Hersh Sagreiya, Dwight Curtis and Chengjie Zheng were my students

Psychological Review
2007, Vol. 114, No. 4, 1105–1110

0033-295X/07/$12.00 DOI: 10.1037/0033-295X.114.4.1105

The Double-Anchoring Theory of Lightness Perception: A Comment on Bressan (2006)

Piers D. L. Howe, Hersh Sagreiya, Dwight L. Curtis, Chengjie Zheng, and Margaret S. Livingstone
Harvard Medical School

Recently, a double-anchoring theory (DAT) of lightness perception was proposed (P. Bressan, 2006), which offers explanations for all the data explained by the original anchoring theory (A. Gilchrist et al., 1999), as well as a number of additional lightness phenomena. Consequently, DAT can account for an unprecedented range of empirical results, potentially explaining everything from the basic simultaneous contrast display to subtle variations of the Gelb effect. In this comment, the authors raised 4 concerns that demonstrate serious theoretical and empirical difficulties for DAT.

Keywords: lightness, grouping, dungeon illusion, White's effect, anchoring

When two regions are under the same illumination, the ratio of their luminances is equal to the ratio of their reflectances. When *lightness* is defined as perceived reflectance, it follows that if the lightness of one region is known, the lightness of a second region can be estimated by comparing the relative luminances of the two regions. According to the double-anchoring theory (DAT), which is based on the anchoring theory of Gilchrist et al. (1999), the human visual system uses the Gestalt laws of perceptual grouping to group regions into collections, known as *frameworks*, in which all regions in the same framework are assumed to be illuminated equally (Bressan, 2006, p. 526). Consequently, for regions within the same framework, the relative lightnesses are equal to the relative luminances. DAT assumes that the lightness of each region is calculated twice and that the region's actual lightness is a weighted average of the results obtained from these two calculations. In one calculation, known as the *HL step*, the highest luminance in the framework is assumed to correspond to a lightness of white, and the lightnesses of the other regions in the framework are calculated relative to this anchor. In the second calculation, known as the *surround step*, the region's surround is assumed to correspond to a lightness of white, and the region's lightness is calculated relative to this anchor. It should be noted that a region can belong simultaneously to more than one framework, in which case its actual lightness is a weighted average of the lightness values calculated in the different frameworks.

How this theory works in practice is demonstrated by its explanation of the dungeon illusion (Bressan, 2001), shown in Figure 1a. The gray disks on the left appear lighter than those on the right, even though they are the exact same shade of gray. This result is surprising, because from simultaneous contrast (von Helmholtz, 1867/1962), one would expect the opposite, as the gray disks on the left are surrounded by white and those on the right by black. Referring to this display, Bressan stated that each set of gray disks participates in two separate frameworks, one including the surrounding disks and one including the background. The first framework is caused by the grouping principles of luminance polarity and shape similarity, whereas the second is due to the grouping principle of retinal proximity. Because luminance polarity and shape similarity are "hard" (i.e., strong) grouping principles, and retinal proximity is "the weakest among grouping principles," (Bressan, 2006, p. 526) by considering both the number and strength of the grouping principles that support each framework, DAT predicts that the first framework will have the greater influence on the lightness of the gray disks. In this framework, the gray disks on the left are white at the HL step and "superwhite" at the surround step, whereas the gray disks on the right are gray at both steps. These predictions are tempered by the influence of the peripheral framework, which links the gray disks to the rest of the visual field; thus, the gray disks on the left are seen as light gray, as opposed to white.

The Frameworks Are Not the Same as the Perceptual Groups

Gestalt grouping principles are conventionally used to determine which objects in a scene will be perceived to group together (Koffka, 1935). Consequently, when we are told that the frameworks are "created by the Gestalt grouping principles" (Bressan, 2006, p. 526), it is natural to conclude that the frameworks are the same as the perceptual groups. If this were true, then the frameworks could be determined simply by viewing the image and noting which regions are perceived to group together.

To test this prediction, we carried out a sequence of experiments, the details of which are listed in the Appendix. In the first experiment, observers were shown a version of the dungeon illusion in which, for technical reasons, the gray disks were replaced by squares. The background, the surrounding squares, and the gray squares oscillated vertically in a sinusoidal fashion. The background and the surrounding squares always oscillated in antiphase with each other. On some trials the gray squares oscillated in phase with the surrounding squares but in antiphase with background. In other trials the converse occurred, and the gray squares oscillated in phase with the background but in antiphase with the surrounding squares. On some trials the surrounding squares were black, and on other trials they were white. As shown in Figure 2, these permu-

Piers D. L. Howe, Hersh Sagreiya, Dwight L. Curtis, Chengjie Zheng, and Margaret S. Livingstone, Department of Neurobiology, Harvard Medical School.

Correspondence concerning this article should be addressed to Piers D. L. Howe, Harvard Medical School, 220 Longwood Avenue, Boston, MA 02115. E-mail: phowe@hms.harvard.edu

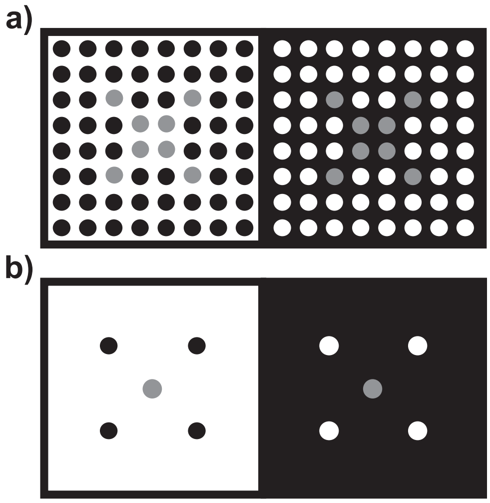

Figure 1. (a) The version of the dungeon illusion discussed in Bressan (2006). Most observers perceive the gray disks on the left as lighter than those on the right. (b) A novel version of the dungeon illusion. Most observers perceive the gray disk on the left as darker than that on the right.

tations resulted in four possible displays. These displays were shown sequentially, in a random order, to each of the 6 observers. In the first part of the experiment, the observer's task was to indicate with which object(s) they perceived the gray squares to group. Common fate has a strong influence on the formation of perceptual groups, and so it is not surprising that, for all four displays, all observers perceived the gray squares to group with whichever object(s) with which they were moving in phase.

In the second part of the experiment, the observers were asked to adjust the luminance of a gray square on a checkerboard background until the gray square appeared to have the same lightness as the gray squares in the version of the dungeon illusion that was being viewed. The results are shown in Figure 3. It was found that, for all observers, the gray squares in Displays 2a and 2b appeared lighter than the gray squares in Displays 2c and 2d. This showed that the lightness of the gray squares was determined primarily by the luminance of the surrounding squares, regardless of whether or not these were the objects with which the gray squares were perceived to be grouped.

To show that this result was not unique to the dungeon illusion, we performed a second experiment, immediately after the first, using the same observers. In this experiment, we used a different illusion, namely White's effect (White, 1979). The white, black, and gray bars all oscillated vertically in a sinusoidal fashion. In all displays, the white bars moved in antiphase with the black bars. Sometimes the gray bars moved in phase with the black bars and sometimes in phase with the white bars. Sometimes the gray bars were flanked by black bars and sometimes by white bars. These permutations resulted in four possible displays, which are shown in Figure 4. In the first part of the experiment, observers were asked to indicate, for each of the four displays, whether the gray bars grouped with the black bars or with the white bars. The gray bars were always perceived to group with the bars with which they moved in phase, regardless of the color of the bars. In the second part of the experiment, the observers were asked to adjust the luminance of a square on a checkerboard background until it had the same lightness as the gray bars in the version of White's effect that was being viewed. The results are shown in Figure 5. It was found that the gray bars appeared lighter in Displays 4a and 4b than in Displays 4c and 4d. This showed that the lightness of the gray bars was determined by the luminance of the flanking bars, regardless of whether or not these were the bars with which they were perceived to be grouped. This experiment therefore provided additional evidence that the groupings that determine lightness perception are not always the same as the perceived groupings.

Before leaving this topic, we should acknowledge that although in our experiments the perceptual groups did not determine the lightness percept, in other circumstances they can (Agostini & Proffitt, 1993). We suggest that the degree to which Gestalt grouping principles influence the lightness percept can be different from the degree to which they influence perceptual groupings. For example, if two surfaces move in synchrony, it is reasonable to assume that they are connected, but it is not reasonable to assume that they are illuminated equally. Consequently, we would expect the grouping principle of *common fate* to influence the perceptual groupings more than it influences the lightness groupings. The point of our experiments was not to show that perceptual groups never influence lightness perception but rather to show that, in some circumstances, they are of little importance.

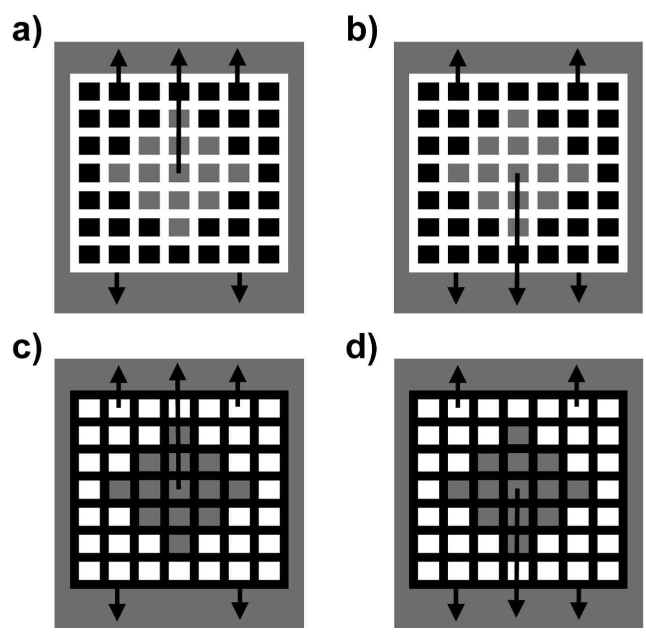

Figure 2. The versions of the dungeon illusion used in the first experiment. In all panels the small black squares, the small gray squares, and the large white square all oscillated vertically in a sinusoidal fashion. In Panel a the small black squares and the small gray squares oscillated in phase with each other but in antiphase with the white background. Panel b is the same as Panel a except that the small gray squares oscillated in phase with the white background but in antiphase with the small black squares. Panels c and d are similar to Panels a and b, respectively, except that the white background and the small black squares of Panels a and b have been replaced by a black background and small white squares in Panels c and d. The gray squares were always perceived to group with the objects with which they oscillated in phase.

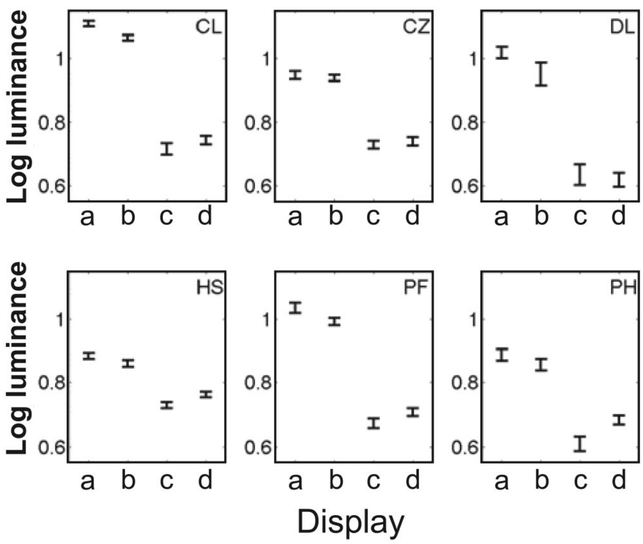

Figure 3. Lightness of gray squares in Displays a–d of Figure 2. The ordinate represents the logarithm of the luminance of the adjustable test patch when the test patch was perceived to have the same lightness as the gray squares. The error bars indicate one standard error either side of the mean. These results show that the lightness of the gray squares was determined by the luminance of the small squares that surrounded them and not by the objects with which the gray squares were perceived to be grouped. CL, CZ, DL, HS, PF, and PH are the initials of the experiment participants.

The Strength of a Grouping Principle Depends on the Context in Which It Operates

Bressan (2006, pp. 529–530) lists the grouping principles that affect lightness perception and categorizes them as hard or soft. She then uses these categorizations to predict the lightness percept, as was illustrated in the discussion of the dungeon illusion. However, this approach can lead to incorrect predictions. Because of the similarities between Figure 1b and the dungeon illusion (i.e., Figure 1a), DAT must analyze them in the same way. In particular, DAT must predict that in Figure 1b each gray disk groups primarily with its contextual disks, as opposed to with its retinally adjacent background, because two hard grouping principles, namely luminance polarity and shape similarity, support the first grouping, whereas only one weak grouping principle, namely retinal proximity, supports the second grouping.

However, most observers perceive the gray disk on the left to appear darker than the one on the right, indicating that, contrary to DAT's prediction, the gray disks group primarily with their retinally adjacent backgrounds. In other words, the grouping principle of retinal proximity proved to be stronger than the combined effects of the grouping principles of luminance polarity and shape similarity. This shows that, contrary to Bressan's assertion, a grouping principle cannot be categorized as hard or soft before the context is known. Therefore, for DAT to make correct lightness predictions, it must first correctly predict the strengths of the grouping principles in the scene being viewed. It remains to be seen if this can be done.

Points Within the Same Region Do Not Always Have the Same Lightness

Bressan (2006) writes that "we aggregate all identical points into a 'region' and treat that as a unity" (p. 530). In other words,

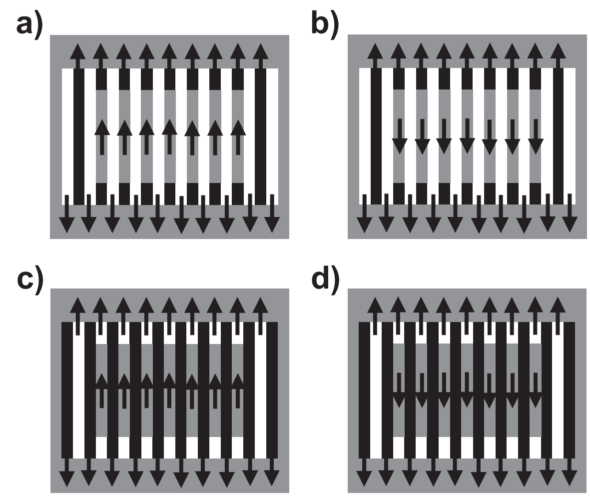

Figure 4. The displays used in the second experiment. In all panels the black, white, and gray rectangles all oscillated vertically and sinusoidally. In Panel a, the black and gray rectangles oscillated in phase with each other but in antiphase with the white rectangles. Panel b is similar to Panel a except that the gray rectangles oscillated in phase with the white rectangles but in antiphase with the black rectangles. Panels c and d are similar to Panels a and b except that the white and black rectangles of Panels a and b have been replaced by black and white rectangles, respectively, in Panels c and d.

DAT does not predict the lightnesses of individual points but instead predicts the lightness of a region, under the assumption that all points in a region have the same lightness and so can be treated the same. This assumption is not always valid, as illustrated by

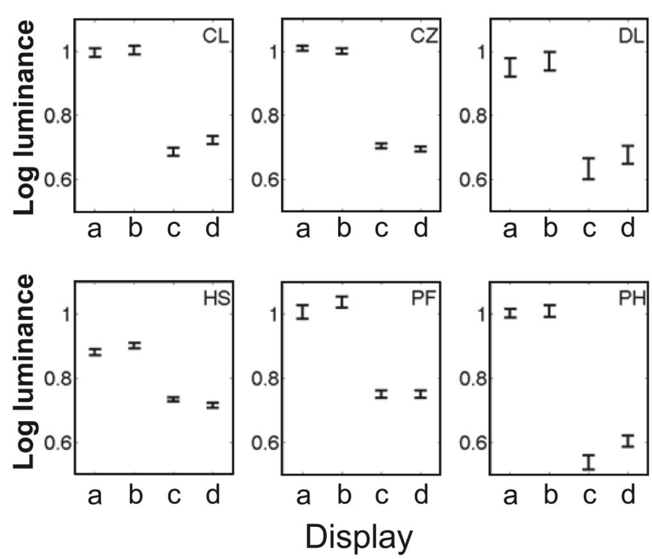

Figure 5. The lightness of the gray rectangles in Displays a–d of Figure 4. The ordinate represents the logarithm of the luminance of the adjustable test patch when the test patch was perceived to have the same lightness as the gray rectangles. The error bars indicate one standard error either side of the mean. These results show that the lightness of the gray rectangles was determined by the color of the rectangle on which they lay and not by the objects with which they were perceived to be grouped. CL, CZ, DL, HS, PF, and PH are the initials of the experiment participants.

grating induction (McCourt, 1982), an example of which is shown in Figure 6. In this figure, all points in the gray bar have the same luminance, and so DAT treats the gray bar as a single region, predicting that all points in the gray bar have the same lightness. However, most observers find that the gray bars appears to consist of alternating light gray and dark gray segments.

The parts of the gray bar that are flanked by white appear darker than those that are flanked by black, demonstrating that the lightness of a point is most affected by the luminance of nearby points. Of course, DAT could explain this illusion if it were to explain lightness perception, not in terms of the luminances of regions but, rather, in terms of the luminance of individual points, where the nearest points are weighted more heavily. However, this would mean that DAT would need to perform a separate calculation for each point to predict that point's lightness, and in performing this calculation, it would need to consider in turn the influence of every other point in the scene. Computationally, this would be prohibitive.

The Region With the Highest Luminance Is Not Always Perceived as White or Luminous

DAT calculates the lightness of a region by comparing that region's luminance to the highest luminance in its framework and also by comparing the region's luminance to the luminance of its surround. These two calculations are known as the HL step and the surround step, respectively. For the HL step, the region with the highest luminance is considered to be white, and in the surround step, the surround is considered to be white. If the region under consideration happens to have the highest luminance in the display, then at the HL step it will appear to be white, and at the surround step it will be assigned a lightness value of white or luminous. In other words, regardless of what the frameworks in the scene are, DAT must always predict the surface with the highest luminance to appear to be white or luminous.

This prediction is not always correct. Gilchrist and Jacobsen (1984) performed an experiment in which there was a miniature room. Everything in this room was painted black. Outside the room was a Munsell chart, and by referring to this chart, observers were asked to indicate the lightness of various points in the room. Observers reported that the lightest surface in the room appeared to be gray.

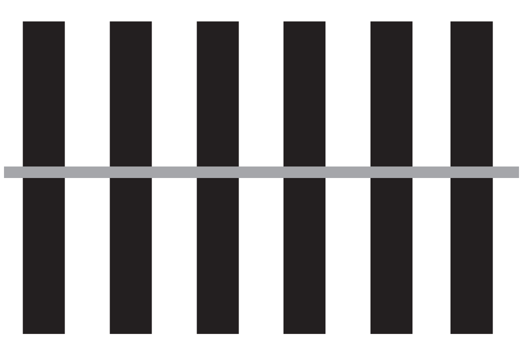

Figure 6. Grating induction (McCourt, 1982). Although the gray bar is actually homogeneous, it appears to consist of alternating light gray and dark gray segments. In the right circumstances the illusion can be very large with the perceived contrast of the induced grating equaling 90% of the contrast of the inducing grating.

It has been suggested that this experiment is confounded and that DAT can explain its result.[1] Because the luminance of the white square in the Munsell chart was higher than the highest luminance in the miniature room, one might think that the lightness of the highest-luminance surface of the miniature room was anchored both to itself and to the luminance of the white square of the Munsell chart. Whereas the first anchoring would predict the highest-luminance surface in the miniature room to appear white, the second anchoring would predict it to appear gray. Combining these two predictions would allow DAT to explain why the highest-luminance surface in the miniature room looked gray.

There are at least two reasons to believe that this explanation is invalid. Although it is possible for the luminance of a scene viewed earlier to affect the lightness of a scene viewed later, this occurs only when there are regions common to both scenes (Annan & Gilchrist, 2004). Because the miniature room was viewed through an aperture, no portions of the room were viewed simultaneously with the Munsell chart, and so, contrary to DAT's prediction, the luminance of the Munsell chart could not affect the lightness of the miniature room. Second, in an additional experiment there was another miniature room, which was identical to the first except that everything was painted white. The illumination of this room was such that all surfaces in this room had a lower luminance than the corresponding surfaces in the miniature black room. If the miniature rooms were indeed partially anchored to the Munsell chart, then the highest-luminance surface in the miniature white room should appear to be darker than the highest-luminance surface in the miniature black room. It did not and instead looked white. This provides further evidence against the suggestion that the lightness of the highest-luminance surface in the miniature black room was affected by the luminance of the white square of the Munsell chart.

[1] This suggestion was made by Paola Bressan in the review process.

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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 × 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 dungeon 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° 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° by 2.7°, and the squares were separated by 1.8°. The luminances of white, gray, and black were 21 cd/m^2, 6.8 cd/m^2, and less than 0.5 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 × 10 checkerboard. The checkerboard subtended 14° × 14°. Centered on it was a 4.9° × 4.9° 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 dungeon 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° × 14°, and each gray rectangle was 4.9° long. The black stripes, white stripes, and gray rectangles oscillated vertically and sinusoidally with an amplitude of 1.4° and a temporal frequency of 1.9 Hz. The luminances of white, gray, and black were 21 cd/m^2, 6.8 cd/m^2, and less than 0.5 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 dungeon-illusion display.

Received August 4, 2006
Revision received January 18, 2007
Accepted January 18, 2007 ■

Postscript: A Reply to Bressan (2007)

Piers D. L. Howe, Hersh Sagreiya, Dwight L. Curtis, Chengjie Zheng, and Margaret S. Livingstone
Harvard Medical School

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.

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