THE EFFECT OF WEIGHT AND SIZE ON MENTAL ROTATION

by

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ABSTRACT

Shepard and Metzler (1971) argued that mental rotation is analogous to the real world in that people imagine the rotation of an object as if it were being physically rotated. This study tested this assertion by exposing participants to physical shapes that increased in size and weight. Participants interacted with blocks designed after Shepard and Metzler mental rotation size that differed in size and weight then performed subsequent mental rotation. We found no difference in reaction time but found that increased size reduced accuracy. We discuss the implications of this study as they pertain to embodied cognition.

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INTRODUCTION

Spatial Ability

Spatial ability is a long-studied topic in cognitive psychology that is typically referred to as the ability to manipulate two- and three- dimensional mental images. It is distinct from other types of abilities such as verbal ability, reasoning or logic ability. Spatial ability is a large subject of investigation that encompasses many perspectives of a multifaceted construct (Carroll, 1993). One factor of spatial ability is spatial visualization, which has been examined with the Paper Folding Test (Ekstrom, 1976). The paper folding test asks participants to make a complex series of mental visual transformations. Other tests of spatial visualization ask participants to take or imagine a viewpoint or perspective that is not their own such as the Guay's Visualization of Views task (Guay & McDaniels, 1976). Others assess participants' ability to correctly distinguish cross sections of objects such as in the Santa Barbara Solids Test (Cohen & Hegarty, 2012). Although there are many ways spatial ability can be delineated, what all these tests have in common is that they assess visual mental actions. The study of these actions may give insight to properties about the mental images participants create, how they use these images, and what information these images take into account when they are created or stored. Spatial ability is an important topic of study in part because it is highly predictive of science, technology, engineering and math (STEM) performance (Wai, Lubinski, & Benbow, 2009). As an example, an engineer who is able to picture every detail of a machine has an expansive mental image with information taken from many sources such as images from books, kinesthetic information from touching the materials of the machine, and practical experience such as which bolts will fit with which nuts. One of the central questions this study aims to address is to what extent does information such as an object's weight or size affect our ability to mentally manipulate them. Does an engineer rotate an airplane the same way one would rotate a bolt?

Mental Rotation

One of the first tests designed to assess spatial ability was the mental rotation task designed by Shepard and Metzler (1971). In this task a pair of images on a screen are compared to each other at varying angles, and participants must decide if the pair of images are the same image or mirror images of each other by pressing a key on a keyboard. If the pair of images are mirror images, no rotation will allow the two to be superimposed on one another. To demonstrate this, one can imagine rotating their right hand onto their left, it will quickly become apparent it is impossible due to the mirror image nature of right and left hands.

Shepard and Metzler's task has been used as an argument that mental rotation is analogous to the real world, because as the angle between the two images increases, participants take a longer time to decide if the pair are a match. Shepard and Metzler reasoned that this is because, just as in the physical world, it will take a longer time to rotate an object the greater degree of disparity. This study is highly replicable, and the relationship between reaction time and angle places very stringent constraints on the nature of the mental actions being performed in the mental rotation task. Shepard and Metzler argued that the visual transformation was accomplished by whole-image rotation, but others have argued that the shapes are rotated in a piecemeal fashion.

Shepard (1970) called this type of representation "second order" isomorphism, which is to say that our mental representations may be very like the real world, even though they may not have to be identical. He argued that they are functionally paralleled, even though they are not structurally identical. What this means is that asking participants to perform an action which is so similar to how actual rotation would appear in the real world almost imposes these constraints on them. This theory has implications for embodied cognition, specifically that these relationships of functional parallelism are created by experience with the world.

Mental rotation has been used as a sensitive metric of mental models in the past, and has been used to discover many facets about human spatial performance. Mental rotation has been found to be sensitive to expertise (Sims and Mayer, 2002). The mental rotation task has been found to be performed differently for different body parts such as hands (Kosslyn et al., 1998). There is also a well-documented male advantage on mental rotation tasks for speed, even though this advantage is not found in other spatial tasks (Tapley and Bryden, 1977). Mental rotation has shown to be sensitive to age-related spatial ability decline (Berg et al., 1982). Finally, complexity of the stimuli has also been shown to decrease mental rotation speed (Bethel-Fox and Shepard, 1988). These studies provide validation for mental rotation's use as a tool to distinguish between different mental states and mental actions.

Embodied Cognition

A shifting paradigm in cognitive psychology is to the embodied nature of cognition. This theory states that all thought is rooted in the body and the body's experience with the outside world (Wilson, 2002). This theory suggests that mental abilities, including mental representations can be modified by experiences with the real world. A deduction of this theory can reach a similar conclusion to the argument Shepard and Metzler made by suggesting that mental rotation is analogous to the real world. Unlike the position Shepard and Metzler would take however, the embodied view would purport that the creation of the mental representations we possess come from a different source, that these mental images we have are created through our experience with the world.

Physical interaction has been shown to be useful for learning in a general way: In a study by Flanagan (2013), third graders learned how to use a Chinese abacus either with a physical abacus, or a replication of one on a computer. Flanagan found that the children did not differ in their ability to perform the simple arithmetic they were explicitly trained in, but the children who interacted with a physical abacus were more proficient in learning more complex mathematical operations on the abacus at a later time. This study supports the notion that an embodied method of learning allows people to free up more of their cognitive resources to learn new principles.

This embodied nature of cognition has been examined in multiple ways as it pertains to mental rotation. For example, Toussaint and Meugnot (2013) performed a mental rotation training study in which participants' left hands were bound with a splint for 48 hours before performing the mental rotation task, and found that this interfered with the ability to improve their mental rotation skill when rotating images of left hands. In a normal scenario, training to perform mental rotation will eventually cause one to gain expertise in the task, participants will become faster, more accurate, and better able to do the task. But by placing participants' left hand in a sling, their expertise became less beneficial to them. Even more interestingly, only the rotation of the hand same which participants' had immobilized was affected. In a second experiment they tested the effects of limb immobilization on mental rotation of numbers and found no effect. This supports the embodied view of cognition by suggesting that interfering with someone's physical state will interfere with his or her ability to learn and manipulate objects for which we have some motor imagery present. In a more extreme version of the previous study, Funk and Brunner (2007) compared the differences in hand mental rotation speed for participants who were born without either a right or left hand. They found that participants were worse at rotating images of hands the same as the hand that had been missing since birth. This is in part an appeal to the expertise factor of spatial ability and mental rotation. Since these participants had no experience viewing their missing hand in different orientations, they were not able to pull from that experience on the mental rotation task. This suggests that experience with the world can in fact alter out mental models.

This theory has support from neural mechanisms as well. In a study by Ganis et al. (2000) transcranial magnetic stimulation of the primary motor cortex caused participants to perform more poorly on a mental rotation task. It is difficult however to establish causal directionality with neural studies however, because activation of the motor cortex can be seen in cases where participants are asked to imagine themselves performing a motor action (Jeannerod, & Frak 1999), or by watching others perform a motor action (Rizzolatti et al. 1996). Whatever the case though, it is clear that the imagination or reproduction of physical actions in one's mind will activate the same brain areas that would be active if one were actually physically performing the action.

Psychophysics

To analyze how a mental action is analogous to an action performed in the real world, we must first describe how an object behaves in the real world. The physical study of motion is best understood if begun with Newton's first law of motion, which is defined as:

Force = mass x acceleration

$$F = m \times a$$

This equation applies to linearly moving objects, and as a result we can see that if a force is applied to an object with “m” mass, it will accelerate at “a” rate. From this equation it should be noted that acceleration and time to travel a distance are inversely related; the faster an object is accelerated, the shorter its traversal will be. However, this equation does not describe the motion of an object rotating and only describes translational movement. Instead, the equation for torque is applied:

Torque = moment of inertia x angular acceleration

$$\tau = I \times \alpha$$

where I = mass x radius^2

These two equations are analogous and simply describe different motion. In other words, torque is similar to force, moment of inertia is similar to mass, and angular acceleration is equivalent to linear acceleration. Rearranged, we see the torque equation is $\alpha = \tau/I$. If we further explore the torque equation, we find that I = mass x radius^2. Plugging I into the equation for torque; $\alpha = \tau$/mass x radius^2, meaning that as mass increases, angular acceleration decreases linearly, and as radius increases, angular acceleration decreases exponentially. Since acceleration is inversely related to time (the faster you accelerate the less time it takes to cover distance x), this shows that the time to rotate is proportional to the moment of inertia. This equation provides a guideline to compare rotation of objects in the physical world with the pattern of imagined rotation. For example, if mental rotation is analogous to the real-world constructs which they represent, the time to mentally rotate an object should parallel the time to physically rotate that object. In short, as the radius of an object increases, reaction time will increase exponentially, and as mass increases, reaction time will increase linearly.

Current study

In the current study, an attempt was made to determine if the weight of a physical object, or the size of a physical object would change participants' mental rotation time of those same objects. Previous research on perception of weight is limited. Weber (1834) noted that the just noticeable difference for weight was about equal to 5%. What has come to be known as Weber's law states that to be able to perceive any difference between two weights, the difference between the respective weights needs to be greater than 5%. Other research concerning motor imagery and weight has been conducted by Cerritelli et al. (2000). In their study, participants performed a Fitt's law task, wherein participants control a stylus and connect one point to another with it. Adding 2 kg of weight to the stylus made no significant difference in the time taken to do to task, but did have a significant effect on time taken when participants were asked to imagine themselves performing the action. This suggests that motor imagery is affected more by the perception of weight, and less by how much it constrains the actual task. In a study by Papaxanthis et al. (2002), participants were told to extend and contract their arms when weights of various sizes were attached. The time required to make the movements was recorded and compared to the time it took participants to imagine themselves performing the same actions. They found that mass affected the speed of the physical movements, and there were similar changes in speeds of the mentally represented actions when participants were asked to imagine themselves performing the task. This study shows that participants can to some degree accurately assess how weight impairs their ability to perform a particular task, specifically in increasing the time it takes to perform it.

In previous research on representation of visual size, Bundesen and Larson (1975) found a linear relationship between the size of the visual shape on a screen and reaction time on a mental rotation task, so that the larger the visual size of the object, the greater the reaction time to decide if the images are the same. This study suggests that participants transformed either the smaller image to match the larger or vice versa, so that as size increases so too does processing speed because of an added mental action: one of size transformation. But it remains to be seen if size information is retained by our mental representations, and to what degree that information affects our mental actions. Recognition of object size has been explored in animal models as well (Peissig et al., 2006). In their study, Peissig et al. trained pigeons to recognize various object images, then tested their ability to correctly identify differently sized versions of the same objects. They discovered that increasing or decreasing the size of the objects caused the pigeons to perform more errors when identifying the objects. This suggests there is a limit to the degree to which mental images can be transformed accurately, and size is one factor which can affect that transformation. These studies support a more ocular-neural basis for mental rotation skill, such that size of the image on the eye changes mental rotation speed and errors performed, and suggests that other information such as weight would be exclude from one's mental image. These studies have a limitation, the perspectives taken are egocentric, which is to say, first-person visual imagery. In contrast to egocentric is allocentric visualization, where the visualization taken is from a perspective not ones own, or exocentric which is more of a third-person perspective taken when the objects manipulated are too large to be considered on the same scale as the human doing the mental visualization. There is evidence that there are differences in spatial tasks when participants are asked to take these other viewpoints (McCormick et al., 2008). For the purposes of this study however, we are restricting our investigation specifically to egocentric visualization, in part because it has the most outstanding relevance to embodied cognition.

The alternative to this ocular-neural theory is that our mental representations are not constrained by our eyesight, and instead take into account more information than what is immediately in front of us when we perform these mental actions. Kosslyn (1975) performed a study where participants were asked to perform mental rotation of a rabbit when it was next to either a mouse, or an elephant. In this way the relative size of the rabbit compared to the other animals was controlled. He found that when the rabbit was near something large like the elephant, participants rotated it more quickly, because the relative size made the rabbit very small. And the converse was true when participants imagined the rabbit near the mouse: its relative large size caused participants to rotate it more slowly. This study suggests that just by imagining objects we have some experience with allows us to take into account not only the most salient information about the object itself, but also the information about its relation with other objects. However, little research has been performed on interacting with physical versions of objects to determine whether properties of these objects will be encoded into one's mental representation and if this could subsequently affect the mental manipulation of them.

While little research has been performed concerning interaction with physical stimuli then performing mental rotation, a study by Flusberg and Boroditsky (2011) is very relevant. These researchers asked participants to manually rotate physical shapes based on Shepard and

Metzler blocks. The researchers manipulated the degree of opposing force the participants were presented with, so that one condition was more difficult to rotate than the other, and found that the hard-to-rotate condition only had an effect on mental rotation reaction time when the participants were explicitly asked to imagine themselves rotating the blocks with their hands. When asked to imagine the blocks rotating on their own, there was no effect of the difficulty of rotation. Flusberg and Boroditsky suggest that physical interaction by itself is not enough to change the mental representation of an object as applied to the mental rotation task. It does however imply that information about the difficulty of rotation was stored in their participants' mind, and was available when asked to recall and use it in a motor representation strategy. However, research by Wraga et al. (2003) discovered that asking participants to mentally rotate images of hands before rotating blocks increased their speed on the mental rotation task, which indicates that using an implicit memory motor strategy facilitates mental manipulation. In our study an implicit association is hard to avoid, because we plan on having participants interact with physical versions of the stimuli they will later rotate. This very interaction will prime participants to use a motor representation when interacting with the objects. On the other hand, the Flusberg and Boroditsky study failed to show an effect for difficulty of physical rotation, and their results suggest that using explicit exposure paradigm may be more effective in affecting participants' mental representations. Because their explicit strategy was shown to be effective for eliciting motor representations in the past, we have decided to approach our research question in the same way. Just as bigger and heavier physical objects are more difficult to rotate, our research hypothesis is that increasing size and weight will increase reaction times on a subsequent mental rotation task, because participants will incorporate the physical properties of the object into their mental representation of the objects. Two within-subjects experiments were conducted to test our hypotheses.

In order to delineate the effects of weight and size on mental rotation, a 2X2 design was used to parse the effects of each property and test for an interaction of size and weight. These four conditions included one condition for light and small, one for light and large, one for heavy and small, and one for heavy and large. While studies have failed to show an effect of color on mental rotation, four low saliency colors were chosen to differentiate the conditions. To determine if color had an effect on mental rotation that could confound the encoding of weight and size information, a pilot study was conducted to evaluate the effect of color on mental rotation for the specific colors chosen to differentiate conditions in the main experiment. Our dependent variables were reaction time, and percent correct. Our hypotheses for the main experiment were that increasing size and increasing weight would both increase reaction time, so that larger and heavier stimuli would take longer to rotate.

PILOT STUDY

Method

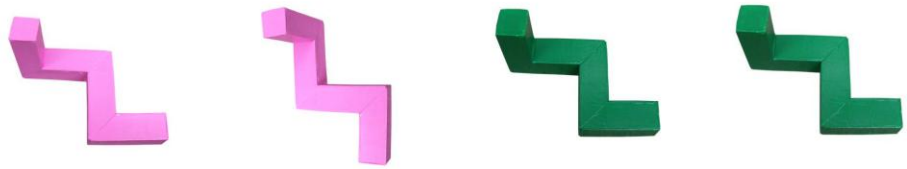
Participants

The 22 participants in this study were randomly assigned from a population of undergraduate students from a large southeastern university. The sample age was representative of a freshman college population (*M* = 18.59 years, *SD* = 1.09 years). The sample consisted of 17 females and 5 males (77% female). All participants were recruited from introductory psychology courses using the online participant management software SONA. For their participation, participants received a small amount of credit in their course.

Materials

For this study four physical Shepard and Metzler blocks were constructed for the main experiment (see main experiment materials for details). The colors of the stimuli (green, yellow, pink, and orange) were chosen for their relative low saliency based on a previous study of visual color saliency (Gelasca et al., 2005) and their ease of differentiation/identification.

These four blocks were photographed, and those photographs were digitally manipulated to create equal sized visual shapes on the screen. These photographs were used as stimuli during the mental rotation task. This ensured that the appearance of the physical block stimuli and the appearance of the mental rotation stimuli were similar enough that participants would automatically make an association between one and the other. The actual size of the images on the screen were 4.5" from the furthest edges of the image. Because all participants were seated at the same distance from the screen the angle the image subtends on the eye was approximately the same for each participant. Examples of these visual stimuli are shown below.



Mirrored pink stimuli at 90 degree counterclockwise rotation and non-mirrored green stimuli at 0 degree rotation

These stimuli were presented with the Superlab presentation software version 4.0 on a desktop computer Dell Optiplex GX620 running windows XP with a screen size of 19’’ and resolution 1440 x 900.

Procedure

Prior to participating in the study, participants were screened by the online SONA system by indicating whether or not they were colorblind, and all participants who indicated colorblindness were unable to sign up for the study. For the pilot study a colorblindness test was not administered, but taking into account colorblindness base rates combined with the screening question we consider the issue is mostly circumnavigated. Participants were first given an informed consent form which outlined their rights as a participant and gave them a brief introduction to the study. They were seated at a computer, and given a short practice task introducing them to the mental rotation task. Participants were given instructions to try to work as quickly as possible without sacrificing accuracy in an attempt to circumvent speed/accuracy tradeoffs. In the practice task participants were presented with upright normal orientation images of the letter “R” and the letter “L,” on the left side of the screen, and on the right side of the screen were presented randomly rotated versions of the same letters. Participants were instructed to press the letter "f" if the stimuli were mirror images and the letter "j" if the stimuli were not mirror images. Participants were given feedback on their responses in the practice task by having the screen flash the words "correct" or "incorrect" respectively. Letters were chosen because of their lack of relationship to the experimental stimuli. This practice task was followed by the experimental stimuli in which participants were shown a random presentation of the four colored stimuli (green, yellow, orange and pink) at random 45 degree counterclockwise increments up to 315 degrees (see appendix B). These combinations provide 64 individual images including the same/mirror images. Participants were presented each image once in two trials for a total of 128 presentations. To control for participants guessing, it was predetermined that if any participant scored less than 80% accuracy in performing the mental rotation task, their data were removed from the analysis. Of the 22 participants run in this study, eight were excluded for scoring less than 80% accuracy in any one color, or for being more than three standard deviations away from the mean for reaction time, so 14 participants' data were analyzed. It is unclear why so many participants performed so poorly on the mental rotation task, but may be attributable to the lack of pre-screening participants for spatial ability skill. Following the mental rotation task participants answered simple demographics about themselves, which included information such as sex, age, and class standing. A subset of this sample also answered questions about the relationships of the colored blocks weight to each other in order to determine if any perceptual biases about the weight of colors was present.

Results

To determine whether the selected stimuli color had an effect on mental rotation reaction time, a within subjects one-way ANOVA was performed analyzing the reaction time differences between the four colors, which yielded a non significant F ratio $F(3, 14) = 2.039$, $p = .124$ and a partial eta squared of .136, indicating a small effect size. There was a significant difference between the reaction time of the green and the pink blocks, $p = .045$. A within subjects one-way ANOVA was performed analyzing the percent correct between the four colors, which yielded a non significant F ratio $F(3, 14) = 1.032$, $p = .389$ and a partial eta squared of .074 indicating a very low effect size.

Discussion

There was a significant difference between the green and pink blocks. There was no significance for the color model, and no other colors were significantly different from each other. We interpret this finding as indicating that the specific low saliency colors selected for the main experiment play little role in mental rotation, and that color by itself it should not affect the second experiment. Little previous research could be found on the expected differences between colors on a mental rotation task, but the saliency of the objects is not the same, and this suggested to us that some effect might be present. There is previous research which indicates that color helps facilitate mental rotation compared to black and white figures, but an article testing mental rotation between colors is missing. This finding in and of itself is interesting, and places further constraints on the nature of mental rotation as a whole. If color contributes to the speed or accuracy, it means that the nature of the mental rotation task takes into account these properties. Practically, this has implications for interface design of computer programs or navigation interfaces. An interesting study to perform would be to imply to participants that one color is rotated more slowly or more quickly than others for some reason, and to test and see if it still remains independent of their performance. This significant effect also deserves to be investigated more thoroughly, perhaps by comparing rotation speed of primary, secondary and other colors.

MAIN EXPERIMENT

Method

This experiment was conducted to determine if explicit information about the weight and size of objects would affect the mental rotation of those objects on a subsequent mental rotation task. A 2X2 design was used to resolve the effects of size and weight and test for an interaction between them.

Participants

The 30 participants in this study were randomly selected from a population of undergraduate students from a large southeastern university. The sample age was similar to the population in experiment one (M = 18.48 years, SD = .99 years). The gender distribution of the sample consisted of 19 females and 11 males, making the sample 63% female. All participants were recruited from introductory psychology courses using the online participant management software SONA. For their participation, participants received a small amount of credit in their course.

Materials

For this study, four physical mental rotation blocks were created based on the Shepard and Metzler blocks. The four conditions of the study (small light, small heavy, large light and large heavy) limited the dimensions and weight of each object. For the blocks with the "small" dimensions, the unit square of each section was chosen to be the cube root of 1 inch (one inch), and for the blocks with the "large" dimension, the unit square was chosen to be the cube root of 2 (1.27 inches). This created two conditions of size, one with twice the volume of the other. The blocks were constructed out of basswood sheets 1/16 inch thick which were cut into the desired dimensions to create a hollow shape. These were then assembled into the final shape and glued together with wood glue. For weight, the small light shape was matched to the weight of the large light shape, and the large heavy and small heavy weights were matched to each other. This weight increase was accomplished by adding small metal spheres to the interior of the object and solidifying them in place with an expanding foam. The final weights of the “light” conditions were approximately 50 grams, and the weight of the “heavy” conditions were approximately 250 grams. This difference in weight is far beyond the just noticeable difference as predicted by Weber’s law. The colors of the stimuli were chosen arbitrarily on the idea that color would not factor into the mental rotation task itself.

Procedure

Participants were first given an informed consent form which outlined their rights as a participant and gave them a brief introduction to the study. Participants were then presented with a modified version of the Ishihara Color Vision Test (1917) and were presented plates 1, 2, 4, 8, 10 and 14. No participants failed the color vision test. They were then presented with the physical stimuli one at a time. To control for order effects, a latin square design was utilized to order the presentation of the stimuli. As participants were handed the blocks, they were instructed to match their block spatially so that their perspective matched that of a target image (see appendix C). The target image was then rotated 180 degrees, and participants were instructed to match their shape to this new orientation to ensure that an implicit rotation was encoded. After all four shapes had been presented to the participants, they were asked to order them first by size, then by weight. They were then instructed to answer a series of factual questions about the relationships of the blocks to each other using a computerized survey. These questions included relationships of size and weight; while answering these questions the blocks were available for participants to interact with. If a participant indicated an incorrect relationship, their error was pointed out by the computer and they were given a chance to correct their error. After answering these questions, the physical stimuli were hidden from view. Participants then performed a practice task identical to the task in the pilot study. Participants were given instructions to try to work as quickly as possible without sacrificing accuracy in an attempt to circumvent speed/accuracy tradeoffs. In the practice task participants were presented with upright normal orientation images of the letter “R” and the letter “L,” on the left side of the computer screen, and on the right side of the screen were presented randomly rotated versions of the same letters. Participants were instructed to press the letter “f” if the stimuli were mirror images and the letter “j” if the stimuli were not mirror images. Participants were given feedback on their responses in the practice task by having the screen flash the words “correct” or “incorrect” respectively. Letters were chosen because of their lack of relationship to the experimental stimuli, and performing this spatial task in between exposure and the experimental condition also serves as a spatial distracter task. This practice task was followed by the experimental visual stimuli in which participants were shown a random presentation of the four colored stimuli (green, yellow, orange and pink) at random 45 degree counterclockwise increments up to 315 degrees on a computer screen(see appendix B). These combinations provide 64 individual images including the same/mirror images. Participants were presented each image once in three trials for a total of 192 presentations. The participants used the same keys as in the practice task to indicate if the images were the same or different. To control for participants guessing, it was predetermined that if any participant scored less than 80% accuracy in performing the mental rotation task of any one stimuli, their data were removed from the analysis. Of the 30 participants run in this study, seven had to be excluded, so 23 participants’ data were analyzed. Following this task was the same demographics form as in the pilot experiment.

Results

A within subjects 2(weight) x 2(size) ANOVA was conducted, weight was varied as either heavy or light, and size was either small or large, the dependent values collected were reaction time and percent of correct responses. The ANOVA was insignificant for weight $F(1, 22) = .005$, $p = .943$, and insignificant for size $F(1, 22) = .028$, $p = .868$, and there was no significant interaction $F(1, 22) = 3.462$, $p = .076$. There was a main effect for percent correct of size which yielded an F ratio $F(1, 22) = 4.517$, $p = .045$ which indicated that large objects were correctly identified less frequently. The main effect for weight percent correct was not significant $F(1, 22) = 1.023$, $p = .323$, and there was no significant percent correct interaction $F(1, 22) = .093$, $p = .763$.

Discussion

The original hypothesis was that weight and size would both increase mental rotation reaction time. We did not find any effect on reaction time, there was however a trend towards a weight by color interaction. In Flusberg and Boroditsky's (2008) study participants were primed with a hard to rotate or easy to rotate figure, and in two conditions were told to imagine themselves physically rotating the object or not while doing the mental rotation task. When participants were told to imagine themselves physically rotating the object with their hand, the difficulty of rotation affected reaction time positively. When they were not told to imagine themselves rotating the object, the difficulty of the priming task had no effect. In our study, difficulty of rotation (a kinesthetic stimulus) was replaced with weight. These are not identical, in one condition you are attempting to rotate against an opposing force and in this experiment the weight is more under free control. As secondary information the weight is only a component of the information, the force is different than an opposing force (and always in the direction of gravity) and less salient to us than an obvious resistance.

The lack of an effect for weight seems to suggest that participants did not use an embodied perspective to mentally rotate objects. If they were using an embodied motor mental imagery strategy, the theory predicts we would have seen an effect as in Flusberg and Boroditsky's (2008) study. This seems to indicate that participants used more disembodied mental imagery to rotate the stimuli, much like when Flusberg and Boroditsky asked the participants to "image the object as if it were rotating on its own." Why participants use this strategy is interesting as well, because it suggests that some mental actions, even those that have information about weight do not take into account the physical constraints which affect them in the real world, in this respect the mental rotation of weight is "disembodied." It seems likely that the reason this might be the case is that our mental models are more flexibly able to be used than these researchers initially though, that sometimes we can imagine objects as if they were happening in the real world, such as imagining jumping over a chasm before we actually jump, which leads to a type of mental practice allowing humans to use information to predict future consequences of our own actions. In contrast with this is a system of mental models which is not constrained by our bodies, a system which acknowledges the fact that if we were to perform an action in the real world, it would be constrained, so it 'removes' or 'neglects' parts of these mental models in order to more efficiently perform the mental action. It seems participants do not consider weight to be important factor to be considered in the mental rotation task, so it remains independent of this factor.

We did find that the percent correct of large stimuli was significantly lower, which suggests that people have more difficulty mentally rotating mental images of objects of increasing size. It is outside the scope of our study to answer why this is the case, but this finding is consistent with the study by Peisseg et. al which was performed with a population of pigeons. This in itself suggests that there is some intrinsic mental difficulty in encoding objects of various sizes then using those images that extends beyond the human species. Theoretically this has implications for mental model theories, which leads to the question of why size interferes with mental rotation, and furthermore leads to discussion of if there is an 'ideal' size to perform mental rotation. Practically it has implications for jobs which require mental manipulation of large objects such as crane operators, tank pilots, and engineers. It remains to be seen if this effect for size would disappear with training. The lack of effect for weight could be because the weight of an object is more easily encoded and utilized, or perhaps encoded differently than size information, such as in semantic or echoic encoding. It also may be the case that size information causes more interference while performing another visual task. A simpler and more likely explanation is that the speed/accuracy tradeoff prohibits the speed finding to appear.

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APPENDIX A

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: **Valerie K. Sims** and Co-PI: **Luke A. Furtak**

Date: **March 12, 2014**

Dear Researcher:

On 3/12/2014, the IRB approved the following human participant research until 3/11/2015 inclusive:

Type of Review:	UCF Initial Review Submission Form
Project Title:	How motor representations influence mental processes.
Investigator:	Valerie K Sims
IRB Number:	SBE-14-09973
Funding Agency:	University of Central Florida(UCF)
Grant Title:	This research recieved a small research grant from the UCF office of undergraduate research.
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 3/11/2015, 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).

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:

Joanne Muratori

IRB Coordinator

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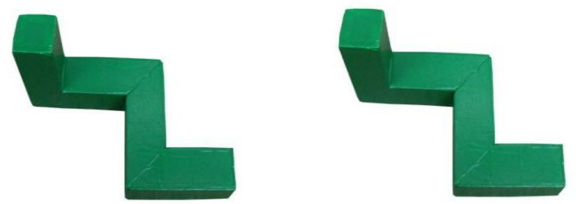
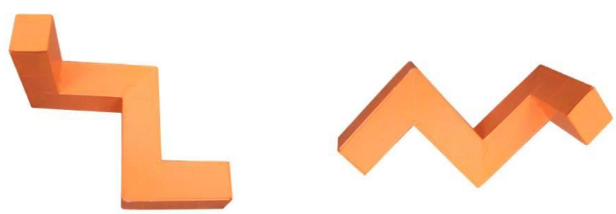
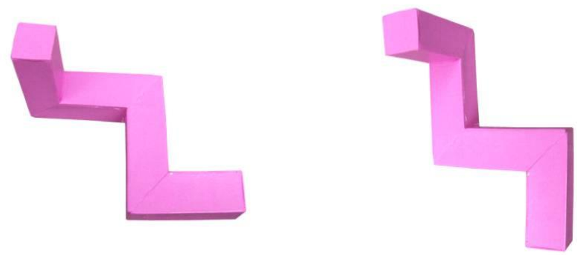
APPENDIX B



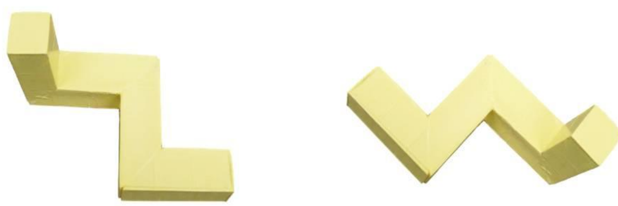
Non-mirrored green stimuli at 0 degree rotation



Non-mirrored orange stimuli at 225 degree rotation

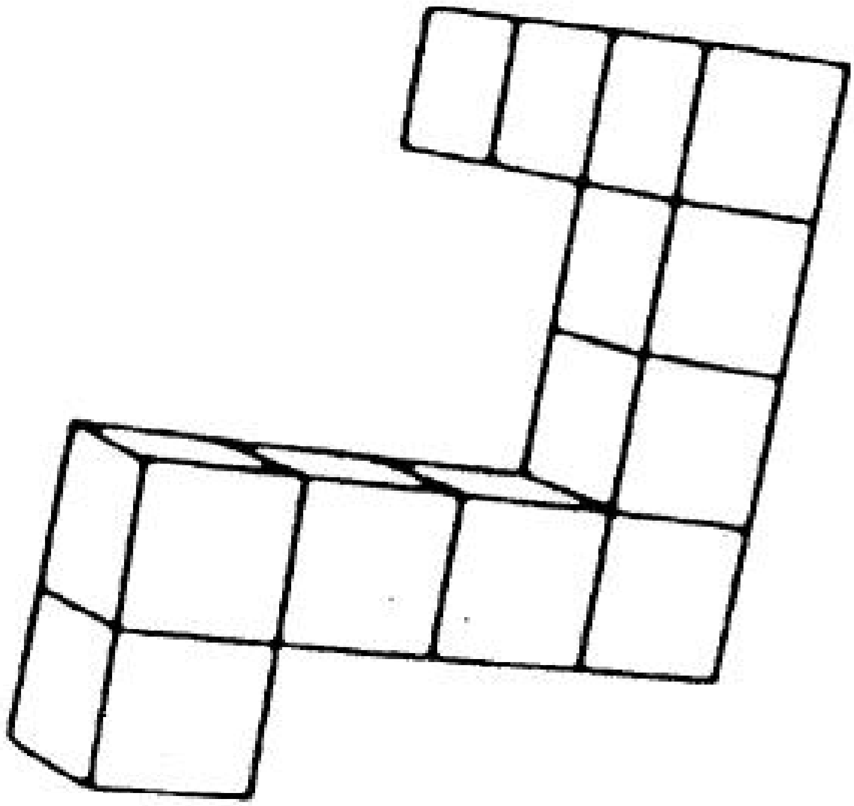


Mirrored pink stimuli at 90 degree rotation



Non-mirrored yellow stimuli at 135 degree rotation

APPENDIX C



Target stimuli participants matched during exposure.