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The Size Perception of Arrays

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Abstract

How do people judge the size of perceptually grouped objects? Experiment 1 examined how array element size influences the array's perceived size. Experiment 2 examined how the orientation of triangular elements influences an array's perceived size. Experiment 3 examined how well the results of the previous experiments would generalize to other array shapes. Experiments 4 and 5 investigated what effect a non- uniform distribution of element centroids may have. Results: the size of the array elements has no influence on the perceived size of the array itself. This suggests that either the midpoint or centroid of the elements is used as a reference point for constructing the perceived size of the array. The results of the second experiment demonstrated that it is the center of gravity and not the midpoint of the elements that is used. In contrast, when the sizes of two explicitly defined circles are compared, one with a thick outline and one with a thin outline, subjects match the sizes based on the radius of the inner edge of the circles and not the center of the outline contour. Conclusions: the perceived size of a circular array is based on the distance between the center of the array and the centroid of the array elements.

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Although seemingly trivial, the process by which we perceive the size of an object is, in fact, quite complex, and understanding the principles that underlie size perception remains a central focus of vision science. At the heart of the problem of perceiving the size of an object are two fundamental questions: what is the object, and how big is it? Although much is known about the processes that resolve each of these questions in isolation from each other, how these processes interact is not fully understood. This article examines such an interaction by investigating the principles that underlie the perceived size of an object that is formed by the constructive processes of perceptual grouping. Specifically, we answer the question of what characteristics of the local elements influence the perceived size of the perceptually grouped object to which they belong.

Because we detect the 3D world with 2D retinal images, directly perceiving the physical size of an object from the projected retinal image is fundamentally impossible. That is because the size of the retinal image is dependent upon both the physical size of the object and its distance from the viewer. To overcome this fundamental challenge to representing the size of an object, the visual system integrates information about the retinal size of the object with other sources of information. For example, if you see someone you know in the distance, how tall they appear to be will be based on how tall they really are (retinal image), as well as other variables such as how far away they are (or appear to be), knowledge you may have about how tall they really are, and how tall they really are relative to other people or objects in the visual scene.

The image of each object in the visual field can provide cues that allow the visual system to extract information about each of these variables. For example: cues such as occlusion and motion parallax provide distance information by indicating which object is in front of the other (Yantis & McBeath, 2013). Similarly, an object's texture gradient can provide viewing distance information as closer objects have more visible detail (Yantis & McBeath, 2013). Object recognition can provide access to prior knowledge about the size of a familiar object (Yantis & McBeath, 2013) and differences in many factors such as geometrical layout and retinal size can provide information about an object's size relative to other objects in the visual scene. Numerous visual phenomena demonstrate that the visual system in fact uses cues such as these to construct the perceived size of an object. For example, many of the illusion outlines such as the Ponzo illusion, which demonstrates the effects of retinal size and perceived distance.

The fundamental goal of size perception is to construct an accurate representation of the physical size of the object and as described above, the size of the retinal image it projects is central to achieving this goal. Intuitively, extracting information about the retinal size of an object seems very straightforward for explicitly defined objects, which are those with boundaries are explicitly designated, such as the continuous contour that defines the shape of a circle. One could imagine any number of analyses,such as those that could operate on the radius of the circle, its area or circumference of its projected image that could provide direct access to its retinal size. However, not all of the objects that we perceive are explicitly defined. A fundamental characteristic of our visual experiences is that they are based in large part on constructiveprocesses that can create objects from spatially and temporally disparate and localized visual elements (Yantis &McBeath, 2013). Stimuli in our environment can be difficult to perceive due to ambiguities brought on by occlusion and the limitations of our visual system. For example, the visual image of a flower projected through a picket fence contains very little direct information about the shape or even existence of the flower.On the retina the flower does not appear as a whole object. Instead, it is a series of segments that are separated by the fence. By integrating the disparate sources of information corresponding to the visible portions of the flower, the constructive processes of perceptual grouping serve an important role in enabling us to experience a stable and sufficiently accurate representation of the world around us: namely the presence of a flower with a given size and shape that is present behind the fence.

The manner in which individual elements in the visual scene become grouped can depend on their shape or size. For example, when looking at a table which is set for dinner, the brain may group the objects by shape, so glasses will be grouped together when a person is pouring the drinks so you can find the glass easily in the visual field, and then plates may be grouped together by their circular shape while food is being served. Alternatively, salad plates can be grouped together in a separate group than dinner plates because of the difference in size. These grouping techniques are flexible so that we can use them to our advantage when interacting with objects in our visual field.

Objects are grouped by good continuation when occluded edges seem to meet behind an occluding object (Figure 1A). If the shapes of the occluded objects are manipulated, it can drastically change how they are grouped (Figure 1B). Grouping by similarity focuses on a specific feature of objects in order to group them together, such as object color or size (Wertheimer, 1923). Changing characteristics of these elements may alter the grouping paradigm.

Becausethe manner in which perceptually grouped objects are defined depends upon the feature characteristics of the individual elements, we are interested in investigating whether properties such as size and shape of the grouped object interact with characteristics of the local elements that define it. For example, will an object formed by grouping large elements appear larger than one formed out of small elements? There is some evidence to suggest that such interactions may indeed exist. For example,when translating across the visual field, the orientation of local Gaussian blobs can influence the perceived shape of an object they are grouped into (McCarthy, Cardeiro & Caplovitz, 2012). Similarly, the perceived shape of an object formed by the grouping of drifting Gabor patches can be influenced by the speed and directions of the Gabors' drift (Whitney, 2006). However, these interactions are not ubiquitous. For example, the perceived speed of a rotating object can depend more on the global shape than the local object speeds (Caplovitz & Tse, 2007; Kohler, Caplovitz, Hsieh, Sun, Tse, 2010).

The following experiments were conducted to investigate if, how, and which form characteristics of individual elements may influence the perceived size of the objects to which they become perceptually grouped. In the experiments we attempt to hold many characteristics of a perceptually grouped object constant while systematically altering characteristics of the local elements. The results of these experiments provide insight into how the visual system constructs the perceived size of a perceptually grouped object.

Methods

Participants

Participants in each experiment (Experiment 1: N=6, Experiment 2: N=6, Experiment 3: N=4, Experiment 4: N=5, Experiment 5: N=4) were students at the University of Nevada, Reno. Each participant was naïve to the goals and specific designs of the experiments, reported normal or corrected-to-normal vision and provided informed consent according to the guidelines of the Department of Psychology and the Institutional Review Board of the University of Nevada Reno. Some participants were given course credit for their participation. In total, eight individuals participated in the study with all but two participating in all five experiments.

Stimuli and General Procedure

Stimuli were created using Matlab and the Psychophysics Toolbox (Brainard, 1997), were presented on a 19” (Refresh rate= 85hz) CRT monitor and viewed at a distance of 57 cm. Stimuli consisted of circular (Experiments 1 and 2) or square (Experiments 3, 4, and 5) arrays of eight equally spaced white (109.4 cd/m^2) elements presented on a black background (.055 cd/m^2), The elements themselves were either filled circles (Experiment 1) or triangles

(Experiments 2-5). On every trial a test array and reference array were simultaneously presented for 500ms such that their centers were positioned 9º (13.8º for Experiment 1) of visual angle to either the left or right of a centrally located fixation spot (0.2º visual angle). On each trial a small amount of random jitter (up to 1.4º) was applied to the center of each array to ensure relative size judgments were formed by comparing the perceived size of the two arrays and not other potentially confounding cues such as their positions relative to the edges of the monitor. Observers were instructed to maintain central fixation and, in a two alternative forced choice manner, indicate by the press of a button which of the two arrays appeared larger: the one on the left or the one on the right. The sides on which the test and reference arrays were presented were randomly determined for each trial. Each experiment applied the method of constant stimuli: on each trial the size of the reference array was held constant whereas the size of the test array was pseudorandomly selected from a predetermined set of array sizes. The details of array and element sizes are provided below, as they are specific to each experiment.

Experiment 1: The influence of element size on the perceived size of a circular array

Experiment 1 was designed to dissociate three plausible hypotheses for how observers judge the size of an array. Specifically, the perceived size of an array may be determined by the distance between the center of the array and the outer edges, the inner edges, or the centers of the individual elements that make up the array. In order to dissociate between these hypotheses this experiment examined the perceived size of arrays constructed from elements of different sizes: small, medium and large. Each hypothesis makes a distinct prediction about how element size should influence the perceived size of the array. If observers use the inner edges of the elements then the test arrays with the small elements should be seen as largest. If observers use the outer edges of the elements then the test arrays with the large elements should be seen as largest. Finally, if observers use the centers of the elements then all three types of arrays should have the same apparent size.

Procedure

In this experiment the reference array consisted of eight, equally spaced, filled circles each with a radius of 0.95º. Each element was positioned so that the distance between its center and the center of the circular array was exactly 6.0º. As illustrated in Figure 2, three different sets of test arrays were examined: those consisting of small circles (0.16º), medium circles (0.95º) or large circles (1.74º). Note: the size of the medium circles matches the size of the circles that make up the reference array. This provides a natural control condition upon which to evaluate how accurately observers are able to discriminate array sizes in general. On any given trial the radius of the test array was pseudo-randomly selected from one of nine possible sizes, (4.7º, 5.5º, 5.8º, 5.9º, 6º, 6.1º, 6.2º, 6.5º, 7.3º) such that there were 20 trials of each size for each of the three circle-size conditions for a total of 540 trials.

Results: Experiment 1:

For each participant, psychometric curves were derived by computing for each trial type, the percentage of trials the test array was perceived as larger than the reference array. This was done independently for each of the three test-array conditions. Sigmoidal shaped curves $f(x) = 100x[e^{b_1+xb_2}/1+e^{b_1+xb_2}]$ were then fit to the average data for each subject. These curves were then used to interpolate, for each subject, the point of subjective equality (PSE, defined as the point at which the observer reported that the test array was larger 50% of the time) for each of the three test-array conditions. As can be observed in Figure 3, there are no differences between the PSEs derived from each of the three conditions (repeated measures ANOVA: $F(2,10) = 0.613$ $p = 0.561$, $\eta p2 = 0.109$). This result suggests that observers are likely using the distance between the center of the array and the centers of the elements, and not their inner or outer edges to judge the size of the array.

Experiment 2: Arrays made with triangular elements

The results of experiment 1 suggest observers use the center of the array elements in judging the overall size of an array. A question that remains unanswered is what constitutes the ‘center’ of an array element? On the one hand it could be the center of gravity; however, an alternative hypothesis is that observers use the average distance between the inner and outer edges of the array elements (i.e. half the distance between the inner and outer edges)[1].

These two alternatives become particularly relevant to the vision scientist in the context of designing
stimuli consisting of circular arrays of elements. Software packages such as the Psychtoolbox render shapes within predefined bounding boxes. It is not uncommon to

Because the elements in Experiment 1 were circles, for which both of these measures are identical, the results of the experiment cannot dissociate between these two possibilities.

In this experiment, the circular elements were replaced with isosceles triangles. As illustrated in Figure 4A, when oriented radially, the center of gravity of an isosceles triangle is distinct from the average distance between its inner and outer edges (i.e. the half height). Experiment 2 was designed to dissociate these two alternatives by investigating the perceived sizes of arrays constructed with inward or outward pointing triangles. If observers use the center of gravity to judge the size of the arrays, then the inward pointing triangle arrays should appear larger than outward pointing ones. If on the other hand, observers are using the half-height of the triangles, then the two sets of arrays should appear to have the same size.

Procedure:

The overall procedure was the same as Experiment 1, with a few changes. Instead of the arrays consisting of filled-circles, the elements that made up each array were filled isosceles triangles (1º base x 1º height). With these dimensions the distance between the center of gravity and the half height of the triangle was 0.17º. The triangles that formed the reference array always pointed inward towards the center of the array and the distance from the center of the reference array to the half-height of each triangle was held constant at 4º on each trial. As

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position the shapes using the center of the bounding box (consistent with ‘half-distance’ definition of center) rather than the center of gravity. of the shape.

illustrated in Figure 4B, there were two sets of test arrays: one in which the triangles pointed inward and one in which the triangles pointed outward. On each trial the size of the test array as measured from the center of the array to the half-height point on any given triangle was pseudo-randomly chosen from this list: 2º, 3º, 3.5º, 3.75º, 4º, 4.25º, 4.5º, 5.5º, 7º. As in experiment 1, the sides on which the test and reference arrays were presented were randomly determined on each trial. There were 20 trials for each size for both sets of test array conditions, for a total of 360 trials.

Results: Experiment 2:

As in Experiment 1, the percentage of trials in which the test array was perceived larger than the reference arrays was computed for each trial type. For each participant this was done independently for each of the two test-array conditions. PSEs were derived using the same procedure as in Experiment 1. As can be seen in Figure 5, the array comprised of inward pointing triangles was perceived to be larger than the array comprised of outward pointing triangles. A paired samples t-test of the PSEs of each participant indicated that there was a significant difference between the arrays with inward pointing triangles ($M=4.03$, $SD=0.075$) and the arrays with outward pointing triangles ($M=4.41$, $SD=0.174$);$t(5)=-4.014$, $p<.01$. The mean difference between the two PSEs was 0.38º. The fact that the two arrays were not perceived as having the same size suggests that observers are not basing their size judgments on the distance between the center of the array and the half-height location of each triangle.

The observed difference of 0.38º of visual angle is not significantly different (paired t-test $t(5) = .251$, $P = .812$) from what would be expected if observers are basing their judgments on the centers of gravity of the array elements, which in the case of the triangles displayed here was 0.34º. The 0.04º difference between the observed data and what would be expected if observers use the center of gravity corresponds to less than two screen pixels. As such, the data are very suggestive that in fact the perceived size of an array depends upon the location of the center of gravity of the elements that make up the array. The following experiments were designed to investigate whether the findings of experiments 1 and 2, derived for circular arrays, would generalize to non-circular arrays.

Experiment 3

In this experiment, the procedure was essentially the same as Experiment 2 with a few changes. The shape of the arrays was changed to form a square instead of a circle (see Figure 4B). The array was still made of triangle shaped elements as in Experiment 2, and the elements were again manipulated to either point toward or away from the center of the array. The size of each array was defined as the distance from the center of the array to the center (the midpoint of the bisector) of one corner object. The reference array always had inward pointing elements and had a size that was held constant across trials at 4.4º of visual angle. The test array could be made up of either inward or outward pointing triangles and had sizes that were pseudo-randomly chosen from a list of nine sizes (2.7º, 3.6º, 4.0º, 4.2º, 4.4º, 4.7º, 4.9º, 5.3º, 6.2º of visual angle). As illustrated in Figure 6A, in order to achieve the square shape, the non-corner elements were positioned such that the entire array could be inscribed by a square. As in Experiments 1 and 2, there were 20 trials for each size for both sets of test array conditions for a total of 360 trials. The sides on which the test and reference arrays were presented were randomly determined on each trial.

Results: Experiment 3:

Again, the point of subjective equality was calculated for each participant per type of stimulus. A paired samples t-test of the PSEs of each participant indicated that there was a significant difference between the arrays with inward pointing triangles ($M=4.45$, $SD=.0497$) and the arrays with outward pointing triangles ($M=4.82$, $SD=.14$);$t(3)=-6.083$, $p<.01$, which can be seen in Figure 6B. These results indicate that the array made of outward pointing triangles again seemed smaller than the array with inward pointing triangles. The mean difference derived here: 0.37º is quite comparable to that derived with the circular arrays in experiment 2 and is again not significantly different ($t(3) = 1.071$, $p=.363$) from what would be expected (0.34º) is observers are basing their judgments on the center of gravity. As such, at least for the case of a square array, the result derived in Experiment 2 using circular arrays can be generalized to non-circular shapes.

Experiments 4 and 5:

These experiments are designed to determine how the perceived size of an array is determined when the centers of gravity of the individual elements are not uniformly distributed. At least three plausible hypotheses exist as to how this question may be resolved. It may be the case that the perceived size of the array is predicated on the distance between the center of the array and the location of the most distal, proximal or the average across element of the centers of gravity. Experiments 4 and 5 were designed to dissociate between these hypotheses. In the following two experiments we examine the case in which each of the test arrays are made up of both inward and outward pointing triangles.

Experiment 4:

Experiment 4 was essentially the same as Experiment 3, except, as illustrated in Figure 7A, the test arrays either had all of their elements pointing inward or had their non-corner elements pointing outward. The reference array elements all pointed inward and had a size of 5.0º visual angle as measured from the center of the array to the bisector midpoint of the corner element. The radius of the test array was chosen from a list of nine sizes (3.0º, 4.0º, 4.25º, 4.75º, 5.0º, 5.25º, 5.75º, 6.0º, 7.0º). There were 20 trials for each size for both sets of test array condition for a total of 360 trials. The sides on which the test and reference arrays were presented were randomly determined on each trial.

Results: Experiment 4:

The point of subjective equality was calculated for each participant per type of stimulus. As seen in Figure 7B, a paired samples t-test of the PSEs of each participant indicated that there was a significant difference between the arrays with all inward pointing triangles (M=5.05, SD=.04) and the arrays in which the non-corner elements pointed outward (M=5.22, SD=.073);t(4)=-5.749, p<.01. This observation allows us to rule out the possibility that the most distal centers of gravity determine the perceived size of the array. This is because the most distal centers of gravity are the same for both test arrays. In order to dissociate between the remaining hypotheses we can compare the observed difference in perceived size to that which each hypothesis predicts. If the perceived size of an array is predicated on the locations of the most proximal centers of gravity then as was is the case in Experiments 2 and 3, one would expect the difference in perceived size to be 0.34° of visual angle. The observed mean difference here of 0.17° of visual angle is significantly less than the prediction (t(4)= -6.317,P<.01). In contrast, the observed mean difference is not significantly different from 0.167° visual angle (t(4)=-.177,p=.868), the value expected if the perceived size of an array is predicated on the average distance of each element's center of gravity from the center of the array.

Experiment 5

This final experiment was designed to test how well the results of Experiment 4 generalize when the orientations of the corner elements are manipulated rather than the non-corner elements. As illustrated in Figure 8A, the test arrays here were composed of all inward pointed elements or had their corner elements pointed outward. In all other ways the experiment was identical to Experiment 4.

Results: Experiment 5:

The point of subjective equality was calculated for each participant per type of stimulus. A paired samples t-test of the PSEs of each participant indicated that there was a significant difference between the arrays with all inward pointing triangles (M=5.03, SD=.048) and the arrays with outward pointing center triangles (M=5.18, SD=.083);t(3)=-3.335, p<.05 (see Figure 8B). As with Experiment 4, the observed difference was significantly less than that predicted (0.34°) if observers based their judgments using the most proximal centers of gravity (t(3)= -4.352,P<.05) and not significantly different from that predicted by the average-distance (0.167°) hypothesis (t(3)= -.441,P=.689). This provides further evidence that when the centers of gravity of the elements that make up an array are not uniformly distributed, the perceived size of the array is based on their average distance from the center of the array.

Discussion

This study investigated the manner in which the visual system may judge the size of perceptually grouped objects. The experiments were explicitly designed to determine whether the characteristics of local elements could affect the perceived size of grouped objects. The experiments examined the effects of element shape and size on the perceived size of two different shaped global objects. The results unequivocally demonstrated that the visual system uses the centroids of local elements to construct the perceived size of an objet to which they belong. This finding demonstrates that local element shape does indeed contribute to global size perception, a novel contribution to the previous body of literature addressing how perceptually grouped objects are perceived.

The results of Experiment 1 indicated that element size had little or no effect upon the judgment of array size. The result was somewhat surprising, as the spatial extend subtended by a group of large elements is greater than that subtended by smaller elements when they are aligned on their centers. This result stands in direct contrast to the classic size-perception literature examining explicitly defined objects. For example, Emmert's Law demonstrates that size perception changes when an object's spatial extent seems to grow when cued with a farther distance (Boring, 1940).

While highlighting the fact that spatial extent does not directly contribute to the perceived size of an array, the results of Experiment 1 do not conclusively indicate what source of information the visual system is in fact using. The stimuli used in Experiment 1 were circles that have an intrinsic symmetry in which the location of their centroids is equidistant from all points along the contour. Because of this, while the large and small elements were aligned on their centroids, it is also the case that they were aligned on other geometric dimensions as well, including, as can be seen in Figure 2, the half-way point between the innermost and outmost portions of their contour (relative to the center of the array). Subsequent experiments using triangular elements demonstrated that this half-way point of the object was less predictive of size judgments when compared to the centroid, and this result generalized across two different array shapes. This result highlights the relative importance of an object's centroid in comparison to other shape characteristics. A similar if not even more dramatic demonstration of this can be found in observers' inability to identify the half-height of an object in which the centroid and half-height are at two different locations (Anstis, Gregory & Heard, 2009). Furthermore, our results indicate that when the centroids of the elements were positioned in such a way that they did not form a coherent line, the average distance of the centroids from the center were utilized to form the judgment of size. All present results indicate that the centroid of the elements is fundamental to the visual system's analysis of size for perceptually grouped objects.

An interesting aspect of these results is how counter-intuitive they appear at first glance. When viewing these stimuli, most notably the circular array with triangular elements, the corners of the triangles form illusory contours which appear to form a circle. Intuition suggests that any size judgment of the array could be easily based upon this contour as well as other similar illusory contours as suggested by studies such as McCarthy, Kupitz, and Caplovitz' examination of the binding ring illusion (2013); yet, the results do not support this conclusion. An analysis of data in this experiment suggests that the centroids of the component elements are more important to the perceived size of a grouped object than the perceived illusory contour.

It seems a curiosity that the centroid is so important to the visual system. Perhaps its utility is ecologically derived, allowing us to intrinsically calculate where the center of gravity lies for an evaluated object. The benefit of having rapid access to this information would yield utility, perhaps because the centroid of an object is representative of the object's size and shape, as well as being integral for motor planning for any interactions with or manipulations of the object given our gravitational environment. Our study strongly supports the hypothesis that this information is not only readily available to the visual system, but also critical for calculations of the size of grouped objects. Our findings are in line with prior reports in which, when asked to point out the center point of an isosceles triangle, people instead were drawn toward the centroid (Anstis, Gregory & Heard, 2009).

Furthermore, the information and affordances gained via estimation of the centroid may also assist in solving the ambiguity problem. Because the visual system gains only so much information from the retinal image of an object, leading to the ambiguity problem, the ability to extract further information via estimation and heuristic evaluation is essential. Knowledge of an object's centroid may be similarly helpful to the visual system in perceptual grouping, inasmuch as it aids in forming a coherent image or gestalt representation from fragmentary retinal images. For example, perceptual grouping allows the visual system to piece together the image of a flower behind a fence (Yantis & McBeath, 2013), yet knowledge of the centroid of that object allows for an evaluation of affordances necessary for manipulation of that object. This has been demonstrated in a study in which participants were found to conduct saccade to an object's centroid immediately prior to grasping the object (Brouwer, Franz, & Gegenfurtner, 2009).

Studies have shown that perceptual grouping occurs as early as V1, and that there are paths of feedback which allow further processing to route back to V1, (Grossberg, Mingolla, & Ross, 1996). It is possible that the location of the centroid of an object is also processed in V1, which would allow further, fast processing of the difference in size of the perceptual objects. Further, the visual system needs at least two elements in order to judge this size, which may make the feedback from V1 necessary. Specifically, if the detection of the centroid location happens very early (perhaps pre-attentively), then the centroid location can be integrated with other size cues in order to construct the size percept of the grouped object. All of this information may then be fed back into V1 with the size information.

The binding ring illusion (McCarthy, Kupitz, &Caplovitz, 2013) demonstrates that manipulating the connection between array elements alters perception of the array's size. This change occurs even though the centroids of each object remain at the same position, meaning the perception of the size of an array may be affected by more than just the centroid position. Future studies may focus upon elucidating these and other factors which contribute to the perception of grouped objects. There may be alternative characteristics of local elements which alter the perception of a global object's shape or size; however, few studies have yet investigated these or related phenomena (McCarthy, Cardeiro&Caplovitz, 2012; Whitney, 2006; Caplovitz&Tse, 2007; Kohler, Caplovitz, Hsieh, Sun, Tse, 2010)

In conclusion, our results confirm that local elements do indeed influence the perceived size of a perceptually grouped object. Perception of grouped objects is a more complicated task than perceiving explicitly defined objects and as such, the methods by which the visual system analyses these objects are not yet fully understood. The results presented here contribute to a growing body of evidence with the intention of assisting in elucidating the components of this process.

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Appendix

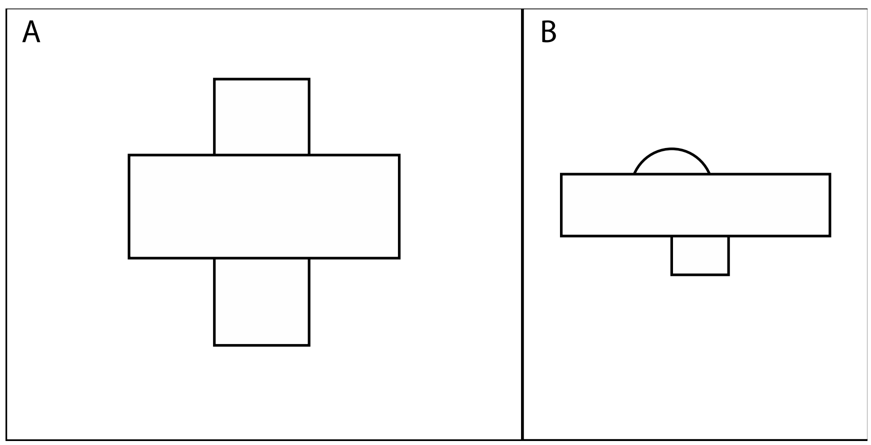

Figure 1: (A)Example of good continuation with an occluded object. (B) Example of an occluded object with no good continuation.

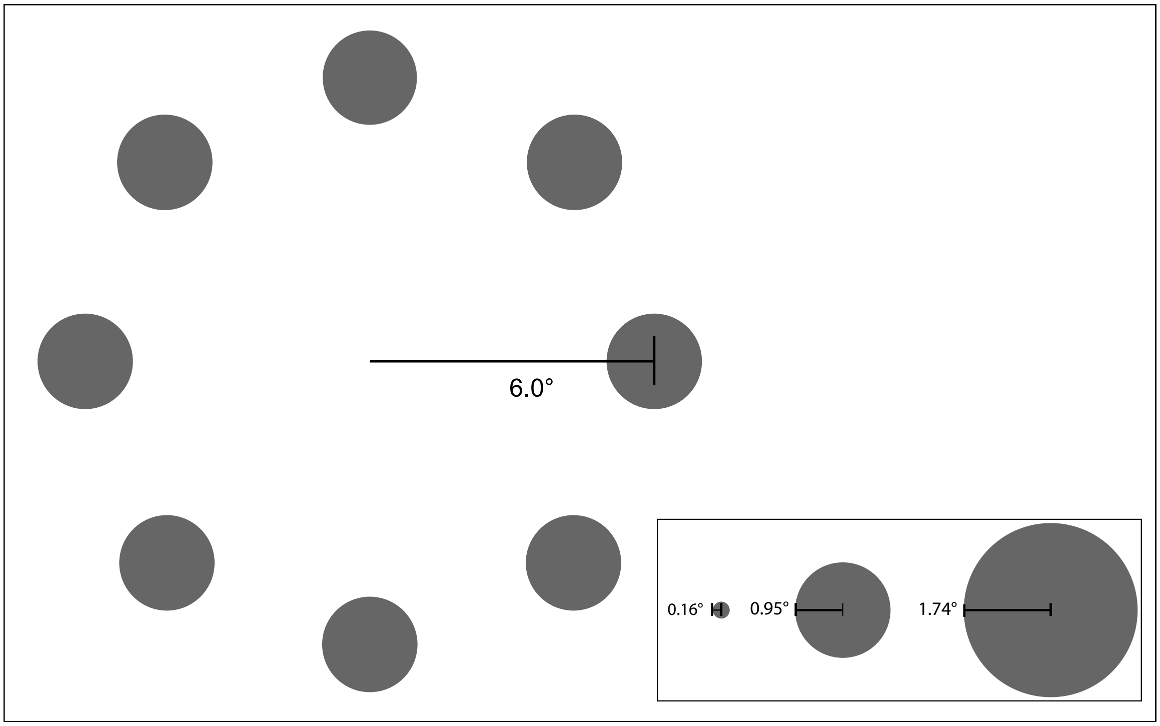

Figure 2: Example of the array stimuli from Experiment 1. Examples of the three element sizes are shown for comparison.

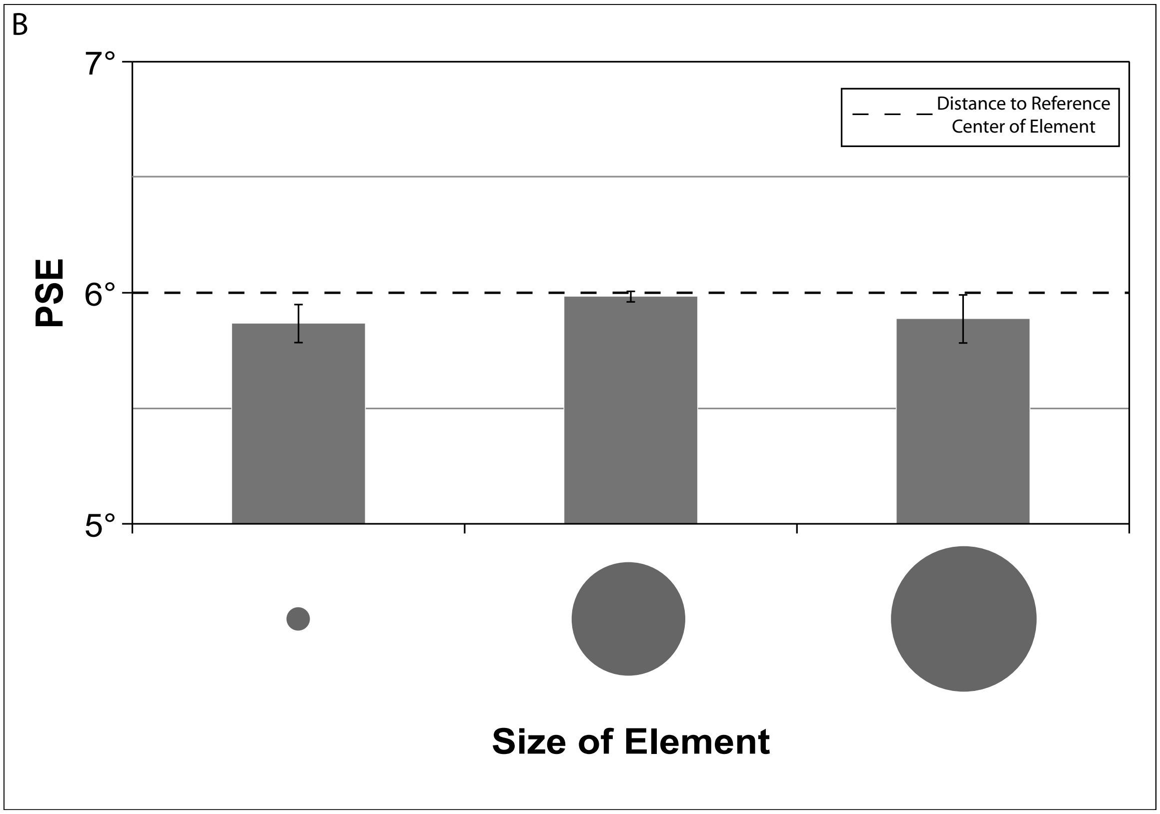

Figure 3: Point of Subjective Equality for the subjects in Experiment 1, which featured circular arrays with circular elements. There was no difference between the different conditions, suggesting that participants were using the center of each element to judge the array size.

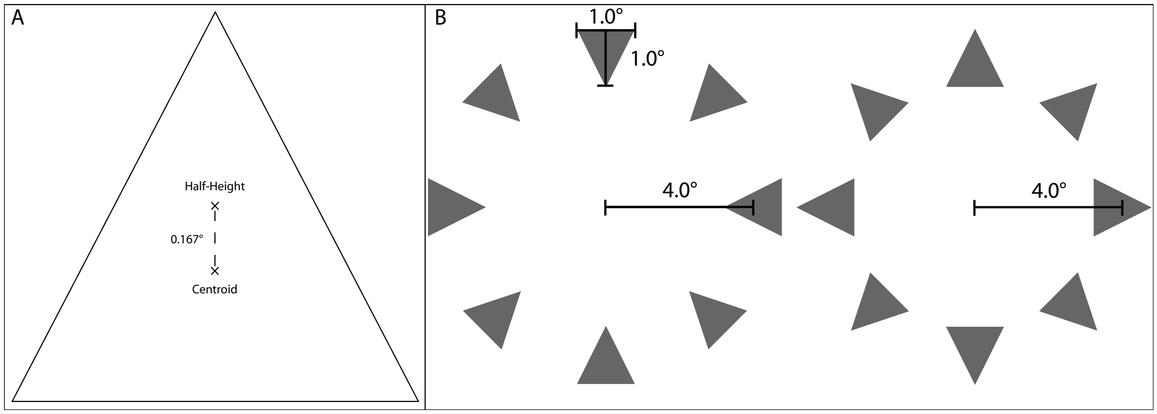

Figure 4: (A) The difference between the triangle's bisector midpoint (half-height) and it's centroid.(B)Example array from Experiment 2, featuring circular arrays with triangular elements. There were two element conditions: either pointing toward or away from the center of the array.

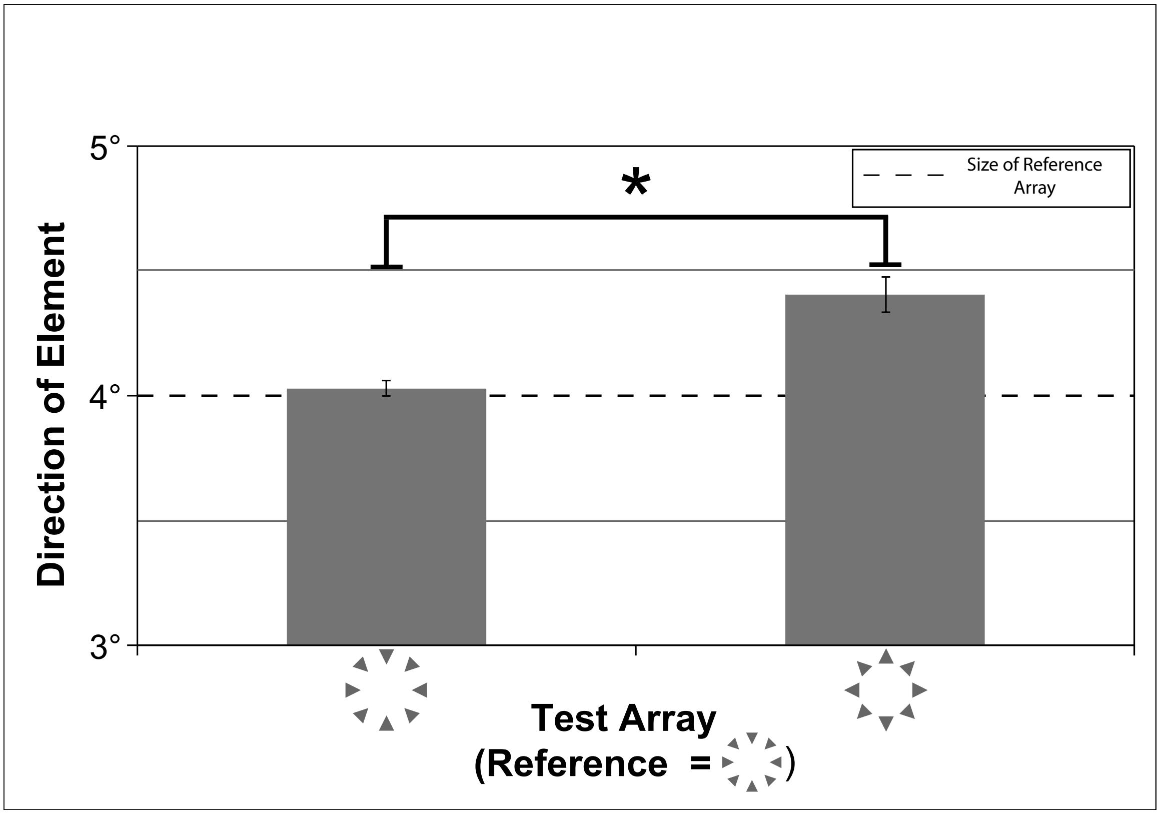

Figure 5: Point of Subjective Equality for participants in Experiment 2. There was a significant difference between the two conditions, suggesting that arrays with outward pointing triangles were seen as being smaller than arrays with inward pointing triangles.

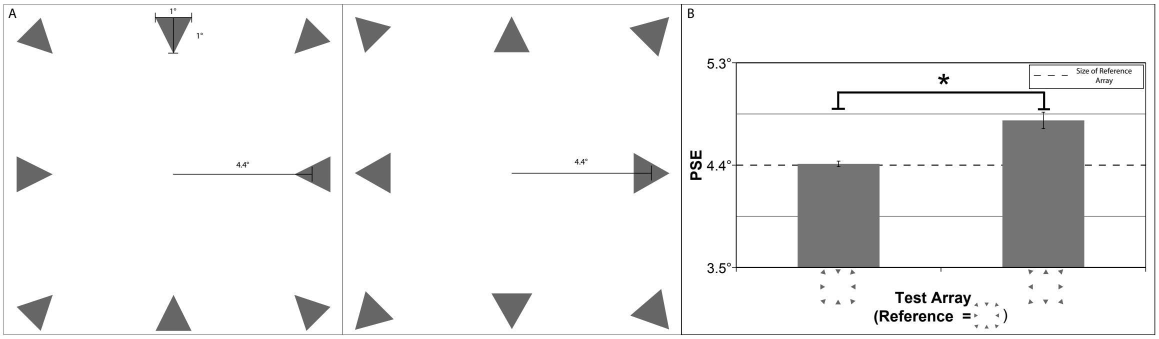

Figure 6: (A) Example array from Experiment 3,featuring square arrays with triangular elements. There were two element conditions: either pointing toward or away from the center of the array. (B) Point of Subjective Equality for participants in Experiment 3. There was a significant difference between the two conditions, suggesting that arrays with outward pointing triangles were seen as being smaller than arrays with inward pointing triangles.

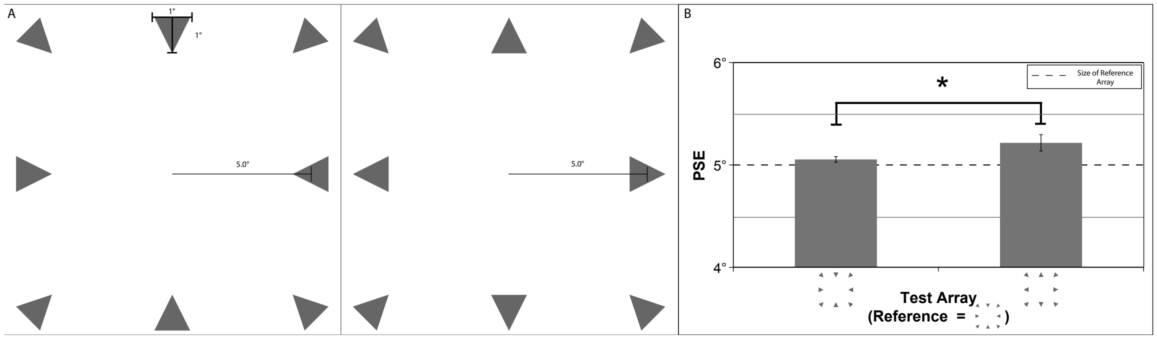

Figure 7: (A) Example array from Experiment 3,featuring square arrays with triangular elements. There were two element conditions: either all elements pointing toward or the center elements pointing away from the center of the array. (B) Point of Subjective Equality for participants in Experiment 4. There was a significant difference between the two conditions, suggesting that arrays with outward pointing triangles were seen as being smaller than arrays with inward pointing triangles. The mean difference here is much smaller, but is consistent with what would be expected if a participant used the average distance of the centroid.

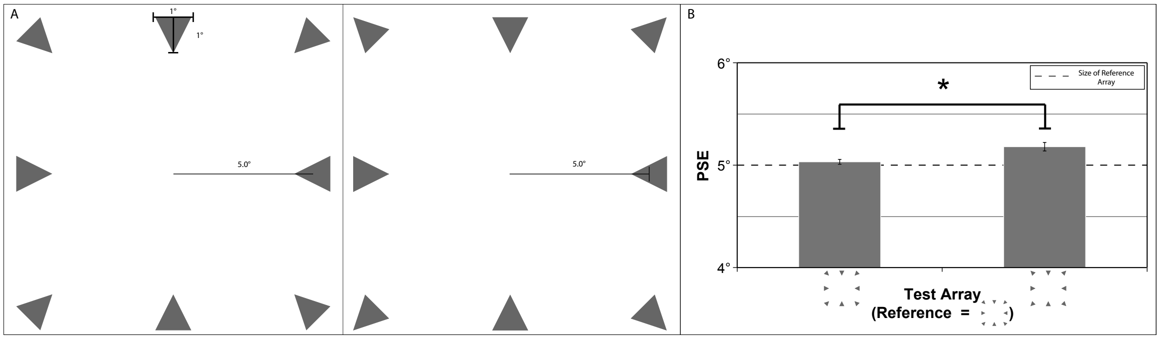

Figure 8: (A) Example array from Experiment 4,featuring square arrays with triangular elements. There were two element conditions: either all elements pointing toward or the corner elements pointing away from the center of the array. (B) Point of Subjective Equality for participants in Experiment 5. There was a significant difference between the two conditions, suggesting that arrays with outward pointing triangles were seen as being smaller than arrays with inward pointing triangles. Like in Experiment 4, the results here suggest that participants are using the average location of the centroids of the triangles to judge the size of the array.