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T-junctions in inhomogeneous surrounds

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Abstract

In an inhomogeneous checkerboard surround, the lighter check darkens an incremental test patch more than the darker check lightens it. However, decremental test patches are influenced equally [Schirillo & Shevell, 1996. *Vision Research*, *36*, 1783–1796]. In the current study, we manipulate the spatial arrangement of a checkerboard surround to produce T-junctions that perceptually group the checks with the test patch. These stimuli alter the inducing effects of the checks. For one modified surround, increments appeared $\sim 8\%$ darker and decrements appeared $\sim 10\%$ lighter over the original checkerboard surround prior to modification. In a second modified surround, that resembled White's illusion [White, 1979. *Perception*, *8*, 413–416], increments again appeared $\sim 8\%$ darker, while decrements appeared a dramatic $\sim 23\%$ lighter over the original checkerboard surround prior to modification. These enhanced induction effects are postulated to result from the addition of specific T-junctions. However, these grouping effects remain subservient to the asymmetrical induction effects found by Schirillo and Shevell (1996). © 2000 Published by Elsevier Science Ltd.

Keywords: Brightness perception; Achromatic appearance; Grouping; Segmentation; Spatial summation

1. Introduction

An incremental test patch centered on a checkerboard surround appears dimmer than an identical test patch centered on a homogeneous surround of the same space-average luminance (Fig. 1) (Schirillo & Shevell, 1996). This inducing effect increases as checkerboard contrast increases. However, decrements appear identical in both homogeneous and checkerboard surrounds and across checkerboard contrasts.

Increment–decrement asymmetries have been reported at detection threshold (Krauskopf, 1980) and at supracontrast discrimination levels (Whittle, 1986). However, Zaidi, Yoshimi, Flanigan and Canova (1992) and Zadi and Zipper (1993) have found that increments and decrements behave similarly. Symmetrical induction has also been reported in White's illusion (White, 1979; White & White, 1985), where gray bars that are boarded more by light than dark regions appear brighter than identical gray bars boarded more by dark than light regions. Moulden and Kingdom (1989) hypothesize that induction in White's illusion involves two distinct mechanisms: a global process that influences the strength of induction and a second, local process that influences when these effects will occur that makes tenable the possibility that various surface intersections or junctions may regulate the illusion.

The current study explores how a specific spatial arrangement of T-junctions produces symmetrical induction in White's illusion, while another, present in Schirillo and Shevell's (1996) checkerboard stimuli, results in asymmetrical induction. Adelson (1993) demonstrated that the spatial organization of surfaces influences their perceptual grouping, which effects the brightnesses of those surfaces. For example, specific perceptual junctions can make surfaces appear to lie in either the same or different depth planes (Anderson, 1997; Guzman, 1968; Waltz, 1975) and impact their inducing properties, as Gilchrist's (1977) coplanar ratio hypothesis suggests. Todorović (1997) and Zaidi, Spehar, and Shy (1997) found that surfaces that cross the stem of a T-junction are perceptually grouped independently from the surface that abuts the top, explaining how T-junctions can serve as a cue to occlusion (Waltz, 1975). Todorović (1997) argues that perceptual grouping across the T-junction stem maximizes the reciprocal inducing properties of these surfaces in two-dimensional images. Zaidi et al. (1997) extended the T-junc-

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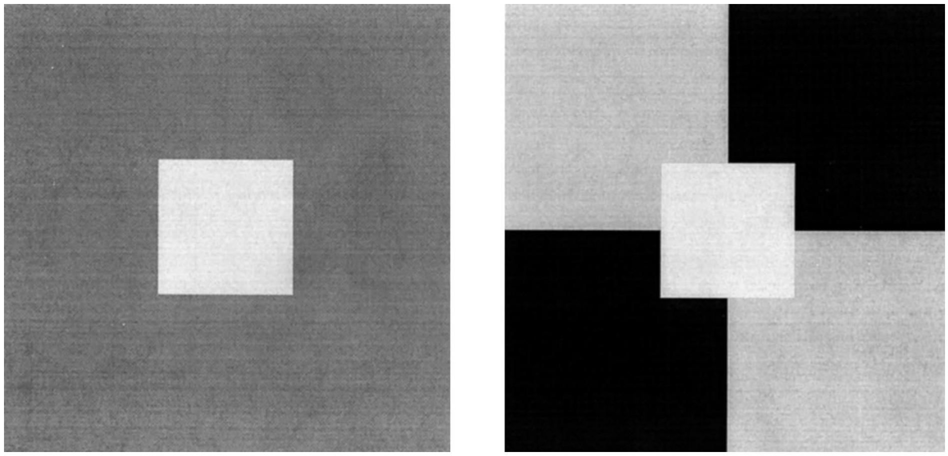

Fig. 1. The original checkerboard display used by Schirillo and Shevell (1996) and in Experiment 1 of the current study.

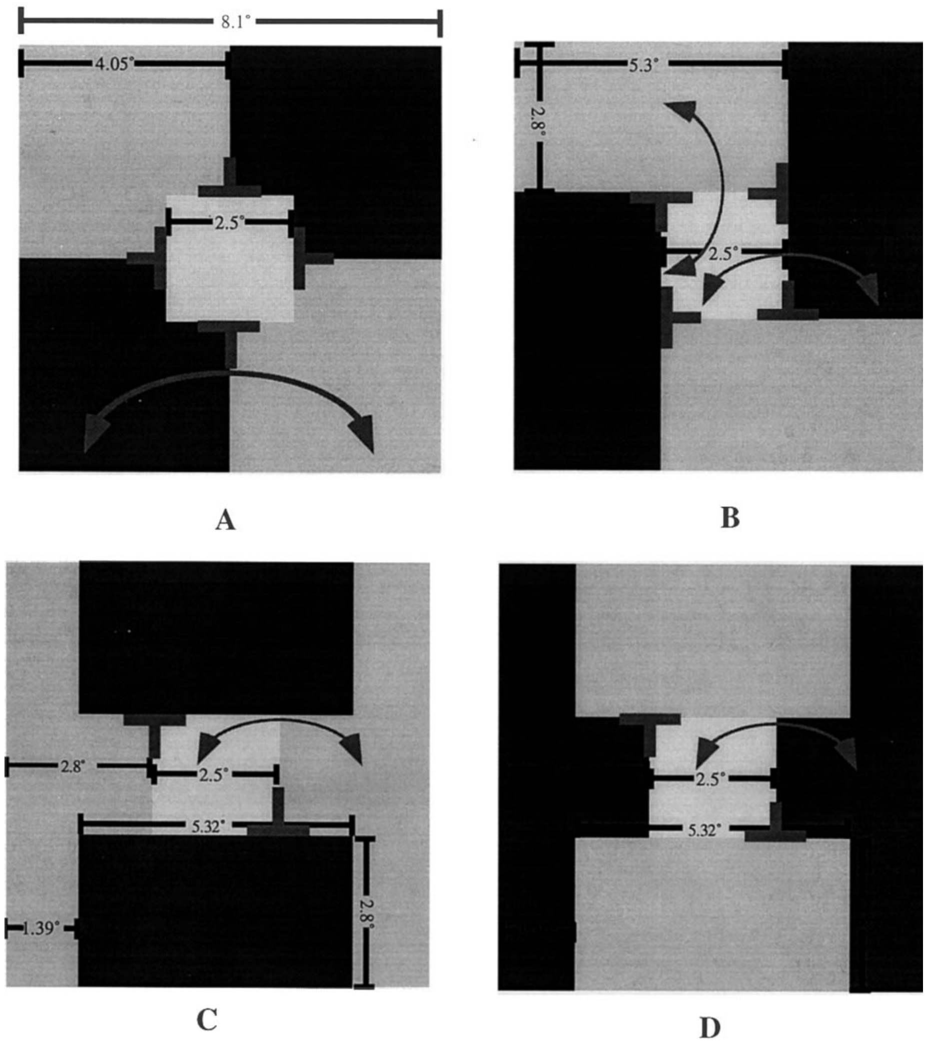

Fig. 2. (A) A checkerboard surround. According to T-junction theory, these checks should influence each other more than they influence the central test patch. (B) A double region T-junction surround. Both the lighter and darker regions should equally influence the test patch. (C) A light single region T-junction surround. Only the light region influences the test patch. (D) A dark single region T-junction surround. Only the dark region influences the test patch.

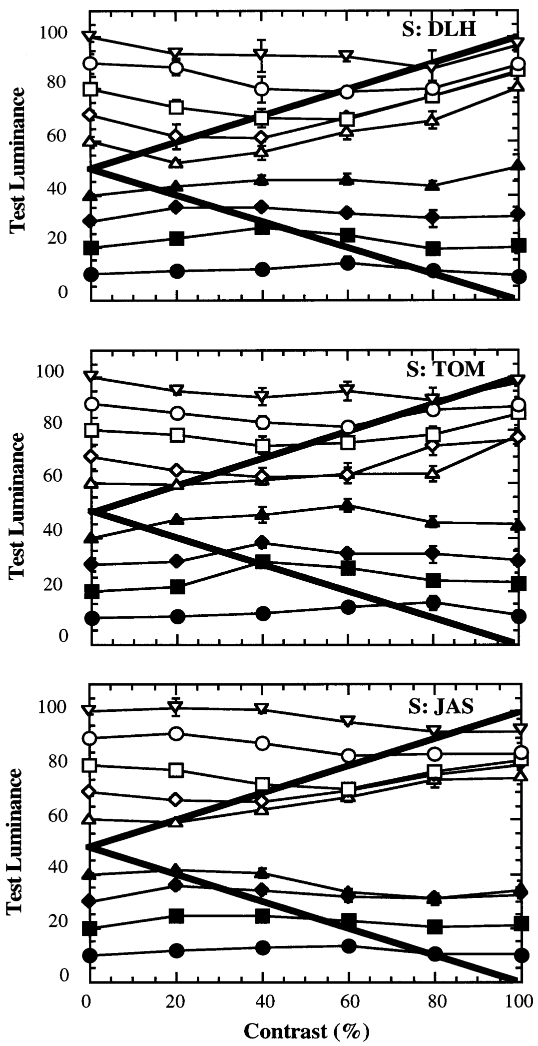

Fig. 3. The test patch luminance matched in brightness to a fixed comparison patch luminance for an original checkerboard display at various contrasts. The two diverging lines show the luminance of the checks. Open symbols indicate comparison patch increments, while solid symbols indicate decrements.

tion hypothesis to show that maximum induction also takes place across the stem, but not the top, of T-junctions in three-dimensional images. In White's illusion, the T-junctions signal that the gray bars embedded within the dark stripes belong to those stripes, causing them to appear brighter than the gray bars embedded within the light stripes.

The spatial arrangement of the checks in Schirillo and Shevell's (1996) study form T-junctions that might cause the checks to influence each other more than they influence the test patch (Fig. 2a). However, the checkerboard can be spatially rearranged to create T-junctions that directly influence the test patch (Fig. 2b–d). In one case, both light and dark regions are adjacent to the test patch across the stem of the T-junction (Fig. 2b). In another, either the light region alone or the dark region alone is adjacent to the test patch across the stem of the T-junction (Fig. 2c,d). Notice the similarity between these latter conditions (Fig. 2c,d) and White's illusion. Equating the areas of the light and dark regions across conditions produces modified surrounds with the same space-average luminance as the original checkerboard surround. Moreover, the light and dark regions also have the same contour length shared with the central test patch (cf. Todorović, 1997). These modified surrounds can be used to selectively enhance induction between either light or dark regions and the test patch.

2. Method

2.1. Apparatus and stimuli

Achromatic checkerboard patterns were generated with a Power Macintosh 7600/132, presented on a Radius Pressview 17SR 17" color monitor. The monitor was calibrated using the ProSense Calibrator by Radius, and achromatic luminances were equated in the four quadrants of the screen using a Minolta Chroma Meter, CL-100. The 832×624 pixel screen produced achromatic stimuli at CIE chromaticity $x = 0.27$, $y = 0.28$. The scan rate was 75 Hz noninterlaced. The luminances set by the software did not vary appreciably across the viewing area. Luminance was approximately constant ($\pm 3\%$) within the central region of the screen that displayed the test and comparison patterns.

Observers viewed the monitor at a distance of 67 cm in a dark room. The CRT screen simultaneously displayed two surrounds separated horizontally by a 2° gap on an otherwise dark screen (e.g. Fig. 1). Each surround was $8.1° \times 8.1°$. The left-hand comparison surround appeared uniform gray (rel. lum. = 50). A 2.5° square comparison patch was centered on the homogeneous surround. The relative luminance of the comparison patch was varied pseudo-randomly by computer from trial to trial in 10% increments from 0 to 100. The right-hand surround was inhomogeneous (as shown in Fig. 2), with a space-averaged luminance of 50, making it equivalent to the homogeneous surround. A 2.5° square test patch was centered on the inhomogeneous surround. The observer used a joystick to vary the relative luminance of the test patch. The contrast of the inhomogeneous surround (contrast = $(L_{max} - L_{min})/(L_{max} + L_{min})$) was varied from 0% (i.e. identical to the homogeneous surround) to 100%, where one region appeared light and the other region dark, in 20% increments in contrast.

Across experiments, the surround configuration varied. However, the total area of each check-region was kept constant. Also, the light and dark regions had the same contour length shared with the central test patch. In the original checkerboard display, the checks were $4.05° \times 4.05°$ (Fig. 2a). The spatial arrangement of the checks created T-junctions that would enhance each check's influence on the other more than on the test patch. In the condition where a light and dark region were on the outer side of the stem of the T (subsequently referred to as the double-region condition), the regions were 2.8° × 5.3° (Fig. 2b). In this condition, the light and dark regions should group with, and thereby influence equally, the test patch. The condition where only one region (either light or dark) was on the outer side of the stem of the T will subsequently be referred to as the single-region condition (Fig. 2c,d, respectively). In this condition only one gray-level region should influence the test patch. In the single-region condition, the regions were comparable in area to the other conditions. In all conditions, the entire display always appeared to be under a single illuminant.

2.2. Procedure

Observers completed several practice sessions before beginning the reported measurements. They maintained a stable head position with a chin rest. Observers dark-adapted for 3 min and then light-adapted for 3 min to a homogeneous screen at the mean luminance level of the test- and comparison-surround luminances that immediately followed. Then they viewed the test and comparison images described above. Each surround configuration was run as a separate session. A session consisted of pseudo-randomly presenting each comparison-patch luminance level at each contrast. Comparison-patch luminances ranged from 0 to 100, in steps of ten, while contrasts went from 0 to100%, in steps of 20%. Three repetitions of each condition were tested in a session. The mean for each condition within a session was taken as the measurement for that session. The means and standard errors plotted in the graphs are based on repeated measures over three sessions.

Observers used a method of adjustment to vary the luminance of the test patch to match the comparison patch in brightness. That is, they were told to spend the same amount of time looking at the right and left halves of the screen by alternating their gaze every few seconds, and to set the test patch to appear identical in intensity to the comparison patch. They controlled test-patch luminance using a joystick, varying it in either coarse (i.e. 4%) or fine (i.e. 0.33%) steps. Once a satisfactory setting was found, a separate button recorded test-patch luminance level, and the trial ended. Each session took about 1 h.

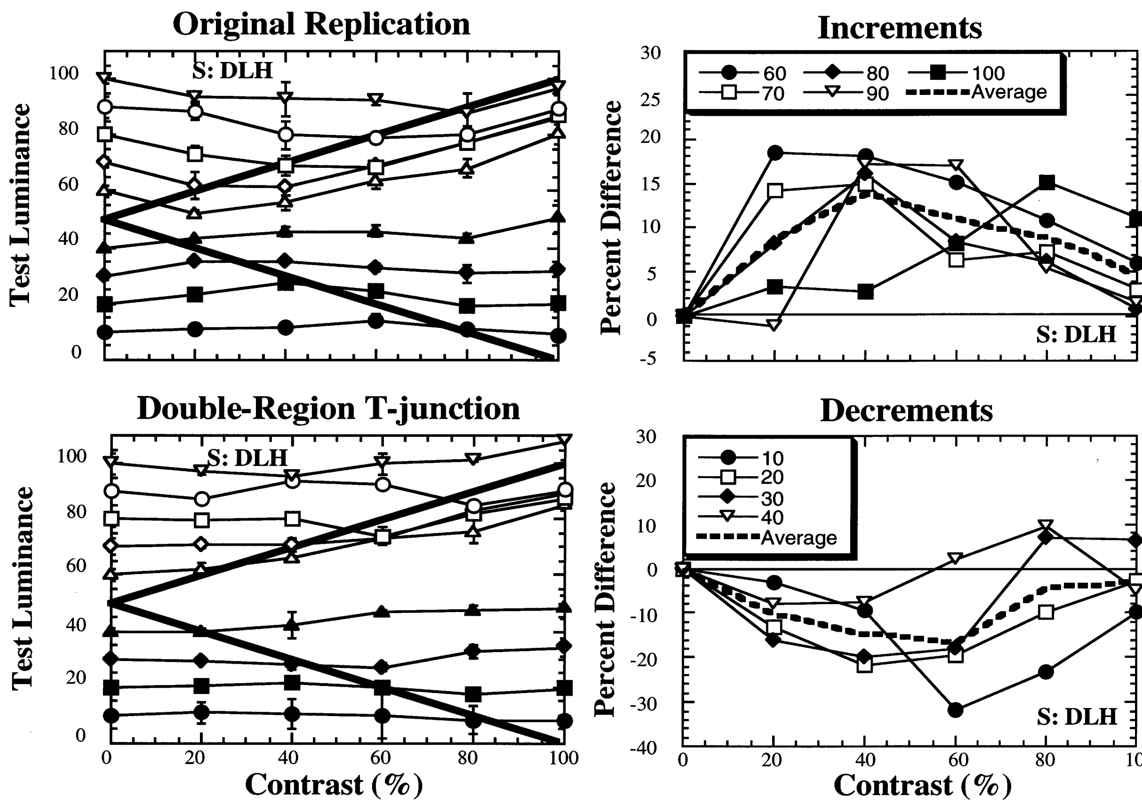

Fig. 4. Top-left graph: Brightness matches made on an original checkerboard surround for observer DLH. Bottom-left graph: Brightness matches made on the double region T-junction surround for observer DLH. Top-right graph: The percent difference for increments between matches made on the original checkerboard surround to those made on the double region T-junction surround for observer DLH. Bottom-right graph: Percent difference for comparison decrements. The thick dashed line in each right-hand graph represents the average percent difference.

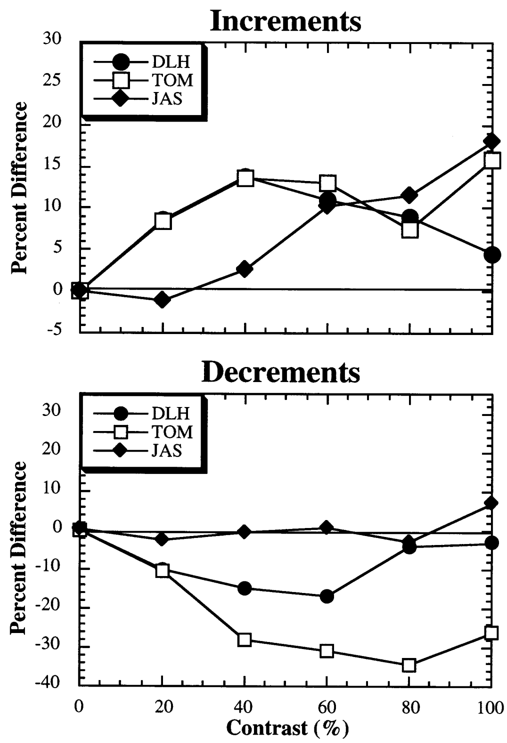

Fig. 5. The percent difference data for the double region condition for all three observers. Top graph: comparison increment data. Bottom graph: comparison decrement data.

2.3. Subjects

The three observers tested had normal or corrected acuity. Observers TOM, a 24-year-old male, and JAS, a 42-year-old male, were knowledgeable about the experimental paradigm. JAS had prior experience making achromatic brightness matches, while TOM was inexperienced. Observer DLH, a 22-year-old male, was inexperienced and also naïve regarding the experimental design.

3. Experiment 1: checkerboard replication

3.1. Results

Findings closely replicate Schirillo and Shevell's (1996) original checkerboard experiment (Fig. 1). Results for the three observers are shown in Fig. 3. A flat, horizontal data-line would indicate that test-patch luminance remained invariant across the checkerboard contrasts. For increments, observers increased the luminance of the test patch when it was dimmer than the lighter check to make a brightness match (i.e. when it was below the upper, thick, diverging line). Thus, for increments, the lighter check in the checkerboard surround was a stronger inducer that the darker check, making the effect of the checkerboard surround unlike the effect of its space-average equivalent. However, for decrements, the data lines are more flat. This suggests that for decrements, the light and dark checks have effects approximately equal to their space-average equivalent.

4. Experiment 2: double-region T-junctions

4.1. Results

To maximize induction with the center test patch, the checks' spatial arrangement was altered so that both the light and dark regions directly influenced the test patch (Fig. 2b represents the right-hand side of the stimulus display). Again, observers varied the luminance of the test patch to match the comparison patch in brightness. The original checkerboard replication results (Experiment 1) as well as the results of this double-region condition are presented in the left-hand graphs of Fig. 4 for observer DLH. In the double-region condition, increments were pushed even closer to the upper, thick, diverging line, compared to the original checkerboard condition. This result suggests that the light region was an even stronger inducer, compared to the original checkerboard condition. The increase only occurred when test-patch luminance was below the luminance of the more intense check. However, decrements were shifted slightly downward, suggesting that they appeared brighter on the double-region condition surround than in the original checkerboard condition.

To reveal the magnitude of these effects, the right-hand graphs in Fig. 4 plot the percentage difference between the test-patch luminance set in the original checkerboard experiment and the new T-junction experiment. The thick, dashed line, shows the arithmetic average for each graph and indicates that, for increments, DLH set the test-patch luminance approximately 8% higher in the double-region condition, compared to the original checkerboard condition. For decrements, DLH showed an 8% decrease on average. This suggests that when T-junctions facilitate perceptual grouping between the checks and the test patch, the dark region can induce lightness into the test patch that the original checkerboard stimuli could not.

The average percent-difference data for all three observers is shown in Fig. 5. Overall, induction in the double-region condition increased 8% on average over the original checkerboard condition for increments. For decrements, the increase in induction is marked for TOM and DLH but negligible for experienced observer JAS.

These results suggest that T-junctions can have a grouping effect that promotes induction. However, the light region only remains the stronger inducer for increments. In contrast, observers TOM and DLH selectively grouped decrements with the dark check, while JAS showed no decremental shift. To resolve this inconsistency, we examined the separate effects on the test patch of either the white check alone or the black check alone.

5. Experiment 3: single-region T-junctions

5.1. Results

To examine the influence on the test patch of one gray-level region only, the spatial arrangement of the test-surround was again manipulated (Fig. 2c,d). Average percent-difference data for the light and dark T-junctions are shown in Fig. 6 for all three observers. For increments, induction increased approximately 8% over the original checkerboard condition when the light region was the T-junction inducer (Fig. 6, upper-left graph). These results resemble those found in the double-region condition (see Fig. 5, upper graph). Unfortunately, the light-region decremental data are too variable to suggest any conclusions regarding induction (Fig. 6, lower-left graph). Dark-region increments show a negligible effect of induction (Fig. 6, upper-right graph), implying that the results from the original checkerboard replication and the single dark-region condition are consistent. Thus, it is possible that, for increments, the same mechanisms underlie the original checkerboard stimuli and the single-region stimuli. However, when the dark region was the T-junction inducer for decrements, there was a consistent dramatic decrease (i.e. 23% on average) over the original checkerboard display (Fig. 6, lower-right graph).

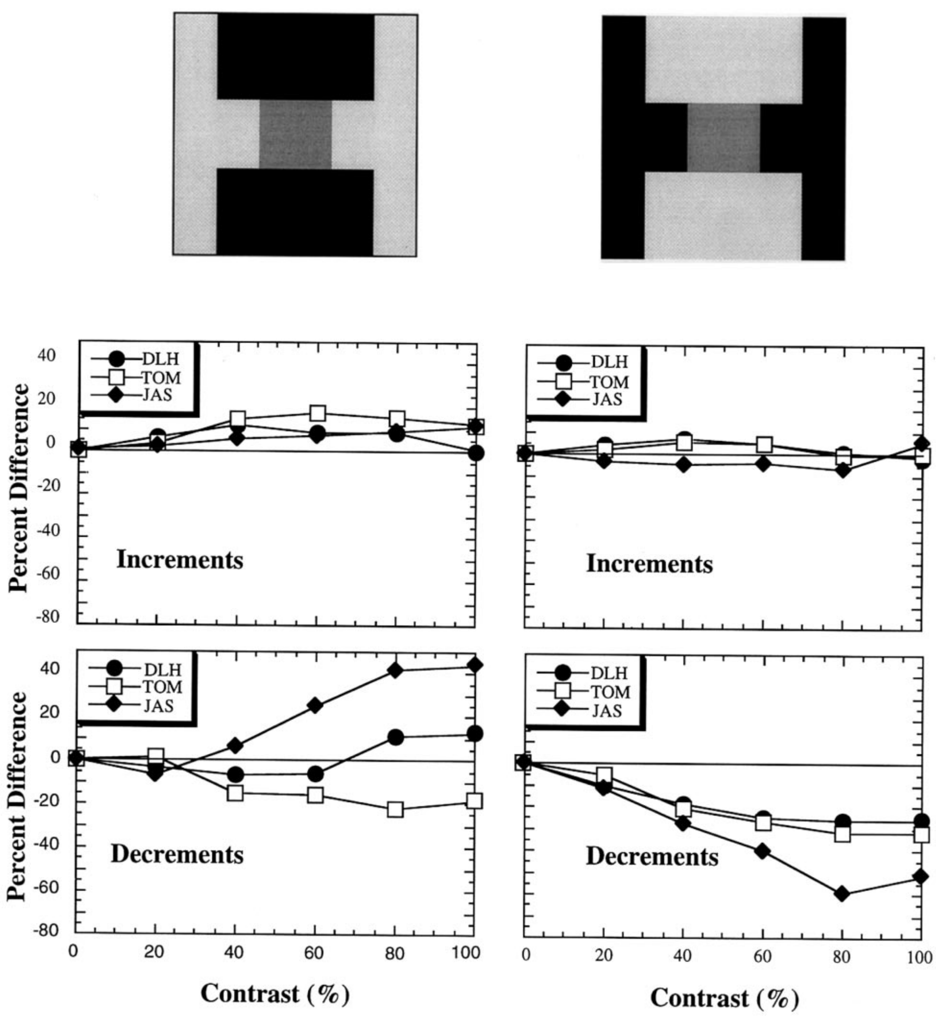

Fig. 6. Data for all three observers. Top left graph: increment percent difference data for the light region T-junction. Bottom left graph: decrement percent difference data for the light region T-junction. Top right graph: increment percent difference data for the dark region T-junction. Bottom right graph: decrement percent difference data for the dark region T-junction.

6. Discussion

These results suggest that T-junctions, by facilitating perceptual grouping, can enhance induction. However, these grouping processes remain subservient to the fact that lighter regions are stronger inducers than darker regions. That is, with checkerboard stimuli, the lighter check has a stronger influence than the darker check on increments. Turning these stimuli into single-region, T-junction stimuli fostered induction for decrements, which were unaffected by induction in the original checkerboard experiment. That is, the dark region now made decrements appear brighter. However, according to the conventional T-junction hypothesis both increments and decrements should have grouped to the darker check (Fig. 2d), making them both appear brighter (Fig. 6, right-hand stimuli and graphs). Yet the increments simply retained their darkened appearance, and only the decrements were lightened. Hence, the T-junction grouping process is subservient to the lighter region producing maximum induction.

Traditional theories based on local retinal induction cannot account for these results. Previous work by Adelson (1993), Logvinenko (1999), Todorović (1997), and Zaidi et al. (1997) suggests that low-level retinal mechanisms based on local contrast are insufficient to account for induction, while perceptual grouping via T-junctions may provide an adequate mechanism. The results of this study simply qualify the gray-level conditions that will activate T-junction processes. For example, in White's illusion, gray bars are embedded within light and dark stripes. The gray bars that are grouped with the dark stripes, because of the placement of T-junctions, are perceived as brighter than the gray bars that are grouped with the lighter stripes. Our data show that making the gray bars light enough to be considered increments, relative to the space-average luminance of the light and dark stripes, prevent them from being grouped with the darker stripes. Instead they group with the lighter stripes and thus appear darker.

It has been proposed that T-junctions may be processed at a cortical level, either by specific end-stop cells (Heitger, Rosenthaler, von der Heydt, Peterhans, & Kubler, 1992) or as a consequence of the output of hyper-complex cells (Grossberg, 1997). However, where in the visual system the asymmetric induction of increments takes place is unclear. Additional research is needed to clarify the anatomical relationship between cites that underlie induction and T-junction grouping mechanisms that regulate surface-level representations.

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