INDIVIDUALS' ERRORS IN THE PERCEPTION OF ORIENTED STIMULI

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Abstract

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The human perceptual system demonstrates poorer performance when discriminating between two oblique angles, rather than when horizontal or vertical angles are involved, even if angular distance is constant. Previous research does not provide a clear picture though on the cause of this. Experiments have been conducted with results that suggest a form of Categorical Perception is occurring during angle discrimination, while other experiments have found results that do not suggest a form of Categorical Perception is occurring during angle discrimination. This study was conducted to attempt to bridge the gap between previously conducted experiments. Our findings suggest that the angled stimuli we used result in a Non-Categorical Perception of angle discrimination. However, another study, using more “object like” stimuli will need to be conducted to better understand the perceptual processes occurring during angle discrimination tasks.

This work is first dedicated to my family, who has always supported me during all of my life's work. Second, I would like to dedicate this to previous and current instructor's that have shaped my life and challenged me to reach this level, especially Jim Zacks and John Henderson, for introducing me to this field while at Michigan State University.

ACKNOWLEDGMENTS

I would like to thank Dale Klopfer, for the many meetings and discussions we have had in order to produce this work. Jeff Friedrich for their help and support during the entire process of this project, along with the entire Experimental Forum members here at Bowling Green State University for their advice and comments throughout my time here.

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INTRODUCTION

Our vision is not perfectly attuned to determine the exact rotational difference between two slightly rotated objects. Some changes in orientation are easily noticed while others are not. Orientation changes that are noticed only confirm what the visual system can do, while the instances in which changes in orientation go unnoticed provide important information toward understanding the processes of the visual system. Errors occurring in orientation discrimination tasks give a unique perspective into the limitations of visual processing. Understanding the processes within the visual system provides insight into what is taking place within the entire mental processing system and the perceptions individuals have of visual stimuli.

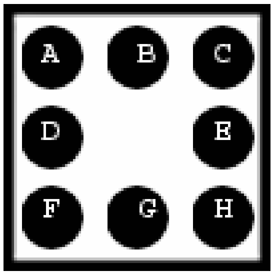
This understanding of the visual system could prevent the design of artifacts within our environment that could lead to ambiguity, where important orientation changes could go unnoticed. If a certain orientation is difficult to perceive, it would be best to avoid this orientation for critical circumstances. For example, if a 30° angle is found as very difficult to differentiate from other angles, then the 30° angle should not be used to indicate an important event, such as a signal of low gas level in a vehicle.

DIFFICULTY IN THE PERCEPTION OF OBLIQUE STIMULI

Oblique Effect Studies

Previous researchers have used very simple stimuli (e.g., straight line) to determine the effects of differences in orientation on an individual's perceptions. By comparing two stimuli with varying orientation changes, researchers observed which changes went unnoticed and which changes were detected. Early research described a particular phenomenon regarding line orientation detection, which was termed the oblique effect (for a review see Appelle, 1972). Oblique orientations are those that are not aligned with the horizontal or vertical axes.[1] The oblique effect refers to the finding that it is easier to detect differences in orientation when a line is oriented in a vertical or horizontal manner, rather than in an oblique manner, with sensitivity to orientation differences being poorest around 45º. Research has also demonstrated that figures oriented obliquely are more difficult to perceive than those that are oriented more toward the horizontal or vertical axes (e.g., Matin, Rubsamen, and Vannata, 1987; Lasaga and Garner, 1983; and Vogels and Orban, 1986).

Figure 1. Stimulus Locations used by Cecala and Garner



In addition, researchers have found that more complex visual processes, such as those involved in vernier acuity tasks (in which the degree of offset between two lines is changed, but they still may appear to be one straight line) reveal an oblique effect (Corwin, Moskowitz-Cook, & Green, 1977). Cecala & Garner (1986) reported that manipulation of the location of a dot's global position within a square or circle leads to individuals exhibiting performance differences with faster responses and higher accuracy for a vertical or horizontal location as opposed to diagonal positions. In that study, participants were asked to signal yes or no via a button press whether a dot was in a specified location (e.g., one of the 8 positions in the square shown in Figure 1). The participants responded more quickly and accurately when the dot was either in the middle upper/lower position or the middle left/right position (e.g., positions BGDE) as opposed to one of the oblique (or as in the case of the square corner) positions (ACFH).

Kahn and Foster (1986) reported that when participants were asked to indicate whether two random dot patterns were the same or were mirror images of each other, accuracy was influenced by the dot patterns' location relative to a crosshair axis presented in the center of the screen. Their research indicated that the discrimination of the dot patterns was more difficult when they were aligned with the oblique axes, rather than when horizontally or vertically aligned with the axis.

It is rare, however, for our visual field to consist of only simple stimuli such as the lines or random dots used in the aforementioned studies. The majority of our visual attention is devoted to the perception of objects within the environment. One of the leading theories of object recognition is Biederman's (1985, 1987) Recognition By Components (RBC). RBC states that recognition of an object involves identifying the geons (primitive volumetric components)[2] the object is composed of and the object-centered spatial relationships among the geons. Object-centered spatial relationships among the geons of a rigid object remain constant no matter what the object's orientation or viewer's perspective may be. If the spatial relationships between any of the object's geons are altered, the object's identity changes and thus the object is classified differently. For example, a coffee mug and a sand pail are both made up of a hollow cylinder with one end closed, one end open. The orientation of the “handle” and the spatial relationship it has with the attachment to the cylinder is what differentiates the two objects.

If objects are to be recognized not only by the geons they are composed of, but also by the alignment of these geons to each other, discrimination of angular differences in geon alignment become important for object recognition. As previously described research has suggested, not all orientations are perceived equally as well as others. Therefore, it is important to determine if the angles created in reference between an object’s primary axis and any protruding geons also create instances of higher difficulty in differentiation.

Two accounts will be discussed below concerning the difference thresholds found in angle discrimination within objects. The first of the two is a categorical account. As discussed by Harnad (1987), categorical perception occurs when stimuli vary across a continuum. Along this continuum, discriminating among stimuli that are members of the same category is difficult, while easy discriminations are found between members of two different categories (despite little difference found across the continuum). This may best be illustrated with the differences found between detecting the difference between two colors of red and between a red color and an orange color (despite the wavelength difference between the compared colors being the same). If angles are perceived categorically, angles may be perceived in specific categories (such as the way colors are, this is also described as categorical perception of angles), and detecting a stimulus difference within a category is more difficult then detecting the same difference across categories. Thus in this view, angular discriminations are a non-linear function of angular size.

Comparable to the aforementioned visual studies, categorical perception has been studied in more depth with voice onset time (VOT). VOT is the time delay that occurs between when a sound begins and the start of vocal cord vibrations. Research by Eimas and Corbit (1973) found an abrupt difference in individual hearing between a /da/ and a /ta/ sound depending upon the VOT. That is, VOTs under 35 ms are perceived as /da/, while VOTs of 40 ms or greater are perceived as /ta/. This difference seems very abrupt to the listener as the stimuli are varied across the continuum. However, the listener detects no difference across the stimuli except for this point of category change.

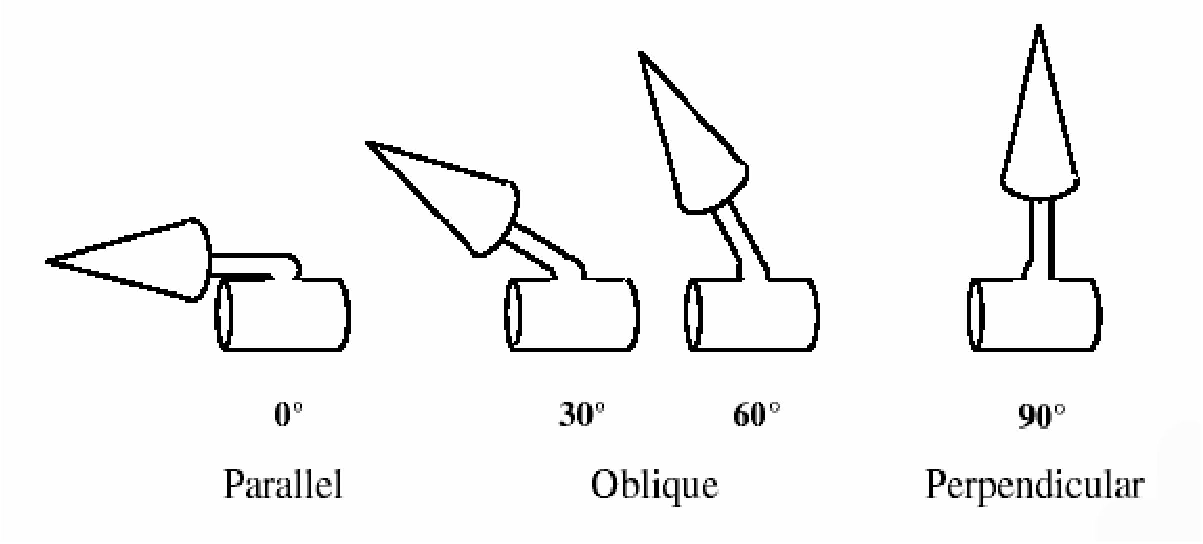
The second account of angle discrimination holds that angles are perceived like other prothetic continua. One possibility, then, is that discrimination of angles adheres to Weber’s law, which states that as an angle increases in size, the difference threshold needed to determine whether a change has occurred also increases.

Categorical Angle Discrimination Studies

Further developments in RBC reveal that oblique angles are more difficult to perceive then those aligned with the vertical and horizontal axes (Hummel & Biederman, 1992). RBC claims that orientation detection of geons within objects is categorically encoded into templates, with a new category every 45°, starting from the vertical position. Research by Rosielle and Cooper (2001) indicated that initial encoding of their stimuli had limited positions of encoded orientation. They found that orientation is represented at one point into three perceptual categories: horizontal, oblique, and vertical.

Rosielle and Cooper (2001) investigated categorical perception of orientation by requiring individuals to make identity judgments about objects whose components varied in orientation. The objects were made up of three geons: a base, an arm connected to the base, and a geon at the end of the arm (See Figure 2). The base geon was always aligned with the horizontal axis, and the arm and end geon were presented at 0°, 30°, 60° or 90° orientations, with respect to the base. Either the base or end geon could be changed (e.g., from a cone to a cylinder), but the shape of the arm was held constant. Stimuli were presented serially in each of their experiments, with a visual mask following each image.

Figure 2. Stimuli Three-Geon Stimuli used by Rosielle and Cooper



Copied from the Stimuli used by Rosielle and Cooper (2001).

In Rosielle and Cooper's (2001) first experiment, participants were instructed to detect any changes between successively presented objects, whether they were due to changes in orientation or to changes in the base or end geon. When only observing the trials in which no geon changes occurred, the results of this experiment demonstrated that individuals were able to detect a difference in arm orientation more accurately and more quickly when there was orientation at 0° or 90°, rather than when just the two oblique positions (i.e., 30° and 60°) were presented. That is, a 30° increase in arm orientation was easier to detect between objects whose arms were oriented at 0° than at 30°, and a 30° decrease was easier to detect at 90° than at 60°. This would suggest that one categorical boundary exists somewhere between 0° and 30°, while a second boundary exists between 60° and 90°.

In their second experiment, Rosielle and Cooper (2001) asked individuals to determine whether two objects were composed of the same geons. The authors' logic was that if categorical perception does occur in angular discrimination tasks, participants should demonstrate faster reaction times (RT) in a discrimination task when the stimuli came from the same category, and should respond slower when the stimuli are from two different categories. The results from this second study indicated that individuals were more accurate and responded faster when the angular difference remained within a category (from when the arm's orientation increased 30° from 30°, rather than from 0°, and from when the arm's orientation decreased 30° from 60°, rather than from 90°).

The findings of experiments 1 and 2 from Rosielle and Cooper (2001) suggest that the participants did treat the two oblique orientations as being within the same category. This is demonstrated either directly (where individuals have trouble differentiating the 30° angular difference between the two oblique stimuli) or indirectly (where individuals gain benefits in recognition of geons located within the same angular category), due to the stimuli being presented within the same category.

Note that in their second experiment, a relatively long inter-stimulus-interval (ISI) was used (over two seconds). In a third experiment, the ISI was reduced to 756 ms (the same ISI used in Experiment 1), and object discrimination was no longer found to be better for oblique conditions: all 30º differences yielded the same discrimination thresholds. This suggested to the researchers that a metric coding of relative orientation was being used for objects held for a very short time in memory, whereas categorical coding was used over longer time frames. Perhaps the ISI was too short for the stimuli's angle to be forgotten for those angle differences in the third experiment.[3]

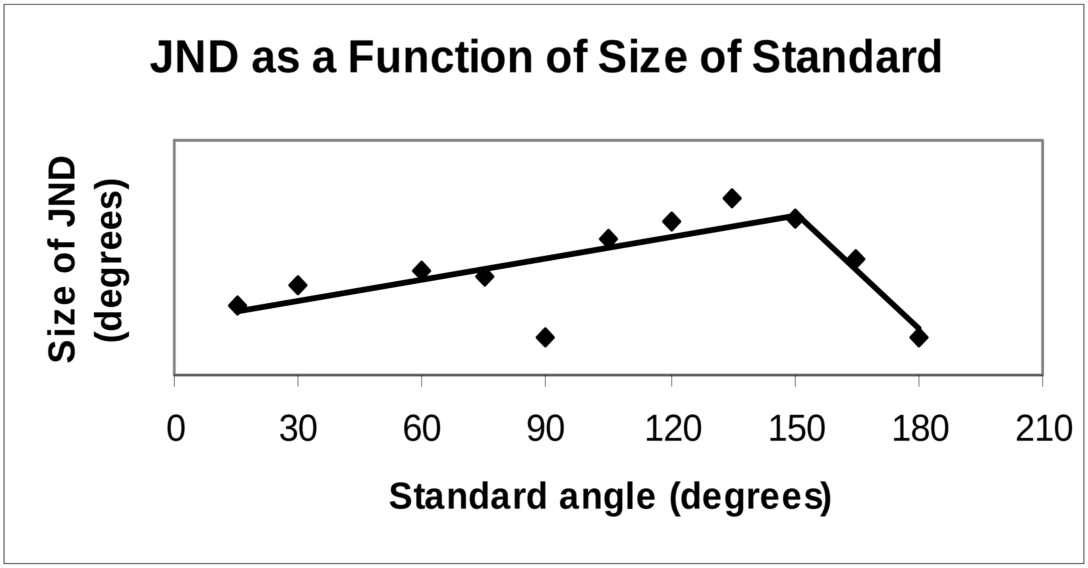
Non-Categorical Angle Discrimination Studies

Categorical Perception of angle discrimination is not the only possibility that has been found in angle discrimination studies. The perceptual system may result in non-categorical perception during angle discrimination tasks. If this were so, one would expect that the perceptual system is able to detect angle changes in a more precise manner than categorically. That is, angles would not be perceived in categories where crossing of distinct boundaries is the best way for differences to be detected, but rather that angles are perceived as similar to angles of similar degree measurement and that a certain size change would need to take place for discrimination of the stimuli. In this portion of the paper, Weber's Law will be discussed as a possible description of how the visual system detects relative orientation in objects.

Weber's Law states there is a linear relationship between the size of a stimulus and the size of the stimulus increment needed to detect that the stimulus has changed in size. Weber's Law holds that the difference threshold (also know as the just noticeable difference, or JND) can be determined by multiplying a constant (known as the Weber fraction) times the size of the stimulus, and can be written as S*K=JND.[4] Weber's Law has been used to describe threshold functions with other visual stimuli (i.e. light intensity, line length), and there is no a priori reason why it would not describe angle discrimination thresholds if angular size is treated as a prothetic continuum.

Indeed, research conducted by Chen and Levi (1995) indicates that the angular discrimination function is best described by Weber's Law. Chen and Levi asked participants to detect differences in angles' sizes using angles that ranged from 15° to 180°. An angle was presented for 400 ms and participants judged whether it was the same size as a studied standard angle. Consistent with Weber's Law, Chen and Levi found discrimination thresholds were smaller with smaller angles, but increased as angles increased. Their data, shown in Figure 3, display a linear increase in threshold as the angle increases, with a sudden dip in threshold detection at 90º (that they could not account for) and an inflection point at 150º (where the JND in Figure 3 begins to plummet), where increases in angular size yield systematically smaller thresholds. The decrease in threshold accompanying increasing angular size beyond 150º is possibly due to an implied horizontal line (180º) being used as a reference, rather then the original angle.

Figure 3. Discrimination Thresholds as a Function of Angle Size (from Chen and Levi)



The diamonds represent the angles and JNDs studied, while the solid line is used to represent the line of best fit for the angles provided, and to give JNDs for angles that were not studied.

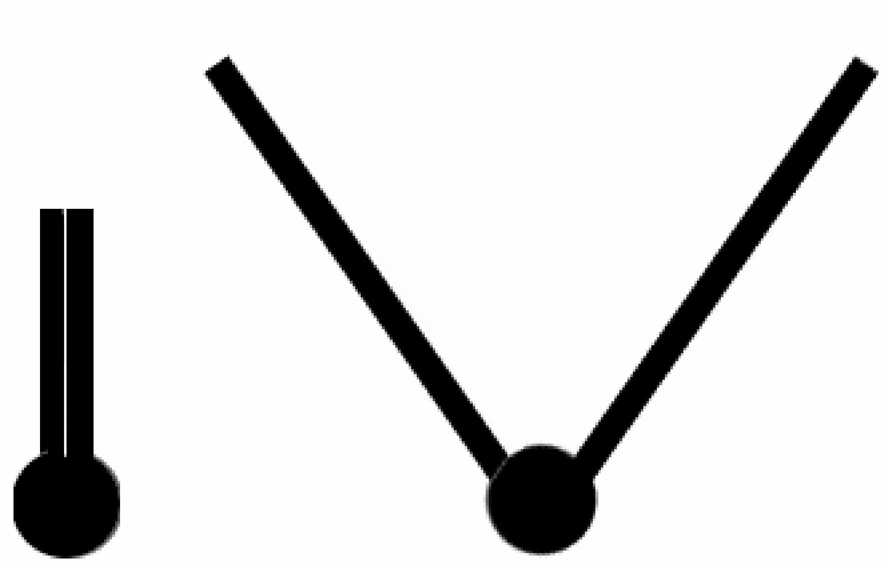
It is important to understand the differences between categorical and non-categorical perception of stimuli. Although it may seem practical that one could easily differentiate stimuli across a continuum, obviously some relatively small changes will go undetected. The key question is whether it is the size of the stimulus that determines the difference threshold, or if certain membership in a perceptual category determines the difference threshold. If the size of the stimulus is most important in determining the threshold, a non-categorical process would be operating. However, if more qualitative aspects of the stimulus – such as whether the angular relationship between parts of the stimulus in parallel, oblique, or orthogonal – determines the threshold, a categorical process would be operating.

To determine which of the two processes is taking place, the experiment discussed below uses smaller angle changes than Rosielle and Cooper (2001), and extends the angle’s total possible measurement to 180° (much like Chen and Levi (1995) had done). This will not only indicate whether angles are perceived categorically, but also will provide a better estimation of where the categorical boundaries are.

EXPERIMENT

The purpose of this experiment is to attempt to determine the nature of the discrimination threshold function of angles using stimuli such as those shown in Figure 4. In order to conduct this study, it became necessary to extend the range of the stimuli to a full straight line (a 180° stimulus) to include the point (150º) where Chen and Levi (1995) found a decrease in size required for discrimination. Three possible outcomes for the process of angle discrimination are discussed below.

Figure 4. Example of Stimuli used in the Current Experiment

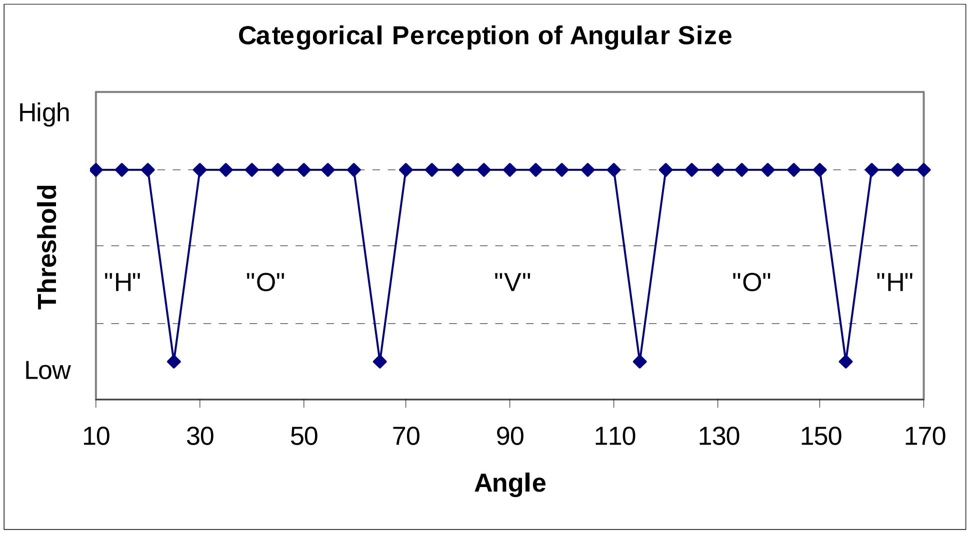


The angles opened symmetrically from the vertical position. The intercept of the two rays were offset from the center of the dot, allowing a 0º Angle Stimulus (AS) to be created (as in the one on the left, which has the short rays). The angle on the right is a long rayed AS with a 70º angle.

Categorical Perception of Angular Size

In accordance with a strong form of categorical perception (see Harnad, 1987) discrimination thresholds within a category should be approximately equal, whereas those across category boundaries should be distinctly lower. If angular size is perceived categorically, findings similar to those shown in Figure 5 would be expected. Here, categorical boundaries are arbitrarily shown at approximately 29º away from the vertical and horizontal axis. These points were chosen because Rosielle and Cooper's (2001) results suggested that the boundary from each axis was somewhere less than 30º. In addition, I am assuming symmetry in category for acute and obtuse angles. This figure shows that stimuli within the same category are equally difficult to differentiate from each other. Stimuli that cross the boundaries of categories, however, are more easily distinguished, as illustrated by the sharp decreases in the thresholds at those points (shown here at arbitrary levels).

Figure 5. Discrimination Threshold Function if Angular Size is Perceived Categorically

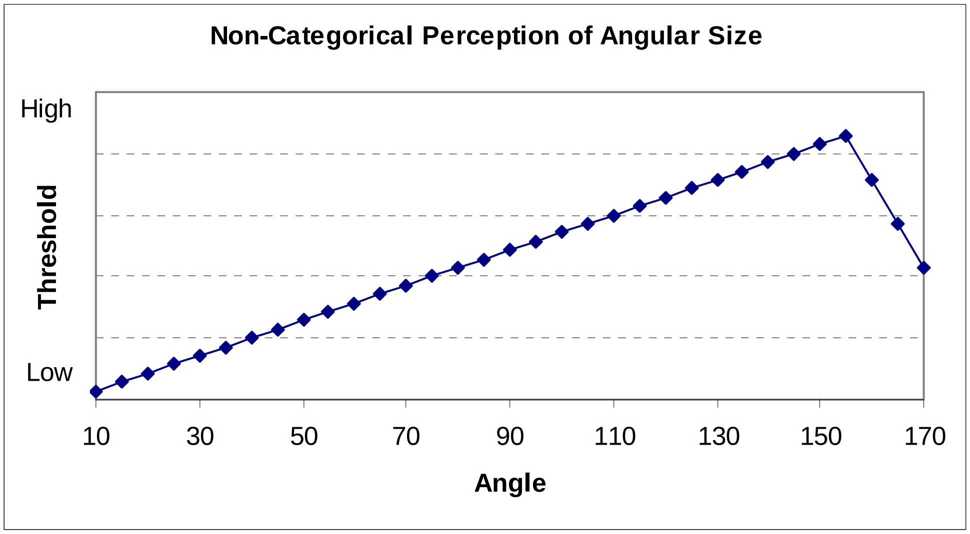


The "H", "O", and "V" indicate possible categories for the Horizontal, Oblique, and Vertical.

Non-Categorical Perception of Angular Size

Similar to the results found by Chen and Levi (1995), individuals could yield results that are consistent with Weber's Law (Figure 6). Here, thresholds would increase as the angles increase in size from the 0°, and then plummet as the stimuli flatten, a straight horizontal line. In a sense, those results suggest that two categories exist: one consisting of angles up to the inflection point (150° in Chen and Levi's study), one then beyond the inflection point. Yet, these two categories would not be categories would not be perceptual categories *per se* because difference thresholds are changing within the categories, and there is no between category reduction of the difference threshold. More will be said later about the processes that Chen and Levi's 'categories' might reflect.

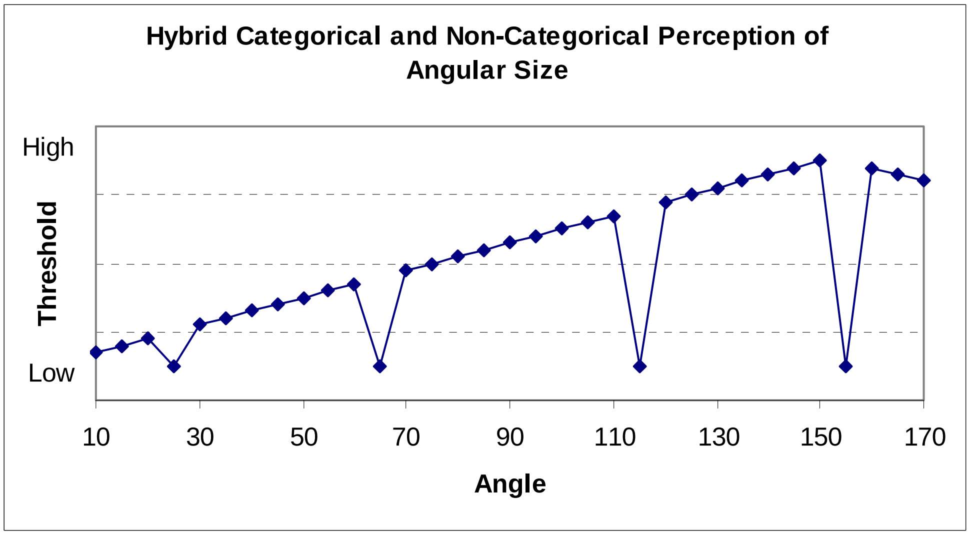
Figure 6. Discrimination Threshold Function if Angular Size is Perceived Continuously



Hybrid: Categorical and Non-Categorical Perception of Angular Size

Finally, it is also possible that the discrimination threshold function will reflect both categorical and non-categorical processes. That is, angles may be perceived categorically, but there may also be threshold differences within a category (Figure 7 represents one of many hypothesized possibilities). These within category threshold differences, however, would be small compared to those that exist between categories.

Figure 7. Example of Discrimination Threshold if Angular Size is Perceived Categorically and Continuously



PROCEDURE

Participants. 14 students (6 males, 8 females) from Bowling Green State University's subject pool participated in the experiment for course credit; the ages ranged from 18 to 19 years. All participants had normal or corrected-to-normal visual acuity, and lacked previous knowledge of the experiments purpose.

Apparatus. The experiment was run on a Dell Dimension 8250 computer with a 2.65 GHz processor using E-prime software (Schneider, Eschman, & Zuccolotto, 2002a, 2002b). The monitor used was a Magnavox Magnascan/17 17 inch monitor with a frame rate of 60 Hz in SVGA mode. The room's illumination was set at a normal brightness. All lights were ceiling mounted and behind the participant.

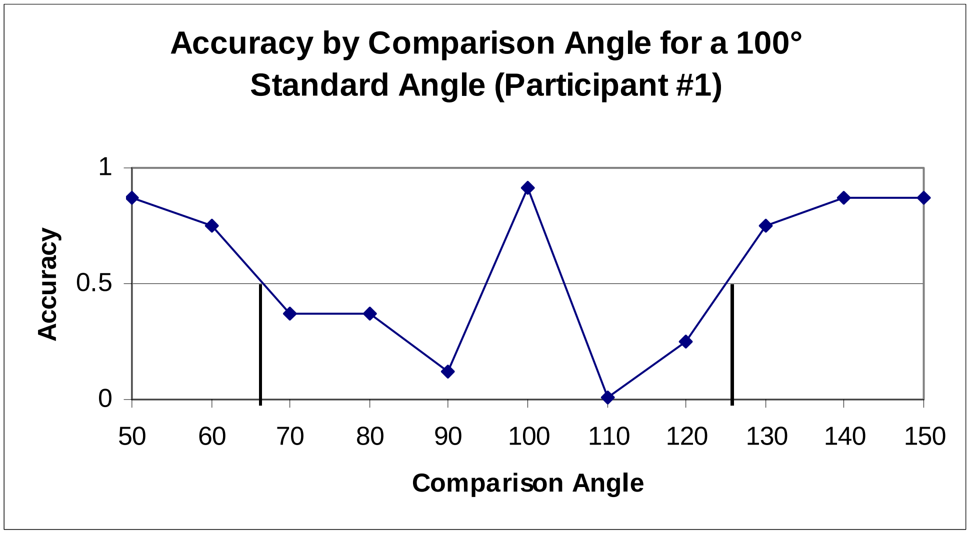
Stimuli. The Angle Stimuli (AS), which were created using Adobe Photoshop, were made up of two separate rays emanating from a single dot (example previously shown in Figure 4). The dot was 9.5 mm in diameter, and located in the center of the screen. The rays were 1.6 mm wide and either 47.6 mm or 27 mm long. The orientation of the ray for this study was created so that the AS resembled V's that are symmetrical about the vertical axis. Each AS was designed with long or short segments in each condition to assure that participants were observing the created angle only (and not the distance between the two endpoints of the rays). The standard AS ranged in angle measurement from 10° to 170°, while the comparison AS ranged from 0° to 180° in measurement.

Procedure. Each participant sat approximately 0.5 meters from the computer screen. At that distance the largest stimulus subtended a visual angle of 6°, and the smallest stimulus subtended a visual angle of 3.2°. Participants read the instructions for the experiment on the computer screen. Participants were told that each trial consisted of a fixation cross lasting 480 ms, presentation of a standard AS for 240 ms, a blank screen for 480 ms, a comparison AS for 240 ms, and a blank screen that would last until a response was made. [5] Participants were instructed to pay attention only to the angular difference between the standard and comparison AS's and to indicate (via a button press) whether the two AS stimuli subtended the same angle. Participants were also instructed that their accuracy and reaction time would be measured and they should try to react as accurately and as quickly as possible. All questions the participants had concerning procedures were answered before the testing began. The task consisted of 2272 trials and lasted on average 100 minutes.[6] Standard and comparison angles differed from 0° up to 50° in measurement (this made it so that a 10° angle only had itself and six other angles compared to it while the 80° angle had itself and ten other angles compared to it).

RESULTS

Individual results were first graphed as a function of each standard angle degree by accuracy (e.g. Figure 8). From these graphs, JNDs were calculated as the first stimulus difference where performance reached accuracy levels of 50% (here, the angles would be 66°, and 125°, or 34° and 25° difference). To determine the participant's threshold for this angle, the average of 34° and 25° would be calculated, thus determining a JND for this individual to be 29.5° for the 100° standard angle.

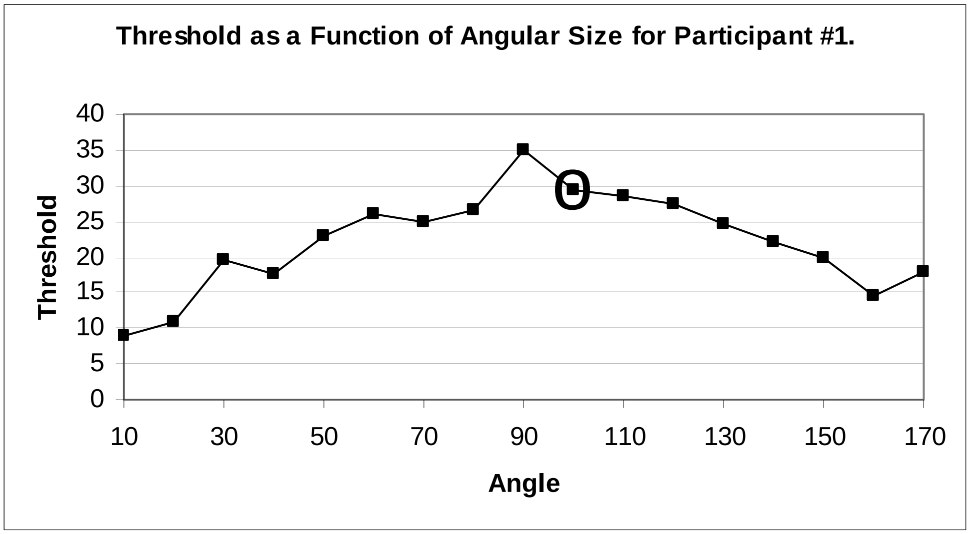
Figure 8. Accuracy as a Function of Comparison Angle (Participant No. 1, Standard Angle 100°)



This was used to determine the 50% accuracy points. One of these was made for each participant for every initial angle studied and was used to construct Figure 9.

After the thresholds for each angle were calculated, they were graphed as a function of standard angle degree for each individual.[7] Figure 9 shows this function for the participant whose data are in Figure 8. One of these was made for each participant to determine their JND's for each angle. Following this, each individual's data were combined to yield mean thresholds, which is demonstrated in Figure 10. A one-way ANOVA performed on the 17 mean thresholds across levels of angle revealed a significant main effect of angle [$F(16) = 45.5$, $MSE = 8.9$, $p < .001$], indicating that mean threshold differed as a function of angle size.

Figure 9. Discrimination Thresholds as a Function of Angular Size: Participant No. 1



Threshold functions such as the one in Figure 9 were derived for each participant. The circled point (100°) was determined from Figure 8.

Because there was a significant difference found across the angles in Figure 10, it became important to interpret the data in light of the three possible outcomes presented earlier in Figures 5, 6, and 7. Inspection of the group data reveals a steady increase in JND from the angles of 20° to 70°, a levelling off between 70° to 120°, and a decrease from 120° to 170°. The flat portion in the middle 1/3 of the function is suggestive of categorical perception taking place between angles of 70° and 120° in that the thresholds are approximately equal, as would be expected within a category. The overall pattern of results however provides no clear cut evidence for one outcome over the others.

Upon examination of individual rather than group data, it seemed that individuals had different positions for the *peaks* in their threshold functions. That is, one individual may have a steady increase in JND until 80°, followed by a steady decrease in JND for angles larger than 80°, whereas another may have shown an increase in JND until 120°, followed by a decrease for angles larger than 120°. Averaging across individual differences, then, may have resulted in the levelling off of the data seen in Figure 10.

Figure 10. Discrimination Thresholds as a Function of Angular Size: All Participants

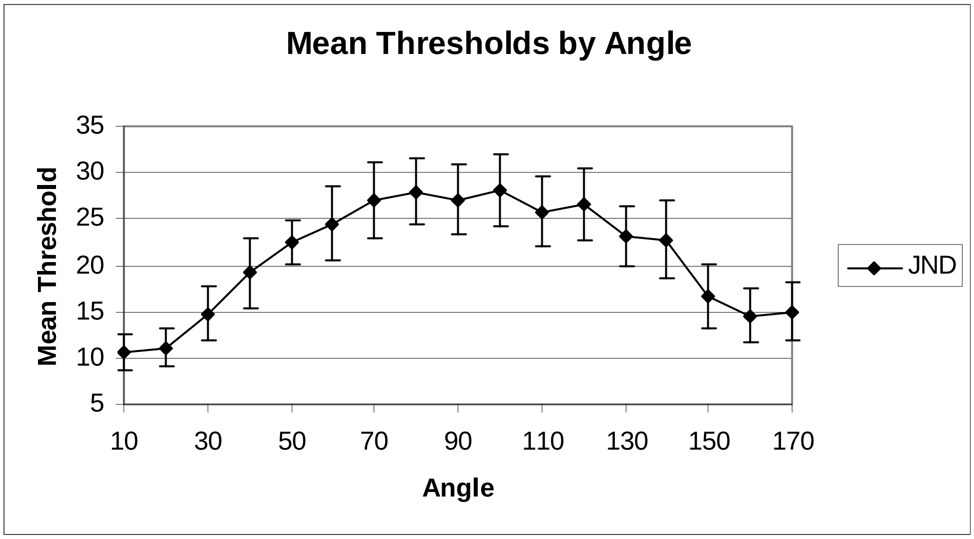


Table 1. An example of one participant's R² for each division

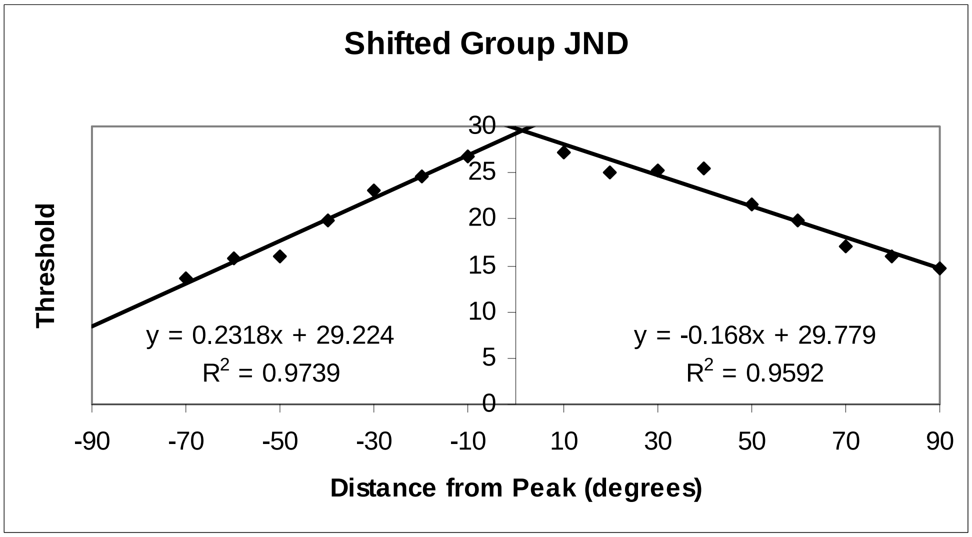
Individual Data Table Used to Determine Peak Point Participant #1										
Location	40/50	50/60	60/70	70/80	80/90	90/100	100/110	110/120	130/140	140/150
Mean	0.27	0.32	0.26	0.47	0.74	0.91	0.87	0.89	0.87	0.84

One of these were made for each participant and used to determine the best two lines of fit for their individual data.

To investigate whether a single-peaked, inverted V function (a la Chen and Levi, 1995) characterizes JNDs of angular size, each individual's data were examined to see if there were single peaks in the threshold functions. Individual peaks were determined by considering each angle, from 40° to 140°, as a possible peak. For each possible peak, the degree to which two straight lines (one ascending to the peak, the other descending from the peak) fit the data was calculated. The angle where the fit was the best was considered the peak. For example, suppose one wanted to test if the peak in Figure 9 for participant 1 occurred in between 40° and 50°. The regression equation for all points from 10° to 40° is $y = 0.325x + 6.25$, $R^2 = 0.5348$. The equation for all points above 40° y = 0.0072x + 23.79, R² = 0.0026. The average R² is 0.27, as shown in the bottom for left box of Table 1. The other entries in Table 1 show how well the data fit a model with peaks between 50° and 60°, 60° and 70° etc. Because the mean R² is greatest between 90° and 100°, the peak for this individual is estimated to fall within that range. The exact location of the peak was calculated by finding the intersection of the two regression lines. Across all individuals, most of the peaks were between 70° and 100°, and the mean R² ranged from 0.74 to 0.91.

After a peak was found for each participant, the threshold functions were aligned so the peaks would match (see Figure 11). JNDs for the other standard angles became angles that differed by a certain positive or negative degree from the peak. That is, if Participant A had a peak of 70°, the +/- 20° angles for Participant A would be their 90° and 50° standard angles respectively. If Participant B had a peak of 100°, the +/-20° angles for Participant B would be their 120° and 80° standard angles respectively.

Figure 11. Discrimination Threshold as a Function of Angular Size: Aligned Data



The solid lines are the regression lines created for each half of the data.

Regression lines for the group data revealed an R^2 of 0.97 for the negative angles and an R^2 of 0.96 for the positive angles, yielding a mean R^2 of 0.965. The same procedures used to create Table 1 were run on the group data in Figure 10, and a midpoint of 90° was found with and average R^2 of 0.91. Although a single inverted V function fits the group data reasonable well, the individual differences in peak location approach seems to do a better job of characterizing the data. Based on this new perspective of the data provided by Figure 11, it seems that individuals were using a pattern of results that could be best explained by non-categorical perception for angle discrimination in this experiment.

DISCUSSION

Although the results of this experiment do not exactly replicate those found by Chen and Levi (1995), the results obtained here are very similar in form. It appears that categorical perception is not taking place in this task because there are no improvements in thresholds across the range of stimuli that would indicate the presence of categorical boundaries. The JNDs in Figure 11 grow larger until a certain point and then begin to plummet (peaking at a smaller angle than Chen and Levi's 150° peak), demonstrating evidence similar to what Chen and Levi found.

The questions that remain are why the results here are qualitatively different from Rosielle and Cooper's (2001) study, and quantitatively different from Chen and Levi's (1995). The major difference between the Chen and Levi's and the present results is in the location of the peaks of the threshold functions. As Chen and Levi suggest, individuals may use the original angle or an implied 180° line as reference points for detecting changes in size. That is, unlike other visual stimuli often studied with Weber's Law (i.e. line length or visual intensity), angles seem to have a perceptual maximum of 180° in that angles that are >180° (e.g., 270°) are generally seen as 360°-n (here, 90°). Because angles can get no larger than 180°, a straight line can serve as a reference point for sizes changes. So, for example, a 33° angle may be seen as just larger than a 30° angle, and a 49.5° angle may be seen as just larger than a 45° angle, in accordance to Weber's Law. On the other hand, a 155° angle may be seen as just larger than a 150° angle – rather than 180° as Weber's Law would predict – because the former is noticeably flatter than the latter. In this second example, a straight line serves as the reference point for making the size discriminate. If both angles are possible reference points for the individuals, it is difficult to know which reference point is being used when discriminating angle changes. Only after the data have been plotted can one begin to infer which of the two reference points were used for each particular angle (assuming individuals are consistent for each angle’s reference point).

Dependent upon the location of this switch, one comparison starting point may be used more than the other (if the peak in JND and switch from the 0° to the 180° comparison angle occurs at the 100° angle, then the individual would be using the 0° angle more as a comparison starting point than the 180° angle). Chen and Levi’s (1995) participants may have switched reference angles around the 150° angle, giving them the pattern of results they found. It would appear logical that the most optimum point to change between the vertical and horizontal reference point for this task would be the 90° angle. The 90° angle is the midpoint between the two reference points, and if used should result in the highest accuracy. However, the data from the experiment suggests that a majority of individuals are using one of the starting points beyond the ideal halfway point of 90°. The reason for the variability in peak locations, however, is unclear.

Another difference between the results of this experiment and those found by Chen and Levi (1995) is that the JNDs were of different magnitudes. Chen and Levi found JNDs in single digits (usually under 5°), while this experiment found JNDs that were as large as 40°. To explain possibilities for the different results, it is important to understand the differences between the two tasks.

Overall, the stimuli used in this study were much larger than those used by Chen and Levi (1995). Here, stimuli consisted of rays measuring 1.6 mm wide and either 47.6 mm or 27 mm long, which at largest subtended a visual angle of 6°. Chen and Levi however used stimuli that at maximum subtended a visual angle of 1.8°. However, it is unknown whether or not this size difference could have made one task easier than the other. Differences that likely made Chen and Levi’s task easier would be the use of well-practiced participants (they used only three individuals, with each one receiving at least 540 practice trials with feedback at each individual angle), and the use of a longer presentation time (400ms), which may have allowed for more precise encoding of the stimuli.

Even though the results of this experiment suggest that categorical perception is not occurring in individual’s discrimination of our stimuli, it is too early to completely reject Rosielle and Cooper’s (2001) conclusion that relative orientation is perceived categorically. One could argue that the stimuli used in this experiment are primitive and they may not posses the features that would require “high-level” processing that might result in categorical perception. Models of object recognition, such as John and Irving’s Model (JIM, Hummel & Biederman, 1992), and Feature Integration Theory (FIT, Treisman & Gelade, 1980) attempt to explain the complexity of object perception and the processes involved.

JIM (Hummel & Biederman, 1992) uses seven “layers” of processing to achieve object recognition. Initial stimuli are processed through each layer, beginning with layer 1, where the image and edges are processed, until layer 7, where objects are identified (orientation is processed in the third layer of this model). Only after images are processed completely through these seven layers are objects perceived. Additionally, FIT (Treisman & Gelade, 1980) describes a similar process. Here, stimuli are analyzed into feature maps, with such differences as color and orientation of features being processed and then bound together, resulting in object perception. In the early stages of FIT, orientation is initially processed by receptors tuned for particular orientations. In both RBC and FIT, a further step needs to be taken. The orientations must be combined to create on angle. If the stimuli is too degraded, such as due to short presentation time, complete processing of the object may not occur, which could lead to a less then accurate perception of the angle created by the objects components. The inability of the perceptual system to reach the point where orientations are combined to create angles could account for why Rosielle and Cooper (2001) found categorical perception of angles for objects.

In addition to the added complexity involved with object recognition, the short ISIs used in this experiment may have resulted in processing of the sort found by Rosielle and Cooper’s (2001) third experiment in which the shorter ISIs yielded non-categorical perception of their stimuli.

Further experiments need to be conducted to better tease apart the differences between non-categorical perception and categorical perception with respect to angular discrimination. At this time, it is unclear as to what influence ISI and “object” likeness of the stimuli may have in the perception of images in the visual system. Once these factors are controlled for, a clearer picture of what is occurring should present itself.

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FOOTNOTES

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[1] Since the experiment in this paper had angles in 10° increments from the vertical or horizontal positions, an orientation will be considered oblique if it is oriented between 10º to 80° with respect to the horizontal position.

[2] Geons are 3-dimensional basic components such as cylinders or cones that can be manipulated (i.e. stretched, curved, or bisected) into differing shapes.

[3] It is important to note however that not all research would suggest a quick decision to be coded metrically, while a longer decision would be coded categorically. For example, Feature Integration Theory (FIT, Triesman & Gelade, 1980) would claim that early processes in vision would begin at a categorical level, and that deeper processing of angles would result in a non-categorical coding of angular measurement.

[4] This equation describes why smaller original stimuli require a smaller change in size to detect a different size, as opposed to larger original stimuli. That is, if originally presented a 1cm line, a change of .5 cm is easily detected. However, if this original line is 100 cm, a change of 0.5 cm is typically unnoticed by an observer.

[5] Rosielle and Cooper used times of 156 ms for stimuli presentation, masks for 756 ms (in experiments one and three, for experiment two, a mask of 2016 ms was used), and all stimuli were presented in a serial fashion to untrained observers. Chen and Levi on the other hand used presentation times of 400 ms for their stimuli, no masks, and had trained observers. For this experiment, a presentation of 240 ms was used for the stimuli as a middle ground between the two previously discussed experiments, with a blanks screen ISI of 480 ms between the standard and comparison angles. Untrained individuals were decided upon for our task.

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[6] The number of trials for each angle differed here due to attempts to make the task short enough that it would be completed without too much fatigue. Specifically, angular differences that had yielded near perfect performance in pilot work (e.g., discrimination between 30° and 120° stimuli) were not included in the present study.

[7] For standard angles of 10° and 170°, it was common for individuals to obtain an accuracy of over 50% for all comparison angles. For these situations, it was clear that at some angle they would have not reached 50% accuracy. To error on the scale of caution, a 9.5° difference threshold was used, which could safely be predicted the largest possible angle measurement for them.