009) tested their model of clutter by having subjects subjectively rate images on how cluttered they were. They then compared the subjective ratings to their predictions based on the C3 model. It was shown that the C3 model is an accurate predictor of clutter based on the high correlation between the subjective ratings and the model's prediction of clutter. This finding demonstrates that color density and saliency can be accurate predictors of the difficulty in distinguishing a target from a background. Though these visual principles are primarily discussed in the visual search domain, they can be used to control the relationship between a stimulus and the background it is presented against. By controlling for saliency and color density across mental rotation stimuli, one would ensure that there is no difference in difficulty in discriminating the mental rotation stimulus from the background. The proposed study controls for clutter across multiple stimuli and backgrounds to ensure that the stimuli have equal levels of color density and saliency. Using stimuli that are the same color and arranging them in an organized grid-like pattern will control color density and saliency.

In conclusion, the above sections have reviewed the principles that will be taken into account when adding a background into the mental rotation task. The most recent section accounted for the organization and color variables that affect how difficult it is to discriminate an object against a background. The section concerning figure-ground reviewed the principles concerning cues associated with form of an object against a background. The figure-ground section accounted for familiarity, symmetry, size, convexity, and lower region. The following section will review the literature that has investigated how an object that is mentally rotated is perceived (encoded).

Perceptual Processing, Backgrounds, and Mental Rotation

The following section will review literature covering perceptual encoding and mental rotation. In the classic models of mental rotation, is it theorized that encoding and mental rotation will occur sequentially (Mumaw, Pellegrino, Kail, & Carter, 1984; Cooper, & Shepard, 1973). Perceptual encoding is the stage in which the object is defined and discriminated from the background. Mental rotation is defined as the stage in which the object is rotated before a mirrored/not-mirrored decision is made. Previous literature investigating the perceptual processing of mental rotation has demonstrated that mental rotation is not a process that occurs on its own (Ruthruff & Miller, 1995). This suggests that the mental rotation processing temporally overlaps with other processes such as perceptual and background discrimination (Ruthruff & Miller, 1995; Heil & Rolke, 2002; and Jolicoeur & Cavanagh 1992). In the classic mental rotation literature, the distinction between background (perceptual) encoding and mental rotation is typically not investigated. Studies are increasingly showing that perception (encoding) and mental rotation do not occur sequentially and may overlap.

In a study by Ruthruff and Miller (1995), it was demonstrated that the perception (encoding) stage, in the functional model of mental rotation, overlaps with the rotation stage. Ruthruff and Miller explored the relationship between perception and mental rotation by having subjects perform a simultaneous color discrimination task alongside mental rotation. Subjects were asked to simultaneously determine the color of characters and mentally rotate the colored characters. The characters were colored letters F, R, and J, and the number 7. Subjects indicated their responses with color mapped to a set of keys and the rotation was mapped to a different set of keys. For instance, if the stimulus were red and concurrently the letter R, the subject should have pressed the "z" key. If the stimulus were green and the mirrored version of the letter R, they would have pressed the "x" key. Because these two tasks, color discrimination and mental rotation, did not take as long to complete when paired together as when done separately, it was shown that perceptual processing can occur while mental rotation processing is occurring. For example, the time to perform the perceptual discrimination took 2 seconds and the mental rotation task took 2 seconds when performed separately. However, if they were performed simultaneously, it would have taken 3 seconds. This finding demonstrates that the perception of properties of the object to be mentally rotated can overlap with the mental rotation of the object. So, if one has to do more perceptual encoding (i.e., discriminating an unfamiliar object from an unfamiliar background) in performing mental rotation, it might make the task more difficult. Though, if the background and object were familiar, less perceptual encoding may need to occur and make it easier to discriminate the object from the background. Heil and Rolke (2002) investigated perceptual encoding and backgrounds in mental rotation.

A study by Heil and Rolke (2002) investigating chronopsychophysiology and mental rotation used a background to decrease perceptual quality of the mental rotation figure. Heil and Rolke hypothesized that by making it more difficult to discriminate the object from the background, it would delay the onset of a mental rotation related negative event-related brain potential (ERP). It is theorized that one can measure the processing of how much a character has to be rotated, to reach 0 degrees, by measuring an ERP over the parietal portion of the scalp. The parietal lobe of the brain is thought to be where spatial processing occurs (Heil & Rolke, 2002). A pronounced positive component (P300) site is extremely positive when comparing objects that are closely matched (i.e. comparing two identical objects) and becomes less positive when the angular disparity between two objects increases. This site becoming less positive, or more negative is known as rotation-related negativity. A delay in rotation-related negativity would indicate that more time was spent in the perceptual encoding portion of the mental rotation task before rotation began. Heil and Rolke measured the onset of this rotation-related negativity by comparing the rotation of objects in high-perceptual quality conditions to conditions in which it was more difficult to perceive the object from the background. They had subjects rotate letters (F, P, R, and L) in either a high-perceptual quality (black letters on a white background) or low perceptual quality condition (Black letters against a background with 50 black or white circles superimposed on a gray base). It was shown that the onset of rotation-related negativity was delayed by making it more difficult to perceive the figure to be rotated from the background. Though Heil and Rolke presented clear evidence for a delay in rotation induced by increased difficulty in perceiving a mental rotation figure from a background, their finding does not provide evidence against perceptual encoding overlapping with the process of mental rotation. Heil and Rolke theorize that because there was a delay in rotation related negativity, when processing figures against a background, mental rotation was delayed due to increased perceptual processing. Does this same delay in processing occur if the object is in a familiar background? Is it simply that backgrounds add processing to the encoding stage in mental rotation or will reaction time be reduced by making the background familiar? These are questions that will be addressed in the current study by familiarizing participants with the background that the object is presented upon. Though, Heil and Rolke (2002) demonstrated that a background can make it more difficult to rotate an object, do different backgrounds have different effects upon mental rotation? Jolicoeur and Cavanagh (1992) address this question.

In addition to Heil and Rolke (2002), Jolicoeur and Cavanagh (1992) also investigated background properties and mental rotation. In the study, the background that the objects were mentally rotated upon were manipulated to give different perceptual properties. They manipulated how the object interacts with the background as can be seen in Figure 10. below.

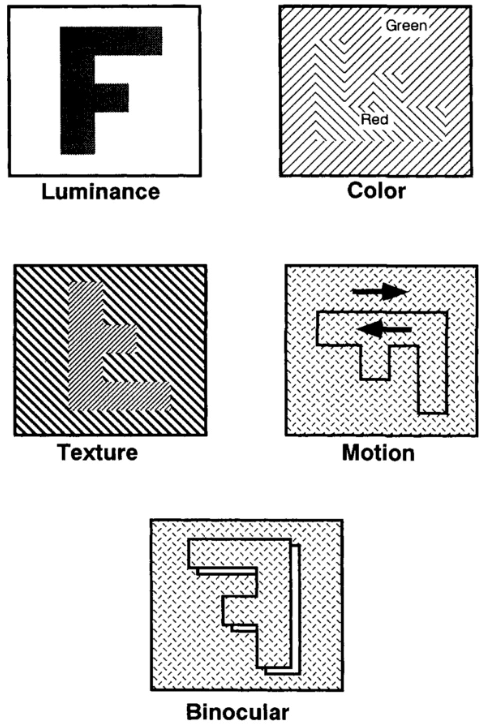


Figure 10. Background Conditions

The above figure illustrates the different conditions manipulated by Jolicoeur and Cavanagh (1992). The "Luminance" condition was one in which the figure had a high saliency contrast with the background. This was accomplished by filling the object and background with a random texture pattern (though not illustrated in the figure published in Jolicoeur and Cavanagh, 1992). The figure had a darker mean luminance than that of the background. The "Color" condition was one in which the figure had a different color than the background. The background was filled with a contrasting light and dark random red dot pattern. The figure was filled with a contrasting light and dark green random dot pattern. In the "Texture" condition the figure was made to have a different texture (read: pattern) than the background. This was done by filling the object's area with a random black/white texture, of equal luminance to the background, to contrast the uniform texture of the background. In the "Motion" condition, the random dot pattern of the background moved, while the pattern of the figure remained stationary. In the "Stereo" condition, the subjects viewed the figures through red/cyan stereogram glasses. The figure and background were filled with random red/cyan dot patterns to give them a three dimensional appearance.

Subjects were asked to make a mirrored/non-mirrored discrimination task for the characters F, G, J, R, 2, and 7, formatted in the manner presented above. Each condition was presented separately from one another. For example, all of the stimuli formatted in the stereo condition were presented together as opposed to being intermixed. In Jolicoeur and Cavanagh (1992)'s study there were significant differences based upon the presentation on different surface medium though did not investigate rate of rotation. Because only overall reaction times, not rates of rotation, were reported a conclusion cannot be drawn about how differing surface mediums could affect perceptual encoding and rate of rotation.

In conclusion, the above studies provide differing results for the relationship between perceptual encoding and mental rotation. Ruthruff and Miller (1995) provided evidence that perceptual encoding and mental rotation overlap, because while the subjects in their study were performing mental rotation they were able to encode the color of the mental rotation stimulus simultaneously. This suggests that while performing mental rotation one is also encoding the perceptual properties of a stimulus. Although, Heil and Rolke (2002) demonstrated that mental rotation related negativity could be delayed by reducing the distinction between the stimulus and the background; it was not shown that perceptual encoding does not continue to occur while the rotation stage is happening. It does not rule out the evidence for an overlapping model of mental rotation presented in Ruthruff and Miller (1995). Jolicoeur and Cavanagh (1992) showed that by altering the visual properties of a background and its relationship to the figure to be rotated, one could affect the overall reaction time for the rotation of that object. Though, since rate of rotation was not reported in the study a conclusion cannot be drawn about whether the differing surface mediums affected the encoding or the rotation of the objects. Overall conclusions drawn from these studies, when considering them as a whole, inform research hypotheses for the proposed study. These studies also demonstrate that including a background in a mental rotation task can have an effect on the perceptual encoding of that figure. The proposed study expands upon the previous studies. It will investigate if during the perceptual encoding of the mental rotation figure, does object and background familiarity play a role in how the object is encoded? Will background familiarity reduce the effects of a complex background on mental rotation? Will object familiarity be as or even more effective than background familiarity in reducing the effects of a complex background? The literature pertaining to object familiarity is reviewed in the following section.

Object Familiarity and Mental Rotation

The relationship between object familiarity and the mental rotation of figures is relevant to the current study because it is investigating whether or not background and object familiarity reduce the effects of complex backgrounds on mental rotation. A study on mental rotation and object recognition by Tarr and Pinker (1989) investigated how an object is stored in long-term memory. Three different hypotheses were proposed. Tarr and Pinker hypothesized that objects could be stored in an orientation invariant representation, a single canonical orientation, or multiple learned orientations in long-term memory.

The orientation invariant hypothesis suggests that objects are stored identically regardless of orientation. The implications of this hypothesis are such that an object is a collection of features in which it is viewed irrespective of size, orientation, or location. The impact for mental rotation would be that an object would be recognized at the same rate regardless of what orientation it is presented in. The second hypothesis is that objects are stored in a single canonical orientation. This single orientation is determined by the orientation that the observer has interacted with the object. Hence it is often known as a "viewer-centered" representation. The single canonical orientation hypothesis would predict that during mental rotation an incremental increase in reaction time would occur the further the object is rotated from the stored orientation. The third hypothesis is that objects are stored in multiple-views. The multiple-views hypothesis implies that through interactions with the object an observer would store multiple orientations of that object. Regarding the multiple-views hypothesis and mental rotation, it would suggest that an object would be rotated to the nearest stored orientation. Furthermore, the multiple-views hypothesis proposes that mental rotation would still occur, it would just be shortened since an individual would have multiple orientations stored in memory.

Tarr and Pinker had subjects perform mental rotation on novel lined objects. Subjects participated in extensive training to rotate the objects at specific degrees, such as 0˚, 90˚, and 135˚. During the training, the rate of rotation decreased dramatically for the objects at those angles. After completing the training, the subjects were presented with the same objects rotated to untrained positions. It was shown that when presented with a familiar object at an untrained rotation position that the rate of rotation speed returned to pre-training levels. During the training the slope of mental rotation reaction time flattened to 1.04 ms/deg. When that object was presented in an unfamiliar orientation, the time to rotate the object had a slope of 4.08 ms/deg; this is the same as the slope prior to the mental rotation training. This finding indicates that though the overall time to rotate the object is decreased with practice, the rate of rotation returns to the same rate prior to training when the object is presented at an unfamiliar orientation. It was shown that, through practice a subject stores multiple orientations of an object. It also was shown that when presented with an unfamiliar orientation of the learned object, the subject would rotate it to the nearest familiar orientation. This finding supports the theory that multiple learned orientations are stored.

Though, other work has shown that familiarization with a single canonical orientation is also an effective way to train mental rotation (Smith & Dror, 2001). Smith and Dror (2001) performed a study examining shape complexity and mental rotation. The primary research question was if familiar complex objects are mentally rotated differently than familiar simple objects. To test this hypothesis, Smith and Dror had subjects mentally rotate meaningless objects made familiar in the experiment. They had subjects perform familiarization exercises involving imagining the objects memorizing them, rating their vividness, and comparing them with other objects. During the familiarization exercises, the subjects were only presented with the objects at a canonical upright view. After the familiarization exercises, the subjects mentally rotated the objects. It was shown that subjects, who were familiarized with the objects, had a reduction in errors during mental rotation, than subjects who were not. This is relevant to the proposed study because it shows that objects can be familiarized using procedures other than mental rotation. The current study utilizes a familiarization method in which the subjects learn to distinguish the target object, to be tested upon later, from three other non-target objects. This is a procedure similar to the one employed in Smith and Dror (2001). There are two research questions that stem from the work on stimulus familiarity, backgrounds, and mental rotation.

Question 1:

If a stimulus is familiar, in addition to a background being familiar, does that decrease the response time of that stimulus in the familiar background?

Question 2:

Does the decrease in reaction time, due to stimulus familiarity, transfer to the rotation of that stimulus against a different unfamiliar background? Do familiar stimuli have less performance degradation due to the effects of being presented in a complex background?

The purpose of this dissertation was to investigate the role that background plays in mental rotation, and to see if stimulus and background familiarity can elucidate the effects of a complex background on mental rotation. This dissertation familiarized abstract stimuli and backgrounds that are contextually neutral and unfamiliar to the subjects. It familiarized the target stimulus by having subjects recognize it from three other stimuli. A similar background familiarization task was also performed. Subjects had to distinguish four different backgrounds from one another. This familiarization task is adapted from the training task used by Tarr and Pinker (1989). Tarr and Pinker familiarized subjects with objects; the current study familiarized subjects with both stimuli and backgrounds. Subjects then performed mental rotation with the Target Stimulus seen in the familiarization session and a Non-Target Stimulus not familiarized, presented upon the Target Background seen in the familiarization session, or a Non-Target Background unseen in the familiarization session.

The following sections summarize the research questions and hypotheses:

Research Questions summarized:

Transfer across stimuli

Does familiarization with a complex background make it less difficult to mentally rotate an unlearned stimulus in the same background?

Transfer across backgrounds

Does familiarity with a stimulus make it less difficult to mentally rotate that stimulus in a novel complex background? Essentially, will the familiarization transfer to an unlearned background? For example, if a person learns to recognize a stimulus, does the person become better at recognizing the stimulus in any background?

Stimulus and Background Familiarity

Is there a compounding effect for both stimulus familiarity and background familiarity? If both stimulus and background are familiar, is there an even greater reduction in the time to rotate the familiar stimulus on the familiar background than each effect individually?

Research Hypotheses

The study proposes three hypotheses.

Research Hypothesis 1

Research hypothesis 1 theorizes that there will be a reduction in the time it takes to rotate the target stimulus due to stimulus familiarity. This reduction in reaction time will occur across all backgrounds, both target and non-target.

Research Hypothesis 2

It is hypothesized that background familiarity will reduce the time to rotate any stimulus, target or non-target, in that background.

Research Hypothesis 3

It is hypothesized that there will be a compounding effect between stimulus familiarity and background familiarity. When subjects are familiar with both the target stimulus and the target background, there will be a significant reduction in the time to rotate the familiar target stimulus on the familiar target background.

CHAPTER THREE: METHOD

Participants

Roughly 113 participants ($M = 19.71$, $SD = 2.02$) were recruited using the University of Central Florida Psychology Department SONA system. The distribution of males and females per condition were roughly equal as seen in the table below.

Table 1. Distribution of participants within Familiarity Conditions

Participants	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus, Non Target Background	Familiar with Non Target Stimulus and Target Background	Familiar with Non Target Stimulus and Non Target Background
Male	9	9	11	9
Female	17	20	19	19
Removed due to poor performance/ noncompliance	28	29	24	20
Total participants included in analyses	26	29	30	28
Total participants recruited*	54	58	54	48

*Please note that for certain conditions more participants had to be recruited to account for attrition in that condition to ensure as equal numbers as possible for between-subjects analyses.

Design

A 2 stimulus familiarity (Familiarized with Target Stimulus, not familiarized with Target Stimulus) by 2 background familiarity (Familiarized with Target Background, not familiarized with Target Background) by 3 background (Target Background, Non-Target Background, Blank Background) by 2 stimulus (Target Stimulus, Non-Target Stimulus) by 12 degrees (0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330) mixed design was employed. In the design, background, stimulus, and degree of rotation were the within-subjects variable. Target Stimulus and Target Background familiarity condition were between-subjects variables. Stimulus examples can be seen on the following pages. Reaction time and percent of errors were response variables for the response conditions that all participants will experience after participating in their familiarization condition. Reaction time was measured in milliseconds and is operationally defined as the time from when the mental rotation stimulus appears on the screen to when the participant makes the same/different decision. Only the correct responses were used when calculating reaction time. Incorrect responses were treated as misses and not be included in the reaction time data. Percent of errors was operationally defined as the total number of incorrect responses out of the total trials shown. For instance, if the participant answered 178 out of 192 trials correctly then that participant would receive a 92% with an 8% error rate. Participants that score below 75% accuracy were excluded from final analyses.

Familiarity Conditions

Table 2. Illustration of Familiarity Conditions and Stimuli Presented in Each Condition

	Target Stimulus	Non-Target Stimulus
Target Background	Familiarized with Target Stimulus and familiarized with Target Background	Not familiarized with Target Stimulus and Familiarized with Target Background
Non-Target Background	Familiarized with Target Stimulus and not familiarized with Target Background	Not familiarized Target Stimulus and not familiarized with Target Background

Target Stimulus/Target Background

In this condition, the participant was measured on reaction time and errors on the Target Stimulus and Target Background that were present in the familiarization exercise..

Non-Target Stimulus/Target Background

In this condition, , the participant was measured on reaction time and errors on a completely novel Non-Target Stimulus that was not present in any of the familiarity conditions. The stimulus was presented upon the Target Background that was present during the familiarization exercise.

Target Stimulus/Non-Target Background:

In this condition, the participant was measured on reaction time and errors on the familiarized Target Stimulus presented on a completely novel Non-Target Background.

Non-Target Stimulus/Non-Target Background:

In this condition, the participant was measured on reaction time and errors for a completely novel Non-Target Stimulus presented on a novel Non-Target Background.

Target Stimulus/Blank Background:

In this condition, the participant was measured on reaction time and errors on the Target Stimulus presented on the Blank Background.

Non-Target Stimulus/Blank Background:

In this condition, , the participant was measured on reaction time and errors for a completely novel Non-Target Stimulus presented on the Blank Background.

Table 3 Response Conditions

	Target Stimulus	**Non-Target Stimulus**
Target Background	Target Stimulus with Target Background	Non-Target Stimulus with Target Background
Non-Target Background	Target Stimulus with Non-Target Background	Non-Target Stimulus with Non-Target Background
Blank Background	Target Stimulus with Blank Background	Non-Target Stimulus with Blank Background

The above table illustrates the organization of the stimuli and backgrounds present in the response conditions. Non-Target Stimulus, Blank Background, and Non-Target Background were not present in any of the familiarity conditions.

Materials

A short demographics questionnaire inquiring about the participant's sex, age, and handedness was presented to him or her after the mental rotation portion of the experiment. Participants were questioned about their familiarity with any of the stimuli prior to the experiment. If any participants indicate prior experience with the stimuli, their data was not used in the analyses.

The mental rotation stimuli used in the current study were images developed in previous mental rotation experiments by Peters and Battista (2008). The stimuli were designed in the same manner as the stimuli from Shepard and Metzler (1971). They were black and white and composed of equal sized cubes. The stimuli chosen for this study were chosen because they were of equal complexity and it was unlikely that the participant had prior interaction with the stimuli. The stimuli created by Peters and Battista were controlled for complexity by composing the objects of equal number of cubes. As seen in the figure below, the stimuli were each composed of 10 equally sized cubes. The background was composed of objects developed using the Attneave and Arnoult (1956) method in Vanderplas (1959). The method developed by Attneave and Arnoult (1956) controls for complexity by composing objects of an equal number of points. The first step is to assign a set number of points to a table of random numbers on a 100x100 grid. The second step is to connect the most exterior points to form a convex object. The third step is to randomly choose the interior points and connect them individually to the exterior points. Lastly, when each point was connected to the interior point, the exterior point that overlapped the area formed by the interior-exterior connection was removed to create a concave area. In using both objects and backgrounds that are equated for complexity, the complexity across stimuli was controlled and equalized. Examples of the background created using objects created using this method follow below. A pilot study was conducted to determine what size the objects in the background should be to have the most effect on mental rotation response times. Details of the pilot study can be found in Appendix A. Taking into consideration the results of the pilot study, it was determined that the background composed of several smaller objects had the largest impact on response times in the mental rotation task. When the stimuli were presented against the background with the smaller objects, it took the longest to rotate the stimuli.

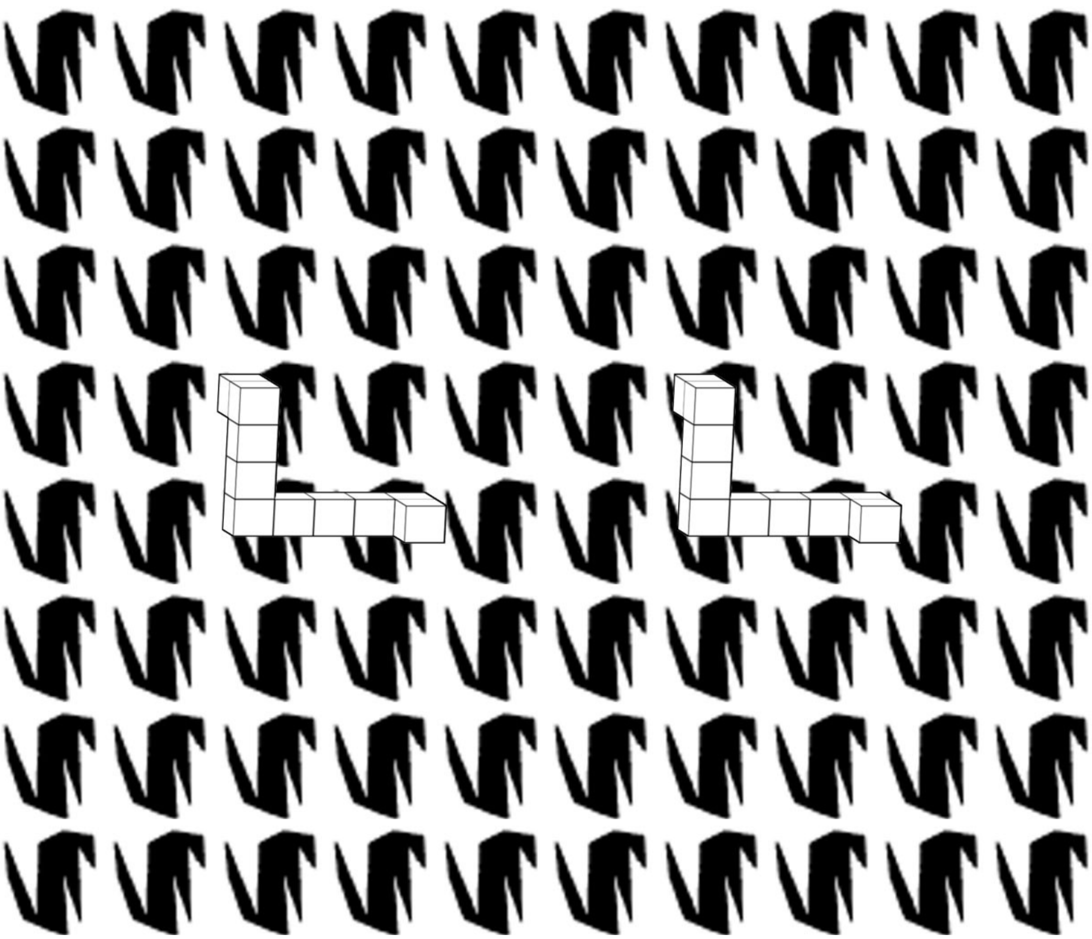
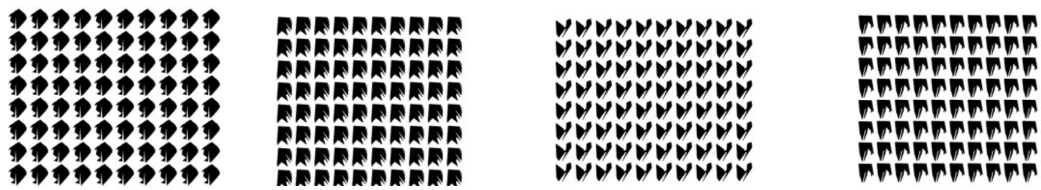


Figure 11. Target Stimulus with Target Background. Response condition

Non-Target Stimulus Non-Target Stimulus Non-Target Stimulus Non-Target Stimulus



Non-Target Background Non-Target Background Non-Target Background Non-Target Background

Figure 12. Distractor Shapes

The above graphic depicts all of the distractor shapes the participants were exposed to in the familiarization exercises. An extra Non-Target Background and Non-Target Stimulus were used in the familiarization exercise as distractors for the conditions in which stimulus or background are not being familiarized for that group.

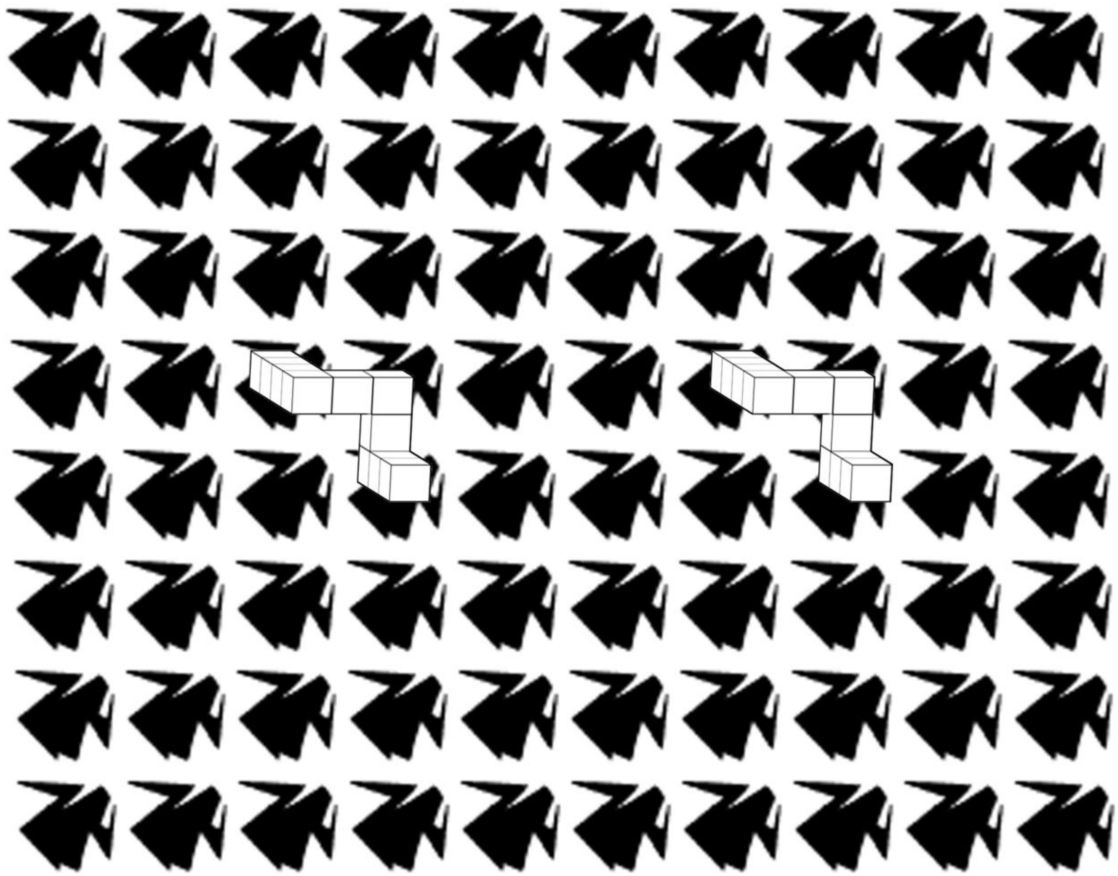
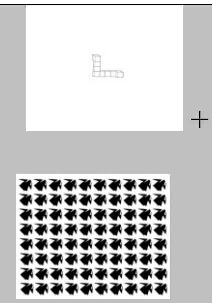
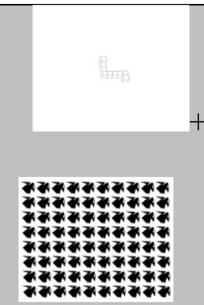
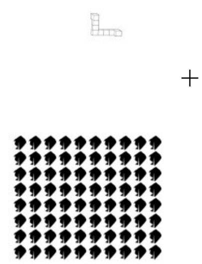
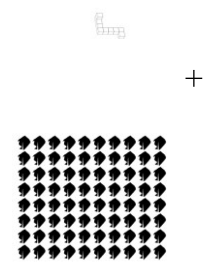


Figure 13. Target Stimulus with Non-Target Background

Graphics of the familiarization conditions and response conditions are presented below. The graphics below illustrate all of the possible stimulus-background familiarity combinations that the participants, depending on the condition they were assigned to, would have experienced.

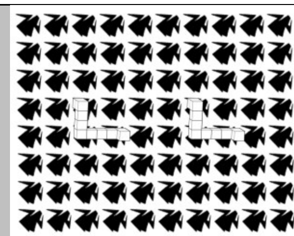
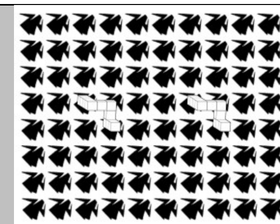
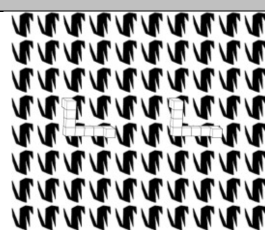
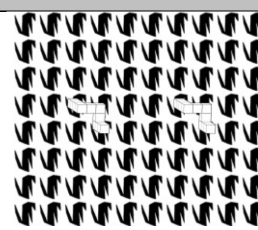
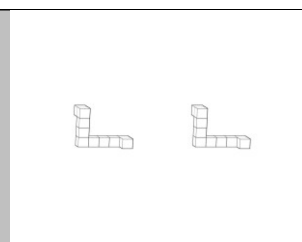
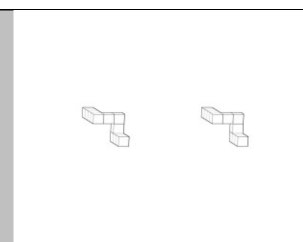
Table 4 Familiarity Conditions

	Target Stimulus	**Non-Target Stimulus**
Target Background		
Non-Target Background		

The above images depict the combinations of backgrounds and stimuli the participants were presented with in the different familiarity conditions.

Response Conditions

Table 5 Within-Subjects Response Conditions

	Target Stimulus	**Non-Target Stimulus**
Target Background		
Non-Target Background		
Blank Background		

Taking into consideration the visual principles outlined in the introduction, the stimuli were designed with consideration for the following factors:

Visual Factors

Familiarity

Familiarity was taken into account by selecting stimuli that would be uncommon for the participant to have had prior interaction with. Participants were asked if they have had any prior experience with the stimuli in the demographics questionnaire. If prior experience was indicated, they were not included in the final analysis. Also, this was taken into account by using backgrounds composed of uncommon stimuli. This is one of the reasons that a realistic scene or image was not used in the familiarity exercise.

Symmetry

Symmetry was taken into account by selecting objects that are not symmetrical and can be judged in a same/different mirror discrimination task.

Convexity

Convexity was taken into account by ensuring that the objects were presented against a repeating pattern and having a majority of the object's angles be larger than the background's protrusion.

Size

Size was taken into account by creating a background with a repeating pattern of smaller objects than the object that is supposed to be the foreground object. The coherent repeating pattern makes the background appear larger than the foreground object. This makes it harder to visually confuse the foreground object for the background when mentally rotating the object.

Lower Region

Lower region was taken into account by ensuring that the object is presented against the background it has a lower center of mass when compared with a portion of the background. Presenting the object against a larger repeating background consisting of smaller objects ensures lower region for figure-ground perception. This is because the background objects are smaller and the overall pattern of the background is larger than the foreground object. This creates lower center of mass for the foreground object when compared with the upper and middle region of the background. This upper and middle center of mass, when combined with the other figure-ground principles, accounts for the lower center of mass of the lower portion of the background when compared to the center of mass for the object to be rotated.

Organization

By organizing the background in a predictable repeating pattern, it guarantees that it will be easy to locate and distinguish the foreground object from the background.

Color Density

Color density was controlled for by making sure that there was a large difference in the distribution of the primary color of the foreground object (white) and the background (black).

Saliency

Saliency was controlled for by ensuring that the background was a substantially different color than the foreground object. In this case the background primarily consists of a repeating pattern of dark figures and the foreground object is a primarily white figure.

Table 6 Influence Factors

The following table is a list of the factors that are taken into consideration and controlled for in the design of this experiment.

Variable	Effect	Estimated impact on study	Decision
Gender	Females tend to not perform as well on mental rotation tasks; this may create differences in performance not related to experimental manipulation. This could increase the chance of making a type 1 error	Medium-Small	Control and create roughly equal numbers of male and female participants in each condition.
Stimulus complexity	Unequal complexity across stimuli may create differences between groups unrelated to experimental	Large	Controlled for by choosing a stimulus set

Variable	Effect	Estimated impact on study	Decision
	manipulation. This also has the possibility to increase the chance for a type 1 error.		that is created to be equal across stimuli.
Background complexity	Unequal complexity in background complexity could create a difference in groups unrelated to experimental manipulation. This has the possibility to increase the chance for a type 1 error.	Large	Controlled for by accounting for number of objects in background.Figure-Ground Discrimination principles: surround, symmetry, convexity, size, familiarity, lower region Visual Search Principles:

Variable	Effect	Estimated impact on study	Decision
			organization, color density, and saliency.
Stimulus/background familiarity	Stimulus/background familiarity could increase figure-ground segregation reducing the amount of interaction between stimulus and background. This has the possibility to increase type 2 error.	Large	Controlled for by using ambiguous stimulus and background that would be unknown to participants, and manipulated as a DV by familiarizing participants on certain stimuli/backgr

Variable	Effect	Estimated impact on study	Decision
			ounds and not others
Familiarity with different stimulus orientations	Familiarity with different orientations during the familiarity exercise has not been investigated and may increase the distinction between stimulus and background during rotation.	Large	Controlled by familiarizing the participants with a single orientation

Apparatus

The stimuli were presented on a thirteen-inch liquid crystal display flat screen monitor using SuperLab 4.0 (Ceadrus) for Windows to present the stimuli, as well as track errors and reaction time. Participants entered their responses using a QWERTY keyboard.

Procedure

First participants began the familiarization exercise involving the stimuli and complex backgrounds. Participants were told to respond as quickly as possible without sacrificing accuracy. Participants were asked to discriminate between four different stimuli presented at the canonical upright. Depending on the familiarity condition that he or she was assigned to, one of the stimuli in the exercise may have been the Target Stimulus, which was present in the response conditions, or a Non-Target Stimulus; which was not present in the response conditions. The three remaining non-target stimuli served as distractors and were not of interest in the experiment. The background familiarization task mirrored the stimulus familiarization task. The participant was told to discriminate between four different backgrounds. If the participant was assigned to Target Background familiarization then the Target Background was present in the exercise. If not, then the Non-Target Background was present in the exercise. The other three non-target backgrounds served as distractors and were not examined in the experiment. The participants completed 512 trials total; 256 stimulus discrimination trials and 256 background discrimination trials. The number of trials was based on the training given to the subjects in Tarr and Pinker (1989). Then, the participant performed a practice exercise. The practice mental rotation exercise featured neutral stimuli (Alphanumeric "L" and "R"). The participantcompleted the practice exercise four times before beginning the mental rotation exercise. After participants completed the practice exercise, they were presented with a mental rotation task featuring six object-background combinations: Target Stimulus with Target Background, Target Stimulus with Non-Target Background, Target Stimulus with Blank Background, Non-Target Stimulus with Target Background, Non-Target Stimulus with Non-Target Background, and Non-Target Stimulus with Blank Background (Please refer back to figure 17.). During the mental rotation exercise, the comparison stimulus was rotated at 12 positions, increasing in 30-degree increments from 0 to 330-degrees. Each position was displayed three times for the mirrored and non-mirrored judgment conditions. Overall, the participant had 72 trials with each stimulus/background combination for a total of 432 trials. All 432 trials were presented in a randomized order to accommodate for variances in performance due to the order of presentation of the stimuli. After participants completed the mental rotation task, they were presented with a short demographics questionnaire asking their sex, age, handedness, and if they had prior interaction with any of the objects presented in the study. Any participants who indicated prior experience with the objects were removed from the analyses. To better illustrate the order of presentation exercises I have provided a flow chart below.

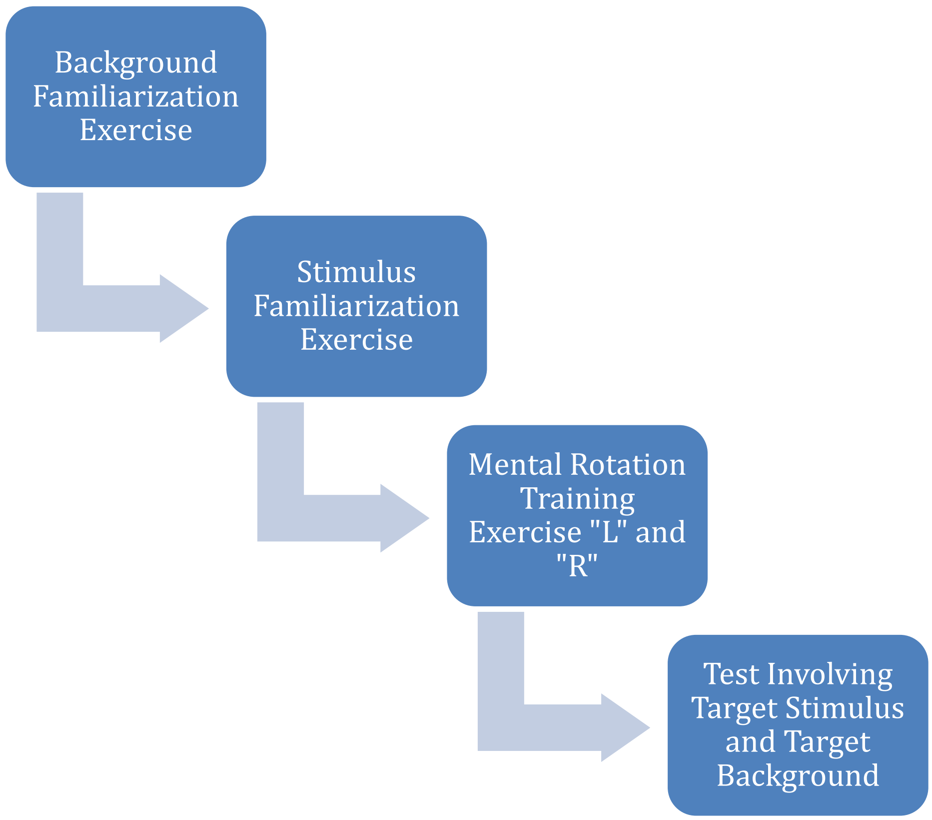


Figure 14 Order of Procedure

CHAPTER FOUR: RESULTS

The data were analyzed using SPSS V. 22 (IBM, 2014) using an alpha level set to .05 unless otherwise indicated. First, the data were inspected for outliers. Outliers were considered any response time greater than three standard deviations from the average response time for that participant. Outliers were not included in the reaction time analyses. Prior to conducting analyses examining the research hypotheses, analyses were conducted to ensure that there were no between-subjects group differences in spatial ability. Next, analyses directly examining the research hypotheses will be presented. In an effort to be thorough, the full analyses will be presented for percent of errors and reaction time. The percent of errors analysis was conducted to inspect whether a speed/accuracy tradeoff occurred. If there were a speed accuracy tradeoff, it would make the results for reaction time not theoretically valid (Herzog, Vernon, Rypma, 1993). Second, the overall analyses for the percent of errors response variable will be reviewed. Third, there will be an in-depth review of the individual stimulus/background response conditions using percent of errors as the response variable. Fourth, the overall analysis for the reaction time response variable will be reviewed. Finally, there will be an in-depth review of the individual stimulus/background response conditions using reaction time as the response variable.

Pre-Study Analysis

To examine whether there were any differences among groups in spatial ability, 2 Stimulus Familiarity (Familiarized with the Target Stimulus, familiarized with Non-

Target Stimulus) by 2 Background Familiarity (Familiarized with the Target Background, familiarized with Non-Target Background) Between-subjects ANOVA was performed on the training stimuli. Reaction time and percent of errors were the dependent variables.

For percent of errors, there was no significant main effects or interactions. There was not a main effect for stimulus familiarity F (1,109) = .42, p = .519, η_p^2 = .003. A main effect was not observed for background familiarity F (1, 109) = .01, p = .996, η_p^2 = .000. An interaction between stimulus familiarity and background familiarity was not observed F (1, 109) = .127, p = .723, η_p^2 = .001.

For reaction time, there were no significant main effects or interaction effects. No main effect was observed for stimulus familiarity F (1, 109) = .418, p = .519, η_p^2 = .011, or background familiarity F (1, 109) = .0001, p = .991, η_p^2 = .000. There was no significant interaction between stimulus familiarity and background familiarity F (1, 109) = .338, p = .563, η_p^2 = .003.

These analyses suggested that there were no prior group differences to spatial ability and thus allow for analysis according to familiarity condition.

Research Hypothesis 1

Research hypothesis 1 theorizes that there was a reduction in the time it takes to rotate the target stimulus due to stimulus familiarity. This reduction in reaction time would have occurred across all backgrounds, both target and non-target.

To examine Hypothesis 1, a 3 Stimulus (Target Stimulus on Target Background, Target Stimulus on Non-Target Background, Target Stimulus on Blank Background) by 2 Stimulus Familiarity (Familiar with Target Stimulus, not Familiar with Target Stimulus) mixed ANOVA was performed. Stimulus was a within-subjects variable. Stimulus Familiarity was between subjects variables. Separate mixed ANOVAs were performed using reaction time and percent of errors as the dependent variable. The results for the analysis using percent of errors will be presented first. To satisfy this hypothesis, we would expect that those who were familiarized with the Target Stimulus to have lower reaction time or percent of errors than those who were not familiarized with the Target Stimulus. This would result in a main effect for the between subjects variable Stimulus Familiarity; between those familiarized with the Target Stimulus and those not familiarized with the Target Stimulus.

Percent of Errors

Overall, there were no differences according to familiarity with the Target Stimulus. F (1,111) = .038, p = .845, η_p^2 = 0.00. Participants who were familiarized with the Target Stimulus (*M* = 9.19, *SD* = 9.58) did not have an percent of errors significantly different from those who were not familiarized with the Target Stimulus (*M* = 8.94, *SD* = 9.83); as seen in Figure 14 below. Since there were no differences according to percent of errors, this allows for an examination of the results using reaction time as the dependent variable.

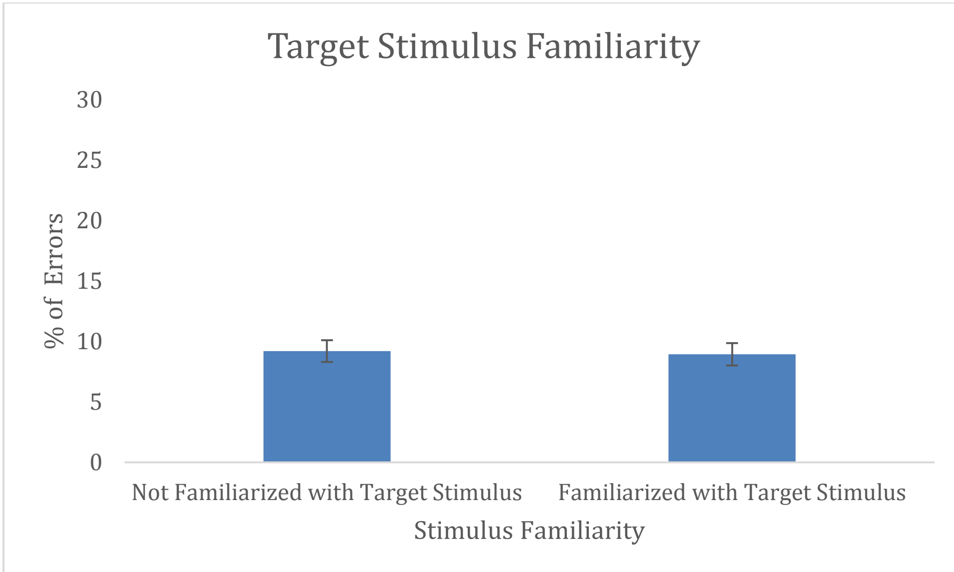


Figure 15 Hypothesis 1-Percent of Errors

Reaction Time

Overall, there were no differences according to familiarity with the Target Stimulus. F (1,111) = .014 p = .905, η_p^2 = 0.00. Participants who were familiarized with the Target Stimulus (*M* = 2623.689, *SD* = 1015.232) did not have a reaction time significantly different from those who were not familiarized with the Target Stimulus (*M* = 2639.689, *SD* = 988.625); as seen in Figure 15 below.

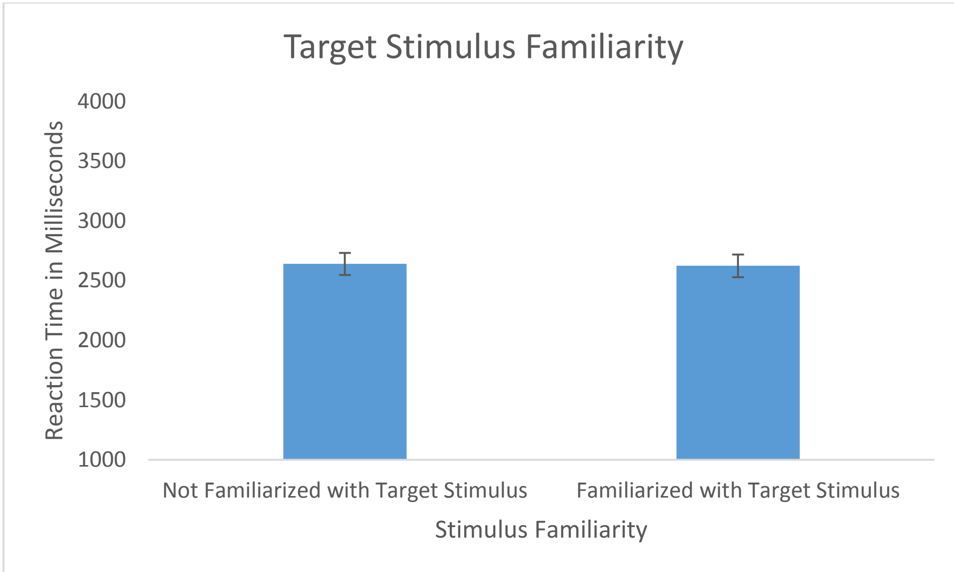


Figure 16. Hypothesis 1-Reaction Time

These results to not appear to fully support Hypothesis 1. To have supported Hypothesis 1 there would have been a main effect for all participants familiarized with the Target Stimulus when compared to those not familiarized with the Target Stimulus.

Research Hypothesis 2

It is hypothesized that background familiarity will reduce the time to rotate any object in that background.

To examine Hypothesis 2, a 2 Background (Target Stimulus in Target Background, Non-Target Stimulus in Target Background) by 2 Background Familiarity (Familiar with Target Background, not familiar with Target Background) mixed ANOVA was performed. Background was a within-subjects variable. Background Familiarity was the between subjects variable. Separate mixed ANOVAs were performed using reaction time and percent of errors as the dependent variable. The results for the analysis using percent of errors will be presented first. To satisfy this hypothesis we would expect that there would be a main effect in which those who were familiar with the Target Background to have a lower reaction time than those not familiarized with the Target Background.

Percent of Errors

Overall, there were no differences according to Background Familiarity F (1,111) = 0.909, p = .343, η_p^2 = .008. Those familiarized with the Target Background (*M* = 12.661, *SD* = 11.353) did not have a significantly different percent of errors than those not familiarized with the Target Background (*M* = 11.228, *SD* = 11.247); as seen in Figure 16 below.

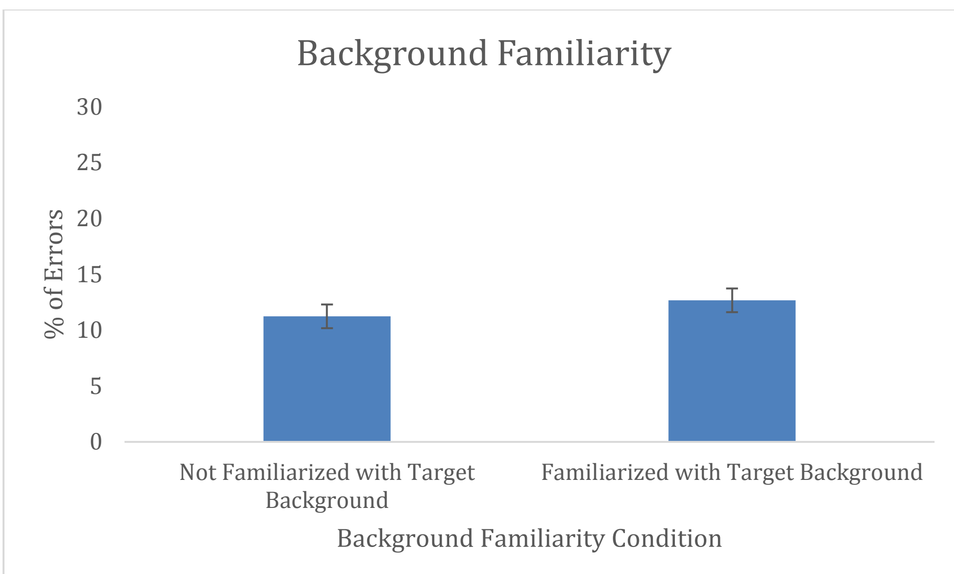


Figure 17, Hypothesis 2-Percent of Errors

Reaction Time

Overall, there were no differences according to Background Familiarity F (1,111) = 0.521, p = .427, η_p^2 = .006. Those familiarized with the Target Background (*M* = 2767.423, *SD* = 1205.65) did not have a significantly different reaction time than those not familiarized with the Target Background (*M* = 2894.746, *SD* = 1195.03); as seen in Figure 17 below.

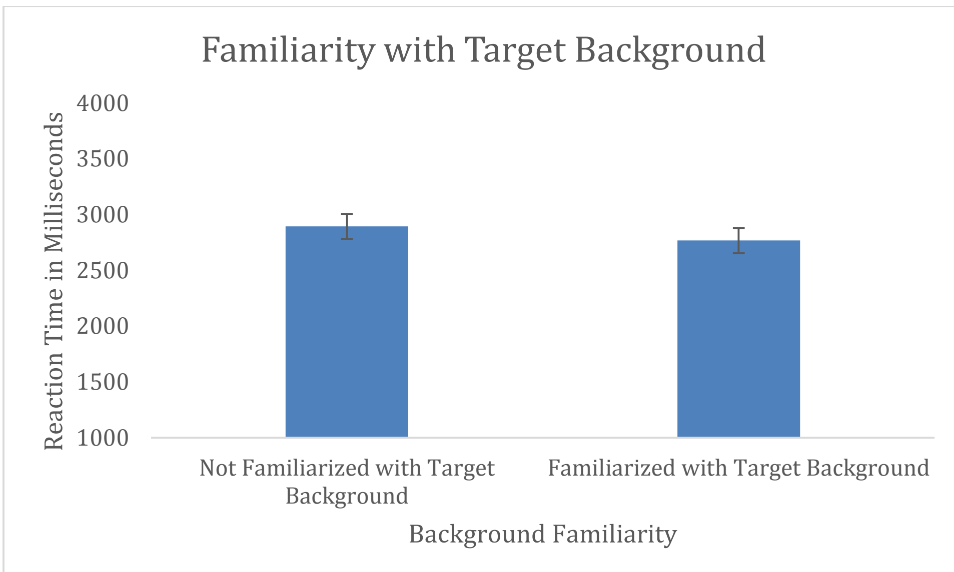


Figure 18 Hypothesis 2-Reaction Time

These results do not appear to satisfy Hypothesis 2. To satisfy Hypothesis 2 a main effect would have occurred when comparing those familiarized with the Target Background and those not familiarized with the Target Background. Further analyses will be presented later that will elucidate these findings.

Research Hypothesis 3

It is hypothesized that there will be a compounding effect between stimulus familiarity and background familiarity. When subjects are familiar with both the target stimulus and the target background, there will be a significant reduction in the time to rotate the familiar target stimulus on the familiar target background.

To examine Hypothesis 3, a 2 Stimulus Familiarity (Familiarized with the Target Stimulus, familiarized with Non-Target Stimulus) by 2 Background Familiarity (Familiarized with the Target Background, familiarized with Non-Target Background) Between-subjects ANOVA was performed. Target Stimulus on Target Background was the response variable. Stimulus Familiarity and Background Familiarity were between subjects variables. Separate ANOVAs were performed using reaction time and percent of errors as the dependent variable. The results for the analysis using percent of errors will be presented first. To satisfy this hypothesis, we would expect an interaction effect in which those who were familiarized with both the Target Stimulus and Target Background would have a lower reaction time than those in all other familiarity conditions.

Percent of Errors

An interaction effect between Stimulus Familiarity and Background Familiarity did not occur for percent of errors F (1, 109) = 1.075, p = .302, η_p^2 = 0.01. The percent of errors for participants familiarized with the Target Stimulus and Target Background (*M* = 10.059, *SD* = 15.477) was not significantly different from the other familiarity conditions; as shown in Figure 19 below.

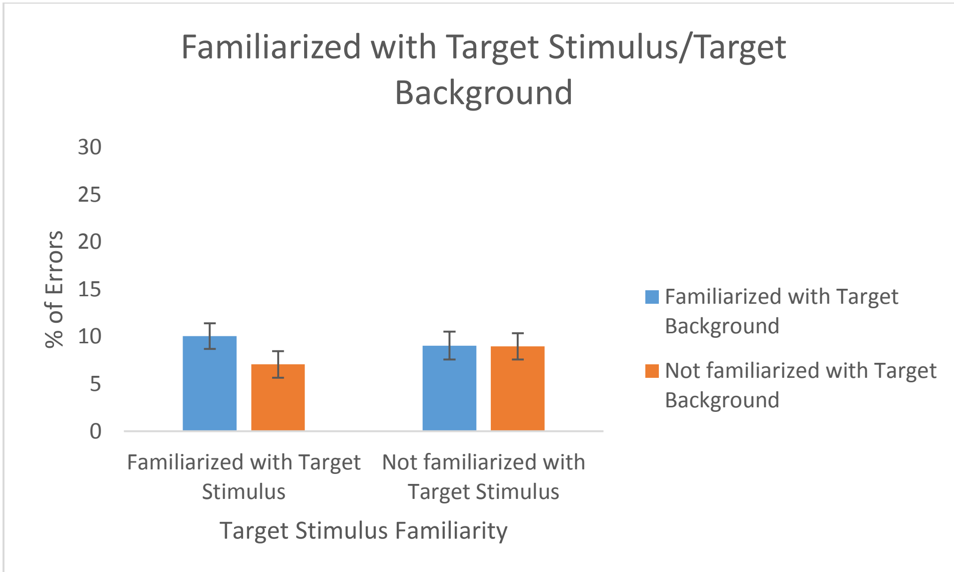


Figure 19 Hypothesis 3-Percent of Errors

Reaction Time

There was an interaction between Stimulus Familiarity and Background Familiarity F (1, 109) = 5.767, p <.05, η_p^2 = .05. Though, contrary to Hypothesis 3 those familiar with both the Target Stimulus and Target Background (*M* = 2700.685, *SD* = 1459.413) did not have the lowest reaction time. The lowest reaction time was observed for those familiarized with the Target Background and not the Target Stimulus (*M* = 2415.088, *SD* = 1358.639); as seen in Figure 20 below.

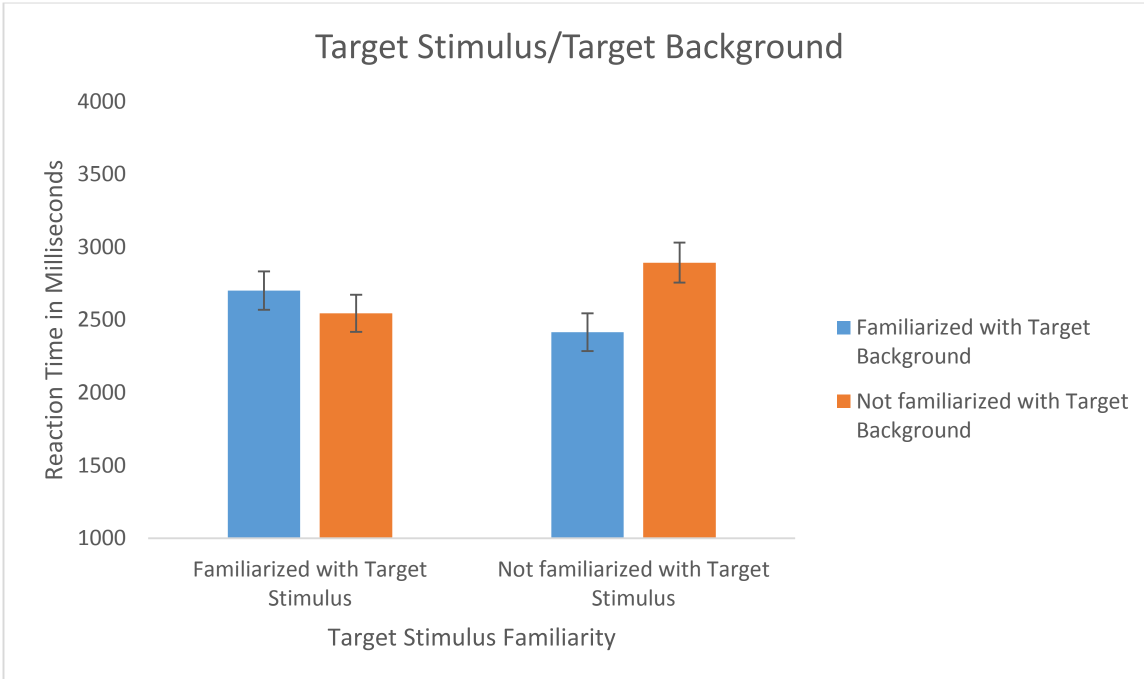


Figure 20 Hypothesis 3-Reaction Time

<u>Full Percent of Errors Analysis</u>

A 2 Stimulus-Familiarity (Familiar with Target Stimulus, Familiar with Non-Target Stimulus) by 2 Background-Familiarity (Familiar with Target Background, Familiar with Non-Target Background) by 2 Stimulus (Target Stimulus, Non-Target Stimulus) by 3 Background (Target Background, Non-Target Background, Blank Background) by 12 Degree (0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330) mixed ANOVA was run using percent of errors as the dependent variable. Stimulus-Familiarity and Background-Familiarity were between-subjects variables. Background, Stimulus, and Degree were within-subjects variables. Across all within-subjects conditions there were violations of sphericity at $p=.05$ using Mauchly's Test of Sphericity. The Huynh-Feldt correction was used to account for this violation of sphericity.

There was a main effect for Stimulus F (1,109) = 82.696, p<.01, η_p^2 = .431. Overall, the Target Stimulus (*M* = 9.225, *SD* = 6.898) had a lower percent of errors than Non-Target Stimulus (*M* = 15.328, *SD* = 9.769). This main effect can be seen in figure 21 below. Interestingly, a main effect was not observed for Background F (2, 218) = 2.052, p = .131, η_p^2 = .018.

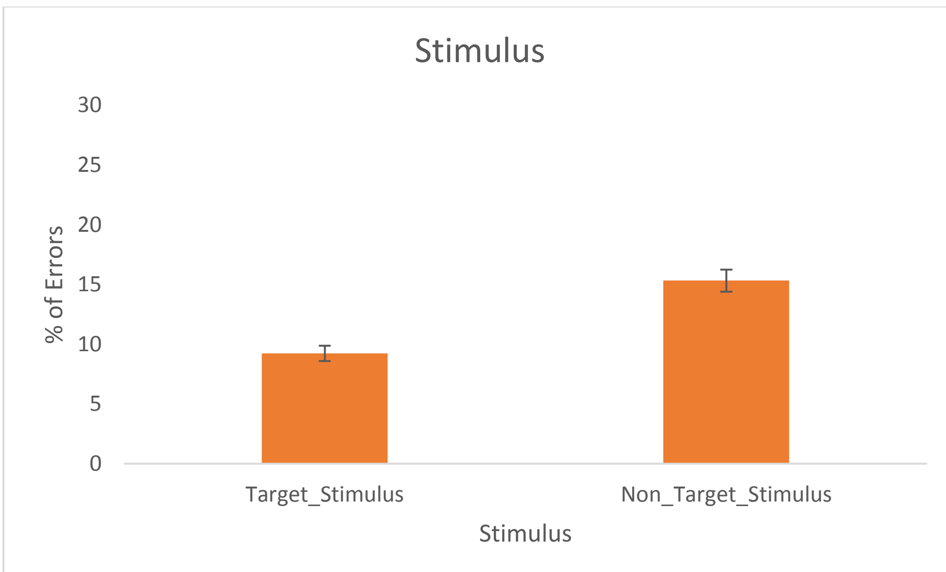


Figure 21 Main Effect: Stimulus

There was a main effect for degree of rotation F (7.381, 804.511) = 42.138 p < .01, η_p^2= .279. Interestingly stimuli presented at 180 degrees (*M* = 84.237, *SD* = 11.629) of rotation did not have largest percent of errors; stimuli presented at 90 degrees (*M* = 16.865, *SD* = 11.736) of rotation had the most. As seen in the figure below, the errors seem to flatten after reaching 90 degrees (*M* = 16.865, *SD* = 11.736) of rotation until 240 degrees (*M* = 15.007, *SD* = 11.438) of rotation.

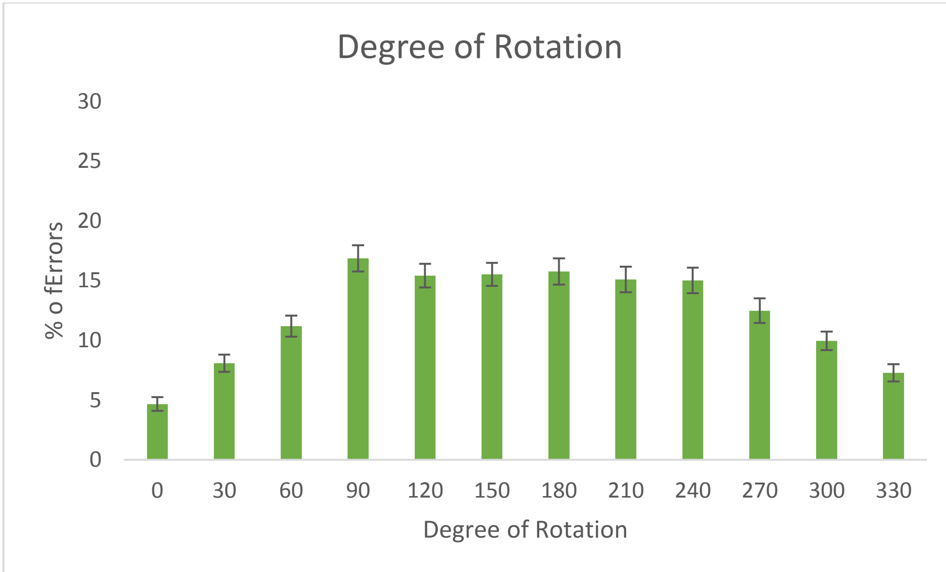


Figure 22 Main Effect: Degree

A significant interaction occurred between background familiarity conditions and degree of rotation F (7.381, 804.511) = 2.515, $p < .05$, $\eta_p^2 = .023$. Interestingly enough, those familiar with the Target Background had a higher percent of errors as degree of rotation increased when compared to those familiar with the Non-Target Background as seen in the figure below.

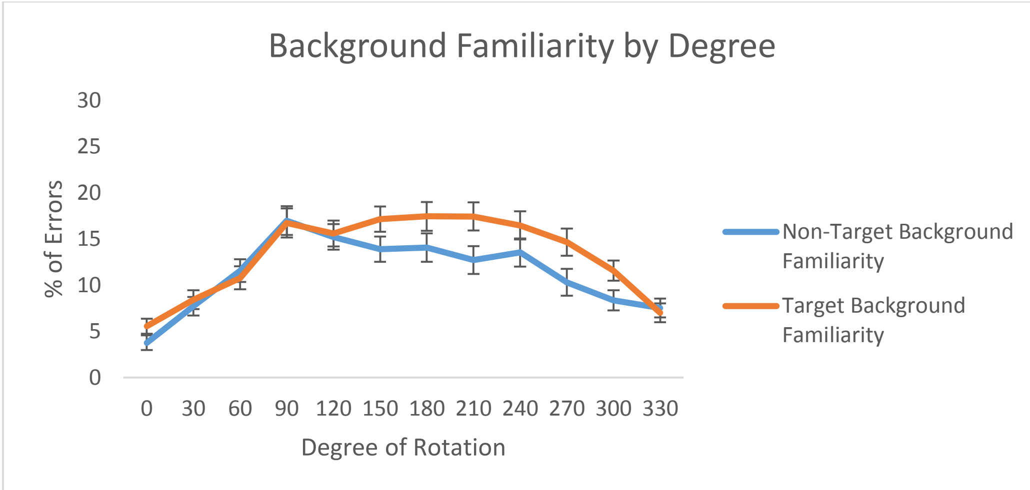


Figure 23 Interaction: Background Familiarity and Degree of Rotation

Another significant interaction occurred for stimulus by degree F (8.597, 937.089) = 8.615, p<.01, η_p^2 = .073. Overall, the Non-Target Stimulus had a larger percent of errors as degree of rotation increased. A fascinating effect occurred where Non-Target Stimulus had the highest amount of errors at 90 degrees (*M* = 24.412, *SD* = 17.901) instead of 180 degrees (*M* = 18.083, *SD* = 14.839).

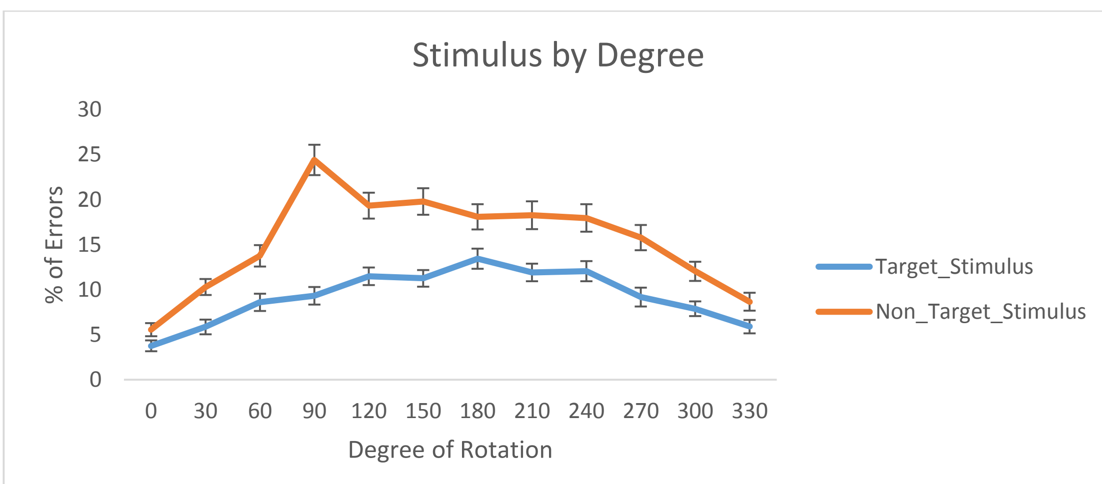


Figure 24 Interaction: Stimulus by Degree of Rotation

A Stimulus by Background by Background Familiarity by Stimulus Familiarity interaction occurred F (1.974, 215.182) = 5.666, p<.01, η_p^2 = .049. As seen in Figure 25 below, it appears that participants that had no stimulus familiarity and had background familiarity had the highest number of errors on Non-Target Stimulus conditions, a stimulus that was unfamiliar to all participants regardless of the familiarity condition they were assigned to, when compared to the performance of the other familiarity conditions on the Target Stimulus.

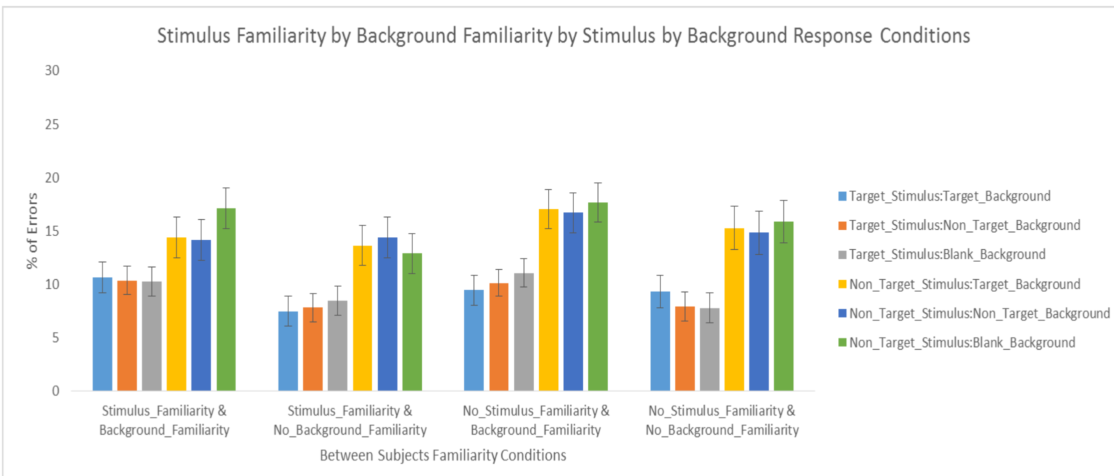


Figure 25 Interaction: Stimulus Familiarity by Background Familiarity by Stimulus by Background

Individual Percent of Errors Analyses

A 2 Stimulus-Familiarity (Familiar with Target Stimulus, Familiar with Non-Target Stimulus) by 2 Background-Familiarity (Familiar with Target Background, Familiar with Non-Target Background) by 12 Degree (0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330) mixed ANOVA was run using percent of errors as the dependent variable. Stimulus-Familiarity and Background-Familiarity were between-subjects variables. A separate ANOVA will be conducted for each response condition. The response conditions will be:

Target Stimulus with Target Background, Target Stimulus with Non-Target Background, Target Stimulus with Blank Background, Non-Target Stimulus with Target Background, Non-Target Stimulus with Non-Target Background, and Non-Target Stimulus with Blank Background. Across all within-subjects conditions there were violations of sphericity at p=.05 using Mauchly's Test of Sphericity. The Huynh-Feldt correction was used to account for these violations of sphericity. Follow up t-tests were conducted to further examine the relationship between familiarity conditions with the response variable. They will be presented in tables following the interaction graphs. They are presented here for completeness, to account for the speed-accuracy tradeoff mentioned earlier, since the same analyses were conducted for the reaction time response variable.

Response Condition: Target Stimulus with Target Background

As expected, a main effect occurred for degree of rotation (F (10.065) = 7.498, $p < .001$, $\eta_p^2 = .064$) in which errors increased as it approached 180 degrees of rotation. Though, as illustrated in Figure 26 below, there seems to be a flattening of the rate as it reaches 90 degrees of rotation.

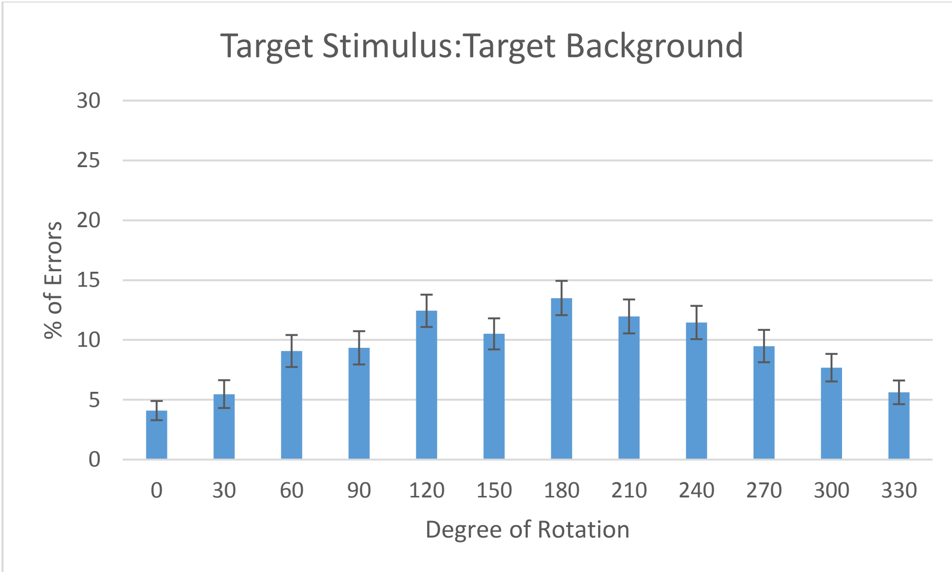


Figure 26 Main Effect: Degree of Rotation

Interestingly, an interaction effect did not occur for Stimulus Familiarity and Background Familiarity (F (1, 109) = 1.109, p = .295, η_p^2 = 01) did not occur. See Figure 27 below.

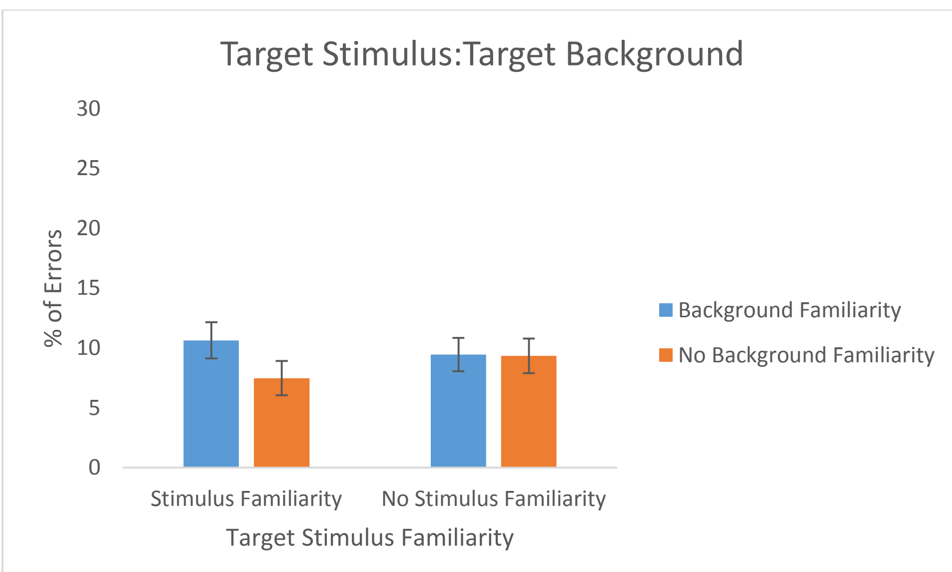


Figure 27 Interaction: Target Stimulus by Target Background

Follow up t-tests were conducted. None were found to be approaching significance.

Table 7 t-tests for Response Condition Target Stimulus with Target Background

Target Stimulus on Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			
Familiar with Target Stimulus and Non-Target Background	p=.129	-		
Familiar with Non-Target Stimulus and Familiar with Target Background	p=.655	p=.285	-	
Familiar with Non-Target Stimulus and Non-Target Background	p=.611	p=.271	p=.966	-

Response Condition: Target Stimulus with Non-Target Background

A main effect occurred for response condition featuring the Target Stimulus in the Non-Target Background for degree F (9.959, 1085.556) = 6.971, p<.01, η_p^2 = .06 as can be seen in the figure below.

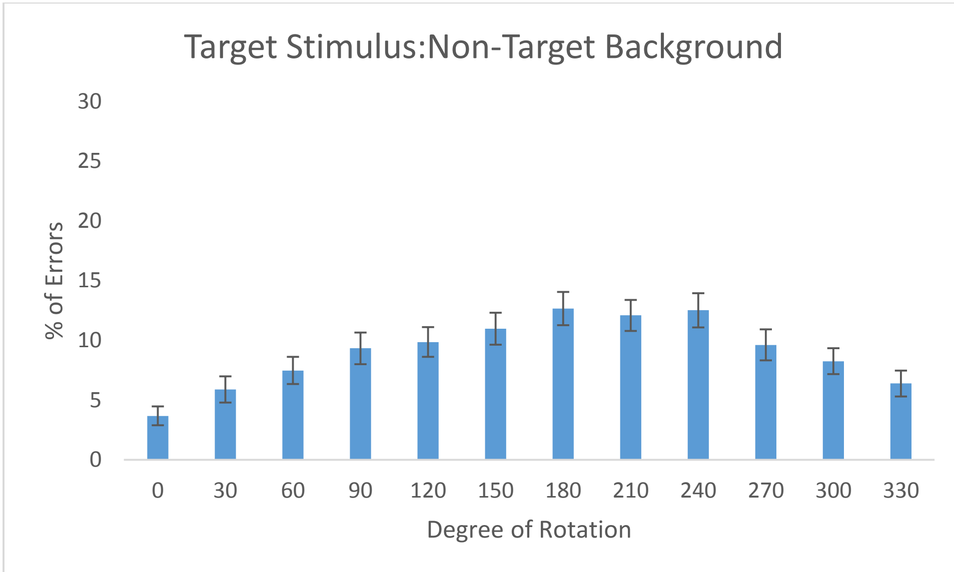


Figure 28 Main Effect: Degree of Rotation

Though there was a higher order effect for Familiarity with the Background and Degree of Rotation on Response condition Target Stimulus/Non-Target Background F (9.959, 1085.556) = 1.904, p<.05, η_p^2 = .017. As seen in Figure 29 below, it appears that those familiar with the Target Background had more errors at the higher degrees of rotation than those not familiarized with the Target Background.

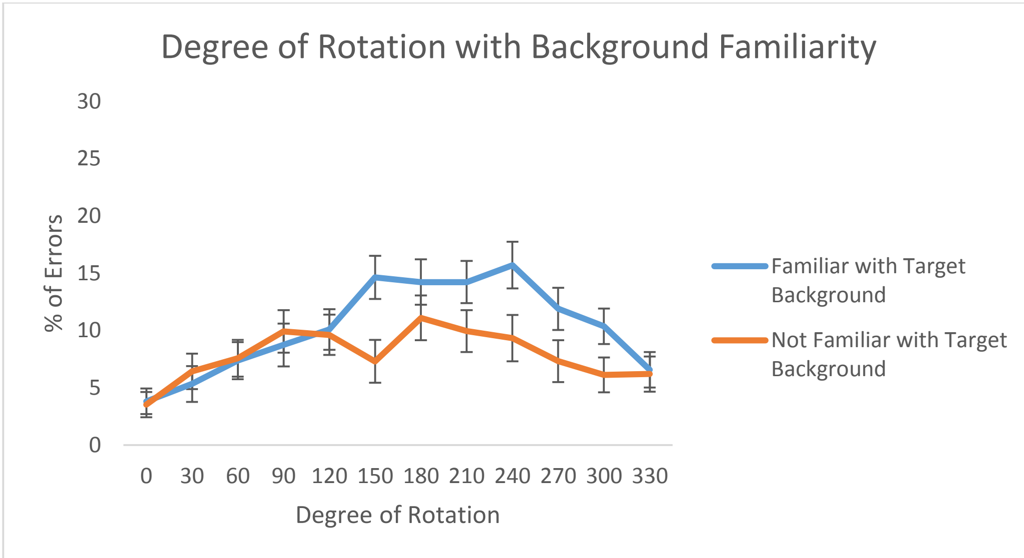


Figure 29 Interaction: Target Stimulus Familiarity by Degree of Rotation

There was not a significant interaction between Stimulus Familiarity and Background Familiarity F (1,109) = .018, p=.894, η_p^2 = .0.; as seen in graph 29 below.

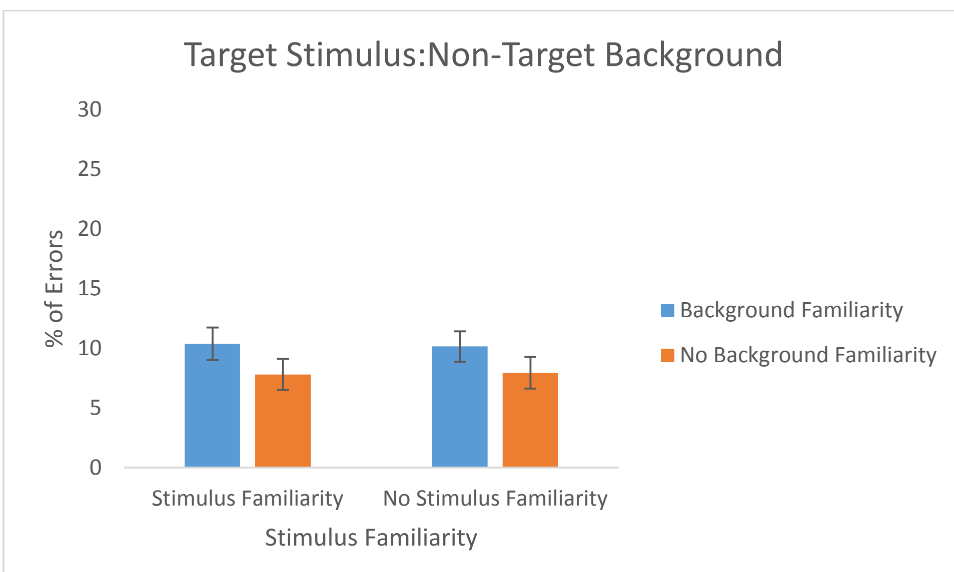


Figure 30 Interaction: Stimulus Familiarity by Background Familiarity

Follow up t-tests were conducted. None were found to be approaching significance.

Table 8 t-Tests for Response Condition: Target Stimulus with Non-Target Background

Target Stimulus on Non-Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			
Familiar with Target Stimulus and Non-Target Background	p=.179	-		
Familiar with Non-Target Stimulus and Familiar with Target Background	p=.919	p=.195	-	
Familiar with Non-Target Stimulus and Non-Target Background	p=.222	p=.931	p=.241	-

Response Condition: Target Stimulus with Blank Background

As expected, there was a main effect for degree of rotation F (9.766, 1064.501) = 8.316, p <.01, η_p^2 = .071 in which the percent of errors increases as it approaches 180 degrees of rotation. This can be seen in Figure 31 below.

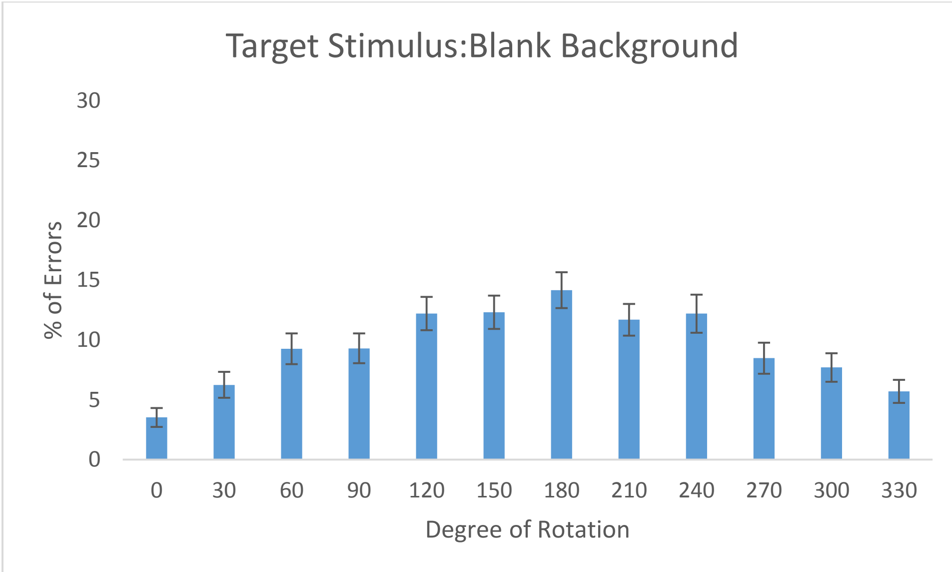


Figure 31 Main Effect: Degree of Rotation

Interestingly, there were no higher order interactions. Specifically, there was not an interaction between Stimulus Familiarity and Background Familiarity F (1, 109) = .299, p =.586, η_p^2 = .003.

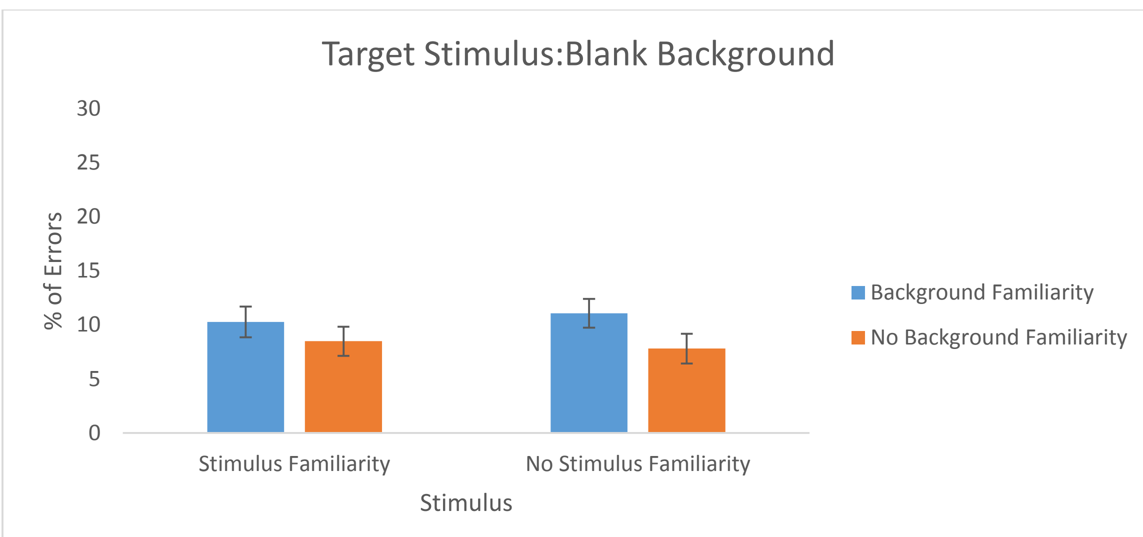


Figure 32 Interaction: Stimulus Familiarity by Background Familiarity

Follow up t-tests were conducted. None were found to be approaching significance.

Table 9 t-Tests for Response Condition: Target Stimulus with Blank Background

Target Stimulus on Blank Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			
Familiar with Target Stimulus and Non-Target Background	p=.349	-		
Familiar with Non-Target Stimulus and Familiar with Target Background	p=.718	p=.189	-	
Familiar with Non-Target Stimulus and Non-Target Background	p=.205	p=.67	p=.104	-

Response Condition: Non-Target Stimulus with Target Background

There was a main effect for degree of rotation F (9.908, 1080) = 17.172, p<.01, η_p^2 = .136 in which errors increased as degree of rotation increased. This can be seen in Figure 32 below.

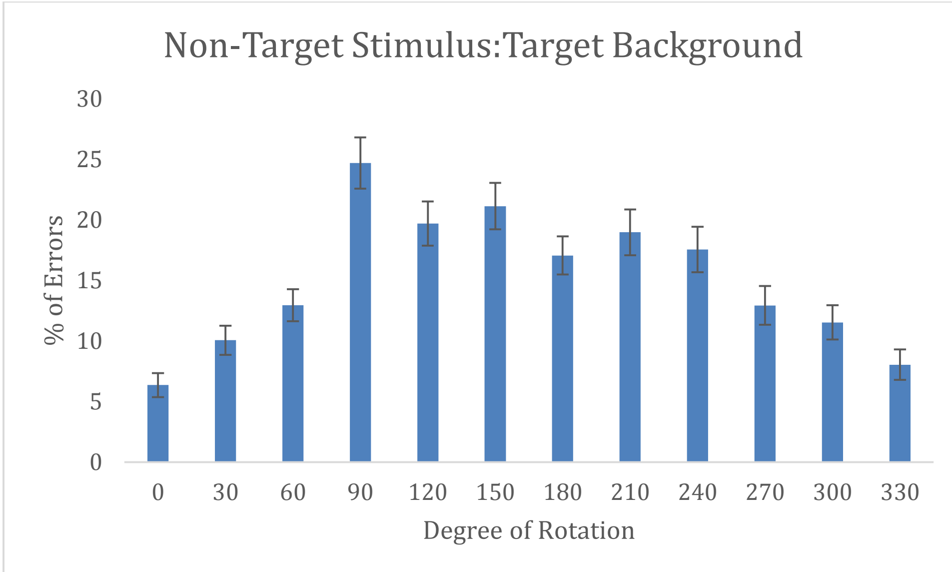


Figure 33 Main Effect: Degree of Rotation

There was not a higher order interaction between Target Stimulus Familiarity and Target Background Familiarity F (1, 109) = .073, p = .788, η_p^2 = .001. This can be seen in Figure 33 below.

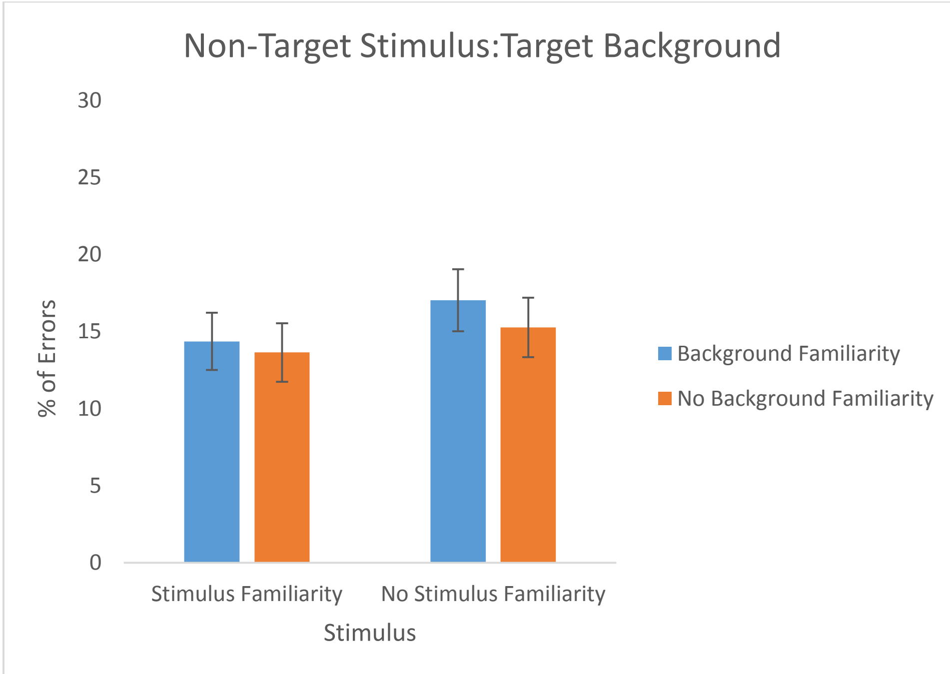


Figure 34 Interaction: Stimulus Familiarity by Background Familiarity

Follow up t-tests were conducted. None were found to be approaching significance.

Table 10 t-Tests for Response Condition Non-Target Stimulus on Target Background

Non-Target Stimulus on Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			
Familiar with Target Stimulus and Non-Target Background	p=.787	-		
Familiar with Non-Target Stimulus and Familiar with Target Background	p=.385	p=.198	-	

Non-Target Stimulus on Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Non-Target Stimulus and Non-Target Background	p=.209	p=.494	p=.529	-

Response Condition: Non-Target Stimulus with Non-Target Background

There was a main effect for degree of rotation F (9.34, 1018.024) = 13.614, p<.01, η_p^2 = .111 in which errors increased as degree of rotation increased. This can be seen in Figure 34 below.

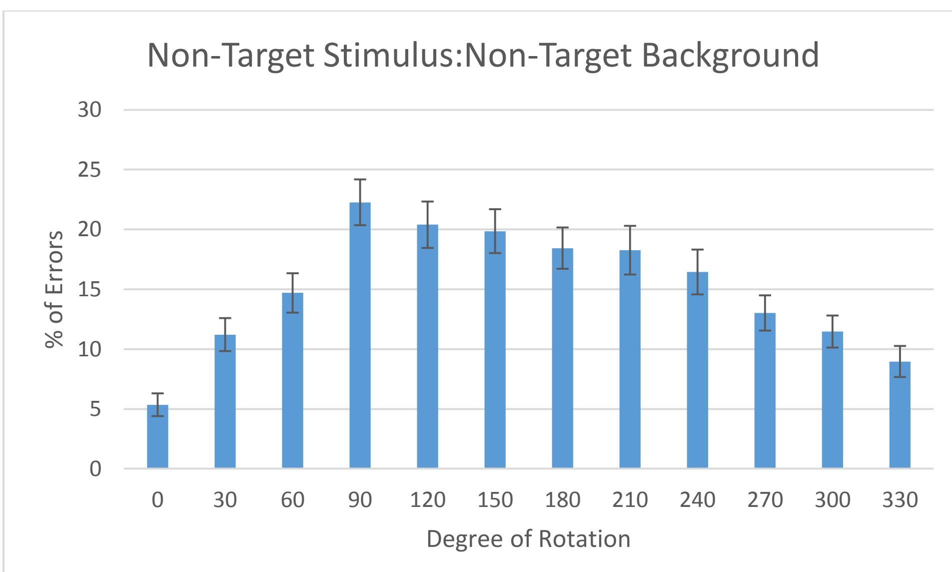


Figure 35 Main Effect: Degree of Rotation

There was no higher order interaction between Shape Familiarity and Background Familiarity F (1, 109) = .305, p = 582, η_p^2 = .003; as seen in Figure 35 below.

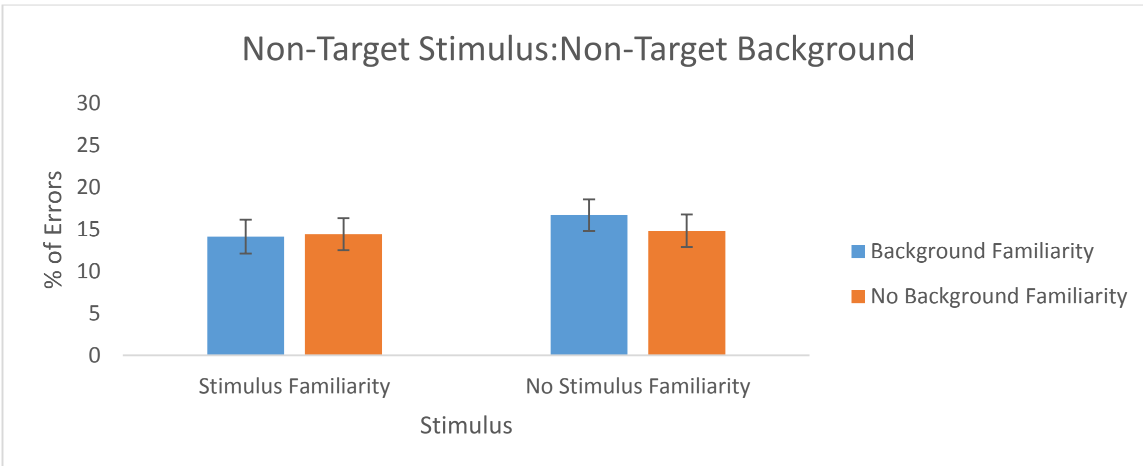


Figure 36 Interaction: Non-Target Stimulus by Non-Target Background

Follow up t-tests were conducted. None were found to be approaching significance.

Table 11 t-Tests for Response Condition: Non-Target Stimulus on Non-Target Background

Non-Target Stimulus on Non-Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			
Familiar with Target Stimulus and Non-Target Background	p=.926	-		
Familiar with Non-Target Stimulus and	p=.385	p=.402	-	

Non-Target Stimulus on Non-Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Background				
Familiar with Non-Target Stimulus and Non-Target Background	p=.807	p=.871	p=.491	-

Response Condition: Non-Target Stimulus with Blank Background

A main effect occurred for degree of rotation F (10.316, 1124.486) = 18.829, p < .01, η_p^2 = .147; as seen in Figure 36 below.

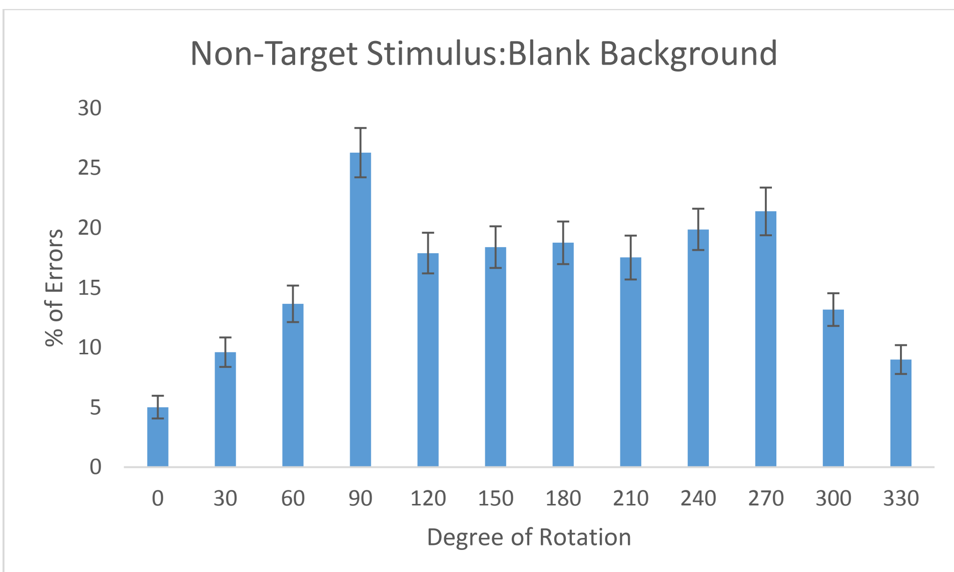


Figure 37 Degree of Rotation: Non-Target Stimulus in Blank Background

Interestingly, there was not an interaction between Target Stimulus familiarity and Target Background familiarity F (1, 109) = .417, p = .52, η_p^2 = .004; as can be seen in Figure 37 below.

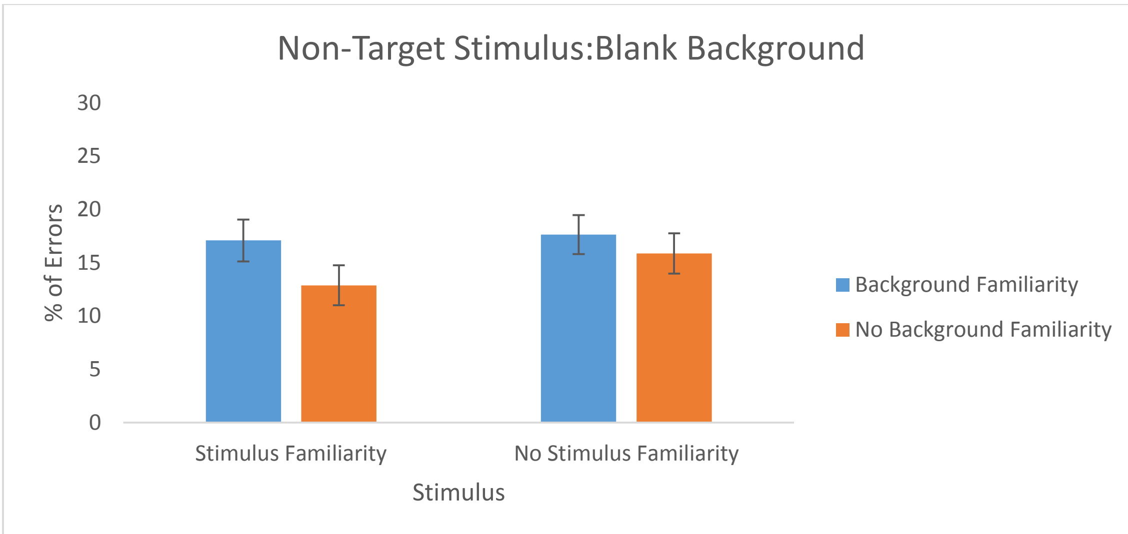


Figure 38 Interaction: Stimulus Familiarity by Background Familiarity

Follow up t-tests were conducted. None were found to be approaching significance.

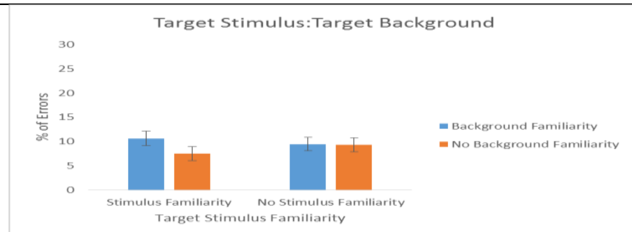
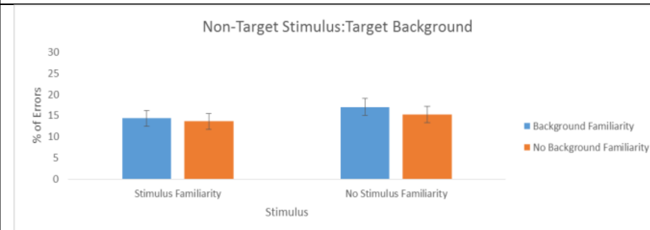
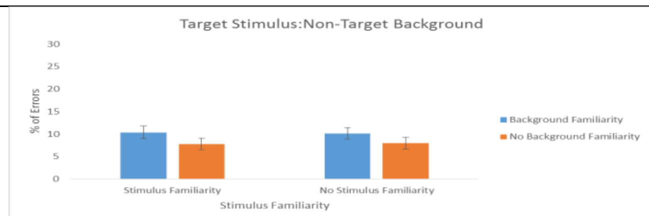
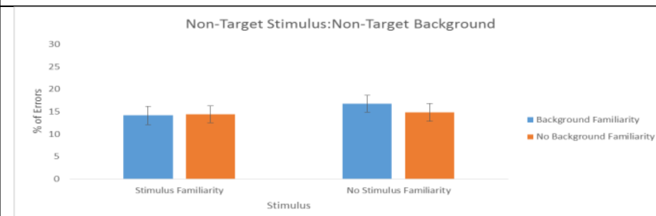
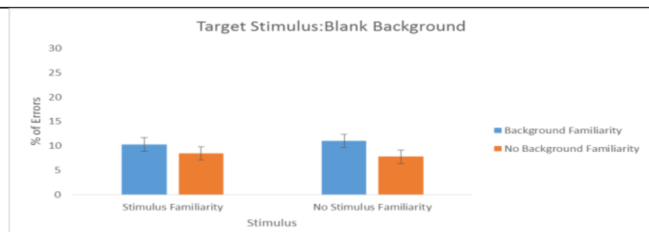
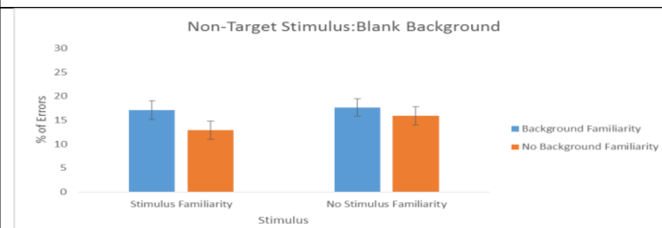
Table 12 t-Tests for Response Condition: Non-Target Stimulus on Blank Background

Non-Target Stimulus on Blank Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			
Familiar with Target Stimulus and Non-Target Background	p=.114	-		

Non-Target Stimulus on Blank Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Non-Target Stimulus and Familiar with Target Background	p=.853	p=.085	-	
Familiar with Non-Target Stimulus and Non-Target Background	p=.644	p=.22	p=.516	-

The table presented on the next page summarizes the individual percent of error analyses for the ease of the reader. None of the individual analyses were significant.

Table 13 Graphs Across Error Response Conditions

	Target Stimulus	Non-Target Stimulus
Target Background		
Non-Target Background		
Blank Background		

Full Reaction Time Analysis

A 2 Stimulus-Familiarity (Familiar with Target Stimulus, Familiar with Non-Target Stimulus) by 2 Background-Familiarity (Familiar with Target Background, Familiar with Non-Target Background) by 2 Stimulus (Target Stimulus, Non-Target Stimulus) by 3 Background (Target Background, Non-Target Background, Blank Background) by 12 Degree (0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330) mixed ANOVA was run using reaction time as the dependent variable. Stimulus-Familiarity and Background-Familiarity were between-subjects variables. Background, Stimulus, and Degree were within-subjects variables. Across all within-subjects conditions there were violations of sphericity at $p=.05$ using Mauchly's Test of Sphericity. The Huynh-Feldt correction was used to account for this violation of sphericity.

A main-effect occurred for Shape $F(1,114) = 48.491$, $p < .05$, $\eta_p^2 = .298$. Further examination revealed that the Target Stimulus (M = 2639.144, SD = 695.076) was rotated significantly more quickly than Non-Target Stimulus (M = 2988.832, SD = 996.225). This main effect can be seen in the figure below.

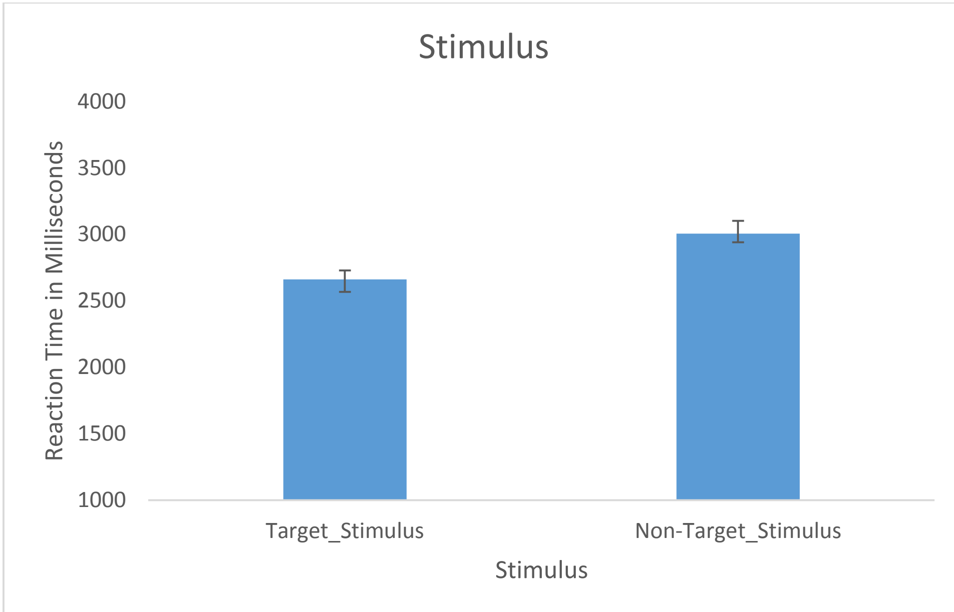


Figure 39 Main Effect: Stimulus

A significant main effect occurred for the variable Background as well F (2,228) = 8.46, p <.05, η_p^2 = .069. Reaction time for stimuli presented when there was Blank Background (M = 2792.139, SD = 808.274) were significantly faster than both the Target Background (M = 2874.091, SD = 850.052) and Non-Target Background (M = 2837.299, SD = 817.32). LSD post hoc analyses reveal significant differences between the Blank Background and the Target Background (p<.05) and the Blank Background and Non-Target Background (p<.01). There was a marginally significant difference between the Target Background and Non-Target Background (p=.052). See graph below.

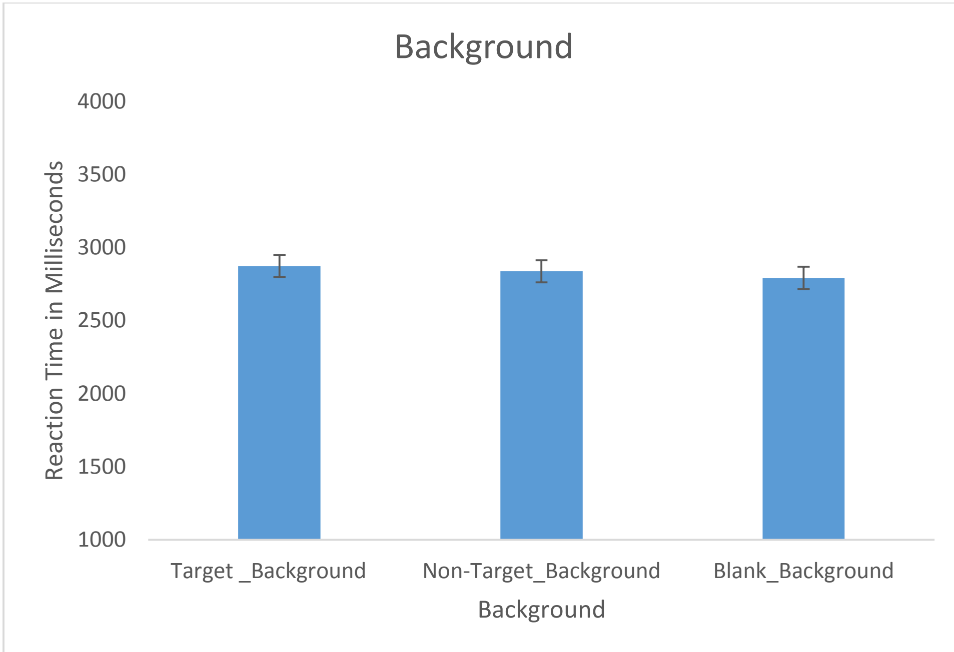


Figure 40 Main Effect: Background

A significant main effect occurred for degree of rotation F (6.971, 759.804) = 159.625, p<.05, η_p^2 = .594. As seen in the graph below, the mental rotation curve, similar to the results from the error analysis, appears to level off after the stimulus is rotated to 90 degrees.

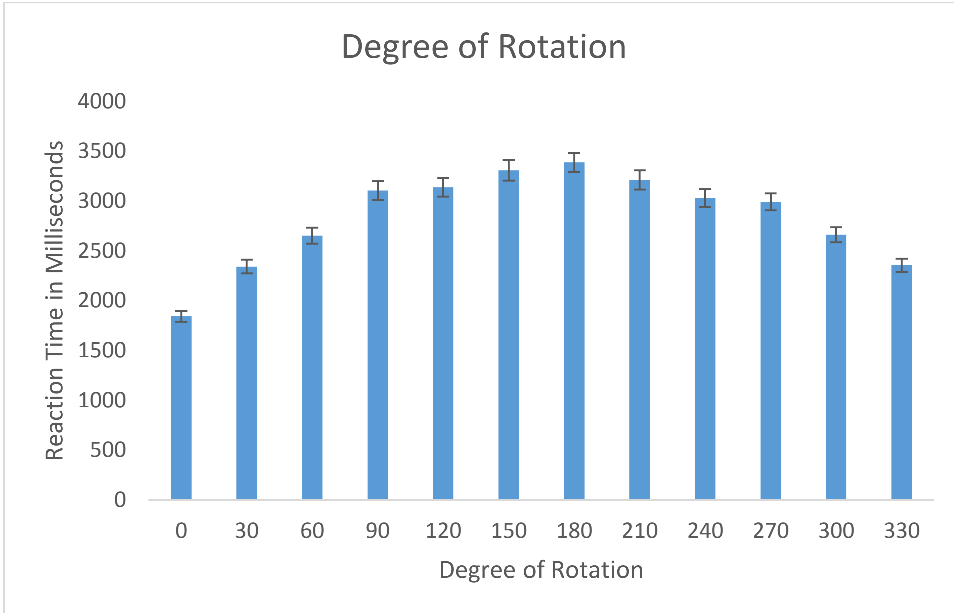


Figure 41 Main Effect: Degree of Rotation

A significant interaction occurred between stimulus and degree of rotation F (8.79, 958.073) = 3.346, p<.01, η_p^2 = .03. As seen in Figure 41 below the Non-Target Stimulus has a higher reaction time overall as degree of rotation increases than the Target Stimulus.

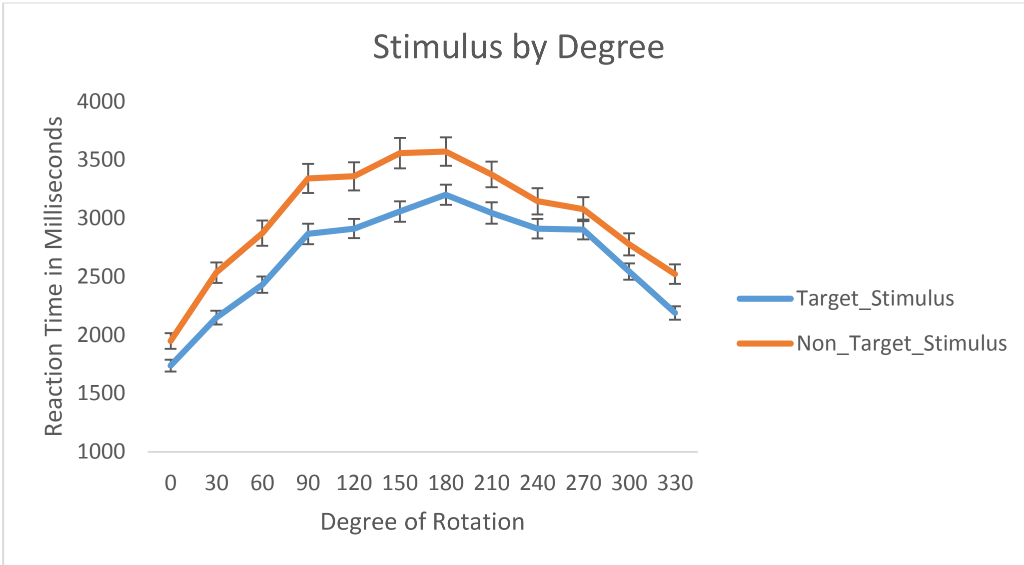


Figure 42 Interaction: Stimulus by Degree

Another significant interaction occurred between Background Familiarity, Stimulus Familiarity, and Degree of rotation F (6.971, 759.804) = 2.081, p<.05, η_p^2 = .019. As seen in Graph 42 below, it appears that as degree of rotation increases it takes longer to rotate the shape when participants are not familiar with the target stimulus or the target background than participants who were familiar with the target background and not the target stimulus.

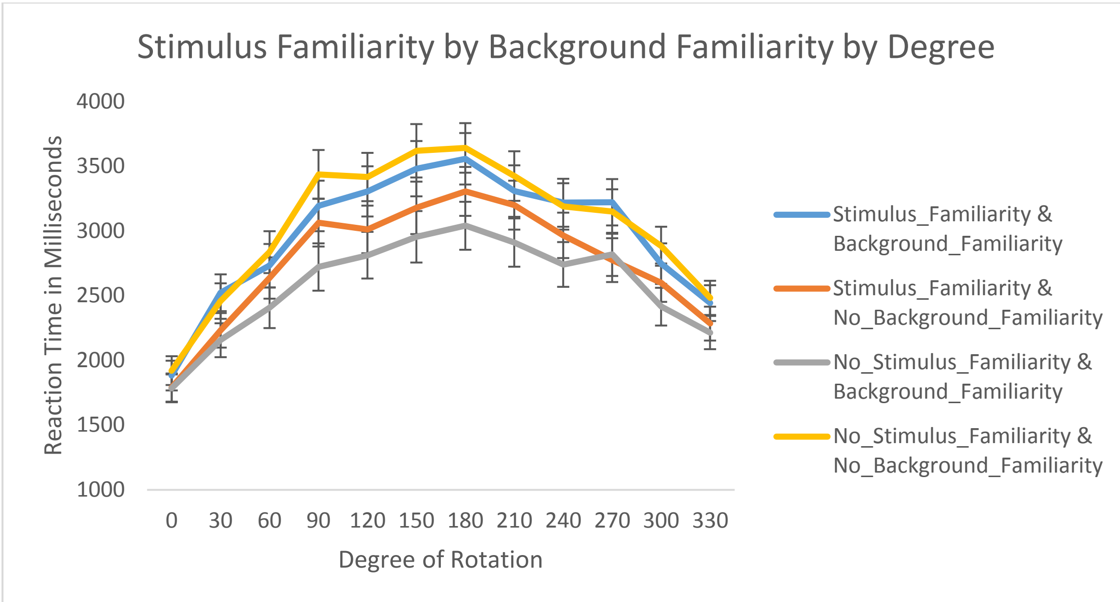


Figure 43 Interaction: Interaction: Stimulus Familiarity by Background Familiarity by Degree

There was a between subjects interaction between Stimulus Familiarity and Background Familiarity conditions F (1, 109) = 4.771 p<.05, η_p^2 = .042. Participants who were not familiarized with the target stimulus but familiarized with the target background had an overall reaction time (*M* = 2580.641, *SD* = 1583.020), across all stimuli and backgrounds, that was lower than the other three conditions; as seen in Figure 43 below.

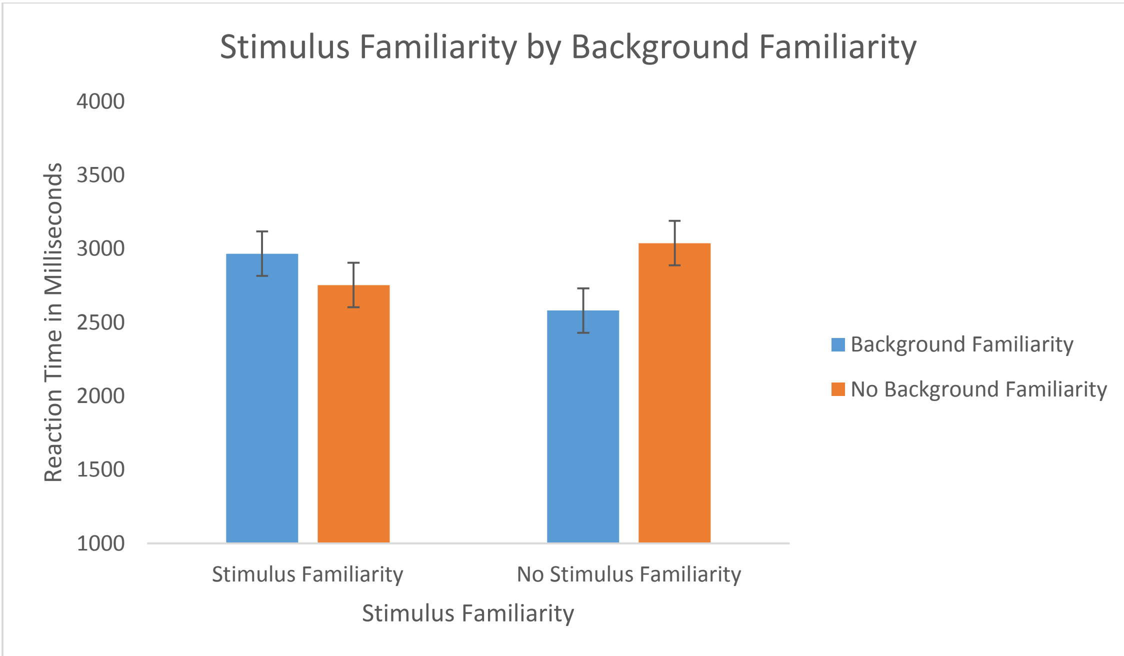


Figure 44 Interaction: Stimulus Familiarity by Background Familiarity

<u>Individual Reaction Time Analysis</u>

A 2 Stimulus-Familiarity (Familiar with Target Stimulus, Familiar with Non-Target Stimulus) by 2 Background-Familiarity (Familiar with Target Background, Familiar with Non-Target Background) by 12 Degree (0, 30, 60, 90, 120, 150, 180, 210, 240, 270, 300, 330) mixed ANOVA was run using reaction time as the dependent variable. Stimulus-Familiarity and Background-Familiarity were between-subjects variables. Separate mixed ANOVAs were conducted for each response condition. The response conditions will be: Target Stimulus with Target Background, Target Stimulus with Non-Target Background, Target Stimulus with Blank Background, Non-Target Stimulus with Target Background, Non-Target Stimulus with Non-Target Background, and Non-Target Stimulus with Blank Background. Across all within-subjects conditions, there were violations of sphericity at p=.05 using Mauchly's Test of Sphericity. The Huynh-Feldt correction was used to account for these violations of sphericity.

Response Condition: Target Stimulus with Target Background

A main effect occurred for response condition Target Stimulus presented on Target Background for degree F (9.218, 1004.774) = 43.403, p<.01, η_p^2 = .285 as can be seen below. Interestingly, as with the previous results, the rate of rotation seems to level off as it approached 90 degrees.

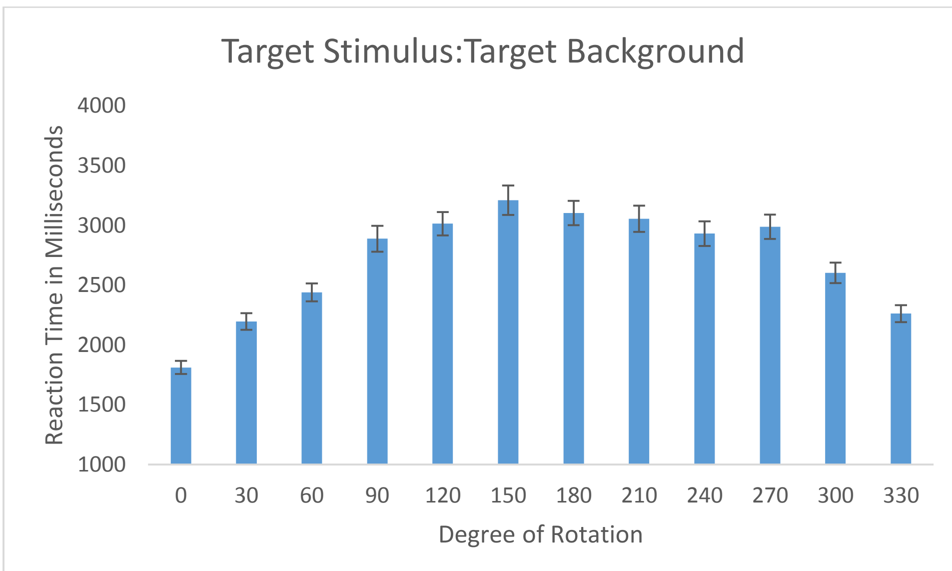


Figure 45 Main Effect: Degree of Rotation

Though there were no higher order effects involving degree, there was a significant interaction between Stimulus Familiarity and Background Familiarity F (1,109) = 5.639, p<.05, η_p^2 = .049. This can be seen in the graph below

.

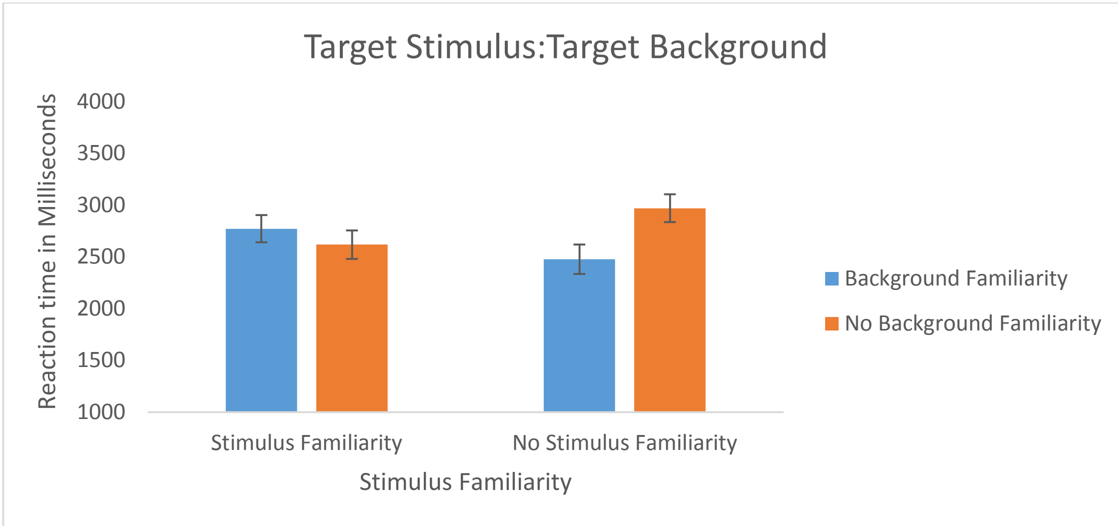


Figure 46 Interaction: Stimulus Familiarity by Background Familiarity

To further examine the results for the response condition: Target Stimulus on Target Background independent samples t-tests were conducted comparing all familiarity conditions to one another. The results are summarized in the table below displaying the p-value for each comparison. It is important to notice that there was a significant difference between participants not familiarized with the target stimulus but familiarized with the target background (*M* = 2476.676, *SD* = 1402.892) had a significantly lower reaction time than participants familiarized with neither the target stimulus and target background (*M* = 2969.24, *SD* = 1452.131). This can be seen in the table below.

Table 14 Post-Hoc Results Target Stimulus by Target Background Response Condition

Target Stimulus on Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			
Familiar with Target Stimulus and Non-Target Background	p=.439	-		
Familiar with Non-Target Stimulus and Familiar with Target Background	p=.089	p=.473	-	
Familiar with Non-Target Stimulus and Non-Target Background	p=.325	p=.096	p=.008	-

Response Condition: Target Stimulus with Non-Target Background

A main effect occurred for response condition Target Stimulus with Non-Target Background for degree F (9.828, 1071.249) = 47.396, p<.001, η_p^2 = .303 as can be seen in the graph below

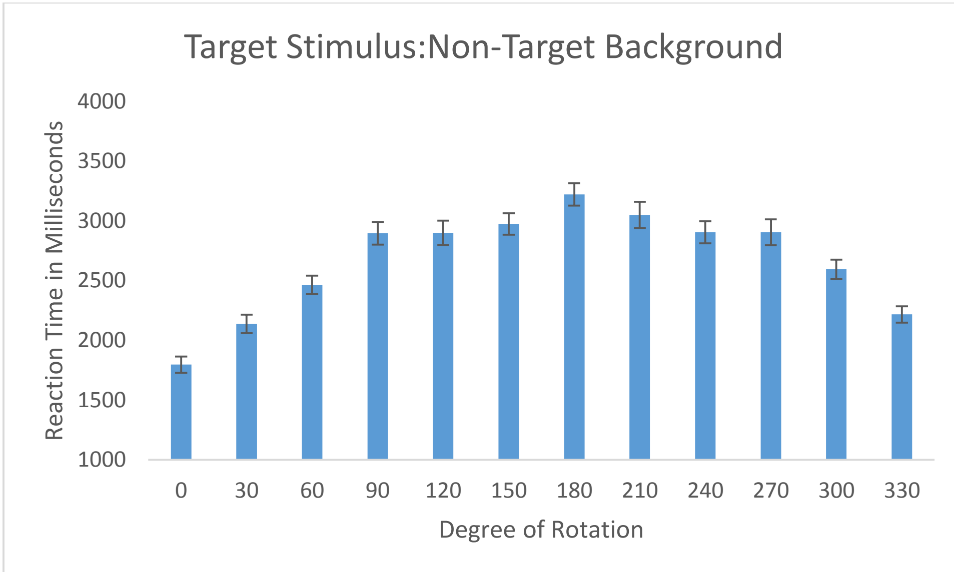


Figure 47 Main Effect: Degree of Rotation

Though there were no higher order effects involving degree, there was a significant interaction between Stimulus Familiarity and Background Familiarity F (1,109) = 5.797, $p < .05$, $\eta_p^2 = .05$.

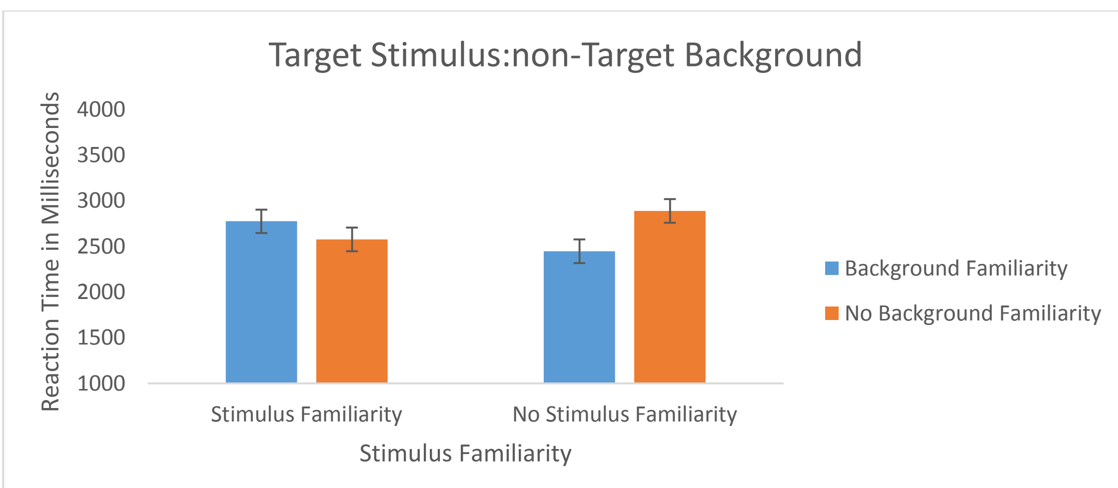


Figure 48 Interaction: Stimulus Familiarity by Background Familiarity

To further examine the results for the response condition: Target Stimulus on Non-Target Background independent samples t-tests were conducted comparing all familiarity conditions to one another. The results are summarized in the table below displaying the p-value for each comparison. As with the Target Stimulus on Target Background condition, there was a significant difference between participants familiarized with the non-Target Stimulus and Target Background (*M* =2405.167, *SD* =1334.873) than participants familiarized with neither the Target Stimulus nor the Target Background (*M* =2889.006, *SD* =1449.171). There was also a marginally significant effect when comparing participants familiarized with the non-Target Stimulus and Target Background (*M* =2405.167, *SD* =1334.873) and participants familiarized with both the Target Stimulus and Target Background (*M* =2743.085, *SD* =1475.763). This can be seen in the table below.

Table 15 Target Stimulus on Non-Target Background

Target Stimulus on Non-Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			
Familiar with Target Stimulus and Non-Target Background	p=.335	-		
Familiar with Non-Target Stimulus and Familiar with Target Background	p=.064	p=.502	-	

Target Stimulus on Non-Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Non-Target Stimulus and Non-Target Background	p=.534	p=.127	p=.013	-

Response Condition: Target Stimulus with Blank Background

A main effect occurred for degree of rotation in the response condition Target Stimulus with Blank Background F (9.691, 1056.321) = 56.708, $p < .01$, $\eta_p^2 = .342$ as can be seen in the graph below.

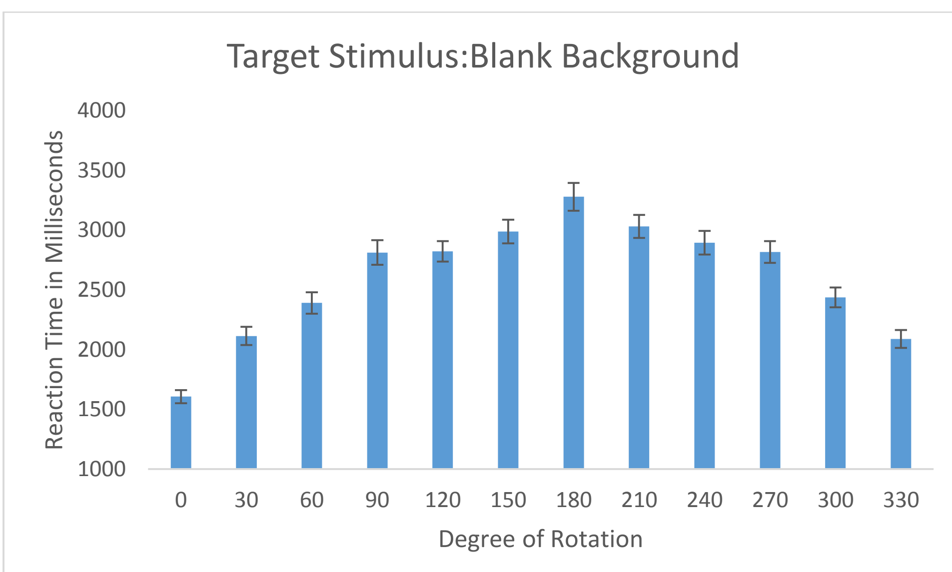


Figure 49 Main Effect: Degree of Rotation

Though there were no higher order effects involving degree, there was a significant interaction between Stimulus Familiarity and Background Familiarity F (1,109) = 9.973, $p < .005$, $\eta_p^2 = .084$.

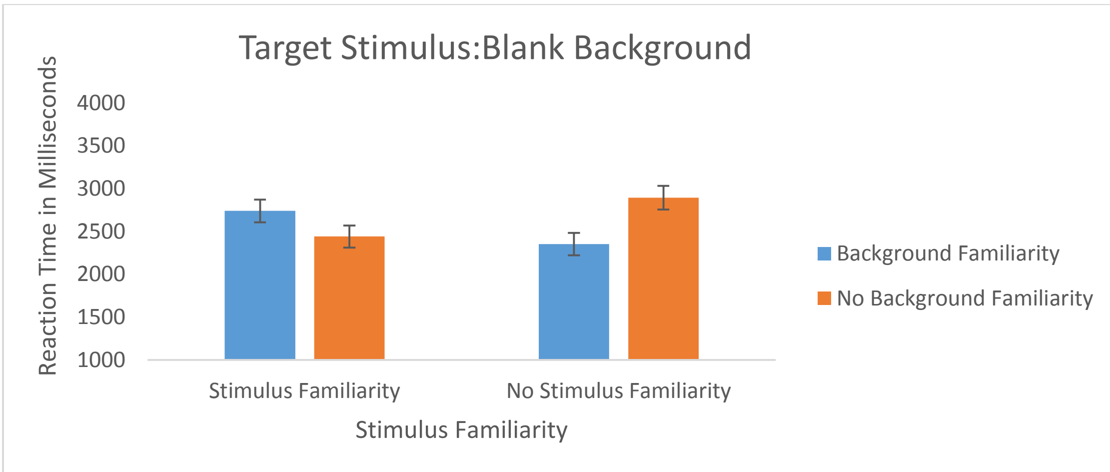


Figure 50 Interaction: Stimulus Familiarity by Background Familiarity

To further examine the results for the response condition: Target Stimulus on Blank Background independent samples t-tests were conducted comparing all familiarity conditions to one another. The results are summarized in the table below displaying the p-value for each comparison. As with the previous response conditions, there was a significant difference between participants familiarized with the non-Target Stimulus and Target Background (*M* = 2352.163, *SD* = 1368.334) than participants familiarized with neither the Target Stimulus nor the Target Background (*M* =2892.899, *SD* =1416.361). There was also a significant effect when comparing participants familiarized with the non-Target Stimulus and Target Background (*M* = 2352.163, *SD* = 1368.334) and participants familiarized with both the Target Stimulus and Target Background (*M*

=2739.859, *SD* =1469.82). Another significant effect occurred for participants familiarized with the Target Stimulus and Non-Target Background (*M* = 2441.611, *SD* = 1391.72) who had lower reaction times than participants familiarized with the non-Target Stimulus and Target Background (*M* = 2352.163, *SD* = 1368.334). This can be seen in the table below.

Table 16 Target Stimulus on Blank Background

Target Stimulus on Blank Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			
Familiar with Target Stimulus and Non-Target Background	p=.15	-		
Familiar with Non-Target Stimulus and Familiar with Target Background	p=.032	p=.618	-	
Familiar with Non-Target Stimulus and Non-Target Background	p=.422	p=.027	p=.003	-

Response Condition: Non-Target Stimulus with Target Background

A main effect occurred for the response condition with the non-Target Stimulus and Target Background for degree F (8.655, 943.386) = 29.659, p<.05, η_p^2 = .214 as can be seen in the graph below.

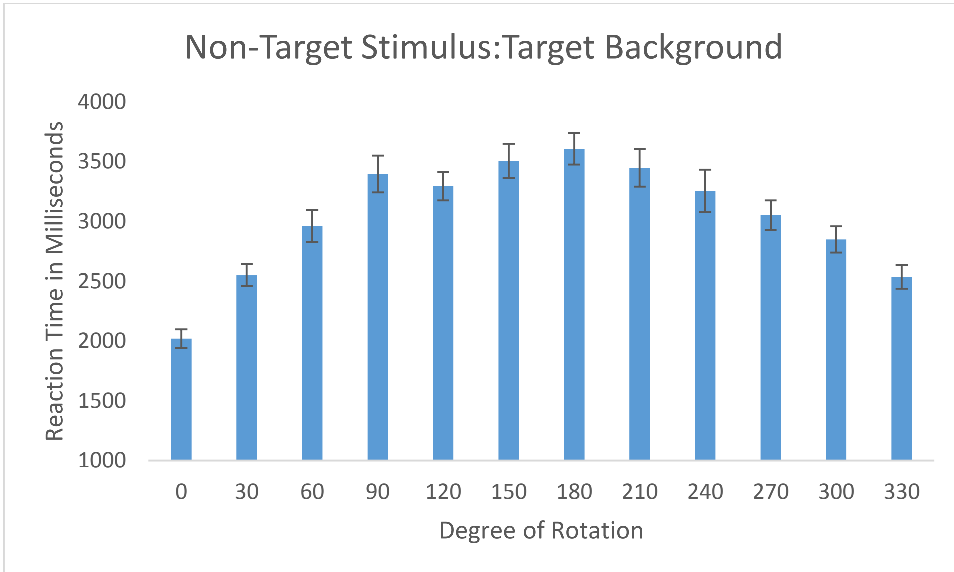


Figure 51 Degree of Rotation, Non-Target Stimulus with Target Background

There were no higher order effects involving degree, and unlike the Target Stimulus response conditions there was not a significant interaction between Stimulus Familiarity and Background Familiarity F(1,109)=2.894, p=.092, η_p^2 = .026; which can be seen in the graph below.

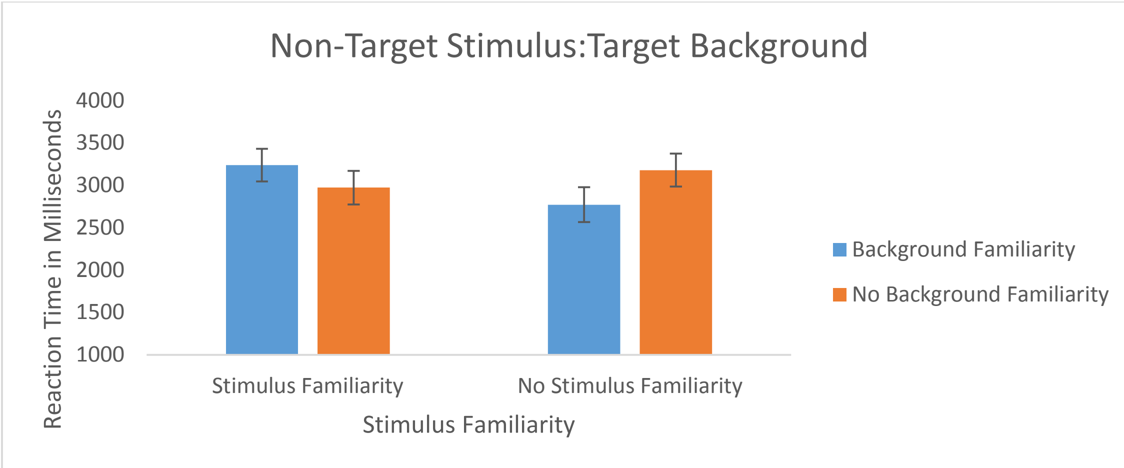


Figure 52 Interaction: Stimulus Familiarity by Background Familiarity

Interestingly though there wasn't a significant interaction effect as with the previous analyses, there was a marginally significance t-test. Participants familiarized with the non-Target Stimulus and Target Background (*M* = 2769.96, *SD* = 2036.92) had a lower reaction time than participants familiarized with both the Target Stimulus and Target Background (*M* = 3237.77, *SD* = 2188.003). This can be seen in the table below.

Table 17 Non-Target Stimulus on Target Background

Non-Target Stimulus on Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			

Non-Target Stimulus on Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Non-Target Background	p=.41	-		
Familiar with Non-Target Stimulus and Familiar with Target Background	p=.063	p=.459	-	
Familiar with Non-Target Stimulus and Non-Target Background	p=.836	p=.508	p=.093	-

Response Condition: Non-Target Stimulus with Non-Target Background

A main effect occurred for degree of rotation for the response condition with the non-Target Stimulus and non-Target Background F (7.365, 802.811) = 33.68, p<.001, η_p^2 = .236 as can be seen in the graph below.

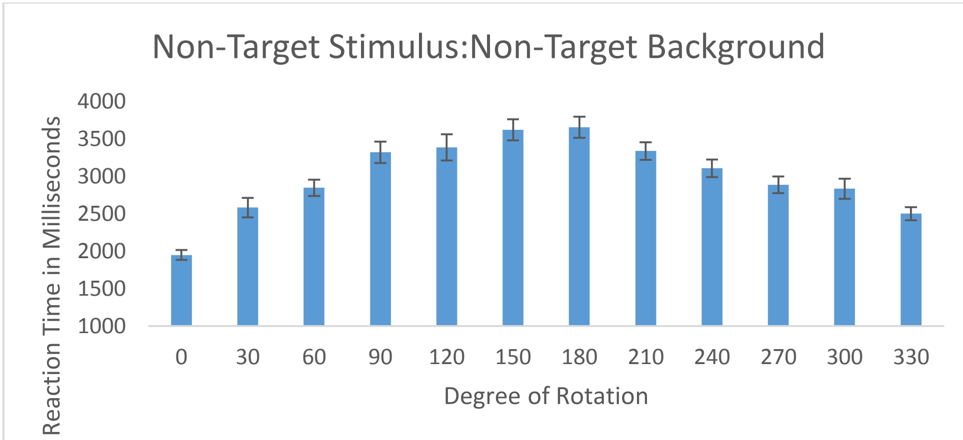


Figure 53 Main Effect: Degree of Rotation

There were no higher order effects involving degree, and similar to the non-Target Stimulus with Target Background response condition there was not a significant interaction between Stimulus Familiarity and Background Familiarity F (1,109)=3.148, p=.0079, η_p^2 = .028; which can be seen in the graph below.

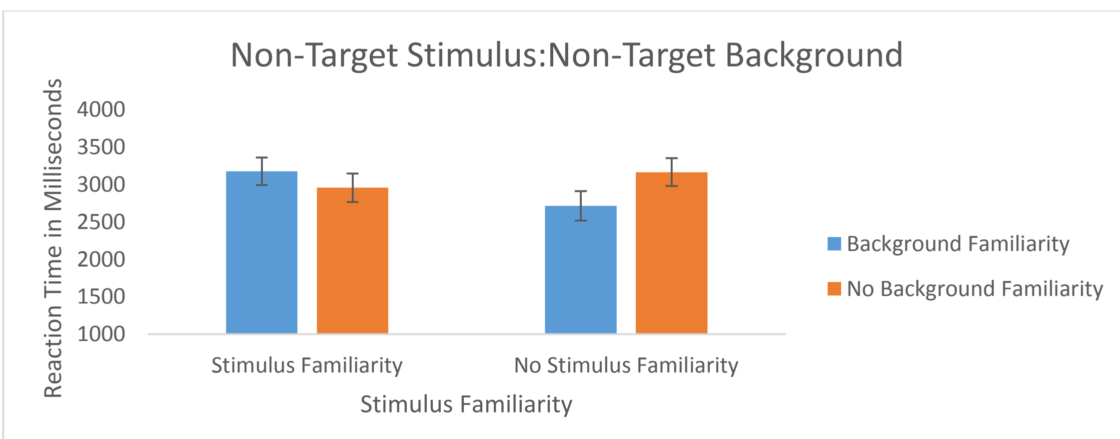


Figure 54. Interaction: Stimulus Familiarity by Background Familiarity

As with the Non-Target Stimulus on Target Background response condition, there were only marginally significant results for the t-tests examining individual responses. There was a marginally significant difference between participants familiarized with the non-Target Stimulus and Target Background (*M* = 2713.77, *SD* = 1946.22) than participants familiarized with neither the Target Stimulus nor the Target Background (*M* = 3164.294, *SD* = 2014.53). This can be seen in the table below.

Table 18 Non-Target Stimulus on Non-Target Background

Non-Target Stimulus on Non-Target Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			
Familiar with Target Stimulus and Non-Target Background	p=.467	-		
Familiar with Non-Target Stimulus and Familiar with Target Background	p=.053	p=.344	-	
Familiar with Non-Target Stimulus and Non-Target Background	p=.965	p=.484	p=.063	-

Response Condition: Non-Target Stimulus with Blank Background

A main effect occurred for degree of rotation for the response condition featuring the non-Target Stimulus with Blank Background F (8.989, 979.781) = 40.413, p<.01, η_p^2 = .27 as can be seen in the graph below.

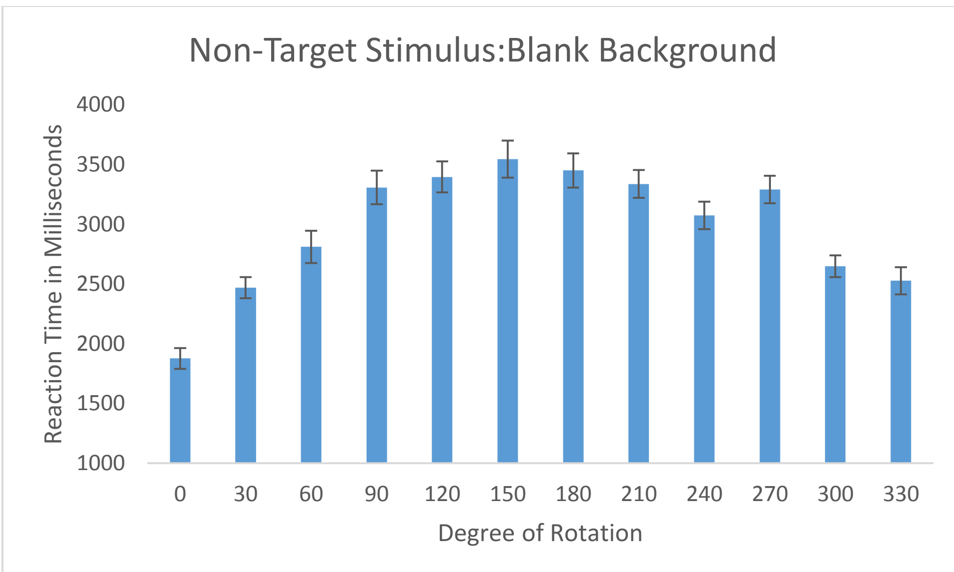


Figure 55 Main Effect: Degree of Rotation

There were no higher order effects involving degree, and similar to the Non-Target Stimulus on Target Background and Non-Target Stimulus on Non-Target Background response conditions there was not a significant interaction between Stimulus Familiarity and Background Familiarity F(1,109)=2.248, p=.137, η_p^2 = .02; which can be seen in the graph below.

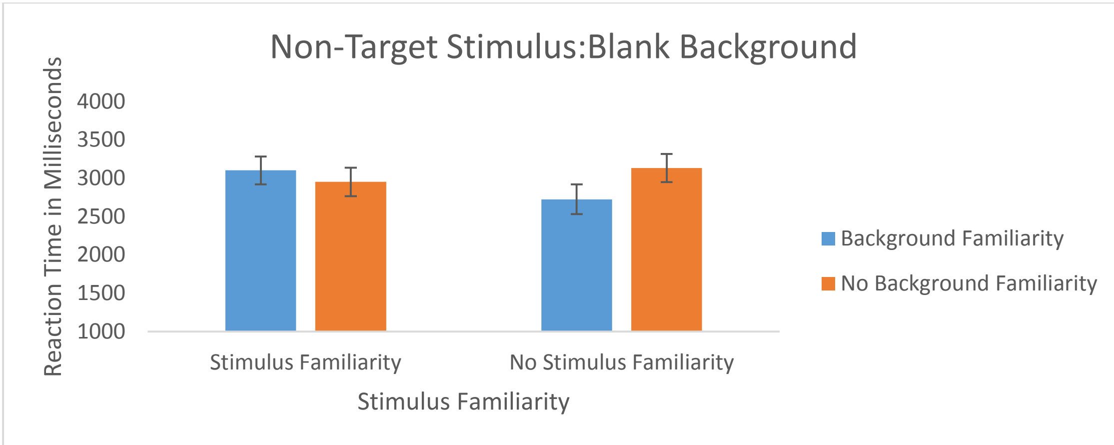


Figure 56 Interaction: Stimulus Familiarity by Background Familiarity

As with the Non-Target Stimulus on Target Background response condition, there were only marginally significant results for the t-tests examining individual responses. There was a marginally significant difference between participants familiarized with the non-Target Stimulus and Target Background (*M* = 2724.75, *SD* = 1916.96) than participants familiarized with neither the Target Stimulus nor the Target Background (*M* = 3132.133, *SD* = 1984.24). This can be seen in the table below.

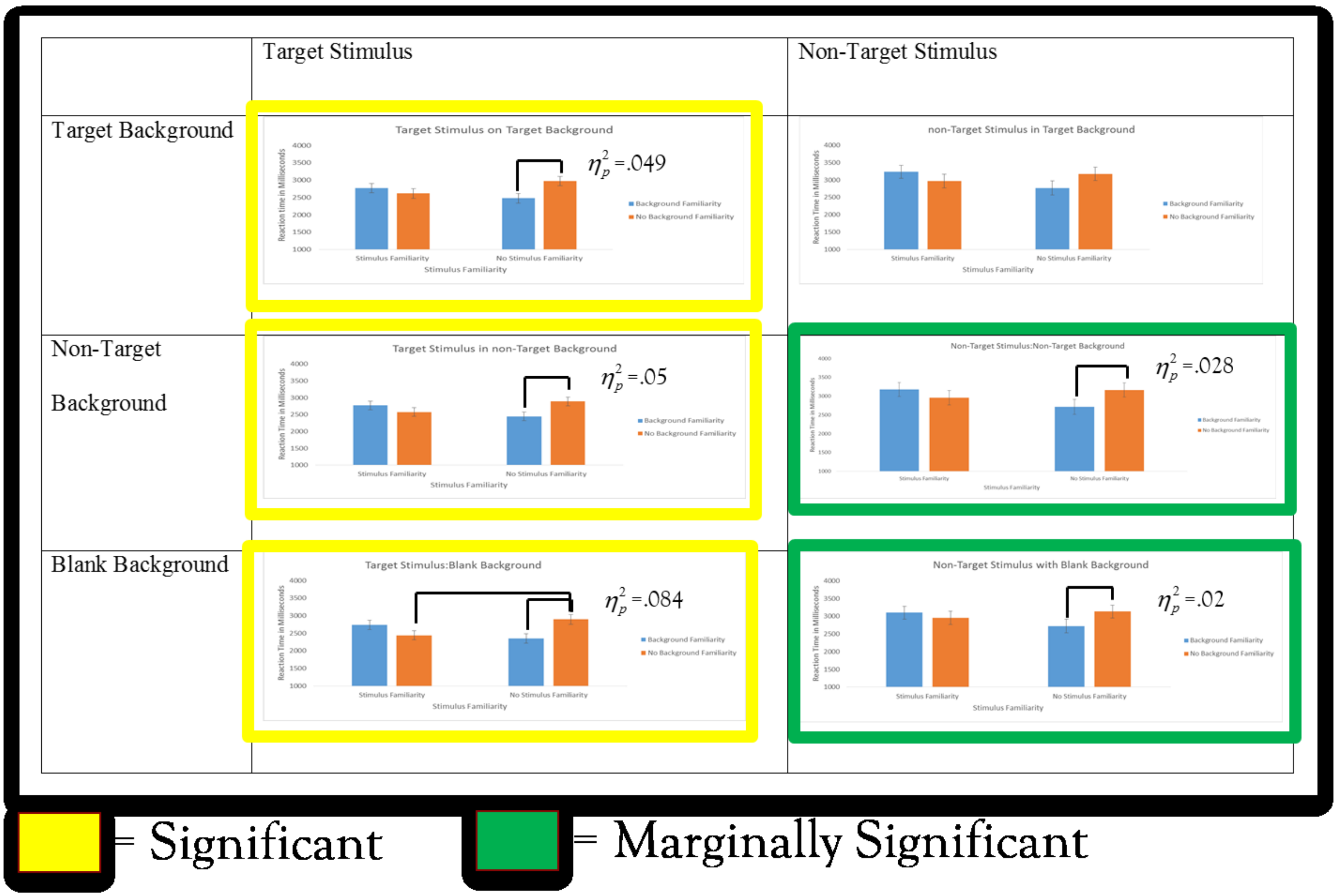
Table 19 Non-Target Stimulus on Blank Background

Non-Target Stimulus on Blank Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Stimulus and Target Background	-			
Familiar with Target Stimulus and Non-Target Background	p=.619	-		
Familiar with Non-Target Stimulus and	p=.101	p=.394	-	

Non-Target Stimulus on Blank Background				
	Familiar with Target Stimulus and Target Background	Familiar with Target Stimulus and Non-Target Background	Familiar with Non-Target Stimulus and Familiar with Target Background	Familiar with Non-Target Stimulus and Non-Target Background
Familiar with Target Background				
Familiar with Non-Target Stimulus and Non-Target Background	p=.965	p=.484	p=.063	-

A summary of the interaction analyses, for response time, is presented on the next page.

Table 20 Summary Graphs Across All Response Conditions



CHAPTER FIVE: DISCUSSION

To examine the effects of complex backgrounds on mental rotation, the familiarity of the target object and target background were manipulated. Participants were assigned to one of four familiarity conditions. They were familiarized with the target stimulus and target background, the target stimulus and not the target background, not the target stimulus and target background, or neither the target stimulus or target background. The purpose of this was to examine how familiarity with the target stimulus or target background would affect percent of errors and reaction time in mental rotation.

<u>Research Hypothesis 1</u>

Research hypothesis 1 theorizes that there was a reduction in the time it takes to rotate the target stimulus due to stimulus familiarity. This reduction in reaction time would have occurred across all backgrounds, both target and non-target.

Overall, research hypothesis 1 was partially supported by the results. It appears as though when participants were familiar with only the Target Stimulus they had a lower reaction time than those familiarized with neither the Target Stimulus nor Target Background. Though, those who were familiarized with both the Target Background and Target Stimulus did not have a response time significantly different than those in the conditions that were not familiarized with the Target Stimulus and Target Background. So, it does not appear that stimulus familiarity has a reduction in reaction times in participants that also were familiar with the Target Background. This ineffectiveness is apparent, because there was not a significant difference between participants familiar with both the Target Stimulus and Target Background did not perform significantly different, in terms of reaction time, when compared to participants who were familiar with neither the Target Stimulus nor the Target Background. Participants that were familiar with only the Target Stimulus had a lower response time, on the Blank Background, than the participants familiarized with neither the Target Stimulus nor the Target Background. This is in line with previous studies on stimulus familiarity (Smith & Dror, 2001) indicating that stimulus familiarity improves mental rotation when a background is not present. Implications about the results for the participants familiarized with both the Target Stimulus and Target Background will be discussed in a later section.

Research Hypothesis 2

It is hypothesized that background familiarity will reduce the time to rotate any stimulus, target or non-target, in that background.

Overall, Research Hypothesis 2 was partially supported by the results. Participants who were familiarized with only the Target Background had a lower reaction time than those not familiarized with either the Target Stimulus or Target Background. Though, participants who were familiarized with both the Target Background and Target Stimulus were not significantly different than those not familiarized with the Target Stimulus or Target Background. In Conclusion, it was not fully supported because not all participants familiarized with the Target Background had a lower reaction time than those who were not. Only the participants who were familiarized with only the Target Background and not the Target Stimulus had a significantly, and marginally significant

($p<.070$), different reaction time than those who were not familiarized with the Target Stimulus and Target Background.

Research Hypothesis 3

It is hypothesized that there will be a compounding effect between stimulus familiarity and background familiarity. When subjects are familiar with both the target stimulus and the target background, there will be a significant reduction in the time to rotate the familiar target stimulus on the familiar target background.

Research Hypothesis 3 was not supported. To support Research Hypothesis 3, there should have been a significant difference between participants familiarized with the Target Stimulus and Target Background when compared to all other participants; this did not happen. Participants familiarized with the Target Stimulus and Target Background did not perform significantly different than participants in all other conditions. Across all response conditions, participants that were familiarized with both the Target Stimulus and Target Background had a higher reaction time than participants with only Target Stimulus or Target Background familiarity.

Theoretical Implications

Implications for Stimulus Familiarity and Complex Backgrounds

The theoretical implications for this dissertation on stimulus familiarity and complex backgrounds are such that stimulus familiarity does not seem to have an effect on mental rotation when a complex background is present. This implies that the effects of including a complex background in the mental rotation task has an effect that is unrelated to the rotation of the stimulus it is presented upon. It also implies that familiarity with the stimulus does not aid in separating the stimulus from the background, which is contrary to the implications from the figure-ground literature. According to the findings from the figure-ground literature (Peterson & Gibson, 1994), familiarization with the stimulus should have aided in separating the stimulus in mental rotation performed with a complex background. This would effect would have been observed in the response conditions in which the Target Stimulus was present with a complex background.

One possibility is that stimulus familiarity may not aid in discriminating the stimulus from the background. Stimulus familiarity may only provide a benefit when there is no background present. This is contrary to much of the mental rotation literature (Tarr and Pinker, 1989), but corroborates the finding from Heil and Rolke (2002). Heil and Rolke presented familiar objects (Alphanumeric characters) with low contrast to a complex background (black letters on a gray background with white and black circles), it was shown that the addition of the background increased the time to rotate the familiar letters. Thus, even when the characters were familiar, the background still increased the time to rotate the familiar stimuli. This effect may occur for both novel stimuli that are trained to be familiar and stimuli that are already familiar; such as letters. Future research can explore the relationship between stimulus familiarity and will be discussed at greater length in a later section.

Implications for Background Familiarity and Mental Rotation

The theoretical implications for familiarity with the background are such that when a person is only familiar with the environment a stimulus is presented upon, it may aid in promoting a strategy during mental rotation that involves separating that stimulus from the familiar background. This is consistent with the visual search literature reviewed earlier (Wang, Cavanagh, & Green; 1994), stating that when the background around an object to be located during visual search, is familiar, it is easier to find the unfamiliar object. This could imply that, when a stimulus is in a background, during mental rotation one must separate the stimulus from the background to perform mental rotation. This extra stage of background separation and processing is not explicitly included in the traditional mental rotation task analysis. In the traditional mental rotation task analysis there is only a stage called "identification of the shape to be mentally rotated". It is not explicitly mentioned whether this indicates that the shape must be separated from other shapes around it, the background it is in front of, or whether other forms of discrimination take place. The implications of this would be that background discrimination and mental rotation are inherently two separate tasks that can be performed either simultaneously or sequentially, similar to the color discrimination task mentioned in the introduction, from Ruthruff and Miller (1995). In Ruthruff and Miller (1995), it was shown that mental rotation and perceptual color discrimination can be processed simultaneously resulting in a shorter reaction time when compared to both processes performed sequentially. Participants familiar with only the Target Background may have been employing a strategy in which they performed mental rotation and background discrimination simultaneously, whereas participants in the rest of the familiarity conditions may be employing a sequential discrimination strategy. Directions and implications for future research will be discussed in the future research section.

Implications for both Stimulus Familiarity and Background Familiarity during Mental Rotation

The implications for familiarity with both stimulus and background in the mental rotation task are such that; when one is familiar with both it appears to inhibit mental rotation performance to an extent. It is theorized that when participants were familiarized with both the stimulus and the background it promoted an inefficient sequential mental rotation strategy. This strategy could be one in which the participant may have focused on the relationship between the object and the background individually instead of trying to separate the two simultaneously. This could be why there was not the same difference in performance, when compared to the group not familiarized with either stimulus or background, as seen in the participants familiarized with only the background. Specifically, in the condition in which the Target Stimulus and Blank Background were present, the participants who were familiarized with both the Target Stimulus and Target Background did not have a difference in performance when compared to the participants not familiar with the Target Stimulus and Target Background. The participants who were only familiarized with the Target Stimulus and not the Target Background had a significantly lower reaction time when compared to the participants familiar with neither the Target Stimulus nor the Target Background. This would imply that familiarity with both the Target Stimulus and Target Background transferred an inefficient sequential mental rotation strategy even when a non-complex blank background was present

Practical Implications

Practical Implications for Mental Rotation and Training

Though the primary impetus of this study was to investigate the relationship between mental rotation and complex backgrounds, there are some implications that can be drawn about familiarization training with stimuli and mental rotation. The implications that a stimulus can be familiarized at a single orientation and improve performance on a blank background are contrary to previous studies that indicate that familiarity only occurs at specific learned orientations. This finding is more in line with the findings from Smith and Dror (2002), which found that familiarity with mental rotation stimuli can be extended to previously unknown orientations. It is not in line with Tarr and Pinker (1989), who found that participants rotated to the nearest familiar orientation and that familiarity only aided participants when the participant was familiar with multiple orientations of the stimulus. The implication of this finding is that one can familiarize participants at a single orientation and that can be generalized to other orientations during mental rotation.

A practical implication for mental rotation and training is in the area of Laparoscopic surgery. Laparoscopic surgery is a procedure in which the surgeon remotely views the procedure using a camera, held by an operator, and viewed on a screen (Stransky, Wilcox, & Dubrowski, 2010). Previous research has shown that improvements in mental rotation and spatial skills can improve performance on Laparoscopic surgery tasks (Stransky, Wilcox, & Dubrowski, 2010). Findings from the current study, demonstrate that one can be familiarized with an object at a single angle and have improvements in mental rotation performance during the mental rotation task.

Future studies could investigate whether or not familiarity with the objects present during the Laparoscopic surgery task at a single angle would improve Laparoscopic surgery performance at untrained angles. This would expand upon the study performed by Stransky, Wilcox, & Dubrowski (2010), since their primary question is whether general mental rotation familiarity improves performance during laparoscopic surgery tasks.

This also has implications for the teleoperation of robots and space operations. It is often the case that tele-operated robots operate in confined spaces and have a limited point of view (Menchaca-Brandan, Liu, Oman, & Natapoff, 2007) when in space. The operator may only be able to see the task at hand from a single perspective and have to rely upon perspective taking and mental rotation in order to accomplish the task using a tele-operated robot. An area that the current dissertation could be of use is in the training for such tasks. The implications are such that one can become familiar with the object at a single orientation and practice the operation at that orientation in simulated exercises prior to launch. This training would then generalize to other orientations during the task on the space station.

Practical Implications and Applications

One practical implication for this study is in the realm of augmented reality (e.g. Microsoft's Hololens, Oculus Rift, Nintendo 3DS). It may be that when one is in an environment that is familiar, i.e. a familiar background, it could be easier to perform spatial manipulations of objects on that background; as found in the current study. This is especially if these augmented reality technologies are meant to be implemented in engineering and other spatially demanding courses in the future. Previous studies have shown that spatial abilities instruction (Hsi, Linn, & Bell, 1997) can be a significant predictor of performance in an introductory engineering course. With the future adoption of augmented reality for engineering applications, implications can be drawn from the current study in that one must consider the background that the augmented reality object is being presented upon. Learning to do the spatial manipulation task in an unfamiliar background may make it more difficult to spatially manipulate objects which could affect course performance. Though, if one begins the task in a familiar environment (read: Familiar Background) then, based on the current results, this experience should transfer to spatial manipulations in unfamiliar backgrounds

Limitations and Future Research

One of the limitations from the current study is that the stimuli were all monochromatic unrealistic fabricated objects. Since this experiment was very novel, there were many visual factors (such as: color density and saliency) that limited the use of realistic stimuli. Future research could investigate the use of more distinctive stimuli, realistic stimuli, and realistic backgrounds. This could allow for more generalizability when applying these results to the domains mentioned earlier; robot tele-operation and augmented reality

Another limitation of the current study is that it was a very controlled laboratory study, this could be expanded upon in future studies by testing out the same principles in a more applied setting. A limitation also stems from the instructions given during the task which required participants to only recognize the stimuli during the task. This may have not made participants familiar with the whole background. Future studies could modify the procedure such that familiarity with the whole background is achieved.

A path for future researchers to tread stems from a limitation of the current study. A limitation is that it does not explore familiarity from multiple sessions over a longer period of time. Studies (Tarr & Pinker, 1989) previously familiarized participants with mental rotation stimuli over a week or more. Future studies could investigate how stimuli and background familiarity interact over a longer period of familiarity training. This could clarify the finding from the current study in which familiarity with both the stimulus and background seemed to not improve mental rotation performance as Hypothesis 3 suggested it would.

Another direction for future research is to investigate the effects of rotation familiarity and background familiarity. One could investigate the effects of pairing a rotation familiarity exercise with a complex background familiarity exercise. This type of exercise may have a stronger effect in allowing participants to learn a mental rotation strategy that involves separating the stimulus, to be mentally rotated upon a complex background, from said background. The current study did not reinforce or teach this strategy, it instead investigated the effects of familiarity on mental rotation and complex backgrounds. A study specifically teaching said mental strategy could be a direction for future research.

APPENDIX A:
PILOT STUDY

Method

Participants

Fourteen participants (M_{age} = 20.86, SD_{age} = 1.89) were recruited to participate in this pilot study using the Psychology Department's SONA system. There were 8 male participants and 6 female participants. Based on a power analysis using G*Power (Fraul, Erdfelder, Lang, Buchner, 2007) it was determined that a power of .84 was achieved.

Design

A one way repeated measures design was employed in the pilot study. There were four different within-subjects response variables: Large Background Object Size, Medium Background Object Size, Small Background Object Size, and Blank Background (meaning that no objects were presented in the background). Response time and percent of errors were the dependent variables. Response time and percent of errors were operationalized in the same manner as the main study. Participants with a percent of errors greater than 20% were excluded from the analyses.

Materials

The stimuli used in the pilot study were constructed using one of the objects from the main study to be the stimuli to be rotated. The backgrounds were composed of one of the objects that make up the background for the main study. The size of the objects composing the background was manipulated. Three different sizes were examined. In the large background object condition, the background objects were double the size of the object to be rotated in the foreground. In the medium background object condition, the background objects were the same size as the foreground object. For the small background object condition, the objects in the background were half the size of the foreground object. Lastly, the blank background condition did not feature any objects, thus size was not manipulated and the condition was used as a control condition. Examples of the stimuli can be seen in the figures below.

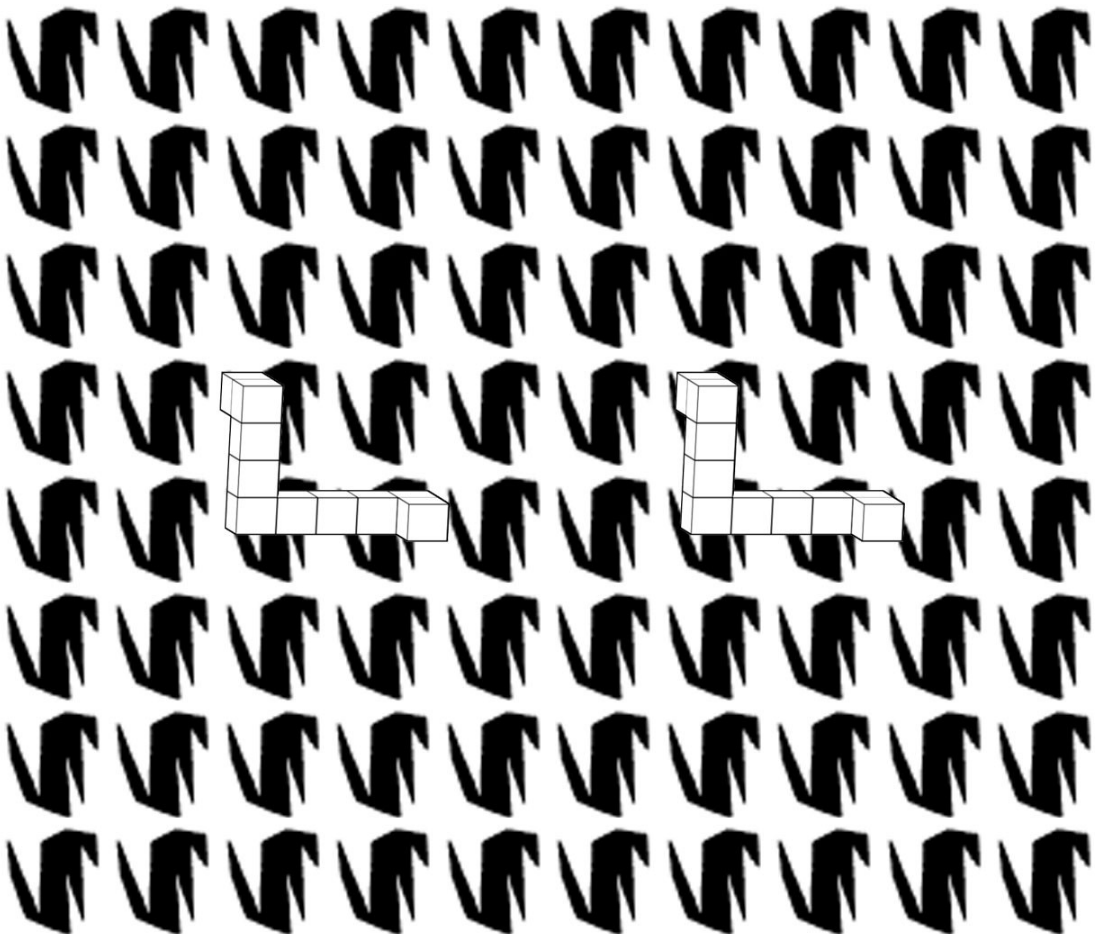


Figure 57 Small Background Objects

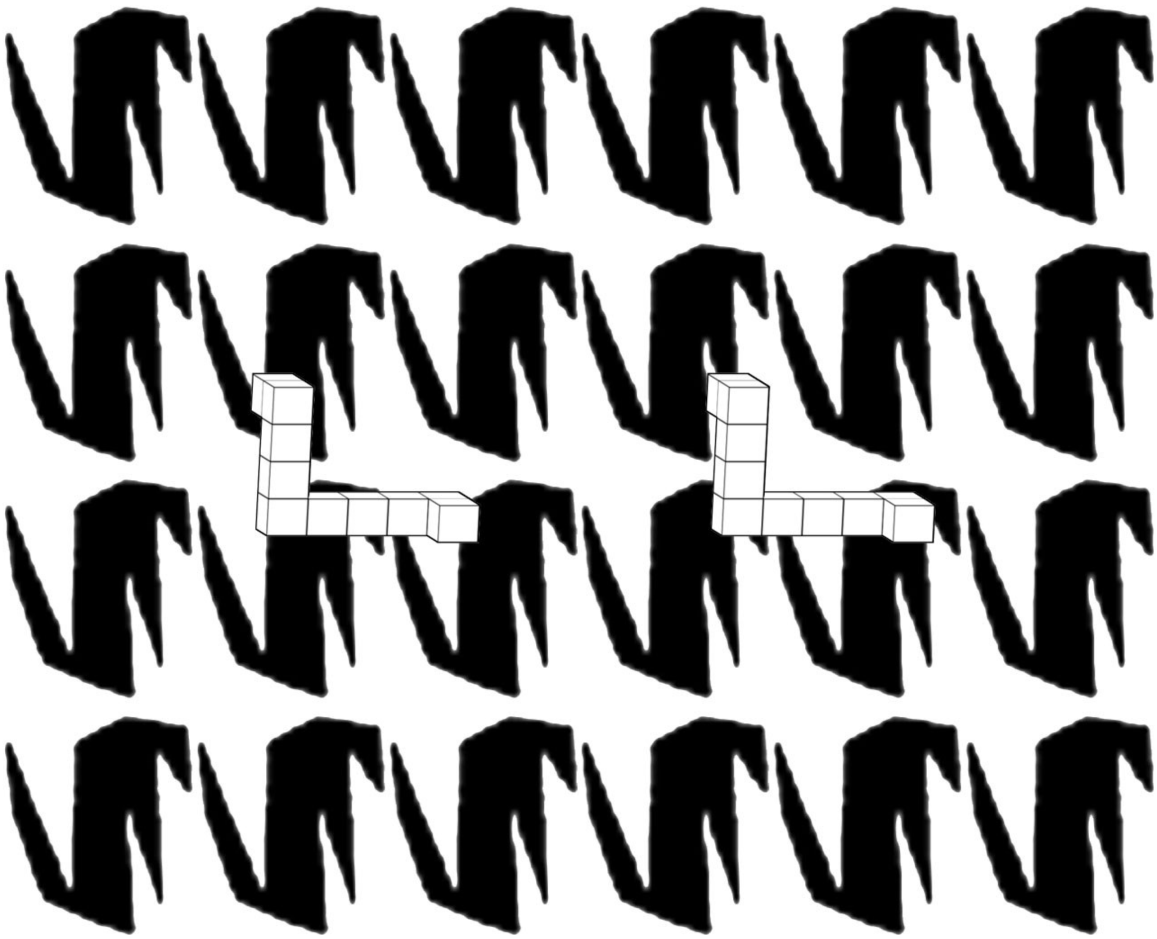


Figure 58 Medium Background Objects

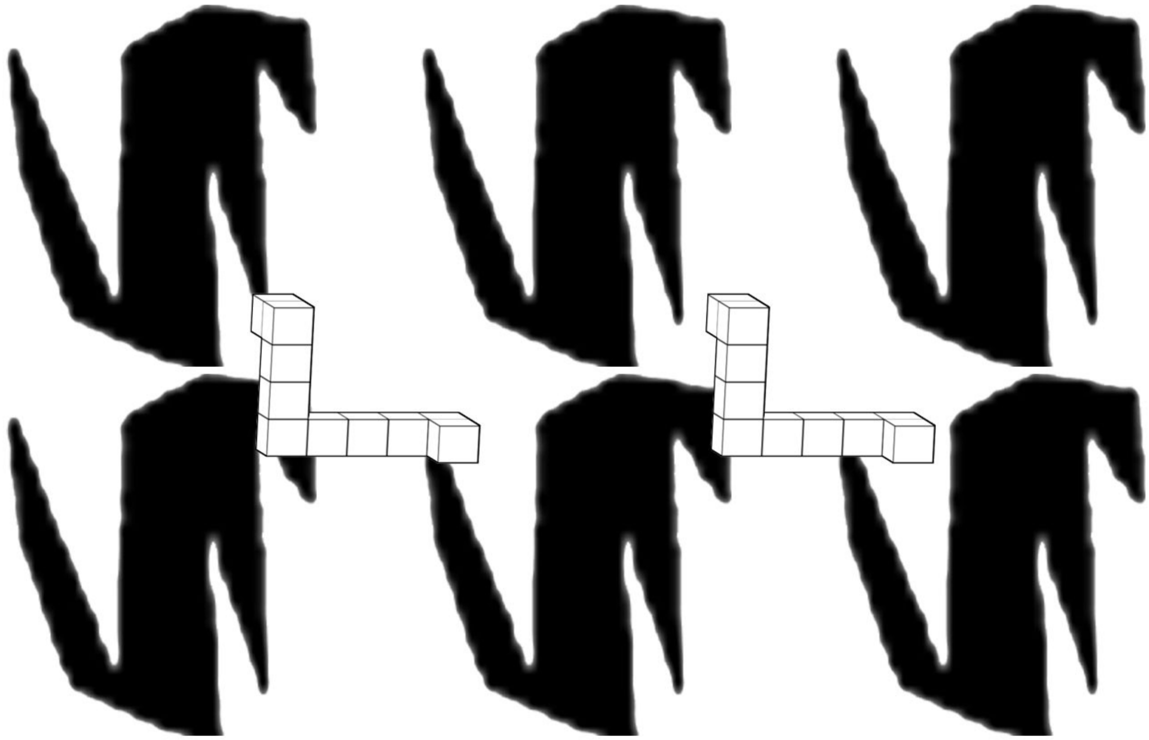


Figure 59 Large Background Objects

Figure 60 Blank Background-No Objects

Procedure

First, the participant performed a practice exercise. The practice mental rotation exercise featured neutral stimuli (Alphanumeric “L” and “R”). The participant must complete the practice exercise four times before beginning the mental rotation exercise. After participants completed the practice exercise, they were presented with a mental rotation task featuring the four background conditions outlined above. During the mental rotation exercise, the comparison stimulus was rotated at 12 positions, increasing in 30-degree increments from 0 to 330-degrees. Each position was displayed two times for the mirrored and non-mirrored judgment conditions. Overall, the participant had 48 trials with each stimulus/background combination for a total of 192 trials. All 192 trials were presented in a randomized order to accommodate for variances in performance due to the order of presentation of the stimuli. After participants completed the mental rotation task, they were presented with a short demographics questionnaire asking their sex, age, and handedness. Participants were measured on response times, in milleseconds, and percent of errors.

Results

A 1 way Repeated Measures ANOVA was conducted for each response variable; response time and percent of errors. The within-subjects variable was background condition (Small Background, Medium Background, Large Background, and Blank Background).

Mauchly's Test of Sphericity indicates that sphericity was not violated X^2 (5) = 8.906, p = .114. A main effect did not occur for Background Condition F (3, 39) = 1.599, p = .215, η_p^2 = .107.

LSD post hoc tests were conducted using p=.10 as criterion for significance. Significant differences were found between the Small Background (*M* = 3249.278, *SD* = 1344.392) condition and Medium Background (*M* = 2965.959, *SD* = 1045.817) condition (p<.05); and between the Small Background (*M* = 3249.278, *SD* = 1344.392) Condition and Large Background (*M* = 3068.736, *SD* = 1231.701) Condition (p<.1). In both of these significant differences the Small Background condition had a greater reaction time than both the Medium Background and Large Background conditions. The means and standard deviations can also be seen in the table below.

Table 21 Background Response Conditions

	Mean	Std. Deviation
Blank	2991.466	992.289
Large	3068.736	1231.701
Medium	2965.959	1045.817
Small	3249.278	1344.392

Conclusions

The conclusions drawn from the pilot study are that the small background seems to have the largest impact on the time to perform mental rotation. This is because the Small Background had a significantly larger mean reaction time when compared to the Medium and Large Background conditions. Though, there was not a significant difference between the Small Background and Blank Background it was still ~258 milliseconds greater than the average reaction time for the Blank Background. Therefore, the backgrounds for the main study will be formatted in the same manner as the Small Background condition from this pilot study.

APPENDIX B
DISSERTATION ANNOUNCEMENT

Announcing the Final Examination of Mr. Anthony Read Selkowitz for the degree of Doctor of Philosophy

Date: July 23rd, 2015
Time: 1:30 p.m.
Room: 301H
Dissertation title: Mental Rotation: Can familiarity alleviate the effects of complex backgrounds?

This study investigated the effects of complex backgrounds on mental rotation by manipulating the familiarity of participants with either the stimulus or background. 113 participants were assigned to one of four familiarity conditions. They were familiarized with the target stimulus and target background, the target stimulus and not the target background, not the target stimulus and target background, or neither the target stimulus or target background. The purpose of this was to examine how familiarity with the target stimulus or target background would affect percent of errors and reaction time in mental rotation. Findings indicate that when a stimulus is presented in a complex background stimulus familiarity does not reduce the time to rotate said stimulus. Though, mixed findings indicate that familiarity with the background does aid in mental rotation. Recommendations for future studies investigating mental rotation and complex backgrounds were made.

Outline of Studies:
Specialization: Applied Experimental and Human Factors Psychology

Educational Career:
B.S., 2009, University of Central Florida
M.A., 2013, University of Central Florida

Committee in Charge: Dr. Valerie Sims
Dr. Florian Jenstch
Dr. Matthew Chin
Dr. Mason Cash

Approved for distribution by Dr. Valerie Sims, Committee Chair, on July 9th, 2015.

The public is welcome to attend

APPENDIX C
IRB APPROVAL LETTER

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Approval of Human Research

From: **UCF Institutional Review Board #1**
FWA00000351, IRB00001138

To: **Anthony R Selkowitz**

Date: **April 20, 2015**

Dear Researcher:

On 4/20/2015, the IRB approved the following minor modifications to human participant research until 02/02/2016 inclusive:

Type of Review:	IRB Addendum and Modification Request Form
Modification Type:	Kyle Mullen, Madeleine LaGoy, and Aislynn Weichman are being added to the study as research assistants and the total number of study participants is being increased to 260 individuals. A revised protocol has been uploaded and a revised Informed Consent has been approved for use.
Project Title:	Advancing Object Recognition
Investigator:	Anthony R Selkowitz
IRB Number:	SBE-15-10937
Funding Agency:	
Grant Title:	
Research ID:	N/A

The scientific merit of the research was considered during the IRB review. The Continuing Review Application must be submitted 30days prior to the expiration date for studies that were previously expedited, and 60 days prior to the expiration date for research that was previously reviewed at a convened meeting. Do not make changes to the study (i.e., protocol, methodology, consent form, personnel, site, etc.) before obtaining IRB approval. A Modification Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at https://iris.research.ucf.edu .

If continuing review approval is not granted before the expiration date of 02/02/2016, approval of this research expires on that date. When you have completed your research, please submit a Study Closure request in iRIS so that IRB records will be accurate.

Use of the approved, stamped consent document(s) is required. The new form supersedes all previous versions, which are now invalid for further use. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Participants or their representatives must receive a copy of the consent form(s).

All data, including signed consent forms if applicable, must be retained and secured per protocol for a minimum of five years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained and secured per protocol. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

In the conduct of this research, you are responsible to follow the requirements of the Investigator Manual.

On behalf of Sophia Dziegielewski, Ph.D., L.C.S.W., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 04/20/2015 01:10:04 PM EDT

IRB manager

Appendix D
Instructions

Welcome and thank you for participating in our experiment. During the following exercise you will be asked to learn and recognize objects.

Please work as quickly as possible without sacrificing accuracy

Figure 61 Screen 1

Nn

During the following task, your job will be to identify the shapes presented upon the screen
Press the corresponding letter according to the diagram presented below. Please press any key to continue to the shape identification task.

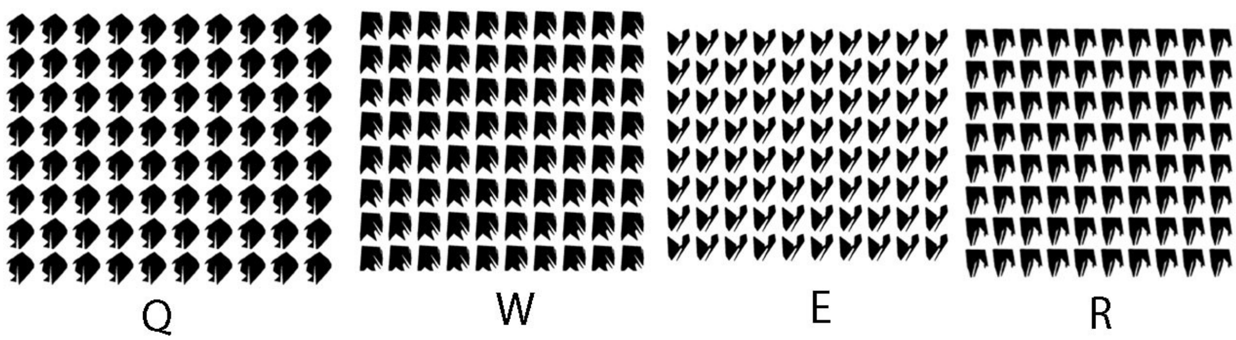


Figure 62 Recognition Instructions

First you are going to perform some practice trials in which the letter that corresponds to the shape is shown on the screen. Please pay attention to the letter that corresponds to the shape, after the practice trials the letter will not be shown in addition to the shape.

Figure 63 Instructions Page 2

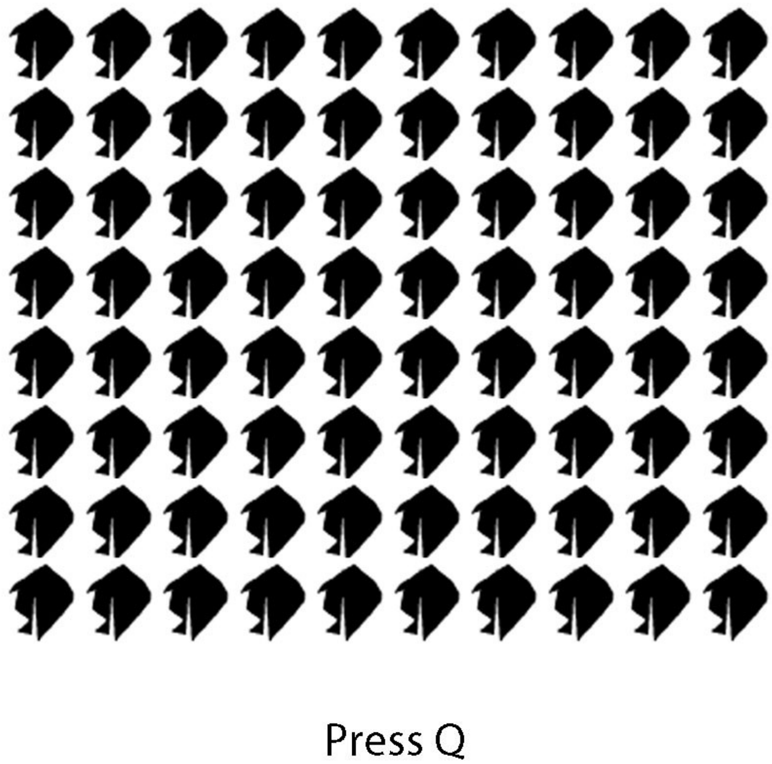


Figure 64 Guided Practice

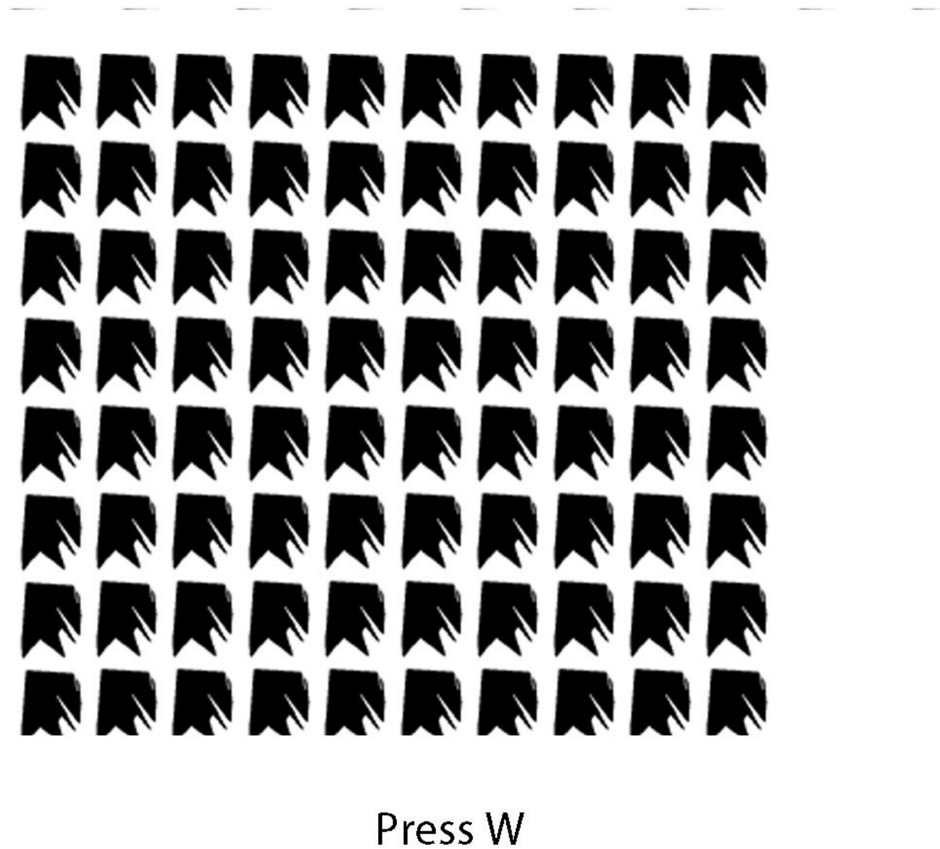
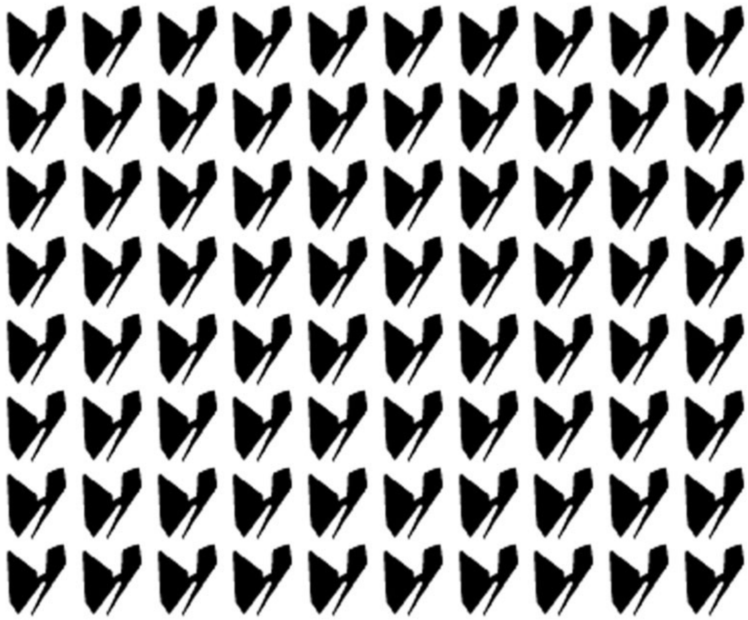


Figure 65 Guided Practice



Press E

Figure 66 Guided Practice

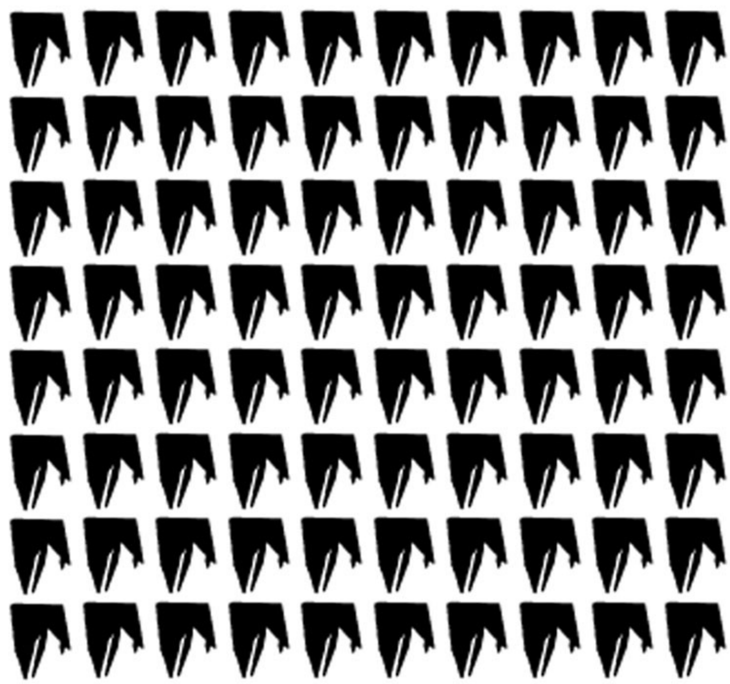


Figure 67 Guided Practice

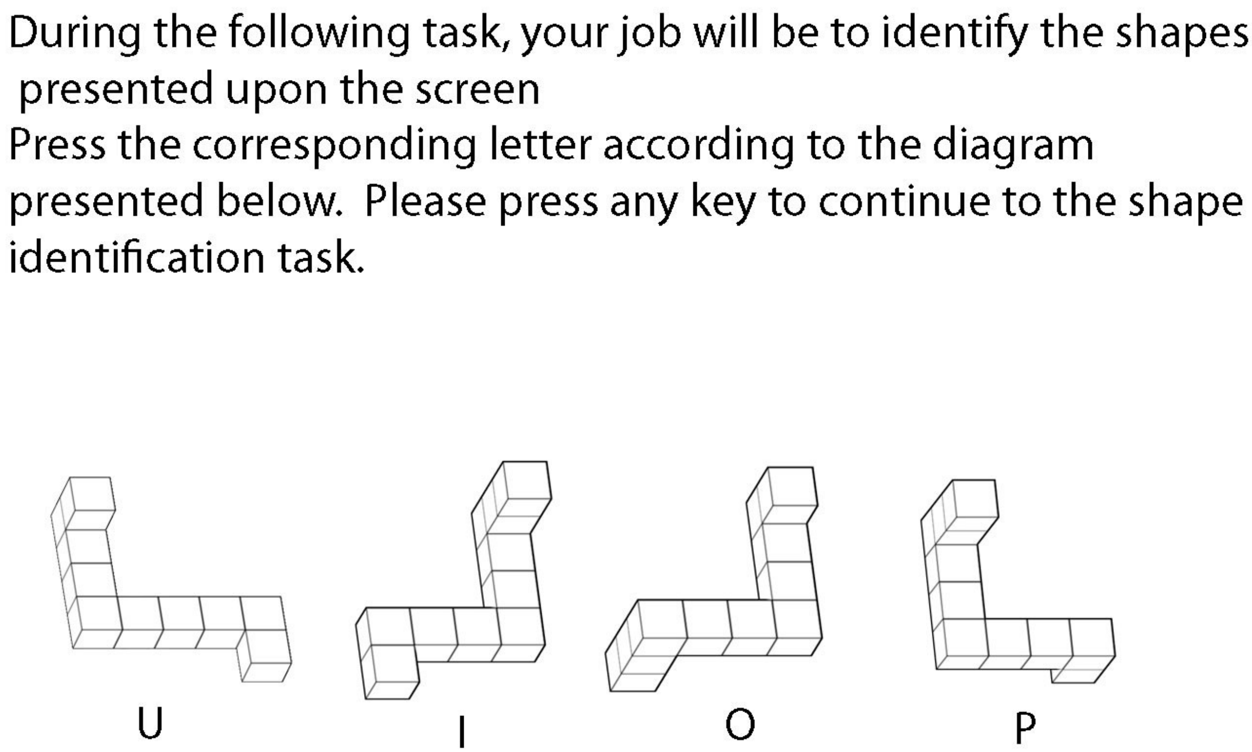


Figure 68 Practice Instructions

First you are going to perform some practice trials in which the letter that corresponds to the shape is shown on the screen. Please pay attention to the letter that corresponds to the shape, after the practice trials the letter will not be shown in addition to the shape.

Figure 69 Object Instructions

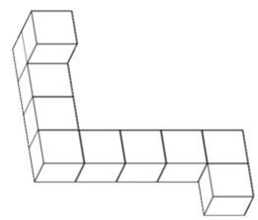


Figure 70 Guided Instruction

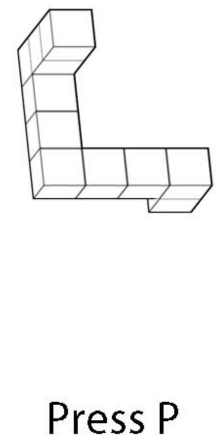


Figure 71 Guided Instruction

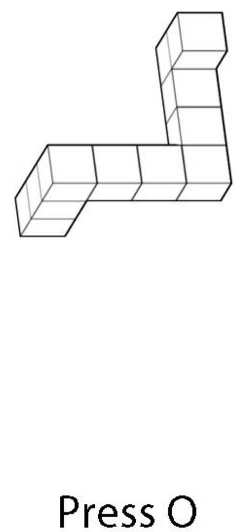


Figure 72 Guided Instruction

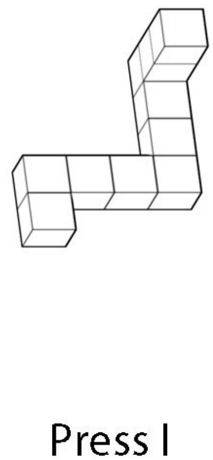


Figure 73 Guided Instruction

Now the recognition trials will begin.

Figure 74 Instructions

First you will recieve a practice exercise using the letters "R" and "L". Afterwards you will perform the same task with different stimuli.

Press any key to continue

Figure 75 Letters Instructions

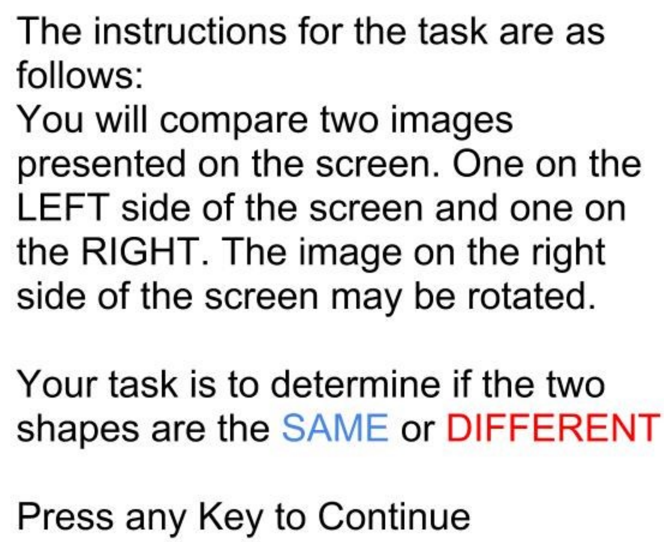


Figure 76 Mental Rotation Instructions

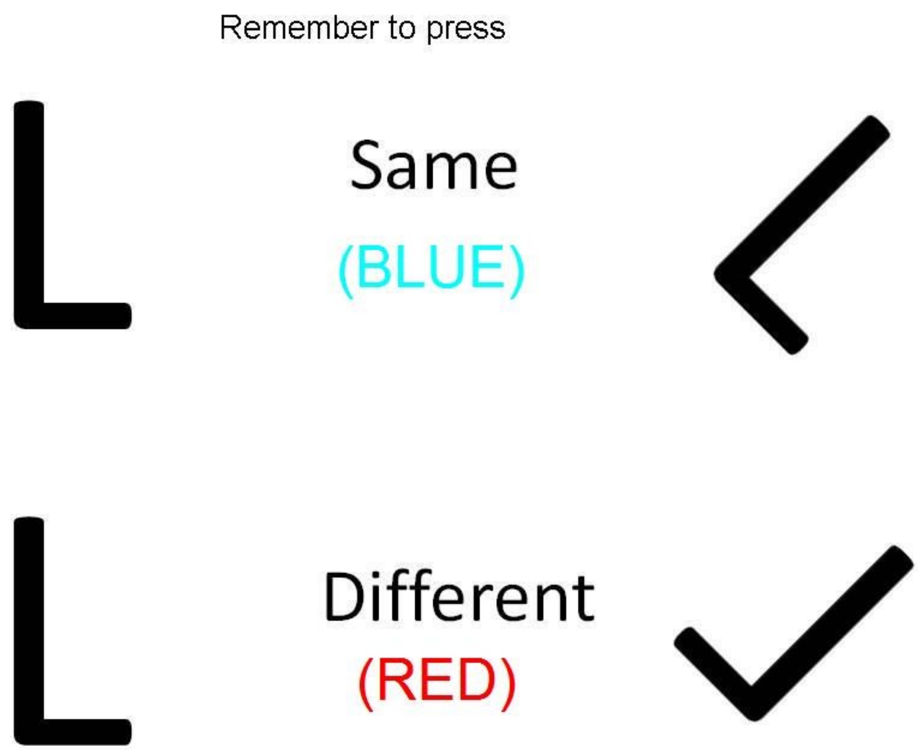


Figure 77 Same Different Instructions

If the images are the SAME, you will be able to rotate the image on the RIGHT to match the image on the LEFT.

In this case you would press the "J" Key marked in BLUE

The next page is an example of two images that are the SAME

Figure 78 Mental Rotation Instructions

Figure 79 Rotation Example

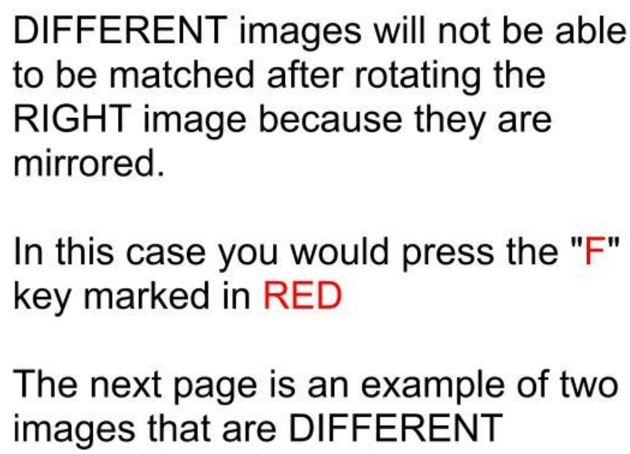


Figure 80 Different Image Instructions

Figure 81 Reversed Example

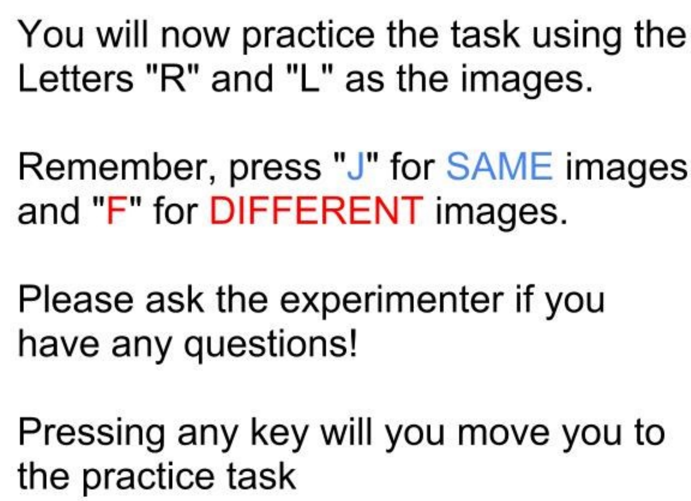


Figure 82 Same Different Reminder

Now you are going to begin the experimental task. It is the same task as the previous one, except it will feature block figures instead of letters. No feedback will be given.

Please work as quickly as possible without sacrificing accuracy

press any key to continue

Figure 83 Experimental Instructions

Please remember that the task is the same as the previous one, press F(RED) for DIFFERENT and J(BLUE) for SAME

Work as quickly as possible without sacrificing accuracy

You may press any key to move on

Figure 84 Speed/Accuracy Reminder

Appendix E.
Permissions and Copyright requests

SPRINGER LICENSE

TERMS AND CONDITIONS

Oct 20, 2015

This is an Agreement between Anthony Selkowitz ("You") and Springer ("Springer"). It consists of your order details, the terms and conditions provided by Springer, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

License Number

3726100446241

License date

Oct 11, 2015

Licensed Content Publisher

Springer

Licensed Content Publication

Perception and Psychophysics

Licensed Content Title

Object recognition contributions to figure-ground organization: Operations on outlines and subjective contours

Licensed Content Author

Mary A. Peterson

Licensed Content Date

Jan 1, 1994

Volume number

56

Issue number

5

Type of Use

Thesis/Dissertation

Portion

Figures/tables/illustrations

Number of figures/tables/illustrations

2

Author of this Springer article

No

Order reference number

None

Original figure numbers

Figure 3

Title of your thesis / dissertation

MENTAL ROTATION: CAN FAMILIARITY ALLEVIATE THE EFFECTS OF COMPLEX BACKGROUNDS?

Expected completion date

Nov 2015

Estimated size(pages)

180

Total

0.00 USD

Terms and Conditions

Introduction
The publisher for this copyrighted material is Springer Science + Business Media. By clicking "accept" in connection with completing this licensing transaction, you agree that the following terms and conditions apply to this transaction (along with the Billing and Payment terms and conditions established by Copyright Clearance Center, Inc. ("CCC"), at the time that you opened your Rightslink account and that are available at any time at http://myaccount.copyright.com).

Limited License
With reference to your request to reprint in your thesis material on which Springer Science and Business Media control the copyright, permission is granted, free of charge, for the use indicated in your enquiry.

Licenses are for one-time use only with a maximum distribution equal to the number that you identified in the licensing process.

This License includes use in an electronic form, provided its password protected or on the university's intranet or repository, including UMI (according to the definition at the Sherpa website: http://www.sherpa.ac.uk/romeo/). For any other electronic use, please contact Springer at (permissions.dordrecht@springer.com or permissions.heidelberg@springer.com).

The material can only be used for the purpose of defending your thesis limited to university-use only. If the thesis is going to be published, permission needs to be re-obtained (selecting "book/textbook" as the type of use).

Although Springer holds copyright to the material and is entitled to negotiate on rights, this license is only valid, subject to a courtesy information to the author (address is given with the article/chapter) and provided it concerns original material which does not carry references to other sources (if material in question appears with credit to another source, authorization from that source is required as well).

Permission free of charge on this occasion does not prejudice any rights we might have to charge for reproduction of our copyrighted material in the future.

Altering/Modifying Material: Not Permitted
You may not alter or modify the material in any manner. Abbreviations, additions, deletions and/or any other alterations shall be made only with prior written authorization of the author(s) and/or Springer Science + Business Media. (Please contact Springer at (permissions.dordrecht@springer.com or permissions.heidelberg@springer.com)

Reservation of Rights
Springer Science + Business Media reserves all rights not specifically granted in the combination of (i) the license details provided by you and accepted in the course of this licensing transaction, (ii) these terms and conditions and (iii) CCC's Billing and Payment terms and conditions.

Copyright Notice:Disclaimer
You must include the following copyright and permission notice in connection with any reproduction of the licensed material: "Springer and the original publisher /journal title, volume, year of publication, page, chapter/article title, name(s) of author(s), figure number(s), original copyright notice) is given to the publication in which the material was originally published, by adding; with kind permission from Springer Science and Business Media"

Warranties: None

Example 1: Springer Science + Business Media makes no representations or warranties with respect to the licensed material.

Example 2: Springer Science + Business Media makes no representations or warranties with respect to the licensed material and adopts on its own behalf the limitations and disclaimers established by CCC on its behalf in its Billing and Payment terms and conditions for this licensing transaction.

Indemnity
You hereby indemnify and agree to hold harmless Springer Science + Business Media and CCC, and their respective officers, directors, employees and agents, from and against any and all claims arising out of your use of the licensed material other than as specifically authorized pursuant to this license.

No Transfer of License
This license is personal to you and may not be sublicensed, assigned, or transferred by you to any other person without Springer Science + Business Media's written permission.

No Amendment Except in Writing
This license may not be amended except in a writing signed by both parties (or, in the case of Springer Science + Business Media, by CCC on Springer Science + Business Media's behalf).

Objection to Contrary Terms
Springer Science + Business Media hereby objects to any terms contained in any purchase order, acknowledgment, check endorsement or other writing prepared by you, which terms are inconsistent with these terms and conditions or CCC's Billing and Payment terms and conditions. These terms and conditions, together with CCC's Billing and Payment terms and conditions (which are incorporated herein), comprise the entire agreement between you and Springer Science + Business Media (and CCC) concerning this licensing transaction. In the event of any conflict between your obligations established by these terms and conditions and those established by CCC's Billing and Payment terms and conditions, these terms and conditions shall control.

Jurisdiction
All disputes that may arise in connection with this present License, or the breach thereof, shall be settled exclusively by arbitration, to be held in The Netherlands, in accordance with Dutch law, and to be conducted under the Rules of the 'Netherlands Arbitrage Instituut' (Netherlands Institute of Arbitration).***OR:***

All disputes that may arise in connection with this present License, or the breach thereof, shall be settled exclusively by arbitration, to be held in the Federal Republic of Germany, in accordance with German law.

Other terms and conditions:

v1.3

Questions? customercare@copyright.com or +1-855-239-3415 (toll free in the US) or +1-978-646-2777.

SPRINGER LICENSE
TERMS AND CONDITIONS

Oct 20, 2015

This is an Agreement between Anthony Selkowitz ("You") and Springer ("Springer"). It consists of your order details, the terms and conditions provided by Springer, and the payment terms and conditions.

All payments must be made in full to CCC. For payment instructions, please see information listed at the bottom of this form.

License Number

3726090712464

License date

Oct 11, 2015

Licensed Content Publisher

Springer

Licensed Content Publication

Perception and Psychophysics

Licensed Content Title

Familiarity and pop-out in visual search

Licensed Content Author

Qinqin Wang

Licensed Content Date

Jan 1, 1994

Volume number

56

Issue number

5

Type of Use

Thesis/Dissertation

Portion

Figures/tables/illustrations

Number of figures/tables/illustrations

1

Author of this Springer article

No

Order reference number

None

Original figure numbers

Figure 1

Title of your thesis / dissertation

MENTAL ROTATION: CAN FAMILIARITY ALLEVIATE THE EFFECTS OF COMPLEX BACKGROUNDS?

Expected completion date

Nov 2015

Estimated size(pages)

180

Total

0.00 USD

Terms and Conditions

Introduction
The publisher for this copyrighted material is Springer Science + Business Media. By clicking "accept" in connection with completing this licensing transaction, you agree that the following terms and conditions apply to this transaction (along with the Billing and Payment terms and conditions established by Copyright Clearance Center, Inc. ("CCC"), at the time that you opened your Rightslink account and that are available at any time at http://myaccount.copyright.com).

Limited License
With reference to your request to reprint in your thesis material on which Springer Science and Business Media control the copyright, permission is granted, free of charge, for the use indicated in your enquiry.

Licenses are for one-time use only with a maximum distribution equal to the number that you identified in the licensing process.

This License includes use in an electronic form, provided its password protected or on the university's intranet or repository, including UMI (according to the definition at the Sherpa website: http://www.sherpa.ac.uk/romeo/). For any other electronic use, please contact Springer at (permissions.dordrecht@springer.com or permissions.heidelberg@springer.com).

The material can only be used for the purpose of defending your thesis limited to university-use only. If the thesis is going to be published, permission needs to be re-obtained (selecting "book/textbook" as the type of use).

Although Springer holds copyright to the material and is entitled to negotiate on rights, this license is only valid, subject to a courtesy information to the author (address is given with the article/chapter) and provided it concerns original material which does not carry references to other sources (if material in question appears with credit to another source, authorization from that source is required as well).

Permission free of charge on this occasion does not prejudice any rights we might have to charge for reproduction of our copyrighted material in the future.

Altering/Modifying Material: Not Permitted
You may not alter or modify the material in any manner. Abbreviations, additions, deletions and/or any other alterations shall be made only with prior written authorization of the author(s) and/or Springer Science + Business Media. (Please contact Springer at (permissions.dordrecht@springer.com or permissions.heidelberg@springer.com)

Reservation of Rights
Springer Science + Business Media reserves all rights not specifically granted in the combination of (i) the license details provided by you and accepted in the course of this licensing transaction, (ii) these terms and conditions and (iii) CCC's Billing and Payment terms and conditions.

Copyright Notice:Disclaimer
You must include the following copyright and permission notice in connection with any reproduction of the licensed material: "Springer and the original publisher /journal title, volume, year of publication, page, chapter/article title, name(s) of author(s), figure number(s), original copyright notice) is given to the publication in which the material was originally published, by adding; with kind permission from Springer Science and Business Media"

Warranties: None

Example 1: Springer Science + Business Media makes no representations or warranties with respect to the licensed material.

Example 2: Springer Science + Business Media makes no representations or warranties with respect to the licensed material and adopts on its own behalf the limitations and disclaimers established by CCC on its behalf in its Billing and Payment terms and conditions for this licensing transaction.

Indemnity
You hereby indemnify and agree to hold harmless Springer Science + Business Media and CCC, and their respective officers, directors, employees and agents, from and against any and all claims arising out of your use of the licensed material other than as specifically authorized pursuant to this license.

No Transfer of License
This license is personal to you and may not be sublicensed, assigned, or transferred by you to any other person without Springer Science + Business Media's written permission.

No Amendment Except in Writing
This license may not be amended except in a writing signed by both parties (or, in the case of Springer Science + Business Media, by CCC on Springer Science + Business Media's behalf).

Objection to Contrary Terms
Springer Science + Business Media hereby objects to any terms contained in any purchase order, acknowledgment, check endorsement or other writing prepared by you, which terms are inconsistent with these terms and conditions or CCC's Billing and Payment terms and conditions. These terms and conditions, together with CCC's Billing and Payment terms and conditions (which are incorporated herein), comprise the entire agreement between you and Springer Science + Business Media (and CCC) concerning this licensing transaction. In the event of any conflict between your obligations established by these terms and conditions and those established by CCC's Billing and Payment terms and conditions, these terms and conditions shall control.

Jurisdiction
All disputes that may arise in connection with this present License, or the breach thereof, shall be settled exclusively by arbitration, to be held in The Netherlands, in accordance with Dutch law, and to be conducted under the Rules of the 'Netherlands Arbitrage Instituut' (Netherlands Institute of Arbitration).***OR:***

All disputes that may arise in connection with this present License, or the breach thereof, shall be settled exclusively by arbitration, to be held in the Federal Republic of Germany, in accordance with German law.

Other terms and conditions:

v1.3

Questions? customercare@copyright.com or +1-855-239-3415 (toll free in the US) or +1-978-646-2777.

REFERENCES

Attneave, F., and Arnoult, M. D. (1956). The quantitative study of object and pattern perception. *Psychological Bulletin*, 53, 452-471.

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in cognitive sciences*, 4(11), 417-423.

Biederman, I., Glass, A. L., & Stacy, E. W. (1973). Searching for objects in real-world scenes. *Journal of Experimental Psychology*, 97(1), 22.

Cooper, L. A., & Shepard, R. N. (1973). Chronometric studies of the rotation of mental images. *Visual information processing*, Oxford, England: Academic, xiv.

Fowlkes, C.C., Martin, D.R., & Malik, J. (2007). Local figure-ground cues are valid for natural images. *Journal of Vision*, 7(8), 1-9.

Heil, M., & Rolke, B. (2002). Toward a chronopsychophysiology of mental rotation. *Psychophysiology*, 39(4), 414-422.

Hertzog, C., Vernon, M. C., & Rypma, B. (1993). Age differences in mental rotation task performance: The influence of speed/accuracy tradeoffs. *Journal of Gerontology*, *48*(3), P150-P156.

Hsi, S., Linn, M. C., & Bell, J. E. (1997). The role of spatial reasoning in engineering and the design of spatial instruction. *Journal of Engineering Education*, 86(2), 151-158.

Jolicoeur, P., & Cavanagh, P. (1992). Mental rotation, physical rotation, and surface media. *Journal of Experimental Psychology: Human Perception and Performance*, 18(2), 371.

Lohrenz ,M.C., Trafton, J.G., Beck, M.R., and Gendron, M.L. (2009). A Model of Clutter for Complex, Multivariate Geospatial Displays. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 51(1), 90-101.

Menchaca-Brandan, M. A., Liu, A. M., Oman, C. M., & Natapoff, A. (2007). Influence of perspective-taking and mental rotation abilities in space teleoperation. *In Proceedings of the ACM/IEEE International Conference on Human-robot interaction* 271-278.

Mumaw, R. J., Pellegrino, J. W., Kail, R. V., & Carter, P. (1984). Different slopes for different folks: Process analysis of spatial aptitude. *Memory & Cognition*, 12(5), 515-521.

Peters, M. & Battista, C. (2008). Applications of mental rotation figures of the Shepard and Metzler type and description of a Mental Rotation Stimulus Library. *Brain and Cognition*, 66, 260-264.

Peterson, M.A., & Gibson, B.S. (1993). Object recognition inputs to figure-ground organization in three-dimensional displays. *Cognitive Psychology*, 25, 383-429.

Peterson, M.A., & Gibson, B.S. (1994). Object recognition contributions to figure-ground organization: operations on outlines and subjective contours. *Perception and Psychophysics*, 56(5), 551-564.

Pomerantz, J. R., & Kubovy, M. (1986). Theoretical approaches to perceptual organization. In: K. R. Boff, L. *Kaufman, & J. Thomas, eds*. New York: John Wiley & Sons.

Ruthruff, E., & Miller, J. (1995). Can mental rotation begin before perception finishes? *Memory & Cognition*, 23(4), 408-424.

Shepard, R. N., & Metzler, J. (1971). Mental rotation of three-dimensional objects. *Science*, 171, 701-703.

Smith, W., & Dror, I.E. (2001). The role of meaning and familiarity in mental transformations. *Psychonomic Bulletin and Review*, 8(4), 732-741.

Smith, G. G., & Olkun, S. (2005). Why interactivity works: Interactive priming of mental rotation. *Journal of Educational Computing Research*, 32(2), 93-111.

Stransky, D., Wilcox, L. M., & Dubrowski, A. (2010). Mental rotation: cross-task training and generalization. *Journal of Experimental Psychology: Applied*,*16*(4), 349.

Tarr, M.(2014, June 24). The Object Databank. Retrieved from http://wiki.cnbc.cmu.edu/Objects

Tarr, M. J., & Pinker, S. (1989). Mental rotation and orientation-dependence in object recognition. *Cognitive psychology*, 21(2), 233-282.

Vanderplas, J. M., & Garvin, E. A. (1959). The Association Values of Random Objects. *Journal of Experimental Psychology*, 57(3), 147-154

Vecera, S.P., Vogel, E.K., & Woodman, G.F. (2002). Lower Region: A New Cue for Figure-Ground Assignment. *Journal of Experimental Psychology: General*, 131(2), 194-205.

Wang, Q., Cavanagh, P., & Green, M. (1994). Familiarity and pop-out in visual search. *Perception & Psychophysics*. 56(5). 495-500.

Wolfe, J.M. (1998). What can 1 million trials tell us about visual search? *Psychological Science*, 9(1), 33-39.