

## Appendix

## Experimental Methods

## Observers

In all experiments, the same 6 participants were used. All had normal or corrected-to-normal vision and, except for PH and CZ, were naïve as to the purposes of the study.

## Apparatus

The stimuli were presented on a 19-in. CRT (Dell M782p) monitor controlled by a Dell Precision M70 computer (Windows XP) running MATLAB 7.1 (MathWorks, Natick, MA) using Psychophysics Toolbox routines (Brainard, 1997; Pelli, 1997). The monitor spatial resolution was set to  $1024 \times 768$  pixels, and the refresh rate was 75 Hz. The observer's head was immobilized by a combined head and chin rest.

## Stimuli and Procedure

*Experiment 1A*

The stimuli were created by replacing the disks in Figure 1a with small squares to generate Figures 2a–2d. This increased the strength of the illusion, allowing us to study the effects of grouping more precisely, and this is how the *dungeo*n illusion was originally presented (Bressan, 2001). Each stimulus was presented on its own at the center of the monitor. In all displays the gray squares, the contextual squares, and the background oscillated vertically and sinusoidally with an amplitude of  $0.35^\circ$  and a frequency of 1.9 Hertz. In Displays 2a and 2c the gray squares oscillated in phase with the contextual squares but in antiphase with the large square, whereas in Displays 2b and 2d the gray squares oscillated in phase with the large square but in antiphase with the contextual squares. The size of each of the small squares was  $2.7^\circ$  by  $2.7^\circ$ , and the squares were separated by  $1.8^\circ$ . The luminances of white, gray, and black were  $21 \text{ cd/m}^2$ ,  $6.8 \text{ cd/m}^2$ , and less than  $0.5 \text{ cd/m}^2$ , respectively. Each of the four displays of Figure 2 was shown to each participant once in a random order. At the start of the experiment, instructions appeared on the computer monitor asking the participant to indicate whether the gray squares grouped more strongly with the contextual squares or with the large background square.

*Experiment 1B*

This experiment was run immediately after the previous experiment. The four displays of the first experiment were used, but this time they were presented individually on the left of the computer monitor. On the right there was a black and white  $10 \times 10$  checkerboard. The checkerboard subtended  $14^\circ \times 14^\circ$ . Centered on it was a  $4.9^\circ \times 4.9^\circ$  gray square. The lightness of the square was initialized to a random value between black and white. At the start of each trial, verbal instructions appeared on the computer monitor asking the participants to use the keyboard to adjust the lightness (i.e., the perceived shade of gray) of the gray square on the checkerboard until it matched the lightness of the gray squares in the *dungeo*n display. Each of the four displays of the first experiment was shown to the participant 20 times in a random, interleaved order.

*Experiment 2A*

Each of the four stimuli shown in Figure 4 was presented on its own at the center of a computer monitor. As before, the observer's head was immobilized by a combined head and chin rest. The size of the stimulus was  $14^\circ \times 14^\circ$ , and each gray rectangle was  $4.9^\circ$  long. The black stripes, white stripes, and gray rectangles oscillated vertically and sinusoidally with an amplitude of  $1.4^\circ$  and a temporal frequency of 1.9 Hz. The luminances of white, gray, and black were  $21 \text{ cd/m}^2$ ,  $6.8 \text{ cd/m}^2$ , and less than  $0.5 \text{ cd/m}^2$ , respectively. At the start of the experiment, instructions were presented on the computer monitor asking the observer to indicate by a key press whether the gray rectangles grouped with the black or white stripes.

*Experiment 2B*

The procedure was identical to that used in Experiment 1B except we substituted White's display for the *dungeo*n-illusion display.

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## Postscript: A Reply to Bressan (2007)

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For the double-anchoring theory (DAT) to predict lightness, it must first determine the frameworks. In response to our previous criticisms, Bressan defines frameworks as "regions of common illumination" (Bressan, 2007, p. iii). Because the amount of light reflected by an object is determined by both the illumination and reflectance, to determine the illumination, the observer must first estimate the object's lightness—the very phenomenon DAT seeks

to explain. Bressan's reasoning is therefore circular. Her method of determining the framework weights is also problematic, because it relies on her personal intuition as to how the various grouping principles will interact with each other in the particular scene under consideration. We need a procedure that will allow any researcher to determine, *in a purely objective manner*, what DAT predicts the frameworks and their relative weights to be.

A second concern we raised was that DAT could not explain grating induction. In her reply, Bressan assumes that neighboring points can have different lightnesses, even if they have the same luminance. Although this allows her to explain grating induction, it also means that DAT can no longer explain several phenomena that it originally could. For example, this new version of DAT

must predict that, by analogy with grating induction, the gray patches in the simultaneous-contrast display should appear to be nonuniform, because those points nearer the edges of the gray patches should be more influenced by the surround than those points nearer the center. As shown in Figure 1A of Bressan (2006), the gray patches look uniform. Bressan goes on to state that DAT predicts that grating induction should occur only when the luminance of the area where the illusory grating is induced is between the maximum and minimum luminance values of the inducing grating. Although in her explanation she referred to a square-wave grating, her reasoning applies equally well to a sine-wave grating, and so we must conclude that DAT predicts that the luminance constraint also applies to sine-wave gratings. It turns out that for low-spatial-frequency sine-wave gratings, this prediction is not correct (Kingdom, McCourt, & Blakeslee, 1997).

Although Bressan argues that the all-black room experiment of Gilchrist and Jacobsen (1984) was confounded by the presence of a Munsell chart, she accepts that if the rooms were not anchored to the Munsell chart, the low-luminance room would still have appeared lighter than the high-luminance one. Bressan suggests that the shadows, gradients, and luminance variations in the rooms provide extra information about the rooms' respective reflectances. However, the original version of DAT did not take into account any of these sources of extra information, and so Bressan has now inserted an entirely new concept into her theory. DAT has therefore been radically changed, and so, until Bressan gives us some indication as to how this new version of DAT is supposed to obtain

and use this extra information, we cannot use DAT to make any predictions.

In conclusion, by modifying DAT to address our previous concerns, Bressan has created more problems than she has solved. Despite her assertions to the contrary, we have demonstrated several major problems with her theory. The authors of the original anchoring theory were well aware that the main failing of their theory was that it lacked rigor and concreteness (Gilchrist et al., 1999, p. 829). In extending their theory, Bressan has chosen not to address this issue and instead has made her extension more subjective and less precise than the original theory. To us, this represents a step in the wrong direction.

#### References

- Bressan, P. (2006). The place of white in a world of grays: A double-anchoring theory of lightness perception. *Psychological Review*, *113*, 526–553.
- Bressan, P. (2007). Dungeons, gratings, and black rooms: A defense of double-anchoring theory and a reply to Howe et al. *Psychological Review*, *114*, 1111–1115.
- Gilchrist, A., & Jacobsen, A. (1984). Perception of lightness and illumination in a world of one reflectance. *Perception*, *13*(1), 5–19.
- Gilchrist, A., Kossyfidis, C., Bonato, F., Agostini, T., Cataliotti, J., Li, X., et al. (1999). An anchoring theory of lightness perception. *Psychological Review*, *106*, 795–834.
- Kingdom, F. A., McCourt, M. E., & Blakeslee, B. (1997). In defence of "lateral inhibition" as the underlying cause of induced brightness phenomena: A reply to Spehar, Gilchrist and Arend. *Vision Research*, *37*, 1039–1047.