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Training reduces the drawing detriments associated with categorical perception

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ABSTRACT

Previous research suggests that categorical perception may interfere with a novice artist's ability to accurately draw simple shapes. Specifically, when asked to draw two shapes of slightly different sizes, participants tend to exaggerate the categorical difference between the two and draw the small shape too small. Similarly, participants tend to draw oblique angles more oblique than they should be when they are close to perpendicular or overlapping. The current set of experiments investigated whether these categorical errors could predict participants' drawing ability on a more complex drawing task. A simple linear regression revealed that categorical errors in angle could significantly predict participants' scores on a face drawing task. In addition several training methods commonly used in art classes were evaluated for their effectiveness to reduce these types of errors for novice participants compared to a control training method and results indicated that explicit knowledge of the categorical and coordinate systems reduced overall errors, while the grid technique and sighting reduced categorical errors.

CHAPTER 1: INTRODUCTION

Drawing is an activity that is likely unique to the human species, and most people have extensive practice drawing in childhood. Despite this, without continued training, most adults cannot accurately draw realistic images of objects they see. Considerable progress has been made in understanding the processes that lead to drawing errors in untrained adults (Cohen & Bennet, 1997; Cohen & Jones, 2008; Mitchell, Ropar, Ackroyd, & Rajendran, 2005; Thouless, 1931). This line of research suggests that most errors in drawing objects can be attributed to the drawer misperceiving the object they are trying to draw. However, there are many ways in which misperceptions can occur and research must be done to clarify the specific nature of these misperceptions.

In addition, there has been a substantial line of research examining the differences between trained artists and novices. This line of research has found many differences, including differing abilities in regards to making decisions about which aspects of an object to draw, differences in visual encoding and working memory, and differences in visual perception (Cohen, 2005; Cohen & Jones, 2008; Glazek, 2012; Kozbelt et al., 2010; Ostrofsky, Kozbelt, & Seidel, 2012; Perdreau & Cavanagh, 2015; Tchalenko, 2014; Thouless, 1932). A possible difference that has not been explored is the extent to which an artist relies on her categorical and coordinate perceptual systems. Also, little research has been devoted to examining which training methods would be most efficient in enhancing the ability to draw realistically. Such an endeavor would have value not only in purely artistic venues, but also in occupations that demand the ability to draw realistically, such as architecture, design, medicine, and biology. Therefore, the goal of the current study is to understand the extent to which artists and novices differ in the coordinate and categorical processing abilities and to discover which training techniques can help bolster the coordinate perceptual system, which may lead to better drawing accuracy.

The Role of Misperception in Drawing Errors

In one of the first studies to examine drawing errors, Cohen and Bennett (1997) proposed four explanations that could account for inaccuracies in drawing: deficits in motor coordination required to draw, the inability to decide which aspects of an object to depict in the drawing, misperception of the drawing, and misperception of the object to be drawn. Through a series of experiments, the authors ruled out the first three explanations and concluded that the final explanation, misperception of the object to be drawn, contributed to most errors when drawing simple objects. In one experiment, they asked participants to either trace or draw a photograph. Tracing requires the participant to make decisions about which aspects of the image to represent and requires motor coordination, but importantly, does not rely on the participant's perception of the image since their task is simply to match point-by-point the image they are tracing. Drawing, however, requires all of the previously mentioned skills. The researchers found that tracings were much more accurate than drawings, suggesting participants had adequate motor coordination and were able to make good decisions about which aspects of the photograph to include in the drawing. To rule out the possibility that bad artists misperceive their drawing, participants in another experiment were asked to draw a photograph and then to rate the accuracy of their drawing as well as the accuracy of the other participants' drawings. A group of independent judges who did not participant in any drawing task were also asked to rate the drawings. Cohen and Bennet argued that if drawing errors are due to misperception of the drawing, then participants who received a low score from the independent judges (and were therefore poor artists) would overestimate the accuracy of their drawings compared to participants who received higher scores from the independent judges. However, this result is not what they found; instead they found that all participants rated the accuracy of all drawings higher than the independent judges, regardless of the artist's ability. This result suggests that having drawn the photograph might make a participant more appreciative of the difficulty of drawing and therefore rate all drawings as more accurate than someone who did not participate in the drawing task, but does not suggest that misperception of the drawing is a principle cause of drawing errors. In summary, Cohen and Bennet (1997) concluded that misperception of the reference object or image is the main contributor to drawing errors.

Much earlier, Thouless (1931) conducted an experiment that supported Cohen and Bennet's (1997) claim. He had participants view circular cards from various angles, so that the image projected onto their retina would be elliptical. Participants were given several outlines of elliptical shapes and asked to pick which one best matched the card they were viewing. They were explicitly told to pick the outline that matched the shape from the angle they viewed, not the actual shape of the card. However, participants systematically picked outlines that were more circular than the elliptical shape they would have seen from their vantage point. In other words, they were influenced by their prior knowledge of the actual shape of the card and could not ignore this information in favor of what they saw in reality (see Figure 1).

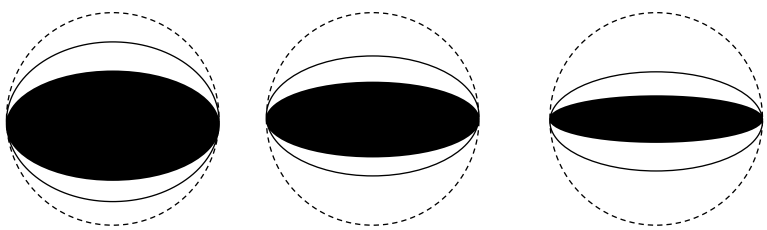

Figure 1: Sample results reprinted from Phenomenal Regression to the Real Object by Thouless (1931). Solid ellipse is the shape that would have been projected to participant's retina. Dashed line represents actual shape of object. Solid line in between is the shape participants drew or picked.

Similar results were found when participants were asked to draw the outline of the card; participants systematically drew an outline that was too circular. Thouless referred to this finding as "phenomenal regression to the real object" and later showed that phenomenal regression also occurs for brightness and hue (Thouless, 1931b). Cohen and Jones (2008) found similar results when participants were asked to view photographs of a window that were taken from various angles and to pick a matching outline of the shape of the window. The shape of the window in the images was trapezoidal due to the angle of the photo, but participants systematically picked outlines that were too rectangular, suggesting their perception was influenced by their knowledge of the actual shape of the window (see Figure 2).

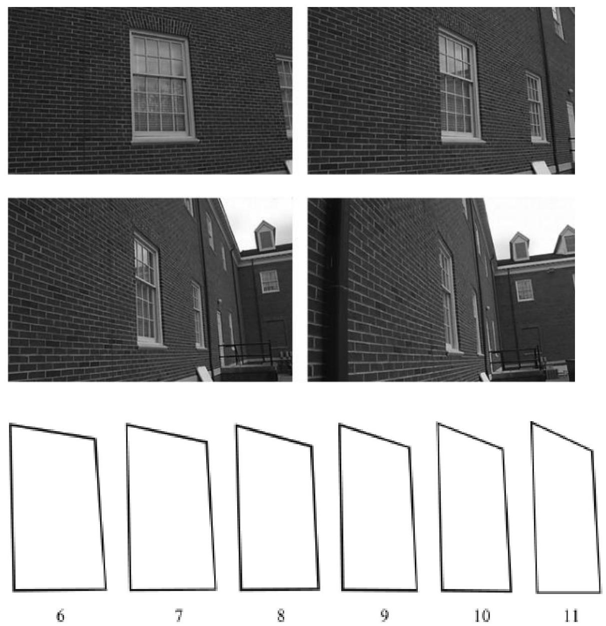

Figure 2: Sample stimuli used in Cohen and Jones (2008). Participants saw the photographs at the top and were asked to pick which outline best matched the window from the bottom.

Mitchell, Ropar, Ackroyd, and Rajendran (2005) distinguished between two types of misperception, delusions and illusions. Delusions occur when prior knowledge of the stimulus interferes with correct perception. Delusions can often be overcome by pointing out the flaw in the previous knowledge. For example, a painter may paint a sky blue when it is actually gray because of their prior knowledge of the color of the sky. Simply alerting them to the fact that the sky is gray may help them paint the sky color more accurately. An illusion, on the other hand, is a low-level perceptual distortion that often cannot be overcome by explanation. Many popular visual illusions fit this definition, such as the Herman Grid illusion and the Ebbinghaus illusion. Mitchell et al. tested the impact of illusion and delusion on participants' ability to draw rectangles in the Shepard illusion, in which two identical parallelograms appear to have different proportions because one is vertical and the other is horizontal. Specifically, it appears the vertical parallelogram is longer and skinnier than the horizontal one. This effect is an illusion because it is a low-level perceptual effect and cannot be overcome through explanation and, when asked to draw the images, participants consistently drew the horizontal rectangle shorter and wider than it should have been. In addition to the effect of illusion, Mitchel et al. looked at the effect of delusions by adding table legs to the parallelograms in half of the participants' images. Prior knowledge of how tables recede in the distance leads to the delusion that the vertical table must be longer and skinnier than the horizontal one. When legs were added to the parallelograms, participants' drawing errors were larger than when parallelograms were presented with no legs, suggesting that prior knowledge of a stimulus can lead to larger errors than illusions alone (see Figure 3).

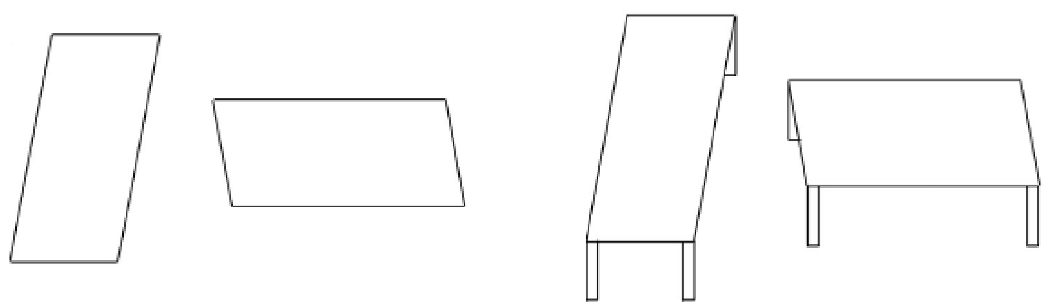

Figure 3: Sample images from Mitchel et al. (2005). Participants were asked to draw the Shepard's illusion either without (left) or with (right) table legs.

Differences Between Expert Artists and Novices

The previously discussed studies all examined how misperception can lead to drawing errors in populations of untrained participants. Another approach from which to understand drawing errors is to examine differences between expert artists who have received formal or informal training in drawing realistically and novice participants who have not received training in art. Several studies have examined these differences and have found several factors that are correlated with expertise. In one study

(Kozbelt et al., 2010), art majors and non-art majors were asked to trace an image of a man's face using a limited number of thin strips of tape. Artists' depictions of the face were much more accurate than non-artists even though both groups were allowed to use the same amount of tape and time to complete their tracings (see Figure 4). The authors of the study concluded that one difference between experts and novices was that experts were better able to make decisions about which aspects of the face to represent in their tape tracing compared to novices.

Figure 4: Face photograph and results from Kozbelt et al. (2010). Left: Image participants were asked to trace with tape. Right Top: Tracings produced by art majors. Right Bottom: Tracings produced by non-art majors.

In addition to decision making abilities, multiple studies have examined how drawing expertise relates to gaze frequency, duration, and efficiency. Cohen (2005) found that the amount of time spent looking at the image to-be-drawn and the frequency of gazes at the image to-be-drawn were positively correlated with drawing accuracy, suggesting that expert artists spend more time looking at the object they are trying to draw and look at it more frequently, whereas novices spend more time looking at their drawing. Similarly, through an observational study, Tchalenko (2014) found that experts often looked at the object they were drawing even while they were simultaneously drawing. He called this behavior "blind drawing" but did not examine whether novices engaged in blind drawing. Glazek (2012) measured drawers' visual encoding efficiency by having participants draw on a tablet with a stylus while their eye movements were tracked. Visual encoding efficiency was quantified as the amount of motor output (measured as number of pixels drawn on the tablet) per unit of visual input (measured as amount of time spent looking at the to-be-drawn object), and results showed that experts had a higher visual encoding efficiency than novices, meaning they produced more motor output per unit of visual input.

Another important distinction between experts and novices is visual working memory. Perdreau and Cavanagh (2015) asked participants to complete a drawing task using two monitors; on one monitor (monitor A), the image they were to draw (randomly generated 10-point polygons) was displayed, and on the other monitor (monitor B), participants used a mouse to draw the image. The experimenters controlled when each monitor was turned on and off, so that participants would see monitor A for one second and then see monitor B until they had drawn one point of the polygon. They were never allowed to view both monitors at once. Additionally, at various times throughout the experiment, one of the points in the to-be-drawn polygon would change and participants were instructed to continually update their drawing to reflect the most recent polygon. Therefore, participants had to utilize their visual working memory to hold in mind the polygon they had seen previously in order to detect a change in the current polygon and to be able to update their drawing accordingly. Results showed that experts were faster at identifying a changed point in the to-be-drawn polygon and were more accurate at updating their drawing to reflect that change, suggesting they had better visual working memory.

Many studies have also found perceptual differences between expert artists and novice artists. Ostrofsky, Kozbelt, and Seidel (2012) found that experts were better than novices at a size constancy task, in which participants viewed images of two spheres, one made to look further in depth than the other, and had to alter the size of one of the spheres to match the size of the other. Perdreu and Cavanagh (2014) showed that expert artists were faster and more accurate at distinguishing between line drawings of impossible 3D objects and possible 3D objects (see Figure 5). Finally, Thouless (1932) conducted a follow-up study to the 1931 study discussed previously in which he found that expert artists experienced less phenomenal regression than novices and Cohen and Jones (2008) showed that errors on their shape-matching window task could predict drawing ability on a face drawing task.

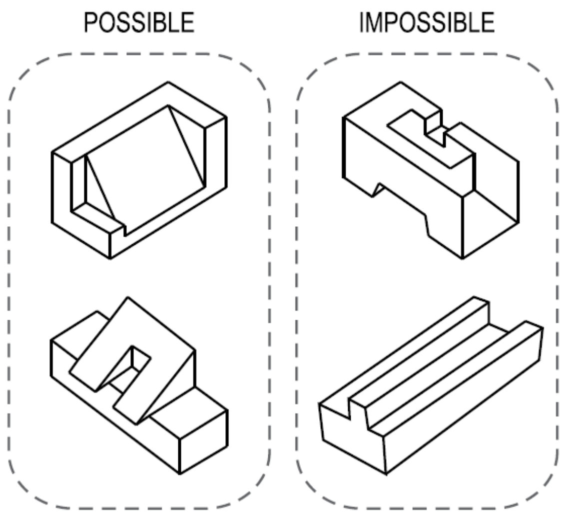

Figure 5: Example stimuli from Perdreu and Cavanagh (2014). Left: Line drawings of possible 3D objects. Right: Line drawings of impossible 3D objects.

Categorical and Coordinate Perception

The previous studies and others make clear that experts and novices differ in their decision making abilities, visual encoding efficiency, visual working memory, and their perceptual abilities. Chamberlain and Wagemans (2016) provide a thorough review of these differences. The current study seeks to add to the growing list of these differences by examining whether experts and novices also differ in the extent to which they rely on categorical and coordinate processing systems. These two systems are qualitatively different and one may be used over the other depending on the demands of the task at hand (Cooper & Wojan, 2000).

Categorical perception occurs when a continuously varying stimulus is perceived in discrete categories. For example, humans perceive the color spectrum in discrete categories such as yellow, green, and blue, even though color consists of light waves of continuously varying wavelengths. Categorical perception is evolutionarily favorable because it allows the organism to focus on the aspects of a stimulus that are important and ignore those that are not. For example, in the early evolution of primates, it would have been important to distinguish between red and green so that fruits could quickly be distinguished from the green foliage of the trees and to determine ripeness and concordant available energy in a fruit. It would not be so important to distinguish between subtle shades of red or subtle shades of green. According to Harnad (1987), perception is considered categorical if it meets the following criteria: first, stimuli along a continuum are parsed into discrete categories, just as the color spectrum is parsed into red, orange, green, blue, etc.; second, discriminating two stimuli within the same category is more difficult than discriminating two stimuli from different categories, even if the degree to which they differ is the same in each condition. For example, it would be more difficult for someone to discriminate between two shades of blue than to discriminate blue from green, even if the difference in hue was the same for each pair (Gilbert, Regier, Kay, & Ivry, 2006, see Figure 6).

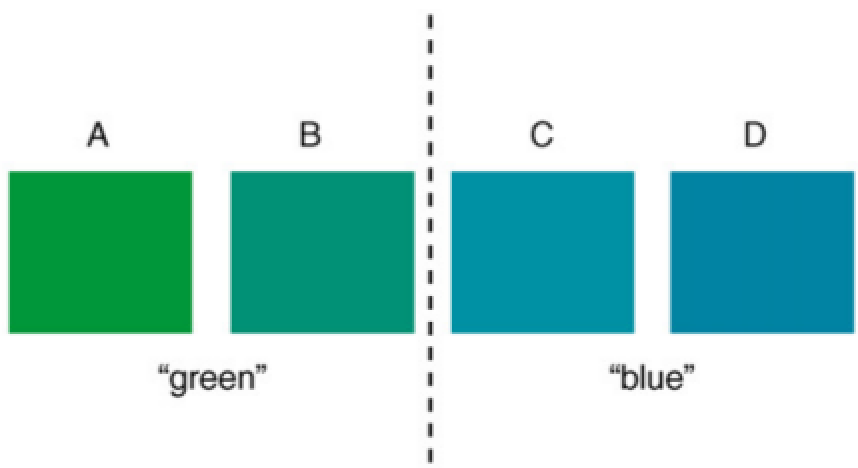

Figure 6: Sample stimuli used in study by Gilbert, Regier, Kay, and Ivry (2006). Participants were slower and less accurate to distinguish within-category colors (C vs. D or A vs. B) than to distinguish between category colors (B vs. C) even though the hues differed by the same amount.

Categorical perception is not just employed in distinguishing colors; it is also present in other aspects of visual perception and in other modalities, such as speech perception (Liberman, Harris, Hoffman, & Griffith, 1957). Biederman (1987) proposed that basic-level object recognition relies on coding of the parts of an object as well as the categorical relations among those parts. For example, a coffee mug would be categorically coded as “a cylinder with a curved cylinder to the side”. Cylinder and curved cylinder are parts of the object, called geons, and “to the side” is a categorical coding of the relative position of the parts. Categorical perception would also be used for relative size, in which one part could be categorically coded as “smaller than,” “larger than,” or “equal to” another part. In addition, relative orientation of two parts could be coded categorically as either “parallel,” “oblique,” or “perpendicular.” Again, this categorical method of coding relations is advantageous because it allows the organism to distinguish between objects based on properties that do not vary as the viewer’s perspective on the object varies. A coffee mug would be coded as “a cylinder with a curved cylinder to the side” from any natural perspective of the coffee mug in which both parts are visible.

Biederman (1987) proposed a finite set of geons that could be used for object recognition and that consisted of collections of nonaccidental properties (i.e. properties of the object that do not change as the observer’s perspective of the object changes). These properties include whether the edges of the object are parallel, whether the axis of the object is straight or curved, and more. Evidence for the use of these features to recognize objects comes from experiments in which line drawings of common objects were degraded such that in some images the nonaccidental properties were apparent but in other images, they were not. Participants were simply asked to name the objects and made significantly more errors if degradation eliminated nonaccidental properties, compared to when degradation kept these properties intact, even though the overall amount of degradation was the same in both conditions (see Figure 7).

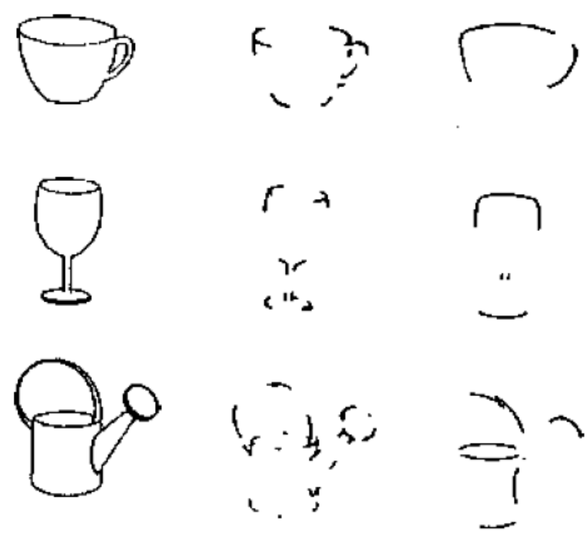

Figure 7: Stimuli used in Biederman (1987). Left is the original image, which participants never saw. Middle is images in which nonaccidental properties have been preserved. Right is images in which nonaccidenttal properties are degraded. Amount of degradation in both columns is equal.

Support for the idea that relations among parts of an object are coded categorically came from a study by Rosielle and Cooper (2001) in which participants performed a discrimination task deciding whether two sequentially presented line drawings were of the same object or not. Each object consisted of two parts with one part either at a 0°, 30°, 60°, or 90° angle from the other part. The results showed that participants had more difficulty distinguishing 30° and 60° versions of the objects than any of the other pairs, even though all pairs differed by 30°. This finding suggests that participants have orientation categories of “parallel,” “perpendicular,” and “oblique” as Biederman (1987) proposed and that participants had difficulty distinguishing between objects that both fell into the “oblique” category. (see Figure 8).

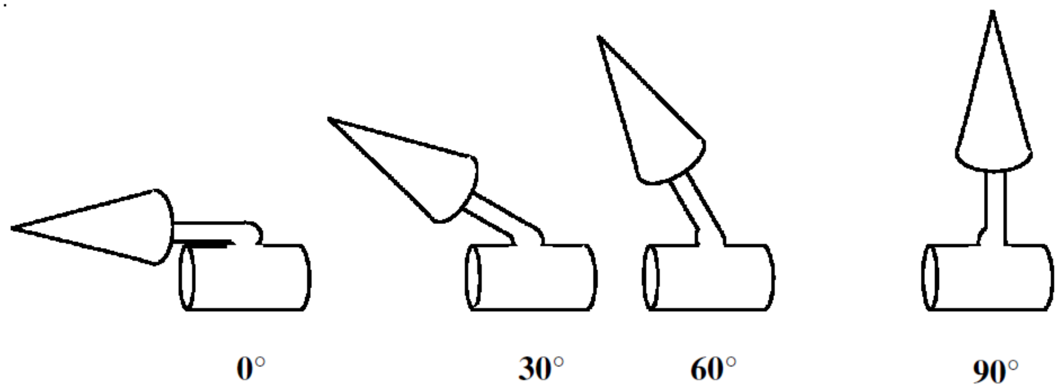

Figure 8: Example stimuli used in Rosielle & Cooper (2001). Participants had difficulty distinguishing between the 30 and 60 degree objects but not any other pairs, suggesting orientation is coded categorically.

Because of its many advantages, categorical perception tends to be the default perceptual system when distinguishing between objects with differing structural descriptions. However, it also has disadvantages, the primary one being that it cannot be used to distinguish between two stimuli that have the same categorical description. For example, it would not help me to distinguish my coffee mug from my husband's mug or to distinguish the faces of my brothers. To make those differentiations, a second perceptual system is necessary that codes the metric properties of a stimulus.

This second perceptual system has several names, including the coordinate system (Brooks & Cooper, 2006; Casner & Cooper, 2006; Cooper & Brooks, 2004; Cooper & Wojan, 2002) and the metric system (Hellige & Michimata, 1989). Throughout this paper, I will refer to it as the coordinate system. The coordinate system is slower and requires more cumbersome calculations to overcome changes in perspective than the categorical system, but it is more precise (Cooper & Wojan, 2002). It utilizes a metric representation of the stimulus that codes the parts of an object and their relations, not using categorical descriptions, but as precise metric units. For example, in a categorical system, a person's face would be represented as "two eyes above a nose which is above a mouth," but this description would be true of any face and would not help distinguish between two faces. A coordinate system, on the other hand, would represent the position of features as coordinates relative to an origin point, so the representation would be something like “one eye at coordinate (4,6), one eye at coordinate (7,6), nose at coordinate (6,4), and mouth at coordinate (5,3)” (see Figure 9). The precise metric information for each feature for each face would differ enough that the coordinate system would be able to distinguish between two faces (Cooper & Wojan, 2002).

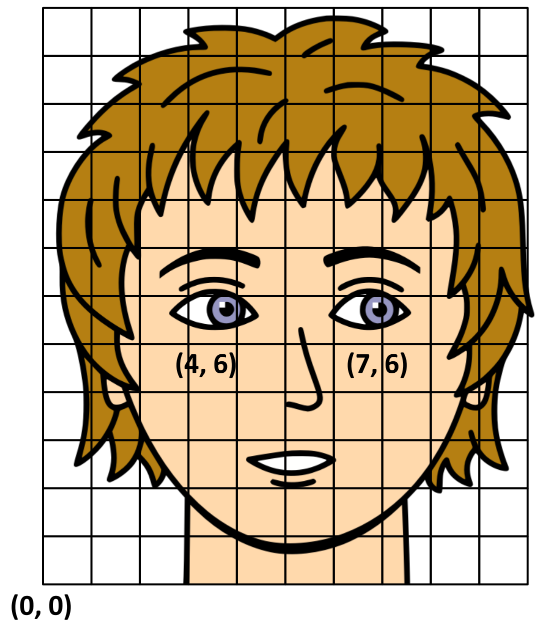

Figure 9: Conceptual illustration of how feature position would be coded in coordinate processing. The left eye would be at coordinate (4,6) relative to the origin and the right eye would be at coordinates (7,6).

The coordinate theory of face processing was offered as an alternative to some earlier theories posited to explain the apparent difference between face and object recognition. The first inkling that the two processes differ came from a neurological dissociation in which some patients could recognize objects but not faces, a condition called prosopagnosia. Prosopagnosia usually results from bilateral or right hemispheric damage to an area called the fusiform gyrus in the ventral occipitotemporal cortex (Barton, Cherkasova, Press, Intriligator, O’Connor, 2004; Damasio, 1985) (see Figure 10). Once this area was implicated in prosopagnosia, researchers began investigating what other behaviors were impacted by prosopagnosia and how the fusiform gyrus correlated with other perceptual measures. Initially, many people believed that this area of the brain was a “face module” and so it was termed the fusiform face area, but early studies dispelled this notion by showing that activity in the fusiform gyrus was also correlated with recognition of stimuli other than faces. These findings led to one of the early theories of the function of the fusiform gyrus, which was that it is necessary for distinguishing objects in a class in which the observer has expertise. For example, bird watchers showed increased activation in the fusiform gyrus when discriminating between similar bird species and car experts showed increasing activation when distinguishing between similar cars (Gauthier, Skudlarski, Gore, & Anderson, 2000) (see Figure 11).

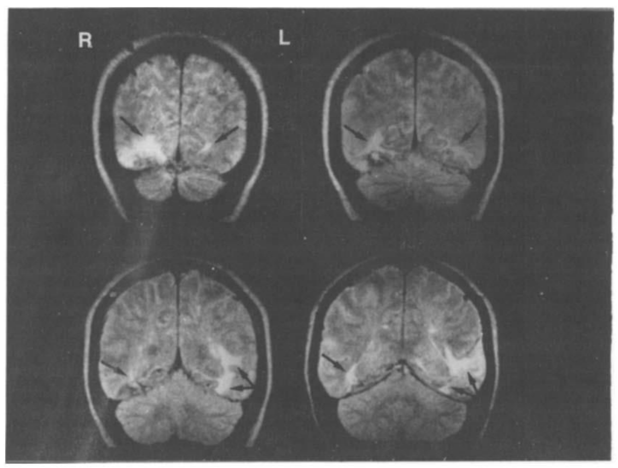

Figure 10: Nuclear magnetic resonance (NMR) image of a prosopagnosic patient with damage in the right and left fusiform gyrus. Damage indicated by lighter color. (Damasio, 1985)

In one well known study, Gauthier, Tarr, Anderson, and Skudlarski (1999) created novel stimuli called Greebles, which were all very similar to one another but differed in subtle ways. Participants learned the names of the Greebles over the course of the experiment, and as their expertise in recognizing Greebles increased, activity in the fusiform area when distinguishing the Greebles also increased. These studies led to the expertise hypothesis of face recognition which suggested that the fusiform gyrus is not a “face module” per se, but rather is devoted to a more general process of distinguishing similar stimuli in which the observer has expertise.

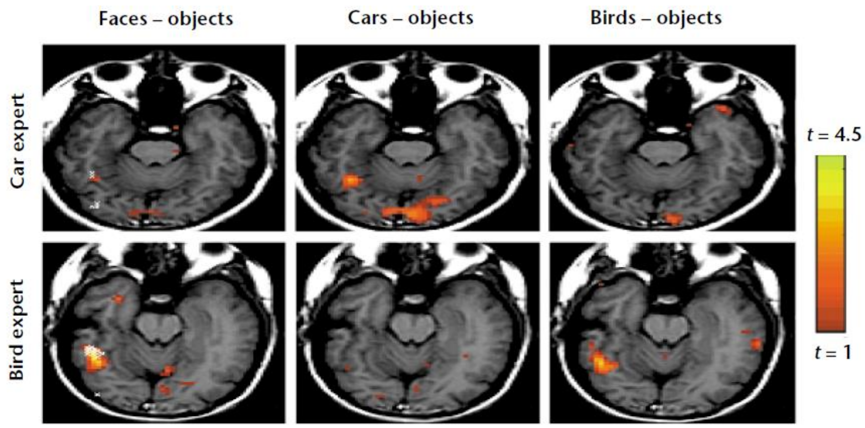

Figure 11: Results from Gauthier et al. (2000). Car experts showed more activation in the fusiform gyrus when distinguishing cars compared to birds or other objects. Bird watchers showed more activation in the fusiform gyrus when distinguishing birds compared to cars or other objects.

One problem with the expertise theory is that it would predict that the fusiform gyrus should be activated when recognizing letters and words, because this is a recognition task in which literate adults are certainly experts. Yet researchers investigating this prediction found that there was no such activation for recognition of letters (Puce, Allison, Asgari, Gore, & McCarthy, 1996). Specifically, letter recognition was correlated with increased activity in the left hemisphere, rather than the right hemisphere which is associated with face recognition. The coordinate processing theory could easily explain these results by positing that letters are recognized categorically. In addition to this advantage of coordinate processing theory, other lines of evidence suggest that it is better able to explain the pattern of deficits expressed in prosopagnosic patients than the expertise theory. For example, some patients with prosopagnosia have difficulty in recognizing other types of objects besides faces that would rely on coordinate processing, such as distinguishing between different animal species with the same categorical description (a donkey vs. a horse), distinguishing similar buildings, and differentiating between real money and play money (Casner and Cooper, 2006).

Another alternative to coordinate processing theory is the idea that the fusiform gyrus is specialized for processing biological entities rather than inanimate objects. (Captiani, Laiacona, Mahon,

& Caramazza, 2003; Caramazza & Shelton, 1998; Chao, Haxby, & Martin, 1999; Joseph, 2001). Support for this hypothesis came from neuroimaging studies that showed increased activation in the right fusiform gyrus when identifying living organisms compared to identifying tools and other inanimate objects (Chao et al. 1999). In addition, as mentioned earlier, prosopagnosic patients often have difficulty distinguishing between similar appearing animals. However, prosopagnosics have shown deficits in non-living objects such as distinguishing two tables that have the same structural description, suggesting that their deficit is not only constrained to living organisms (Casner & Cooper, 2006). In addition, the coordinate processing theory would predict that animate objects would rely on the coordinate system as many living organisms have similar or identical structural descriptions. For example, almost all animals' faces consist of two eyes above a nose above a mouth and the structural description for the bodies of all four-legged animals would be similar. Interestingly, Casner and Cooper (2006) found that a prosopagnosic patient could not distinguish biological entities when they shared a structural description (dog vs. wolf) but had no problem distinguishing animals with different structural descriptions (dog vs. eagle). This finding is better explained through the coordinate processing theory than through the biological recognition theory.

A similar alternative understanding of the face recognition system is the subordinate-level recognition hypothesis, which suggests that the fusiform face area is necessary for making subordinate-level identifications (e.g. eagle), not for basic level identifications (e.g. bird) (Damasio, Damasio, & Van Hoesen, 1982; Gauthier, Tarr, Moylan, Anderson, Skudlarski, & Gore, 2010; Tarr & Gauthier, 2000). Gauthier, Tarr et al. (2000) had participants perform a name-verification judgment in which an image was displayed and a word was presented auditorily. The participant's task was to decide whether the spoken name matched the picture. In the subordinate-level version of the task, the specific species was named (eagle), while in the basic-level version of the task, the type of animal was named (bird). Increased activity in the fusiform gyrus was seen during the subordinate-level task compared to the basic-level task. Again, however, the coordinate processing hypothesis has no problem explaining these findings, as the coordinate system would be necessary to recognize whether an image of a bird is an eagle, a hawk, or some other bird, but would not be necessary to recognize that it is a bird.

Coordinate Perception May Facilitate Better Drawing Accuracy

Taken together, the previous studies suggest that the two systems likely utilized in object and face recognition are the categorical and coordinate perceptual systems, respectively. What is less established is whether or not use of these two systems varies between individuals. For example, it may be the case that trained artists rely more heavily on the coordinate perceptual system while drawing than do novice artists. Utilizing the coordinate system over the categorical system would enable an artist to more precisely draw the exact relative sizes, angles, and positions of the parts of the object they are drawing, leading to a more accurate and realistic drawing than if they were to rely on the categorical system. Further, it is possible that different training methods used in formal and informal art education may lead to increased ability to utilize the coordinate system.

Some of the evidence that higher reliance on the coordinate system leads to advantages in drawing accuracy comes from the correlation between brain structures involved in coordinate processing and in drawing. The earliest example of this relationship was found examining the abilities and deficits of patients who had undergone commissurotomy, a neural surgery in which the corpus callosum, a thick cable of nerves connecting the two hemispheres of the brain, is completely severed. This surgery is most often done to alleviate seizures in patients with intractable epilepsy (Sperry, 1968) and patients with the surgery are often called “split-brain patients”. Initially, these surgeries seemed to indicate that the corpus callosum was not an important structure in the brain as severing it had little impact on patients’ functioning and daily life. However, through carefully designed experiments carried out over the course of several years, researchers were able to show that the corpus callosum was necessary for communication between the right and left hemisphere of the brain.

In some studies (Sperry, 1968), split-brain patients were allowed to see or feel common objects in their right or left visual field or their right or left hand. Information from the right visual field and right hand are sent to the left hemisphere of the brain and vice versa. Sperry showed that when presented with information to the right side of the body (or left side of the brain), participants could easily vocalize their experience. For example, if they were shown a picture of a key through their right visual field/left hemisphere (RVF-LH) they would say that they had seen a key. When the information was sent to the right side of their brain, they were not able to say what they had experienced. However, later studies showed that they were able to draw what they had experienced. For example, if they were shown a key in their left visual field/right hemisphere (LVF-RH) they could not communicate what they had seen through language, but if participants were given a pencil in their left hand (controlled by the right hemisphere of their brain), they could draw what they had seen. These results suggested that both hemispheres of the brain can see equally well, but that a nonverbal method like drawing is required for the right hemisphere to communicate what it saw. Though Sperry did not directly test whether the left hemisphere could draw what it had seen, he concluded that "in some tests, the minor [right] hemisphere is found to be superior to the major [left], for example, in tasks that involve drawing spatial relationships…" (Sperry, 1968, p.732). Some have suggested that this ability of the right hemisphere is due to its propensity to see things as they are in the present, or in other words, to ignore previous knowledge one may have about an object that interferes with how it is perceived from a particular perspective (Edwards, 1999).

Evidence suggests that coordinate processing may be lateralized to the right hemisphere, just as drawing ability is. Hellige and Michimata (1989) had participants do categorical or coordinate versions of a dot and bar task presented to either the RVF-LH or the LVF-RH. In the categorical version of the task, participants were shown an image of a bar with a dot either above or below it and were simply asked to indicate whether the dot was above or below the bar. In the coordinate version of the task, participants were presented with the same stimuli but were asked if the dot was more or less than 2 cm away from the bar (see Figure 12). Results showed that participants' reaction times and error rates were significantly smaller on the coordinate task when stimuli were presented to the LVF-RH and were smaller on the categorical task when the stimuli were presented to the RVF-LH, though the latter effect was only marginally significant. Neural network simulations (Baker, Chabris, & Kosslyn 1999; Kosslyn, Chabris, Marsolek,& Koenig, 1992) suggest that the differences in processing between the two hemispheres may be due to differential input from visual neurons with varying receptive field sizes.

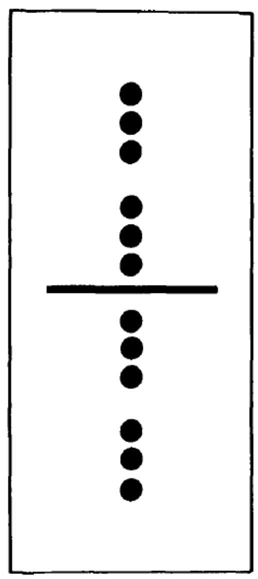

Figure 12: Stimuli used in Hellige and Michimata (1989). Participants would see the bar and only one of the 12 dots presented to either the left or right visual field. In the categorical version of the task, they were asked if the dot was above or below the bar. In the coordinate version of the task, they were asked if the dot was within 2 cm of the bar or not.

Further evidence that coordinate processing is lateralized to the right hemisphere comes from studies involving patients with unilateral brain damage. Laeng (1994) examined 62 such patients, half with damage in the right hemisphere and the other half with damage to the left hemisphere.

Participants were asked to identify coordinate or categorical changes in photographs, and results showed that patients with damage in the left parietal lobe had difficulty with the categorical task, while patients with damage to the right parietal lobe had difficulty with the coordinate version of the task. In addition, neuroimaging studies (Baciu et al., 1999; Kosslyn, Thompson, Gitelman, & Alpert, 1998) showed greater activation in the right hemisphere during coordinate tasks compared to the left hemisphere or categorical tasks.

The previously discussed studies show that both drawing ability and coordinate processing may be lateralized to the right hemisphere, and therefore could be related. A more direct piece of evidence is a study which found that the ability to process faces is related to drawing ability in novices. Devue and Grimshaw (2018) had participants complete a drawing task, in which they were asked to draw a photograph of a face, as well as a battery of face recognition and memory tests, such as the Cambridge Face Perception Test (Duchaine & Nakayama, 2006). They found a significant correlation between scores on the face drawing task and scores on the face recognition battery, suggesting that face identification, which relies on the coordinate perceptual system, is related to drawing ability.

While the previous research suggests that drawing expertise and coordinate perception are related, other studies further suggest that novice artists may be bad at drawing accurately because they rely too heavily on their categorical perceptual system and make errors driven by this system. In one study (Rosielle & Hite, 2009) participants with no drawing experience were presented with images of two shapes, one smaller than the other, but close to being the same size. The researchers reasoned that if participants were relying on categorical perception, they would code the small shape as “smaller than” the larger shape. When trying to reproduce the image, they could make two types of mistakes. They could make the smaller shape too large, which would make the smaller shape the “same as” the larger shape. To detect this error they would need to make a between category distinction, which should have been simple. If, however, they made the smaller shape too small, it would still be in the category of "smaller than" the other shape. To detect this error, participants would have to make a within-category distinction between the to-be-drawn image and their drawing, which according to categorical perception theory, should be very difficult. In other words, if the participants were using categorical perception to code the relative size between the two shapes, they would be more likely to draw the small shape too small than to draw it too large (note that the focus here on the smaller shape is arbitrary; the same logic could be used to say instead that they would draw the larger shape too large). This pattern of errors is exactly what Rosielle and Hite found. Some may question the external validity of measuring simple attributes of an image such as angle and proportion and relating them to drawing accuracy. However, previous research has found that these kinds of measures correlate highly with subjective measures of drawing accuracy (Chamberlain, McManus, Riley, &Rankin, 2014).

A similar study was conducted by Arnold and Cooper (2018), who found the same results when the shapes were connected as one object, rather than separate. In addition, the researchers included a second stimulus condition in which the smaller shape was significantly smaller than the larger shape so that drawing the smaller shape too small or too large would both result in a shape that was still in the category of "smaller than" the larger shape. In this condition, the average relative size drawn by participants was not significantly different from the correct relative size, suggesting that participants were just as likely to draw the small shape too small as they were to draw it too large. Similar results were also found for the relative orientation of two lines. Participants were asked to draw simple images which contained a target angle of either 15°, 45°, or° 75°. According to categorical perception theory, all angles would be coded as oblique, but 15° and 75° are close to a category boundary (parallel and perpendicular, respectively), whereas 45° is far from a category boundary. When reproducing these angles, participants should be more likely to draw the 15° angle too large, because doing so leaves the angle as oblique and they would have to make a within-category distinction to detect this error. Similarly, they should be more likely to draw the 75° too small, because doing so results in an oblique angle, whereas drawing it too large results in a perpendicular angle. Results confirmed these predictions, suggesting that novice artists relied on categorical perception and that this processing led them to make systematic errors in their drawings. Perhaps expert artists rely on categorical perception to a lesser degree, reducing their errors overall and resulting in a pattern of errors in which they are equally likely to err in either direction. However, neither of the two previously discussed studies tested expert artists.

Purpose of the Current Experiments

The current set of experiments serves multiple purposes. First, I wanted to replicate the results that were found in a previous study (Arnold & Cooper, 2018) and to extend the method of the previous study to examine whether categorical errors made on a simple drawing task could predict participants' ability in a more complex drawing task. Second, several experiments were conducted to examine the effectiveness of various training techniques to reduce categorical errors made by novice artists. In Experiment Two, I tested whether explicit knowledge of the categorical and coordinate systems could reduce errors. In experiments three and four, I examined the effectiveness of two techniques often taught in formal art education to reduce categorical errors, and in Experiment Five, I verified that findings from experiments two through four were not due to simple practice effects by examining the effectiveness of a control video that did not offer any technique to help overcome categorical errors.

CHAPTER 2: EXPERIMENT ONE

The purpose of this experiment was to examine whether the ability to accurately draw complex stimuli, such as a photograph of a face, was associated with participants' categorical errors in a simple drawing task. Recall that when relying on the categorical perceptual system, participants are likely to make a predictable pattern of errors, in which errors on relations near a category boundary will be biased away from that boundary, while errors on relations far from a category boundary will be unbiased. Reliance on the coordinate perceptual system, on the other hand, would result in unbiased and smaller errors for both image types. Many trained artists use methods that could bolster their coordinate system, decreasing the likelihood of making categorical errors or the magnitude of these errors if they were to occur. Therefore, it is likely that categorical errors in a simple drawing task, like that used in the experiments by Arnold and Cooper (2018), could predict participants' abilities to draw more complex stimuli accurately.

Method

Participants

Thirty participants were untrained artists who were undergraduates from the Iowa State University psychology participant pool. They were given course credit for 50 minutes of participation. In addition, 17 trained artists were recruited from Iowa State University's biological/premedical illustration program. Students in this program take several courses in which they are trained to draw accurately and realistically. They were given $10 for 50 minutes of participation.

Materials

There were 20 target images as well as one practice image and four distractor images (for a total of 25 images). Eight of the target images had two connected shapes of varying size. In four of these images, the shapes were slightly different sizes (the smaller shape was 75% the area of the larger shape), while in the other four, the shapes were substantially different sizes (the smaller shape was 25% the area of the larger shape). All eight images consisted of pairs of same shapes (e.g. two squares, two circles, two triangles, etc. The other eight images contained two lines forming an angle of either 15, 45, or 75° (there were four images with each angle). These angles were embedded in more complex figures consisting of lines and simple shapes (see Appendix A). The practice image and distractor images also consisted of simple shapes and lines, but did not have any targets of interest and only served to keep participants naïve to the purpose of the experiment, because they did not have any 15, 45, or 75° angles or size relationships of 0.25 or 0.75. The order of the images was randomized and this order was presented to approximately half of the participants, while the reverse order was presented to the other half. All images were placed onto PowerPoint slides with proportions equal to an 8.5" x 11" paper and were projected onto a projector screen at the front of the classroom.

The final slide presented a black and white photograph of a face. The photograph was of playwright Samuel Beckett. This photo was selected for its visual complexity, but also because its subject is likely not well known to many of the participants. In addition, this photo has been used in previous research on drawing ability (Kozbelt et al., 2010).

Each participant was given a folder which contained an informed consent document, a demographic sheet, instructions (see Appendix B), 26 sheets of paper that were blank except for a number in the top right corner, and finally a debriefing form at the end. Each participant was also provided two sharpened pencils.

Procedure

Participants were tested in groups ranging in size from 1 to 12 students in a classroom with a projector at the front of the room. They were each given a packet and asked to fill out the informed consent and demographic forms. The experimenter read through the instructions and answered any questions about the experiment. Then, each of the 25 images was displayed on the projector screen, one at a time for one minute each. Participants were instructed to draw each image as accurately as possible on the appropriately labeled blank sheet and instructions emphasized the need for accuracy and speed while discouraging the use of artistic style. Participants were also told that they could erase mistakes and redraw if necessary. After completing all 25 images, the photograph of the face was displayed for approximately 10 minutes, during which time participants were instructed to draw the face as accurately as possible. Finally, participants were debriefed and allowed to leave. All materials and procedures were approved by the Institutional Review Board (IRB) (see Appendix C).

Results and Discussion

All images were scanned onto a computer and measured using Adobe Photoshop. For the images containing two shapes of varying sizes, each shape in each image was filled and a pixel count was used to determine the area of each shape. Then the ratio between the smaller shape and the larger shape was calculated. Next, for each image, constant error was calculated by subtracting the participant's drawn ratio from the correct ratio (0.75 for slightly different images and 0.25 for substantially different images). Absolute error was used in most analyses and this number was obtained by taking the absolute value of the constant error. For images in which the target was an angle, the protractor tool in Photoshop was used to measure the angle drawn by participants, and this angle was subtracted from the correct angle (15, 45, or 75°) to get constant error, and again, in some analyses the absolute value of this number was taken for the absolute error.

For the drawings of the photograph of the face, images were also scanned, cropped to the edges of the drawing, and size was standardized. To standardize size, the average width of all images was calculated and then all images were adjust so that their width was equal to the average. Height was adjusted proportionately to width so the proportions of images were not distorted. The drawings of the faces were rated by 4 judges. Each judge saw each face 3 times, presented on a computer screen next to the reference photograph. The images were rated on a scale of 1 to 20, with a score of 1 meaning the drawing was a poor representation of the photograph, while a score of 20 meant the drawing was a very realistic and accurate representation of the photograph. Face drawing scores were averaged for each participant.

To examine whether there were differences in magnitude of error between expert artists and novices, two separate two-way mixed ANOVAs were conducted (one for size images and one for angle images) with participant type (expert vs. novice) as a between-subjects factor and image type (substantially different vs. slightly different for size images and 15° vs. 45° vs. 75° for angle images) as a within-subjects factor. Theoretically, experts should have been more likely to utilize their coordinate perceptual system while drawing, while novices should have been more likely to rely on their default categorical perceptual system. If this statement was true, then novices should have shown a pattern of errors similar to the results reported in Arnold and Cooper's (2018) study. Recall that while drawing the target relation in the images, participants could either err by drawing the relation too small or too large. According to categorical perceptual theory, for images near a category boundary (slightly different sized, 15, and 75 degree images), participants should err away from that boundary. However, when drawing images far from a category boundary, participants could err in either direction. The bias present in the images near a category boundary would therefore result in larger errors than the images in which the target relation was far from a category boundary. Relying on the coordinate system instead of the categorical system would change this pattern of errors, so that errors on images near and far from a category boundary should not differ significantly. Therefore, if experts make less categorical errors than novices, the expected result was an interaction in which experts would make smaller errors on drawings near a category boundary than novices while errors on drawings far from a category boundary would not differ significantly between the two groups.

For size images, the results showed that there was not a significant interaction between participant type and image type $F(1,45) = 0.10$, p=.75. There was also not a significant main effect of participant type, showing no significant difference between experts ($M = .08$, SD= .01) and novices ($M = .10$, $SD = .01$), although this result was trending in the expected direction $F(1,45) = 3.48$, p = .07. However, there was a main effect of image type, with slightly different sized images ($M = .11$, $SD = .04$) producing larger errors than substantially different sized images ($M = .07$, $SD = .04$), $F(1,45) = 36.37$, $p < .001$, partial $\eta^2 = .45$ (see figure 13).

The results from the size images were not consistent with the prediction that experts rely more heavily on their coordinate system than do novices. Contrary to the predicted results, there was not a significant difference in magnitude of error between the two groups on either slightly different or substantially different sized images. This result suggests that both experts and novices were relying on the same perceptual system while drawing images in which the relevant relation was size.

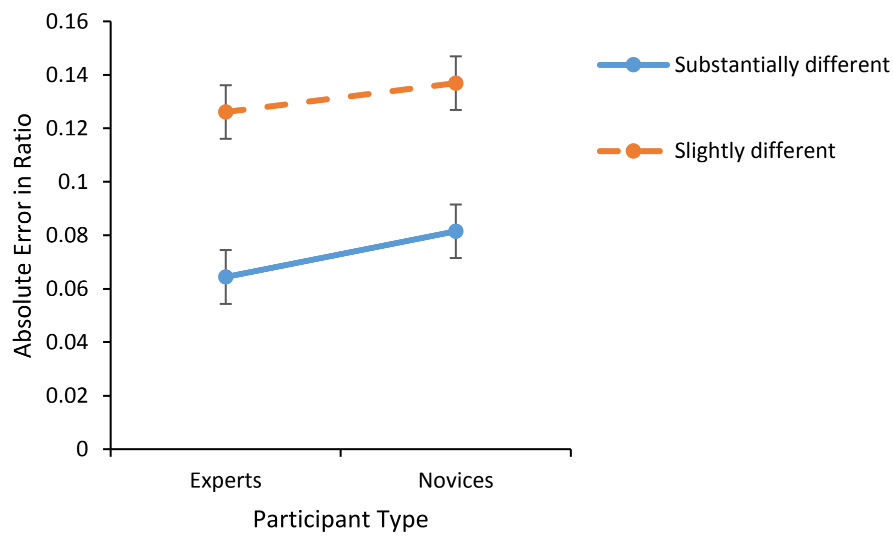

Figure 13: Results from size drawings for experiment one show significant main effects of image type. Error bars are standard error.

For angle drawings, there was a significant interaction between participant type and image type *F*(1,45) = 8.75, $p < .001$, partial $\eta^2 = .16$, so simple main effects were examined. This analysis revealed that for 15 degree drawings, experts had lower magnitude of error (*M* = 4.16, *SD* = 1.90) than novices (*M* = 8.49, *SD* = 3.02), *F*(1,45) = 27.32, $p < .001$, partial $\eta^2 = .38$. For 75 degree drawings, experts also had lower magnitude of error (*M* = 5.29, *SD* = 2.10) than novices (*M* = 9.82, *SD* = 3.35), *F*(1,45) = 24.25, $p < .001$, partial $\eta^2 = .35$, and for 45 degree drawings, there was no significant difference in magnitude of error between experts (*M* = 4.76, *SD* = 1.90) and novices (*M* = 4.92, *SD* = 2.42), *F*(1,45) = 1.28, $p = .26$ (see figure 14).

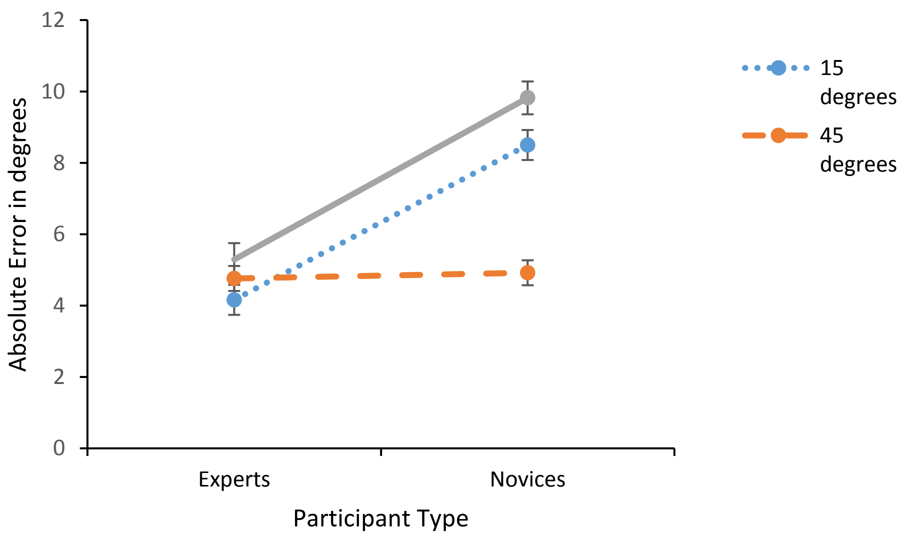

Figure 14: Results from angle drawings for experiment one show significant interaction between image type and participant type. Error bars are standard error.

Analyzing the difference between the two groups revealed that experts and novices differed in their magnitude of error for angle images, and specifically, that experts made smaller errors than novices for angle images that were near a category boundary (15 and 75 degree images), but not for those far from a category boundary (45 degree images). This pattern of results strongly suggests that for images in which the relevant target was orientation, expert participants relied more heavily on their coordinate system, allowing them to have lower magnitude of error on images near a category boundary than novice participants who were relying on their categorical perceptual system, leading to biased and larger errors for images near a category boundary compare to images far from a category boundary.

To follow up these analyses, regression analyses were performed in order to determine if magnitude of error in different image types could predict participants' performance on the face drawing task. These analyses were conducted because, although there is a clear difference between experts and novices it is also true that there is some variation within each group so that some of the novices may have much higher skill than other novices and some of the experts may be less skilled than other experts. Regression analyses may better capture these continual levels of expertise than an ANOVA.

Data were examined to evaluate whether participants' errors showed a pattern consistent with categorical perception by meeting the following criteria. First, participants' errors on images in which the target was near a category boundary should have been biased in a direction away from the category boundary. For example, when drawing images with 75 degree angles, participants should have been biased to draw the angle too small, in order to avoid crossing from the correct category of "oblique" to the incorrect category of "perpendicular. The average constant error for all participants in this scenario would be a large positive number (constant error is equal to the real angle minus the drawn angle), while average constant errors for 15° angles would be a large negative number, because they were predicted to draw the angle too large. Second, participants' errors for images in which the target was far from a category boundary should not have been biased in any direction and therefore, their mean constant error on these images should not have been significantly different from 0. This pattern of results was found by Arnold and Cooper (2018).

To test these predictions, single sample t-tests were conducted, comparing average constant error on each image type to zero. Results revealed that size images did not show the predicted pattern of categorical errors. Drawings of slightly different sized images had constant errors (M = .05, SD = .06) that were significantly higher than 0, $t(46) = 5.50$, $p < .001$, 95%CI[.03, .06], which is consistent with the predicted results. However, substantially different sized images also had constant errors (M = -.02, SD = .05) significantly different from 0, $t(46) = 3.27$, $p = .002$, 95%CI[-.04, -.01], which was not consistent with categorical errors and did not replicate the results from Arnold and Cooper (2018).

Errors from angle images followed the predicted pattern of results and replicated what was found by Arnold and Cooper (2018). Both types of images in which the relation was near a category boundary had errors that were significantly different from 0. Images with 15° angles had errors (M =-6.81, SD = 3.57) that were significantly lower than 0, $t(46) = 13.10$, $p < .001$, 95%CI[-7.86, -5.77], suggesting participants systematically drew these angles too large. Drawings with 75° angles had errors (M = 7.26, SD = 3.75) that were significantly higher than 0, $t(46) = 13.26$, $p < .001$, 95%CI[6.16, 8.37], showing that angles were drawn too small and 45° errors (M = -.84, SD = 3.68) were not significantly different from 0, $t(46) = 1.57$, $p = .12$, 95%CI[-1.92, .24].

In order to evaluate whether categorical errors predicted participants' scores on the face drawing task, several simple linear regressions were conducted, using absolute error on each image type as the predictor variable and the participant's score on the face drawing task as the criterion variable. The first of these analyses examined whether average absolute errors on 15 and 75 degree angle drawings could predict participants' performance on the face drawing task. The regression analysis showed a statistically significant linear relationship between the two variables $F(1,45) = 15.923$, $p < .001$ and combined errors on the 15 and 75 degree angle images accounted for 26.1% of the variability in participants' scores on the face drawing task. The regression equation was: predicted face drawing score

= 13.90 + (-.737 x 15 and 75 degree combined error) (see figure 15). Next, a simple linear regression was conducted to see if errors on 45 degree drawings could predict participants' performance on the face drawing task. This regression showed that there was not a significant linear relationship between the two variables $F(1,45) = .01$, $p = .93$ (see figure 16).

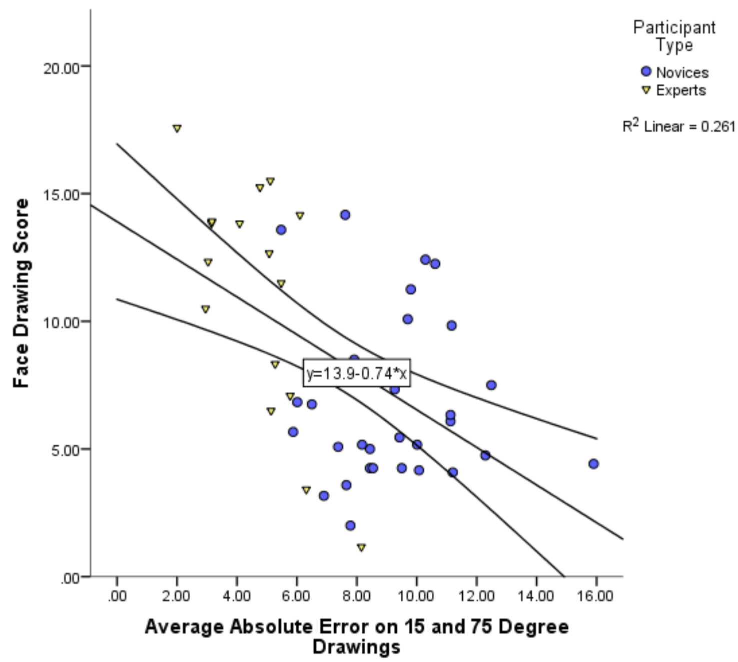

Figure 15: Scatterplot of regression data from experiment one shows a significant negative relationship between combined errors for 15 and 75 degree images and participants' score on the face drawing task. Plot includes mean confidence intervals.

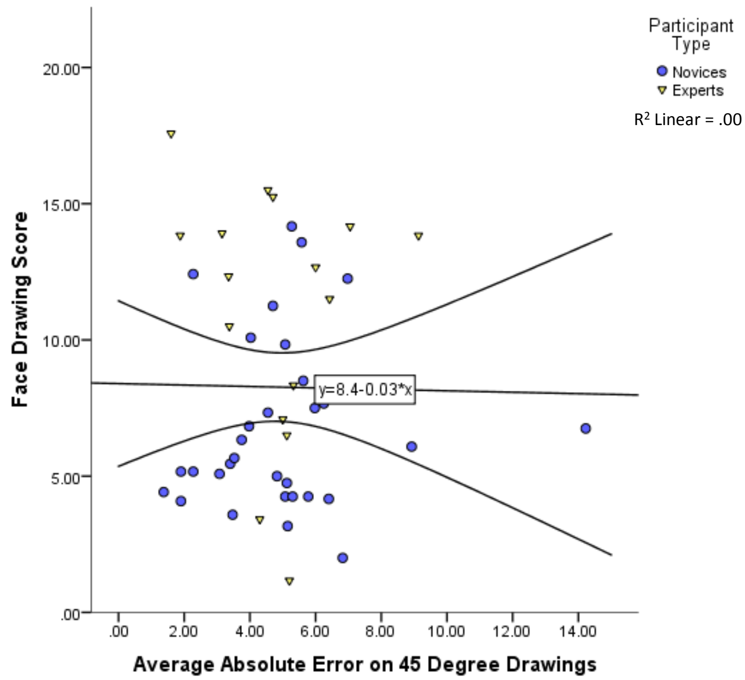

Figure 16: Scatterplot of regression data from experiment one shows no significant linear relationship between errors on 45 degree images and participants' score on the face drawing task. Plot includes mean confidence intervals.

Although drawings from the size images did not show a pattern of categorical errors, for the sake of thoroughness, linear regressions were conducted to examine whether errors on slightly different sized and substantially different sized images were linearly related to participants' scores on the face drawing task. The regression analysis for slightly different sized images revealed that there was not a significant relationship between absolute errors on this task and participants'' face drawings score, $F(1,45) = .54$, $p = .47$. Similarly, there was not a significant linear relationship between errors on the substantially different sized images and participants' scores on the face drawing task $F(1,45) = .29$, $p = .60$ (see figure 17).

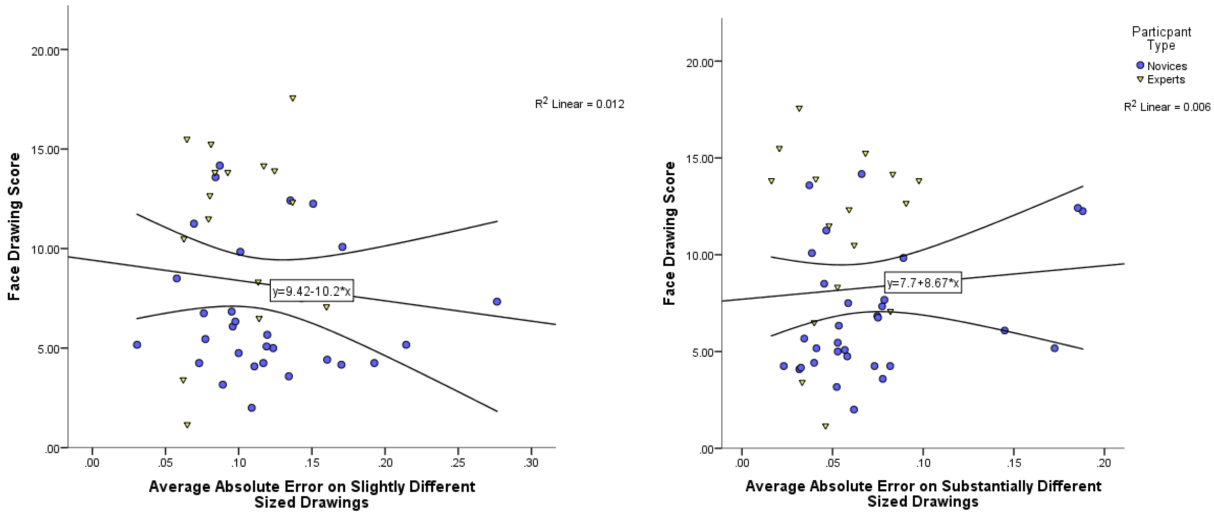

Figure 17: Scatterplot of regression data from experiment one shows no significant linear relationship between errors on slightly different sized images and participants' score on the face drawing task (left) or between substantially different sized images and face drawing scores (right). Plots include mean confidence intervals.

Consistent with the hypothesis that categorical errors are related to drawing ability, these regression analyses showed that the only significant predictor of participants' face drawing scores were errors on angle images near a category boundary (15° and 75° images), while errors on angle images far from a category boundary did not predict participants' performance on the face drawing task. Contrary to the predicted results, however, the absolute errors from size images near a category boundary did not have a significant relationship to participants' face drawing scores. A possible explanation for this result is considered below.

Results from Experiment One are partially consistent with previous literature and with the predicted hypotheses. One glaring discrepancy in these results is that size images did not show a pattern of errors consistent with categorical perception. Specifically, participants' errors on the images far from a category boundary (i.e. the substantially different sized images) showed errors that were biased in one direction while theories of categorical perception would suggest that errors in these images should have been equally likely to go in either direction. One possible explanation for this finding is that participants in this experiment were given one minute to complete these drawings, whereas in previous research (Arnold & Cooper, 2018), they were only given 30 seconds. Given how simple the size images are, one minute may have been enough time for participants to switch to the slower coordinate system to draw the shapes, resulting in a pattern of errors that cannot easily be explained in terms of categorical perception. The results of the angle images were consistent with categorical perception even though participants also got one minute to draw these images, but this apparent contradiction may be due to the fact that the angle images are more complex than the size images. Therefore, even with one minute, participants may not have had enough time to use the coordinate system for these more complex images. However, in the following four experiments, the results for size images were consistent with categorical errors and replicated results from Arnold and Cooper (2018) even though participants also had a full minute to draw the images in these experiments, so its also possible that the lack of categorical errors in the size images from Experiment One was simply an erroneous finding.

The more interesting and important finding of Experiment One is that categorical errors in the angle drawings were able to predict participants' scores on the face drawing task and account for a large amount of variability in scores on this task. Specifically, errors on drawings in which the relevant angle was close to a category boundary (15 and 75 degree angles) were significantly related to participants' abilities on the face drawing task (see figure 18), while errors on images far from a category boundary (45 degree angles) did not show the same pattern. This finding is consistent with the predicted hypotheses and suggests that ability to overcome categorical errors may be an important skill in drawing realistically. Therefore, experiments two through five examined different training techniques that may be used to help inexperienced participants rely more heavily on their coordinate system in order to overcome categorical errors.

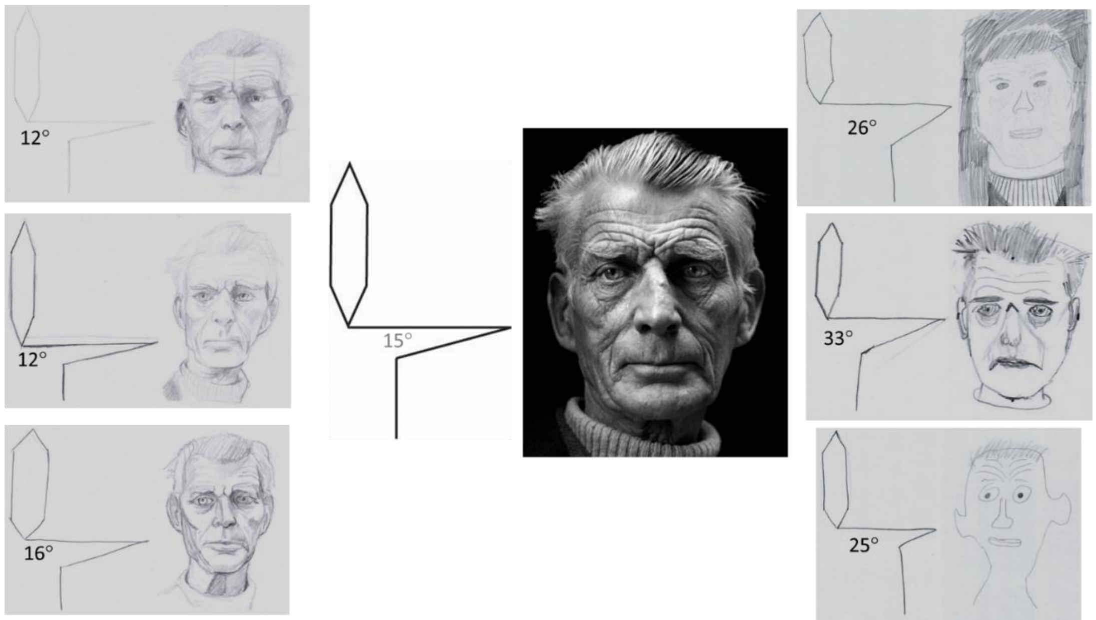

Figure 18: Sample drawings from experiment 1. Middle: Example 15° image and face reference photo; Left: 3 highest rated face drawings with same participants' drawing of 15° image; Right: 3 lowest rated face drawings and accompanying 15° drawing

CHAPTER 3: EXPERIMENT TWO

The purpose of Experiment Two was twofold. First, it was designed to examine whether explicit knowledge of the categorical perceptual system and its detriments would help participants overcome the errors associated with categorical perception. Recall that previous researchers (Mitchell et al, 2005) suggested there are two types of misperception, illusion and delusion. Delusions can be overcome with explicit knowledge of the misperception, while illusions cannot. Therefore, providing explicit knowledge to participants may help them overcome categorical errors if this type of misperception is analogous to a delusion. To test this, participants drew some images without any prior knowledge of the categorical perceptual system, then they watched a video explaining categorical perception and the common errors associated with it. After the video, participants drew another set of images, and the errors in size and angle drawn by participants before and after training were compared. Second, this experiment tested whether the results from Arnold and Cooper (2018) could be replicated. The prediction was that images far from a category boundary (substantially different sized and 45 degree angles) should not have errors significantly different from zero, while images near a category boundary (slightly different sized, 15 and 75 degree angles) should have errors significantly different from zero. This finding was not fully replicated in Experiment One, so it was important to test whether the results found in Arnold and Cooper (2018) are tenuous or robust.

Method

Participants

Participants were 30 undergraduate students from the Iowa State University psychology participant pool who received course credit for 50 minutes of participation.

Materials

Materials were the same as those used in Experiment One, with the addition of an approximately 10-minute prerecorded video lecture explaining common errors that are made by participants in this type of experiment. The video began by posing the question of why people are bad at drawing and provided a brief summary of some of the background research on the topic. Then the narrator in the video (a male volunteer) explained the categorical and coordinate perceptual systems and discussed the types of errors novices typically make when drawing simple images like those used in the experiment. The video ended by emphasizing that participants should avoid making these types of errors (e.g. avoid drawing the 75 degree angle too small). The visual content of the video consisted of overhead shots of my hand drawing on a whiteboard as well as simple animations created in PowerPoint[1] (see figure 19).

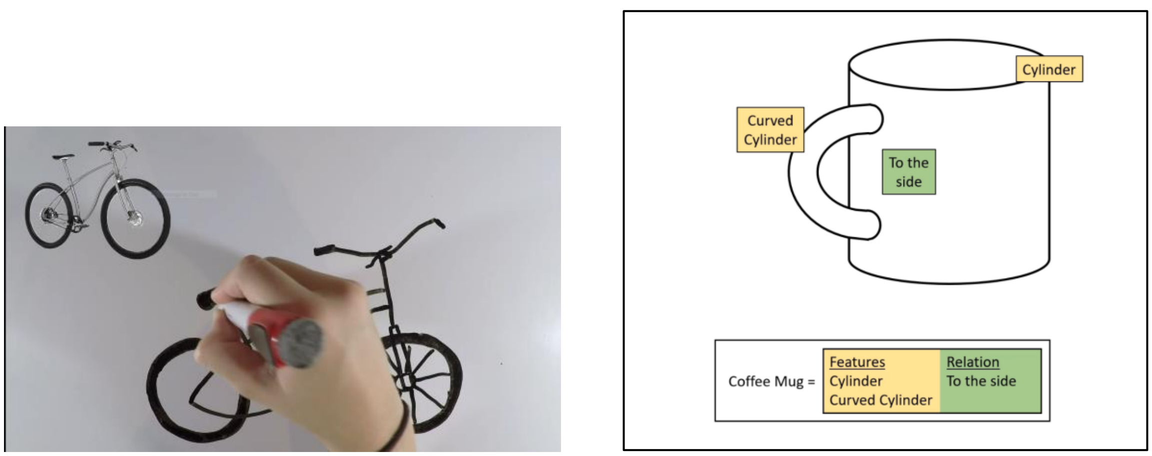

Figure 19: Two screenshots taken from the video used in experiment two.

Procedure

The procedure was identical to that used for Experiment One with the following exceptions. First, after the instructions for the experiment had been read, participants drew half of the images (4

[1] Video available upon request.

size images, 6 angle images, and 4 distractor images). Then, they were shown the video about common categorical errors, and then they completed the remaining half of the trials. Images used before and after training were counterbalanced across participants. Participants in this experiment did not complete the face drawing task.

Results and Discussion

Drawings were measured as they were in Experiment One. One of the goals of the current experiments was to see if results from Arnold and Cooper's (2018) previous studies could be replicated. In their study, participants were all novices and were untrained, so the relevant data to examine from the current experiment was the pre-training images. The prediction of the current experiments and the results from Arnold and Cooper's (2018) experiments were that images far from a category boundary (substantially different sized and 45 degree angles) should not have constant magnitude of error significantly different from zero, while images near a category boundary (slightly different sized, 15 and 75 degree angles) should have errors significantly different from zero. Single sample t-tests were conducted for each image type and this prediction was supported. Specifically, slightly different sized images were shown to have an magnitude of error (M = .05, SD = .12) significantly higher than 0, $t(29)$ = 2.34, p = .03, 95%CI[.01, .10], meaning participants drew the ratio between the two shapes too small, as predicted. For substantially different sized images, the magnitude of error (M = -.02, SD = .07), was not significantly different from 0, $t(29)$ = 1.83, p = .08, 95%CI[-.05, .00]. For angle images, errors on 15 degree drawings (M = -6.50, SD = 3.67) were significantly lower than 0, $t(29)$ = 9.69, p < .001, 95%CI[-7.86, -5.12], meaning participants drew the angle too large, while errors on 75 degree drawings (M = 7.90, SD = 4.61) were significantly higher than 0, $t(29)$ = 9.38, p < .001, 95%CI[6.18, 9.62], showing that participants drew the angle too small. Errors on 45 degree drawings (M = -1.85, SD = 5.03) were not significantly different from 0, $t(29)$ = 2.01, p = .06 95%CI[-3.73, .033]. These results replicate the results found by Arnold and Cooper (2018) and are consistent with the prediction that novice participants relied primarily on their categorical perceptual system prior to training.

Next, analyses were conducted to determine whether the video had an impact on participants' errors. Therefore, the variable of interest was the absolute error in participants' drawings before and after the training video. Absolute error was used as opposed to constant error for two reasons: first, absolute errors and constant errors showed the same pattern of results for all images near a category boundary (i.e. slightly different sized, 15 degree, and 75 degree images), so using absolute error did not obscure any information for these images when compared to constant error. Second, constant errors for images far from a category boundary were predicted to be near zero; however, absolute errors were not predicted to be near zero. One of the predictions was that, if training targets categorical perception specifically, then participants' errors should improve for images near a category boundary, but not those far from a category boundary. Using constant error to analyze improvement may hide improvements in images far from a category boundary, while absolute errors will not. For example, prior to training, participants could hypothetically draw 45 degree angles either 15° too large or 15° too small. Taking the average constant error across participants would result in an average error of 0. After training, they may have improved and drawn 45 degree angles either 5° too large or 5° too small. Averaging their constant error would still result in an error of 0, even though they clearly improved. Using absolute error, on the other hand, would give an average error of 15 in the pre-training images and an average error of 5 in the post-training images, revealing the improvement. In conclusion, absolute error is a more transparent measure of participants' improvements for images near and far from a category boundary and is therefore better for testing the predictions.

Two repeated measures two-way ANOVAs were conducted (one for size and one for orientation) to examine main effects of training (before and after training) and image type (substantially different and slightly different for size images and 15 degree, 45 degree, and 75 degree for angle images) as well as their interaction. For size drawings, the interaction effect between training and image type was not statistically significant $F(1,29) = 0.92$, $p = .35$, so main effects were examined. A statistically significant main effect of training was found with images drawn after training ($M = .09$, $SD = 0.04$) having a lower magnitude of error than those drawn before training ($M = .10$, $SD = .03$), $F(1,29) = 4.56$, $p = .04$ partial $\eta^2 = .14$, with a mean difference of .02, 95%CI[.00, .04]. In addition, a main effect of image type was found revealing that the slightly different sized images' errors ($M = .11$, $SD = .05$) were higher than errors for the substantially different sized image ($M = .07$, $SD = .04$), $F(1,29) = 15.17$, $p = .001$, partial $\eta^2 = .34$, with a mean difference of .04, 95%CI[.02, .06] (see figure 20).

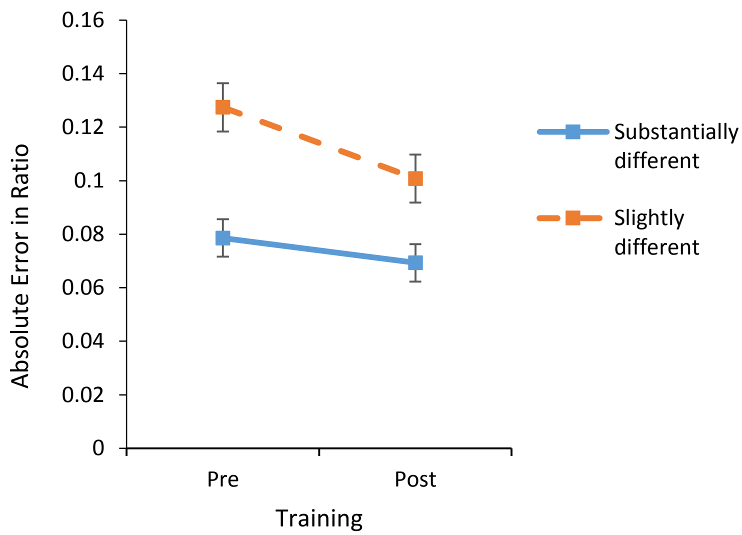

Figure 20: Results from size drawings for experiment two show significant main effects of image type and training. Error bars are standard error.

Angle drawings showed a similar pattern of results. There was not a significant interaction between training and image type $F(2,58) = .01$, $p = .99$, but main effects of training and image type were significant. Images drawn after training ($M = 6.23$, $SD = 1.81$) had significantly lower errors than those drawn before training ($M = 6.96$, $SD = 1.88$), $F(1,29) = 5.82$, $p = .02$, partial $\eta^2 = .17$, with a mean difference of 0.74, 95%CI[.11, 1.37]. The main effect of image type showed that errors for 75 degree images (M = 8.53, SD = 3.49) were significantly higher than errors for 15 degree (M = 6.34, SD = 2.92), with a mean difference of 2.19, 95%CI[.11,4.27] and 45 degree (M = 4.92, SD = 2.48) images, $F(2,58)$ = 10.58, $p < .001$, partial $\eta^2 = .27$, with a mean difference of 3.61, 95%CI[1.32,5.89], while there was no significant difference between errors for 15 and 45 degree images (see figure 21).

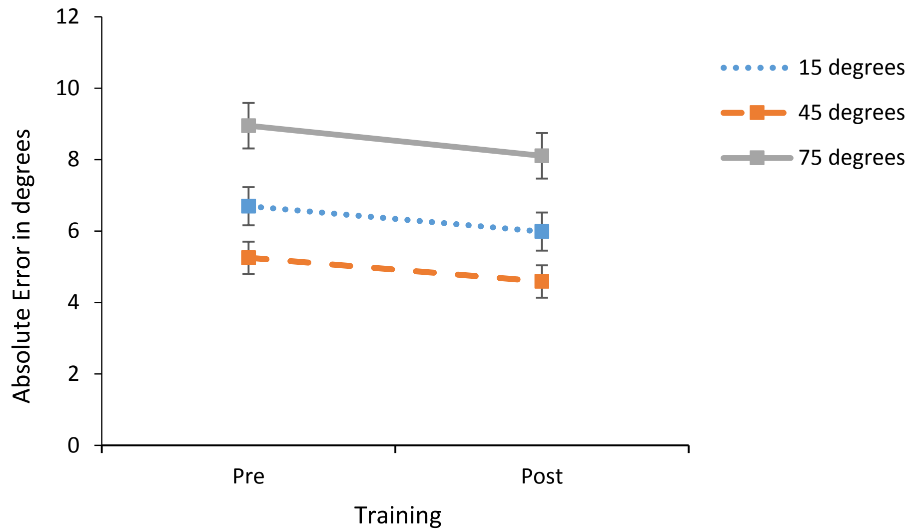

Figure 21: Results from angle drawings for experiment two show significant main effects of image type and training. Error bars are standard error.

Results from Experiment Two were partially consistent with the idea that a video explaining categorical and coordinate perception may help participants to draw more accurately. Considering that participants made smaller errors after watching the video than before watching it, information about the two perceptual systems seems to have been effective in reducing errors. However, the interaction between training and image type was not significant, suggesting that the video helped participants overall, but did not train them to avoid categorical errors specifically. This finding may be due to simple demand characteristics. The video concluded by explicitly telling participants the types of errors people make and to avoid them. This information could have simply made participants aware of the target relation in each image, so that they focused on drawing relative size and angle correctly for all images, regardless of whether the target relation was near or far from a category boundary.

CHAPTER 4: EXPERIMENT THREE

The purpose of Experiment Three was to examine the effectiveness of a training technique that is often used in drawing classes (Edwards, 1999) and specifically to look at its impact on categorical and coordinate perception. This technique has participants first pick an image to draw, then to draw a grid over this image, and finally to reproduce the image on grid paper, often focusing on one square at a time. Other variations of this technique can be used to draw from three-dimensional still-life settings by placing a window with grid lines in front of the 3D object to be drawn. In either case, the grid is supposed to help the artist with the difficult task of converting what they see in their three-dimensional reality into a two-dimensional flattened image on paper. The grid helps break up the image or object they are viewing into more manageable components and importantly, gives the artist a vertical and horizontal reference which they can use to determine the angles and proportions of all the parts of the image they are trying to draw. This technique is often used only in the very beginning stages of drawing instruction and after time, the artist will hopefully learn to imagine the grid in their mind's eye, rather than relying on a physical grid on paper or in the world to help them measure proportions (Edwards, 1999). Although there is no evidence that the coordinate system literally functions by overlaying a grid onto the visual world, this metaphor has often been used to describe the processing of the coordinate system and utilizing the grid technique may help bolster the coordinate system, because it forces artists to focus on the metric properties of the image to be drawn and to ignore categorical properties.

Method

Participants

Participants were 29 undergraduate students from the Iowa State University psychology participant pool and they were given course credit for 50 minutes of participation.

Materials and Procedure

Materials and procedure were the same as those used in Experiment Two, with one change. Rather than all images being presented on blank white paper, half of them were presented on a 1 inch grid. Participants were also given 1 inch grid paper to draw on for the last half of the images. Participants watched an approximately 3-minute long video (Valentine, 2013) explaining the grid method of drawing, in which they were encouraged to focus on one square of the grid at a time and draw what was in that square, then to move on to the next square, and so on until the image was completed. This video was taken from Youtube and was cropped in the PowerPoint presentation to remove a distracting URL in the lower left-hand corner. After watching the video, the researcher emphasized that participants should try their best to utilize the grid technique for the preceding drawings and then, participants sat quietly for approximately five minutes in order to equal the amount of time between pre and post-training drawings in Experiment Two (~10 minutes).

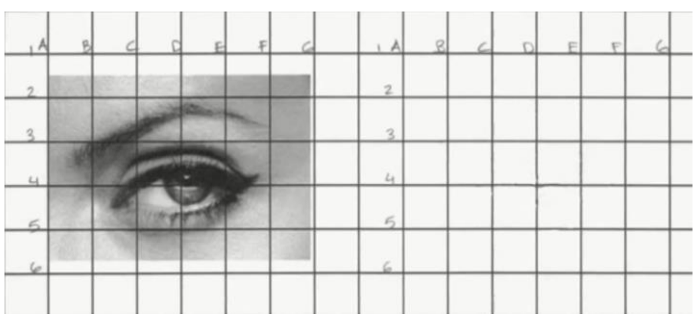

Figure 22: Screenshot taken from the video used in experiment three.

Results and Discussion

As in Experiment Two, the first step was to determine whether results from the current experiment replicated Arnold and Cooper's (2018) findings as well as the results from Experiment Two. Single sample t-tests were conducted for each image type and result from Experiment Two and from previous research were replicated. Slightly different sized images were shown to have an magnitude of error (M = .11, SD = .10) significantly higher than 0, $t(29) = 6.12$, $p < .01$, 95%CI[.07, .15], meaning participants drew the ratio between the two shapes too small, as predicted. For substantially different sized images, the magnitude of error (M = -.01, SD = .05), was not significantly different from 0, $t(29)$ = .68, p = .5, 95%CI[-.01, .02]. For angle images, errors on 15 degree drawings (M = -9.57, SD = 4.07) were significantly lower than 0, $t(29) = 12.66$, $p < .001$, 95%CI[-11.11, -8.02], meaning participants drew the angle too large, while errors on 75 degree drawings (M = 7.95, SD = 4.55) were significantly higher than 0, $t(29) = 9.41$, $p < .001$, 95%CI[6.22, 9.68], showing that participants drew the angle too small. Errors on 45 degree drawings (M = .10, SD = 6.02) were not significantly different from 0, $t(29)$ = .09, p = .93 95%CI[-2.19, 2.40]. Again, these results replicate what Arnold and Cooper (2018) found and the results from Experiment Two and suggest that participants' errors are consistent with categorical perception prior to training.

Next, drawings were measured and analyzed the same as in Experiment Two with two repeated measures ANOVAs in order to determine if the video had an impact on participants' magnitude of error. For size images, there was a significant interaction between training and image type $F(1,29) = 5.14$, p = .03, partial η^2 = .16. Therefore, simple main effects were examined. Errors for drawings in which the shapes were substantially different did not significantly differ between those drawn before training (M = .06 SD = .04) and those drawn after training (M = .04, SD = .03) $F(1,29) = 3.01$, p = .09. However, training did have an effect on drawings in which the shapes were slightly different sizes, so that images drawn before training had higher errors (M = .15, SD = .08) than those drawn after training (M = .09, SD = .06) $F(1,29) = 14.80$, p = .001, partial η^2 =.35 with a mean difference of .06, 95%CI[0.02, 0.10] (see figure 23). These results follow the predicted pattern and show that categorical errors on size images could be reduced using the grid method.

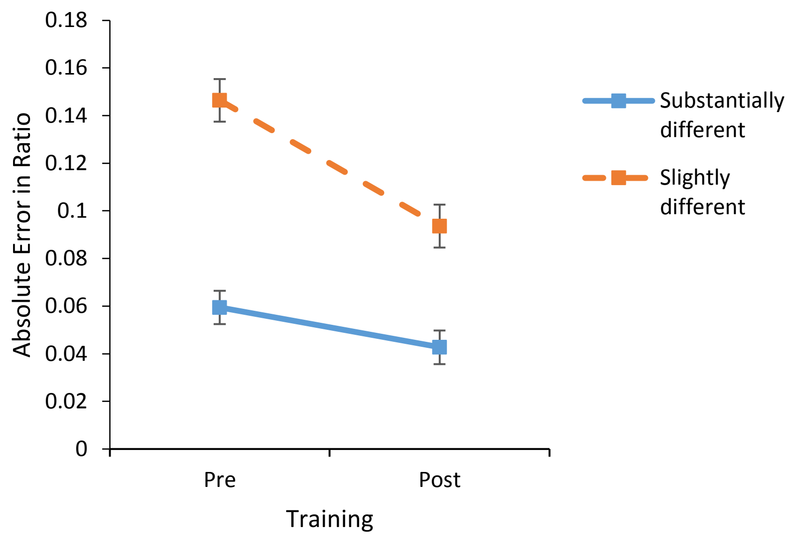

Figure 23: Results from size drawings for experiment three show significant interaction between training and image type with slightly different sized images benefiting from training more than substantially different sized images. Error bars are standard error.

For images in which the target was an angle, there was not a significant interaction between training and image type $F(2,54) = 2.542$ $p = .09$, but main effects of training and image type were significant. Images drawn after training ($M = 5.64$, $SD = 2.12$) had significantly lower errors than those drawn before training ($M = 8.20$, $SD = 2.96$), $F(1,27) = 22.25$, $p < .001$ partial $\eta^2 = .45$ with a mean difference of 2.56, 95%CI[1.45, 3.67]. The main effect of image type showed that errors for 45 degree images ($M = 4.95$, $SD = 2.40$) were significantly lower than errors for 15 degree images ($M = 7.45$, $SD = 3.68$) with a mean difference of 2.50, 95%CI[1.06,3.93] and 75 degree ($M = 8.37$, $SD = 2.61$) images, $F(2,54) = 14.15$, $p < .001$, partial $\eta^2 = .34$ with a mean difference of 3.42, 95%CI[1.90, 4.94], while there was no significant difference between errors for 15 and 75 degree images (see figure 24). These results show that utilizing the grid technique did have an effect on reducing errors, but it did so for all image types, so it did not target categorical errors specifically.

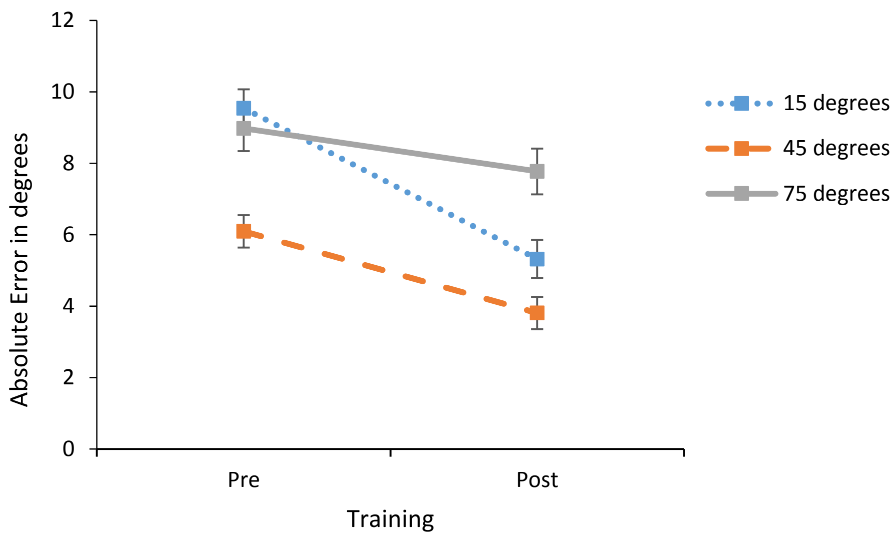

Figure 24: Results from angles images for experiment three show significant main effects of image type and training. Error bars are standard error.

Results from Experiment Three suggest that the grid method is an effective technique in reducing errors and particularly in decreasing categorical errors in the size images. The interaction found between image type and training for the size images showed that participants' errors were reduced for images in which the shapes were slightly different in size by using the grid technique. However, using the grid technique had no effect on errors in the substantially different sized images. This result is consistent with the idea that breaking the image up into smaller squares helps participants to focus on the metric properties of the image they are drawing, rather than on the categorical relations of "larger than," "smaller than," and "equal to" so they are less likely to err away from category boundaries when a relation is near one.

However, this pattern of results did not carry over to the images in which the relation of interest was an angle. There was not a significant interaction for these images; instead, the results show that training reduced errors for all images, whether they were close to a category boundary or not.

CHAPTER 5: EXPERIMENT FOUR

Another method that is commonly employed by trained artists is to use the tools at their disposal to measure the image or object to be drawn (Edwards, 1999). For example, art students are often encouraged to hold their pencil between themselves and the object to be drawn, using the pencil as a ruler to measure different parts of the object. This method is called sighting and it allows the artist to have a more accurate metric representation of the relative sizes of parts of the object they are trying to draw because it allows the artist to more accurately examine the proportions in the objects and images they are trying to draw. To sight, an artist must hold their pencil or other similar utensil in front of them with one eye closed and their elbow fully extended and placed directly in front of the object or image they are trying to draw. Using this consistent view, they then choose a part of the reference image to serve as a base unit. For example, if drawing a glass bottle, they may use the neck of the bottle as their base unit. They measure the base unit with their pencil, using their thumb to mark how far along the pencil the base unit extends. Then, this base unit is used to measure all the other parts of the image. For example, they may use this base unit to discover that the width of the bottle is equal to one unit while the height of the bottle is equal to 4 units. Although this method was not likely developed with an explicit knowledge of categorical and coordinate processing in mind, it is implicitly teaching art students to focus on the metric properties of an object, while ignoring its categorical properties. Sighting, according to Edwards, allows us to "see things as they are out there in the external world" (Edwards, 1999, p. 142) and to overcome the conflicts that occur between our previous knowledge of an object and the way it appears from a particular perspective. This description of how sighting helps the artist sounds quite similar to how the coordinate perceptual system functions, in that it allows the observer to perceive the object more precisely and overcome the biases associated with categorical perception.

Method

Participants

Participants were 29 undergraduate students from the Iowa State University psychology participant pool and were given 2 credits for 50 minutes of participation.

Materials and Procedure

Materials and procedure were identical to those used in experiments two and three with the addition of a short video explaining how to use a pencil to sight objects (Triner, 2013). This video was taken from Youtube and was clipped in some places to remove irrelevant parts of the video. After editing, the video was approximately 5 minutes long. After the end of the video, the researcher asked participants to quickly hold their pencil in front of them and briefly practice sighting some of the objects in the room. This short practice was done to make participants comfortable holding the pencil in front of them, since participants were in groups and may have felt self-conscious doing this procedure in front of other students. Participants were also encouraged to use the technique in the following drawings. After the video and practice time, participants completed the last half of the drawings.

Figure 25: Screenshot taken from the video used in experiment four.

Results and Discussion

Replication of past research by Arnold and Cooper (2018) and the previous experiments was analyzed through single sample t-tests comparing constant error on each image type to zero. Slightly different sized images were shown to have an magnitude of error (*M* = .10, *SD* = .12) significantly higher than 0, $t(29) = 4.51$, $p < .01$, 95%CI[.06, .15], meaning participants drew the ratio between the two shapes too small, as predicted. For substantially different sized images, the magnitude of error (*M* = .00, *SD* = .06), was not significantly different from 0, $t(29) = .14$, $p = .89$, 95%CI[-.02, .03]. For angle images, errors on 15 degree drawings (*M* = -7.56, *SD* = 4.48) were significantly lower than 0, $t(29) = 9.09$, $p < .001$, 95%CI[-9.26, -5.85], meaning participants drew the angle too large, while errors on 75 degree drawings (*M* = 8.44, *SD* = 5.06) were significantly higher than 0, $t(29) = 8.99$, $p < .001$, 95%CI[6.51, 10.36], showing that participants drew the angle too small. Errors on 45 degree drawings (*M* = -1.33, *SD* = 4.95) were not significantly different from 0, $t(29) = 1.45$, $p = .16$, 95%CI[-3.22, .55]. Similar to experiments two and three, these results replicate the results from Arnold and Cooper (2018) and show a pattern of categorical errors.

Next, images were analyzed as in experiments two and three to determine if the video affected participants' drawing errors. Specifically, two repeated measures ANOVAs were conducted. For size images, there was a significant interaction between training and image type $F(1,28) = 5.21$, $p = .03$, partial $\eta^2 = .16$. Therefore, simple main effects were examined. Errors for images in which the shapes were substantially different did not significantly differ between those drawn before training (*M* = .07, *SD* = .05) and those drawn after training (*M* = .08, *SD* = .05) $F(1,28) = .63$, $p = .44$. However, training did have an effect on images in which the shapes were slightly different sizes, so that images drawn before training had higher errors (*M* = .15, *SD* = .09) than those drawn after training (*M* = .11, *SD* = .06) $F(1,28) = 4.57$, $p = .041$, partial $\eta^2 = .14$ with a mean difference of .04, 95%CI[0.01, 0.08] (see figure 26).

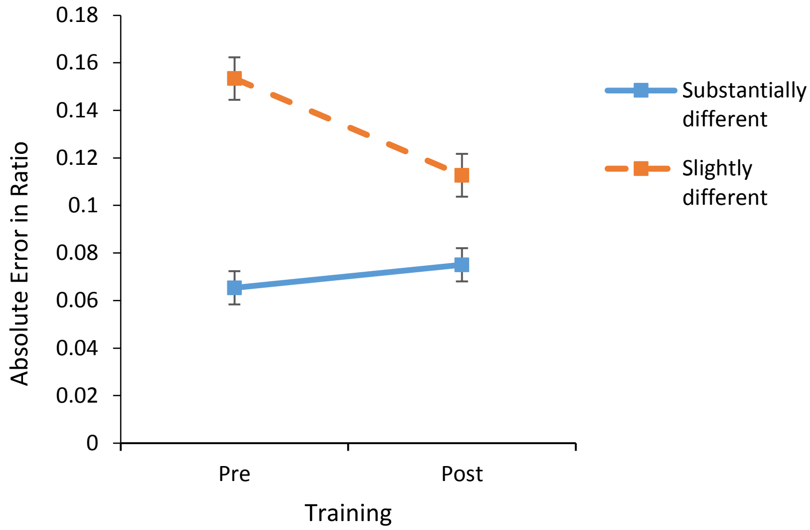

Figure 26: Results from size images for experiment four show significant interaction with errors decreasing for slightly different sized images after training but not for substantially different sized images. Error bars are standard error.

For images in which the target was an angle, there was not a significant interaction between training and image type $F(2,56) = 1.32$, $p = .28$, but the main effect of image type was significant and showed that errors for 45 degree images ($M = 5.78$, $SD = 2.25$) were significantly lower than errors for 75 degree images ($M = 7.95$, $SD = 3.28$), $F(2,56) = 4.34$, $p = .018$, partial $\eta^2 = .13$ with a mean difference of 2.18, 95%CI[.44, 3.91] but neither 45 degree or 75 degree image errors were significantly different from errors on 15 degree images ($M = 7.33$, $SD = 3.13$). Errors for images drawn after training ($M = 6.58$, $SD = 1.90$) and those drawn before training ($M = 7.46$, $SD = 2.39$) did not differ significantly, $F(1,28) = 3.27$, $p = .08$ (see figure 27).

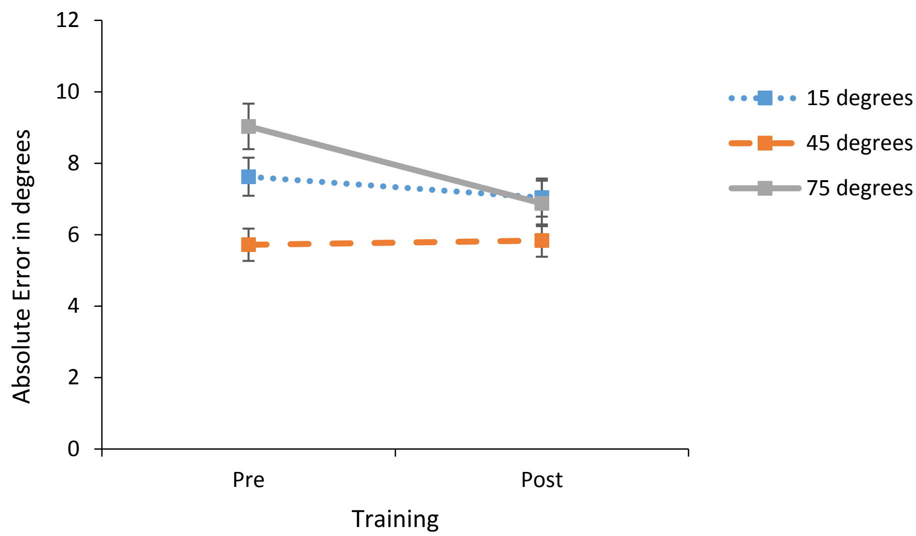

Figure 27: Results from angle images for experiment four show significant main effect of image type. Error bars are standard error.

The findings of Experiment Four are almost identical to those from Experiment Three, suggesting that sighting and the grid technique are both useful techniques for overcoming categorical errors in images in which the relative size of shapes is important, but neither technique improves categorical errors in angles. These similarities are not surprising given that both methods allow the artist to focus on the metric properties of the image or object they are trying to draw.

CHAPTER 6: EXPERIMENT FIVE

The purpose of Experiment Five was to determine whether the results from experiments two through four were not simply due to watching any generic training video or a result of simple practice effects. Therefore, participants in Experiment Five watched a control video that explained how to shade shapes to make them appear three-dimensional. While this video was clearly about an artistic technique, none of the information in the video should have helped participants to rely more heavily on their coordinate system and therefore should not have reduced categorical errors.

Method

Participants

Participants were 32 undergraduate students from the Iowa State University psychology participant pool and were given course credit for 50 minutes of participation.

Materials and Procedure

Materials and procedure were identical to those used in the previous experiments. However, the video (Fussel, 2016) used in this experiment described how to properly shade two dimensional shapes in order to give them a three-dimensional form and was approximately 10 minutes long.

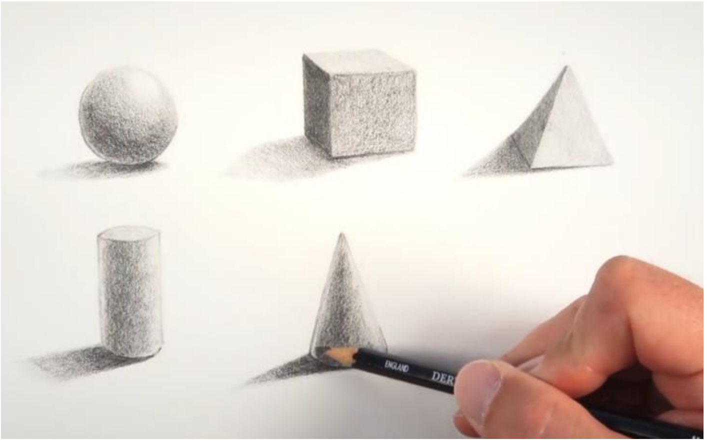

Figure 28: Screenshot taken from the video used in experiment five.

Results and Discussion

To test whether results replicated past research by Arnold and Cooper (2018) and the previous experiments single sample t-tests were conducted comparing constant error on each image type to zero. Slightly different sized images were shown to have an magnitude of error (M = .08, SD = .09) significantly higher than 0, $t(29) = 4.81$, $p < .01$, 95%CI[.05, .11], meaning participants drew the ratio between the two shapes too small, as predicted. For substantially different sized images, the magnitude of error (M = .002, SD = .06), was not significantly different from 0, $t(29) = .19$, $p = .85$, 95%CI[-.02, .02]. For angle images, errors on 15 degree drawings (M = -7.15, SD = 4.3) were significantly lower than 0, $t(29) = 9.40$, $p < .001$, 95%CI[-8.69, -5.59], meaning participants drew the angle too large, while errors on 75 degree drawings (M = 9.20, SD = 6.06) were significantly higher than 0, $t(29) = 8.59$, $p < .001$, 95%CI[7.02, 11.38], showing that participants drew the angle too small. Errors on 45 degree drawings (M = -1.24, SD = 5.7) were not significantly different from 0, $t(29) = 1.23$, $p = .23$, 95%CI[-3.30, .81]. Following the pattern seen in the previous experiments, these results replicate the pattern of categorical errors found by Arnold and Cooper (2018) and show a pattern of categorical errors for images drawn prior to watching the training video.

Results for Experiment Five were analyzed using a procedure identical to the previous experiments. For size images, the interaction effect between training and image type was not statistically significant $F(1,31) = .10$, $p = .76$, so main effects were examined. A main effect of image type was found revealing that errors in the slightly different sized images (M = .13, SD = .05) were higher than errors for the substantially different sized image (M = .07, SD = .03), $F(1,31) = 34.02$, $p < .001$, partial $\eta^2 = .52$ with a mean difference of .06, 95%CI[.04,.08]. Analysis of the main effect of training showed that errors after training (M = .11, SD = .05) were not significantly different from errors before training (M = .10, SD = .05), $F(1,31) = 1.82$, $p = .19$ (see figure 29).

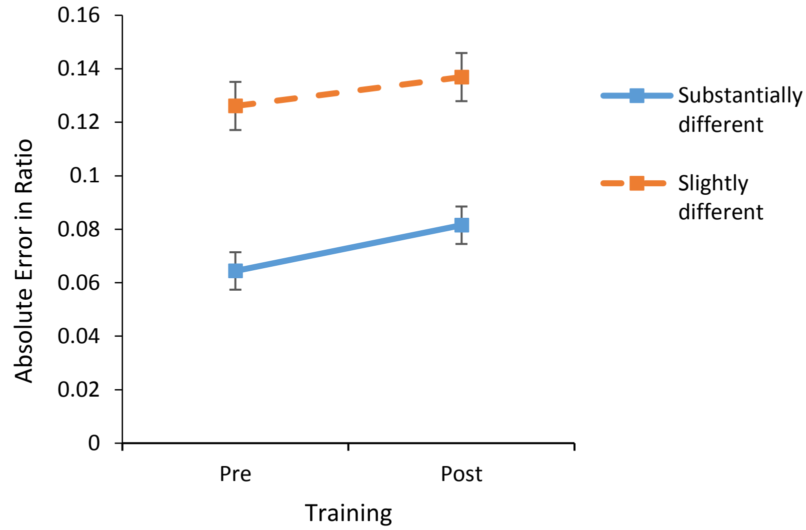

Figure 29: Results from size images for experiment five show significant main effect of image type but no effect of training. Error bars are standard error.

For images in which the target was an angle, there was not a significant interaction between training and image type $F(2,62) = .25$, $p = .78$. The main effect of image type was significant and showed that errors for 75 degree images ($M = 9.78$, $SD = 4.12$) were significantly higher than errors for 15 degree images ($M = 7.57$, $SD = 3.87$) with mean difference of 2.21, 95%CI[.15,4.27] and 45 degree images ($M = 5.61$, $SD = 2.57$) with a mean difference of 4.18, 95%CI[1.99,6.36], while errors for 15 degree and 45 degree images were not significantly different $F(2,62) = 12.47$, $p < .001$, partial $\eta^2 = .29$. Errors for images drawn after training ($M = 7.78$, $SD = 3.13$) and those drawn before training ($M = 7.53$, $SD = 2.31$) did not differ significantly, $F(1,31) = .25$, $p = .62$ (see figure 30).

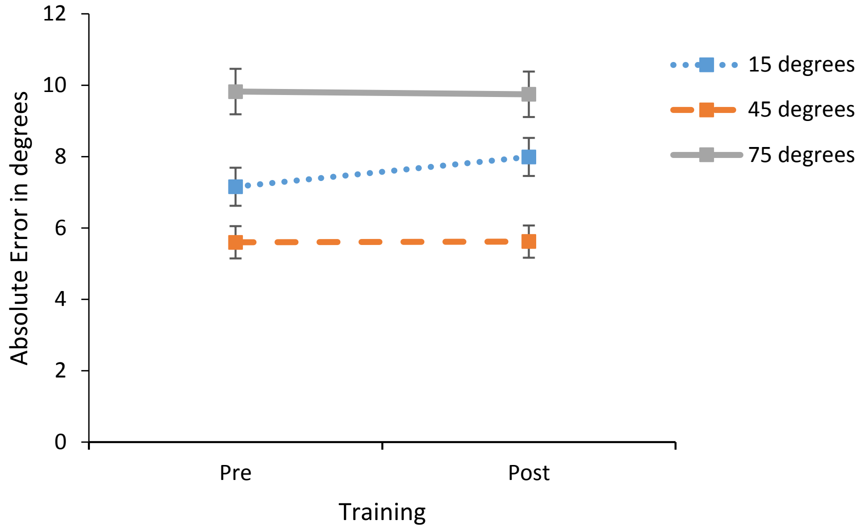

Figure 30: Results from angle images for experiment five show significant main effect of image type but not for training. Error bars are standard error.

The purpose of Experiment Five was to test alternative explanations to the results found in experiments two through four. Specifically, this experiment shows that the reductions in categorical errors in the previous experiments cannot be due to simple practice effects or due to watching any artistic video. This conclusion is supported by the fact that there was not an effect of training from watching the video about shading, as would be expected considering the video provided no technique or information that would help participants shift to their coordinate processing system.

CHAPTER 7: GENERAL DISCUSSION

Prior research (Cohen & Bennet, 1997; Cohen & Jones, 2008; Mitchell, Ropar, Ackroyd, & Rajendran, 2005; Thouless, 1931) suggested that the majority of errors made while drawing objects are due to the artist misperceiving the object they are trying to draw and drawing what they perceive instead of what exists in reality. This conclusion was supported both through studying the pattern of errors made by novice artists (Cohen & Bennet, 1997; Cohen & Jones, 2008; Mitchell, Ropar, Ackroyd, & Rajendran, 2005; Thouless, 1931) as well as by understanding the differences between novices and experts (Cohen & Jones, 2008; Perdreau & Cavanagh, 2015; Thouless, 1932). Although the researchers involved in both lines of inquiry have made substantial progress in understanding drawing inaccuracies, there still exist holes in the literature. A more precise accounting of the types of misperceptions that novices undergo is necessary to understand how to improve these errors. It is also important to continue exploring which differences can be added to the list of contrasts between novices and experts. One possible difference is the extent to which both groups rely on their categorical and coordinate perceptual systems.

As discussed in the introduction, these two systems utilize different processes in order to recognize stimuli under different conditions. According to Biederman (1987), objects are recognized utilizing a system which codes objects as their parts plus the relations among them. These relations are coded categorically. Relative size is coded using the categories 'smaller than,' 'larger than,' and equal to'. Relative orientation of two parts is coded using the categories 'oblique,' 'parallel,' and 'perpendicular.' Using these categories, rather than precise metric relations, allows the observer to easily distinguish objects which have different categorical descriptions and to do so quickly and easily. However, the categorical system cannot easily distinguish two objects which share the same categorical description. For example, using the categorical system, all faces would be coded as "two eyes above a nose above a mouth" and this representation would not be able to differentiate one face from another.

To complete this task, the observer must switch to the coordinate system which codes relations in a more precise metric manner.

This coordinate system would be ideal for drawing accurately, because it would better translate the precise relations of the reference image onto the page. A seminal drawing book (Edwards, 1999) talks at length about the ability of a skilled artist to see the world as it is and to overcome prior knowledge that conflicts with what the artist may see of an object at any given moment. The techniques used to overcome these conflicts sound remarkably similar to the processes used by the coordinate perceptual system and there is direct evidence that use of the coordinate system and drawing ability are related (Devue & Grimshaw, 2018).

In addition, recent research (Arnold & Cooper, 2018; Rosielle & Hite, 2009) suggests that categorical perception may play a large role in the errors made by novices while drawing simple stimuli. This line of research shows that novices rely heavily on their categorical perceptual system, rather than their coordinate system, while engaged in drawing tasks and that this reliance leads to systematic and predictable errors. Specifically, when presented with images in which a target relation is near a category boundary, participants typically err in the direction away from that boundary. Doing so results in large biased errors. The same result does not occur when presented with images in which the target relation is far from a category boundary. This pattern of errors has been shown in novices, but prior to the current experiments, was not evaluated in expert artists. In addition, no work has been done to examine if specific training techniques used in art education may help novices to overcome this pattern of categorical errors.

One goal of the current experiments was to address whether experts and novices differ in the extent to which they make categorical errors on a simple drawing task and to examine whether errors on this task could predict performance on a more complex drawing task (i.e. drawing a photograph of a face). Experiment One showed that experts make significantly smaller errors on angle images near a category boundary than do novices, but that experts' and novices' errors on angle images far from a category boundary do not differ. The same pattern of results was not observed for size images, however. Both experts and novices made larger errors on size images near a category boundary than they did on images far from a category boundary. One possible explanation for this result may be that the amount of time provided to draw the size images was long enough for all participants to switch to the slower, more cumbersome coordinate perceptual system, resulting in similar results for novices and experts. Analysis of the pattern of errors made in size images supports this idea, because, contrary to results reported by Arnold and Cooper (2018), size images in Experiment One did not show a pattern of categorical errors. Specifically, participants' errors on substantially different sized images, which are far from a category boundary, were significantly different from 0, which is not consistent with categorical perception.

To follow-up the between-subjects analyses in Experiment One, regression analyses were conducted to examine the continual relationship between errors on the various image types and participants' scores on a face drawing task. These analyses showed that absolute errors on images in which an angle is near a category boundary can predict participants' scores on a face drawing task. This finding suggests that the ability to overcome categorical errors may be important in drawing accurately and realistically. In contrast to the results found with angle images, errors from size images of both types (near and far from a category boundary) were not significantly related to scores on the face drawing task. Again, this result may be due to the lack of a pattern of categorical errors on the size images. Future studies should replicate the current experiment but utilize a 30 second trial time to see if categorical errors in the size images can be elicited and used to predict participants' abilities to accurately draw complex stimuli, such as a photograph of a face.

A note to make about Experiment One is that the more complex drawing task was to draw a photograph of a face. Research (Brooks & Cooper, 2006; Casner & Cooper, 2006; Cooper & Brooks, 2004; Cooper & Wojan, 2002) shows that faces are recognized using the coordinate system. Given this fact, it is not surprising that use of the coordinate system on the simpler images would be related to drawing ability when drawing a face. In order to determine if there is a broader relationship between drawing ability and categorical errors, a future experiment could replicate the current experiment but utilize a photograph of an object, rather than a face, for the complex drawing task. Theoretically, if categorical errors are related to overall drawing ability, then this kind of experiment should produce the same result as the current experiments.

Another goal of the current experiments was to see whether novice artists could be trained using various techniques utilized in art classes and textbooks to help them reduce their categorical errors. Considering that experts make smaller categorical errors than novices, it follows that giving novices similar training may help reduce their categorical errors as well. To this end, several training videos were used that theoretically could bolster the coordinate perceptual system. The first video provided explicit information about the two systems, the types of categorical errors participants typically make, and how to avoid those errors. The second video demonstrated how to use the grid technique, a method in which the artist utilizes a grid to help bring out the metric properties of the reference image to draw more precisely. A third video showed participants how to use the sighting technique, in which the artist holds an object such as a pencil at arms-length in front of them and uses it to gauge proportions in the reference image. A final control video was used to examine whether results from the training videos were actually due to the videos or were simple practice effects. This video explained how to shade two-dimensional shapes and, although it explained an artistic technique, there is no theoretical reason that it should have helped participants switch to the coordinate system and focus on the metric properties of the reference image. Overall, results from these experiments showed that the training videos can improve errors, and that for size images in particular, the grid and sighting technique reduced categorical errors.

In Experiment Two, participants watched a video which explained the categorical and coordinate systems and how to avoid categorical errors. Although watching this video decreased participants' errors, it did so equally for images that were near and far from a category boundary. This result suggests that the video did not specifically decrease categorical errors, but, more likely, it simply alerted participants to the relevant targets in each image, so that they drew relative size and angle more accurately for all images, whether the relevant target was near a category boundary or not. Even though this result is slightly different from what was predicted, it still seems that teaching illustration students about the two systems and their impact on drawing may be beneficial, considering that it did help reduce overall errors.

Experiments Three and Four showed that two popular drawing techniques, the grid method and sighting, helped to reduce categorical errors for size images and to reduce overall errors for angle images. As proposed in the introduction, this reduction in errors is likely due to these techniques allowing participants to more effectively utilize their coordinate systems to focus on the precise metric properties of the reference images in order to render more accurate relative sizes and angles. One piece of anecdotal support for this idea is that many of the illustration students in Experiment One spontaneously used sighting and a version of the grid technique to draw the simple images. Several students were seen raising their pencil in front of them to sight the reference image and when scanning and measuring their drawings, I found a few in which the illustration students had lightly sketched small grids in which they drew the simple images. Although there was no formal measurement of how often these techniques were used by illustration students, this observation further suggests that art students are taught these techniques and that they help reduce categorical errors by allowing the artist to switch to the more cumbersome, time-consuming, but more precise coordinate system.

Comparing the different training techniques, it seems that the grid technique and sighting are both better at reducing categorical errors than explicit knowledge of the categorical and coordinate systems. The effect sizes from the grid technique were slightly larger than those from sighting. One reason for this finding may be because participants were provided a grid on every sheet of paper for drawings after the training video, meaning they likely utilized the grid technique for every image. In contrast, with the sighting technique, participants were encouraged to first sketch the image quickly and then if they had time remaining to use the sighting technique to check their angles and proportions. Some participants were not able to use the sighting technique for every single image drawn after training because they ran out of time before they could get to it. Lack of time could also explain why neither training technique seemed to specifically affect categorical errors in the angle images. Because the angle images are more complex than the size images, it is likely that participants had less time to employ the techniques they learned when drawing the orientation images. Future studies should replicate these methods using size images that are more complex and angle images that are less complex.

Another important point to make about time is that each of these training videos was between 5 and 10 minutes. Even with such a short training period, categorical errors were reduced. Given this result, it is likely that if students were given more extensive training in the grid technique and in sighting, categorical errors would be further reduced.

Experiment Five provided evidence that the improvements seen in experiments two through four could not be explained through simple practice effects, because there was no improvement between images drawn before and after training with the shading video. Future studies could go a step further and see if there are specific training techniques that may actually increase categorical errors. For example, in caricature drawing, artists are taught to exaggerate certain features of a face in order to make it more recognizable. For example, they may be told to draw Barack Obama’s ears particularly large because this feature is one that helps distinguish him from other people. This technique is analogous to exaggerating the categorical relations of an object. Therefore, if participants were to watch a video explaining caricature drawing, their categorical errors on the simple images used in the current experiments may be increased.

The current set of experiments may also provide some insight into how categorical and coordinate perception fit into some of the distinctions made in earlier research. For example, Mitchell et al (2005) suggested that there are two types of misperception, illusion and delusion. One way to distinguish these two is that delusions can be overcome through explicit knowledge, while illusions cannot. Considering that explicit knowledge of the categorical and coordinate systems reduced errors in the drawing task, and that other training methods reduced categorical errors specifically, it would seem that categorical perception is more similar to a delusion than to an illusion. One problem with trying to compare these results to others is that most of the studies discussed in the introduction utilized real objects as stimuli. Cohen and Bennet (1997) used photographs of real objects, Thouless (1932) used actual circular disks and Cohen and Jones (2008) used photographs of windows. Many of these studies discuss the influence of participants' prior knowledge of the stimuli they drew, but in the current set of experiments in which stimuli were abstract objects that don't exist in reality, participants could not have had prior knowledge of the stimuli. Future studies may replicate the methods used in the current experiments but utilize line drawings or photographs of real objects, rather than nonsense objects in order to compare results to research which uses real objects as stimuli. Prior knowledge of a stimulus may actually result in stronger categorical effects, assuming that the reference object has consistent categorical relations. For example, a coffee mug almost always has a handle that is smaller than the mug. Therefore, when asked to draw a coffee mug, the categorical representation of the size relation "smaller than" may be more deeply engrained than it would be for a novel object. Theoretically then, real objects may result in even stronger categorical errors than nonsense objects, although this suggestion is pure speculation without data to support it.

A final important goal of the current experiments was to replicate the findings from Arnold and Cooper's (2018) previous study. In their experiment, untrained novices drew all image types and their drawings were evaluated for categorical errors. Therefore, the novices in Experiment One and the images drawn before watching the training videos for Experiments Two through Five were direct replications of Arnold and Cooper's (2018) experiment. The only difference between the current experiments and the previous experiment was that the latter utilized a 30 second trial time and displayed images on paper on a an ELMO, while the current experiments used a one-minute trial time and displayed images on a PowerPoint slide. To determine whether a pattern of categorical errors occurred, constant errors on all image types were compared to 0. Arnold and Cooper (2018) found that participants' constant errors for images near a category boundary were significantly different from 0, with the direction of errors always away from the category boundary. Images far from a category boundary produced constant errors that were not significantly different from 0. These results were fully replicated in every experiment except Experiment One. Experiment One replicated the results for angle images, but not size images. As discussed previously, this may have been due to the extended trial time. However, given that experiments two through five replicated the results for size images even though they also utilized a one-minute trail time, it is possible that the size results from Experiment One are erroneous.

Taken together with previous literature, the current set of experiments emphasizes the importance of understanding categorical and coordinate perception and how these two systems are utilized. While there exist many differences between expert artists and novices, the use of these two systems may partially explain experts' abilities, and understanding how to train participants to properly switch from one system to the other may lead to programs that can more quickly produce expert artists in fields like art, architecture, medicine, design, and more.

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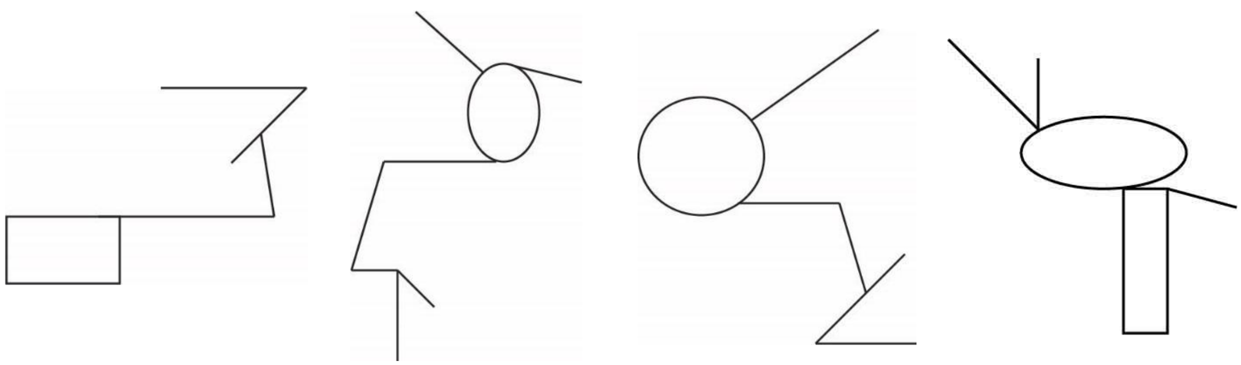
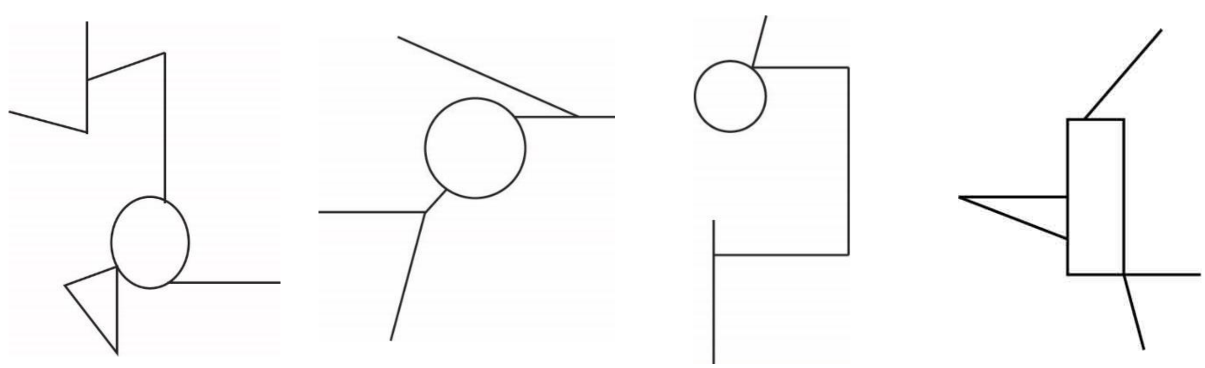
APPENDIX A. STIMULI

15° Images

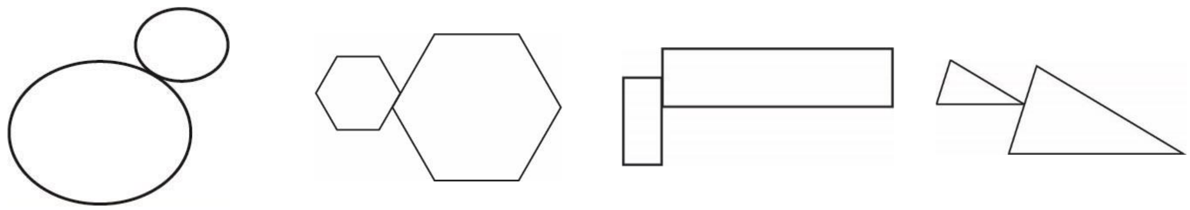
45 ° Images



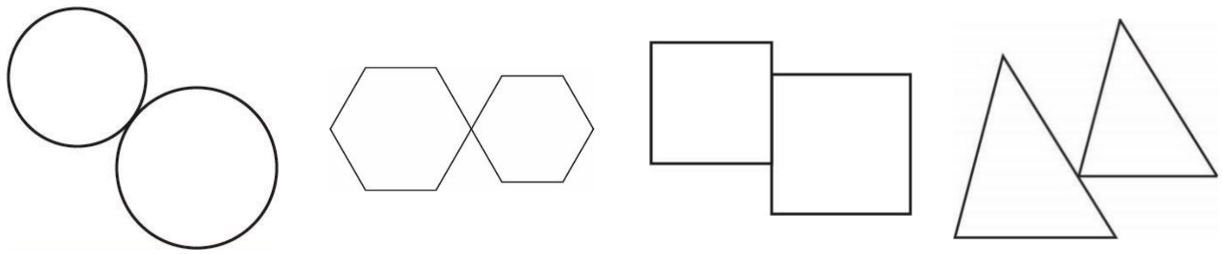
75° Images



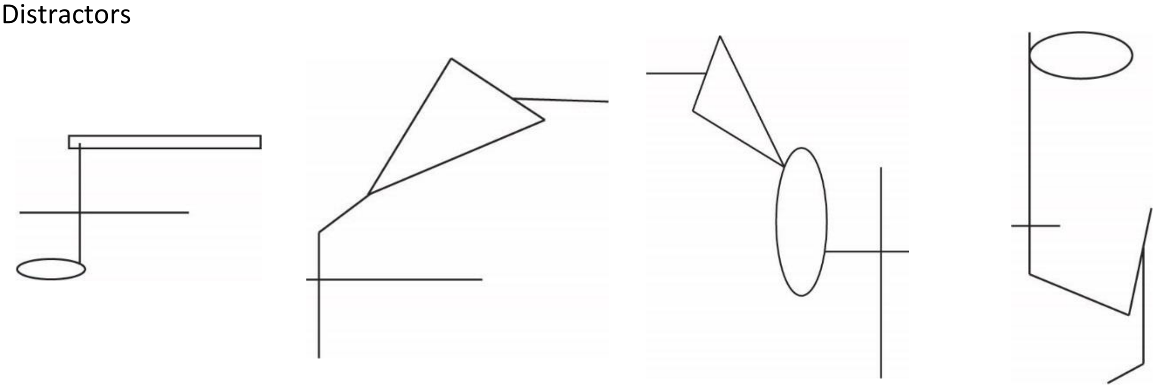
Substantially different size Images



Slightly different size images



Distractors



APPENDIX B. INSTRUCTIONS

Thank you for participating in this experiment. In this study, you will be asked to draw 24 simple line drawings as accurately as possible. These images will be displayed, one at a time, on the screen at the front of the room.

Each image will be numbered. Please draw the image on the corresponding numbered paper in your packet.

You will have one minute to complete each drawing. Please draw the image as accurately as possible. You may erase mistakes and redraw your image, but it is important that you finish the entire image within one minute.

Please do not talk to other students or look at their papers throughout the experiment. Please silence or turn off your cell phone and any other electronic devices. If you have questions, please ask the experimenter.

The first image is a practice drawing to familiarize you with the procedure.

APPENDIX C. IRB APPROVAL MEMO

IOWA STATE UNIVERSITY
OF SCIENCE AND TECHNOLOGY

Institutional Review Board
Office for Responsible Research
Vice President for Research
2420 Lincoln Way, Suite 202
Ames, Iowa 50014
515 294-4566

Date: 10/20/2017

To: Larissa Arnold
3901 Quebec St
Ames, IA 50014

CC: Dr. Eric Cooper
W273 Lagomarcino

From: Office for Responsible Research

Title: Does categorical perception explain people's inability to draw accurately?

IRB ID: 13-415

Approval Date:	10/20/2017	**Date for Continuing Review:**	10/20/2019
Submission Type:	Continuing Review	**Review Type:**	Expedited

The project referenced above has received approval from the Institutional Review Board (IRB) at Iowa State University according to the dates shown above. Please refer to the IRB ID number shown above in all correspondence regarding this study.

To ensure compliance with federal regulations (45 CFR 46 & 21 CFR 56), please be sure to:

- **Use only the approved study materials** in your research, **including the recruitment materials and informed consent documents that have the IRB approval stamp.**
- **Retain signed informed consent documents for 3 years after the close of the study,** when documented consent is required.
- **Obtain IRB approval prior to implementing any changes** to the study by submitting a Modification Form for Non-Exempt Research or Amendment for Personnel Changes form, as necessary.
- **Immediately inform the IRB of** (1) **all serious and/or unexpected adverse experiences** involving risks to subjects or others; and (2) **any other unanticipated problems involving risks** to subjects or others.
- **Stop all research activity if IRB approval lapses,** unless continuation is necessary to prevent harm to research participants. Research activity can resume once IRB approval is reestablished.
- **Complete a new continuing review form** at least three to four weeks prior to the **date for continuing review as noted** above to provide sufficient time for the IRB to review and approve continuation of the study. We will send a courtesy reminder as this date approaches.

Please be aware that IRB approval means that you have met the requirements of federal regulations and ISU policies governing human subjects research. **Approval from other entities may also be needed.** For example, access to data from private records (e.g. student, medical, or employment records, etc.) that are protected by FERPA, HIPAA, or other confidentiality policies requires permission from the holders of those records. Similarly, for research conducted in institutions other than ISU (e.g., schools, other colleges or universities, medical facilities, companies, etc.), investigators must obtain permission from the institution(s) as required by their policies. **IRB approval in no way implies or guarantees that permission from these other entities will be granted.**

Upon completion of the project, please submit a Project Closure Form to the Office for Responsible Research, 202 Kingland, to officially close the project.

Please don't hesitate to contact us if you have questions or concerns at 515-294-4566 or IRB@iastate.edu.