A Size–Distance Scaling Demonstration Based on the Holway–Boring Experiment

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A Size–Distance Scaling Demonstration Based on the Holway–Boring Experiment

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Abstract

We explored size–distance scaling with a demonstration based on the classic Holway–Boring experiment. Undergraduate psychology majors estimated the sizes of two glowing paper circles under two conditions. In the first condition, the environment was dark and, with no depth cues available, participants ranked the circles according to their angular sizes. In the second condition, the environment was illuminated and, with depth cues available, the students ranked the circles according to actual physical size. The demonstration replicated the key elements of the original experiment, and objective and subjective measures indicated that it improved understanding of size–distance scaling. We also describe variants of the experiment suitable for different instructional environments.

Keywords

depth perception, size–distance scaling, size constancy, Holway and Boring

Among the most impressive feats of vision is the perception of depth and size. Textbooks and instructors commonly group these two processes because size perception can facilitate depth perception and vice versa. The size–distance scaling equation summarizes the relationship between the two functions:

$$S = kRD,$$

where S is the perceived size of an object, R is the retinal image size, D is the perceived distance between the observer and object, and k is a scaling constant (Boring, 1940; Goldstein, 2010). The values R and D are inversely related and, as targets approach or retreat, the perceived size (S) remains constant.

Discussing the classic Holway–Boring (1941) experiment gives instructors an opportunity to deconstruct the size–distance scaling equation and demonstrate the importance of depth perception in estimating size. By removing depth cues, Holway and Boring (1941) concluded that the only remaining cue, the size of the retinal image, determined the perceived size. A modified version of the size–distance scaling equation shows the relationship between size perception and retinal image size in the absence of depth cues:

$$S = kR.$$

With an observer positioned at the intersection of two hallways, Holway and Boring (1941) projected a luminous standard circle in one hallway, on an 8-ft × 8-ft screen positioned anywhere from 10 to 120 ft from the observer. In the other hallway, a second screen displayed a comparison circle 10 ft from the observer. The experimenters instructed observers to adjust the diameter of the comparison circle until the two circles were equal in size. Although the experimenters conducted their work at night, in a dark hallway, stray light illuminated surfaces of the corridor, providing "a sensory ground for the perception of the stimulus" (Holway & Boring, 1941, p. 30). Our efforts to recreate the original environment, in a hallway devoid of stray light, suggest that participants could also see the edges of the projection screens. With the features of the hallways visible, the original participants used depth cues like linear perspective to estimate the distance between themselves and the two stimuli. In this condition, observers easily matched the comparison stimulus to the true physical size of the standard stimulus, and estimates could be explained as a product of retinal image size and perceived distance, or $S = kRD$.

On subsequent trials, the experimenters proceeded to remove environmental depth cues and, as they did, the size estimates were no longer good indicators of physical size. First, the experimenters removed binocular depth cues by occluding one of the observer's eyes. Then, they removed monocular depth cues by having the participants view the standard circle through an extendable occlusion tunnel that blocked all peripheral environmental depth cues, including the edges of the projection screen. In this final condition, observers were unable to judge distance to the standard stimulus and made poor estimates of

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physical size, but accurately matched the circles according to retinal image size, summarized as $S = kR$.

Although others have described effective ways to demonstrate size–distance scaling (Kunkel, 1993; Lumsden, 1976), we wanted to develop a method that captured elements of the original Holway–Boring (1941) experiment for students in sensation and perception. Like Holway and Boring (1941), we asked our participants to compare the sizes of two glow-in-the-dark circles. Instead of having participants manipulate and match the stimuli, and instead of progressively removing depth cues, we asked them to simply rank two circles according to size under two different conditions, with the room lights on and with the room lights off.

We assessed the pedagogical effectiveness of the demonstration with a short quiz administered before and after the exercise. We also hypothesized that subjective reports would support the objective findings. The value of the demonstration, of course, depends on how well it replicates the results of the original experiment (Holway & Boring, 1941, p. 30). Therefore, we also hypothesized that participants would rank the circles according to physical size when the lights were on and depth cues were available, as predicted by $S = kRD$ and that participants would rank the circles according to angular size, which is proportional to retinal image size, when the lights were off and depth cues were not available, as predicted by $S = kR$. We tested these hypotheses with a naïve group of psychology majors, who had not studied the Holway–Boring (1941) experiment, as well as a group of sensation and perception students who knew our objectives.

Method

Participants

This experiment complied with the standards of Millersville University's Institutional Review Board. Fifty-six naïve psychology majors who had not studied the Holway–Boring (1941) experiment participated in exchange for course credit. A second group of 27 students from a sensation and perception class performed the experiment as part of a unit on depth perception and size–distance scaling.

Materials

We conducted the experiment in a university building that had several classrooms and offices on each floor. We placed the circles in a 12-ft × 8-ft office room and, although the room had no exterior windows, the door to the room had a window that made the interior visible from the hallway. We occluded this window with cardboard except for a 2-cm^2 aperture, 120 cm above the floor. It was small enough to prevent binocular viewing. The office room was not cleared or prepared in any particular way; desks, chairs, computers, and bookshelves were easily visible through the aperture and served as environmental depth cues when the room's interior was illuminated.

We cut two circles from glow-in-the dark paper and positioned them in the room, as shown in Table 1 and Figure 1.

Table 1. Features of the Stimulus Circles.

Circle	Distance to Aperture (cm)	Angular Size (Diameter in Centimeter)	Actual Size (Height in Degrees)
A	376	8.3	1.27
B	60	3.8	3.63

Note. Angular size in degrees = 57.29 (diameter of circle)/(distance to aperture).

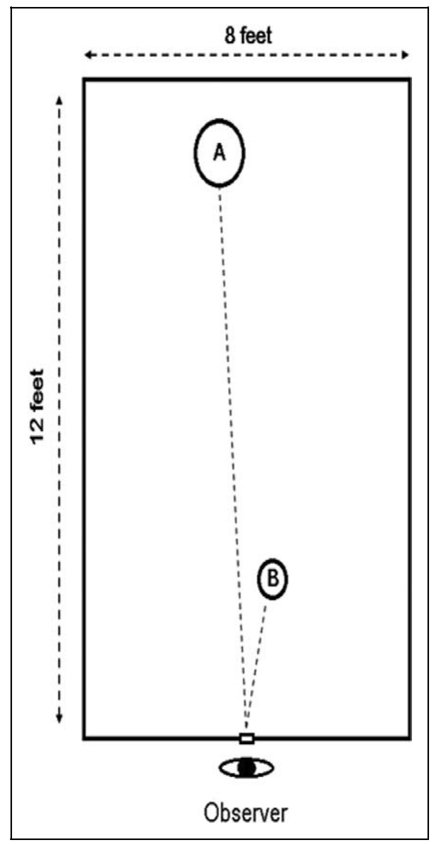

Figure 1. Diagram showing the relative positions of the observer and two circles. Letters did not appear on the actual circles.

We taped each circle to a $1 bill and then taped the bill to the end of a 120-cm long dowel rod. A wooden base secured the bottom of each rod. The dollar bills served as a familiar size depth cue visible only in the illuminated condition and may have aided size estimations in our study in the same way that the two identical projector screens probably facilitated size judgments in the original study (Holway & Boring, 1941). The center of each circle was 120 cm above the floor and positioned to make the line of sight from the viewing aperture normal to each luminous face. When viewed through the aperture, the circles appeared side by side along the horizontal and when the room interior was not illuminated, the circles were the only visible objects in the room (see Figure 2). We chose sizes and locations that made the physical size of Circle A larger than that of Circle B and the angular size of Circle B larger than that of Circle A (see Table 1).

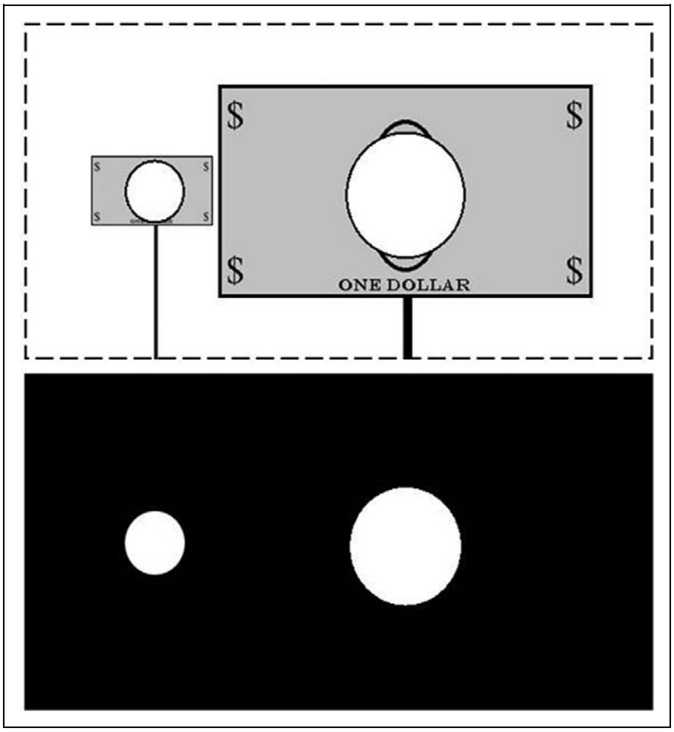

Figure 2. Simulated participant perspective in the illuminated condition (top) and in the dark condition (bottom).

Procedure

Naïve students ($n = 56$) participated in counterbalanced groups of six to eight. We told them that that they were going to view and identify the larger of the two paper circles. We asked the participants to form a line in the hallway outside the room containing the circles and approximately 10 ft from the viewing aperture. We then gave each participant a black marker and a piece of paper with the letters A and B printed left to right in 100-point Arial font. We instructed them not to communicate with each other and monitored them during the experiment. One by one, we led them to the aperture where they could see two yellow circles. We told them that Circle A was on the left and Circle B was on the right and asked them to identify the larger circle by circling the corresponding letter on the paper. The experimenter then took the paper, handed the participant an identical sheet, and summoned the next participant. After all the group members had made their first estimates, we told the participants that we needed a moment to set up the next part of the experiment. One experimenter led the participants around a nearby corner where they could no longer see the door to the room, and the other experimenter changed the experimental condition by turning the room lights on or off. This delay was no more than 30 s, but it allowed the participants to entertain the possibility that the experimenter rearranged or changed the circles. Finally, the participants made estimates under the second condition.

The sensation and perception students participated one day after reading about the Holway–Boring (1941) experiment and taking a short pretest quiz (Appendix) made up of questions from the textbook's question bank (Wurst, 2007). Because knowledge of the size–distance equations could bias these students, we thought that they would be likely to anticipate our intentions and, after seeing the true size and locations of the circles in the illuminated condition, would not be deceived by the absence of depth cues in the dark condition. We therefore tested all of these students in the dark condition first. An informal posttest survey confirmed that most assumed that the experimenters had not manipulated the circles between conditions. These students took the quiz again on the following day, at the beginning of the next class meeting.

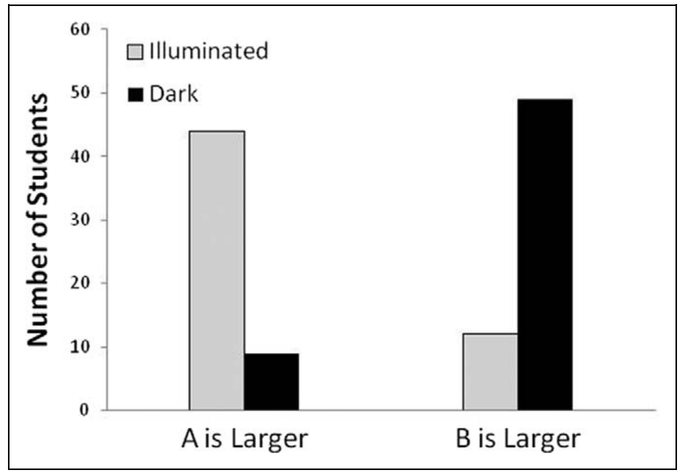

Figure 3. Number of naïve students choosing either Circle A or Circle B as the larger circle in each of the two conditions. Circle A was physically larger and identified as the larger circle by most participants when the room was illuminated. However, Circle A had a smaller angular size which made Circle B appear larger in the dark condition, when depth cues were absent.

Results

For the 25 sensation and perception students who completed the pretest and posttest quiz, posttest scores ($M = 4.04$, $SD = 0.98$) were significantly higher than pretest scores ($M = 2.88$, $SD = 1.17$), $t(24)=3.82$, $p = .001$ (two-tailed), $d = 0.76$. Of the 26 responding sensation and perception students, 22 agreed that the demonstration improved their understanding of the Holway–Boring (1941) experiment by answering *d* or *e* on Item 6 of the posttest quiz. The five students who reported that the demonstration did not improve their understanding stated that they did so because the textbook description of the original experiment was sufficient.

As expected, most participants chose Circle A as the larger circle when the room was illuminated, but most chose Circle B when the room was dark and depth cues were not available. There was a significant relationship between viewing condition and circle choice for the counterbalanced naïve group, $\chi^2(1, n = 56) = 45.56$, $p < .001$, $\varphi = 0.90$ (see Figure 3), as well as the sensation and perception students, $\chi^2(1, n = 27) = 19.32$, $p < .001$, $\varphi = 0.85$.

Discussion

The pretest–posttest quiz results suggest that this demonstration enhanced understanding of the classic Holway–Boring (1941) experiment. History effects, of course, threaten the validity of any pretest–posttest investigation, but this simple, low-cost exercise successfully captured the key elements of the Holway–Boring experiment, yielded similar results, and subjective reports were positive.

Without depth cues, the size–distance scaling equation predicts that perceived size will be proportional to angular size which is, in turn, proportional to the size of the image on the retina. In the dark condition, the participants perceived only the angular sizes of the glowing circles and, as predicted, most chose Circle B as the larger of the two. In the illuminated condition, participants were able to use depth cues to estimate actual physical size, which is directly proportional to the product of retinal image size (R) and perceived distance (D), assuming accurate estimates of distance. As predicted, when participants could see the interior of the room, and especially the dollar bills taped to the backs of the circles, most were not misled by the fact that angular size was a poor indicator of physical size; the circle projecting the smallest retinal image was perceived as distant and correctly identified as the physically largest whereas the circle casting the largest retinal image was perceived as very close and correctly identified as the physically smallest.

Results from the sensation and perception class indicate that the size–distance scaling effect is still apparent in a biased sample. Interestingly, Holway and Boring (1941) were participants in their own study and also exhibited the effect, despite knowing the experimental objectives. Sensation and perception instructors may prefer to conduct this exercise before introducing size–distance scaling in order to collect an unbiased set of data and then present the results while discussing the Holway–Boring experiment, but we believe that the demonstration is a more effective educational exercise when presented in context. Our results indicate that the size–distance scaling effect is apparent in both naïve and informed samples.

This demonstration is simple and we estimate that, with planning, two experimenters can test groups of up to 100 students in less than an hour. We have found that comparative judgments are easier and data collection is faster with glowing squares that allow participants to compare the heights of their vertical edges. We used circles in an attempt to approximate as much of the original experiment as possible. If running the experiment as described here is still impossible, instructors can use a large-group simulation by showing students photographs taken from the perspective of the aperture in the illuminated condition and then simulating the dark condition with an image similar to the one at the bottom of Figure 2. The experiment can also be set up in a variety of windowless rooms. We have replicated the experiment in large computer labs and small storage closets.

The design presents many opportunities for elaborations, which could include asking the participants to estimate distance to the circles in order to determine if they perceive the circles as equidistant from the aperture in the dark condition and to see if and how depth estimates change with condition. Students could incorporate these estimates into the size–distance scaling equations and explain their perceptions mathematically.

Appendix

Assessment questions edited and drawn from an instructors manual (Wurst, 2007) for the course textbook (Goldstein, 2010). Correct answers are underlined. Item 6 appeared only on the posttest and was not used to assess understanding of size–distance scaling.

1. Holway and Boring found that
   a. size constancy holds under all viewing conditions.
   b. the law of visual angle does not work in humans.
   c. <u>size constancy occurred if participants could see the features of the hallway</u>.
   d. size constancy does not occur under binocular viewing conditions.
   e. more than one of the above.
2. An object's angular size is determined by
   a. its physical size alone.
   b. its placement in the visual space.
   c. the distance between the object and the observer.
   d. the speed at which it is moving.
   e. <u>more than one of the above.</u>
3. In the absence of depth information, size estimates are based largely on
   a. size constancy.
   b. the actual physical size of an object.
   c. the physical distance of an object.
   d. <u>the angular size of an object.</u>
   e. more than one of the above.
4. The equation for size–distance scaling is $S = kRD$. The term D stands for
   a. <u>perceived distance between observer and object.</u>
   b. actual distance between observer and object.
   c. true physical diameter of the object.
   d. size of the distal stimulus.
   e. more than one of the above.
5. You step outside the building after class and spot your friend's car as it leaves the parking lot. Which terms of the size–distance scaling equation, $S = k\ R\ D$, change as you watch the car pull away?
   a. S and R.
   b. S and D.
   c. <u>R and D.</u>
   d. only one term changes.
   e. all of the terms change.

6. Select the answer that describes how much you agree or disagree with the following statement: *This demonstration improved my understanding of the Holway–Boring experiment*.
   a. Strongly disagree
   b. Disagree somewhat
   c. Neutral
   d. Agree somewhat
   e. Strongly agree

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