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Afterimages, grating induction and illusory phantoms

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Abstract

Under some conditions (dark or light inspection areas) illusory gratings often appear to be in-phase with the inducing gratings and under others (gray inspection area) illusory gratings often appear to be out-of-phase with the inducing gratings. McCourt reported that point-by-point brightness matches reveal only out-of-phase illusory gratings, no matter what the luminance of the inspection area (McCourt, M. E. (1994). *Vision Research*, *34*, 1609–1617). Since the technique used might have led to afterimages which mimic out-of-phase illusory gratings, the present series of experiments was undertaken to determine how such afterimages might bias illusory grating judgments. Afterimages were induced during fixation with brief flashes of inducing gratings within the inspection area (Experiment 1), or by vertical shifts in the entire stimulus which exposed the retina to real gratings prior to judgments within the inspection area (Experiment 2). Experiment 2 was replicated with drifting inducing gratings (Experiment 3). The subjects were asked to indicate whether illusory gratings appeared in- or out-of-phase. The results of all three experiments reveal that out-of-phase illusory gratings predominate, and that afterimages can only bias judgments with stationary displays. It is suggested that grating induction is perceived when subjects attend to local contrast differences, while phantom visibility is facilitated when attention is captured by the more global aspects of the stimulus. © 1999 Elsevier Science Ltd. All rights reserved.

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1. Introduction

Tynan and Sekuler (1975) reported that a drifting square-wave grating covered by a dark occluder, occasionally gave rise to the perception of moving phantom bars which appeared to drift in front of the inspection area. These phantoms had the same spatial frequency and phase as the inducing grating. On the other hand, using a stationary display, McCourt (1982) discovered the grating induction effect in which a vertical inducing grating produces the appearance of an opposite phase grating within a homogeneous gray inspection area. The question of whether or not phantoms and grating induction are produced by the same mechanism has been discussed in numerous reports (Gyoba, 1983, 1994; Foley & McCourt, 1985; Sakurai & Gyoba, 1985; McCourt, 1994). Sakurai and Gyoba (1985) revealed that the luminance of the inspection area can determine which of the two phenomena predominate. Phantom visibility is maximal when the inspection area luminance is close to the maximum or the minimum level of the inducing grating, and between these levels, especially at mean luminance, the grating induction effect is dominant. Recently, McCourt (1994) suggested that the phantom grating is not in-phase with the inducing grating as commonly assumed, but is actually in opposite phase (180° out-of-phase) with it. He used a point-wise brightness matching technique where an adjustable target square located above the upper inducing grating was matched in brightness to particular points along the horizontal extent of the inspection area. McCourt found out-of-phase brightness matching functions whether the inspection area was gray, white, or black. Therefore, McCourt suggested that stationary phantoms may be a manifestation of the same processes underlying grating induction. The possibility exists that the point-wise brightness matching paradigm might have involved the production of successive brightness effects (afterimages). Observers using the point-wise brightness matching technique would have had to re-

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peatedly sweep their eyes from the adjustable target to the inspection area and back again to make their matching judgments. This behavior may have led to negative afterimages of the inducing grating which persisted long enough to bias judgments made within the inspection area. Thus, this technique might have affected observers' judgments of relative brightness and/or the criteria they adopted to perform the task, in favor of the production of grating induction. The present study was designed to evaluate the influence of afterimages on judgments of illusory gratings with a brightness judgment technique performed only within the inspection area.

2. Methods

2.1. Subjects

Three female subjects at the University of New Orleans served as observers in all three experiments. Two were graduate students in psychology (MLB and KMR) and one was a senior undergraduate majoring in psychology (EET). All three were naive as to the hypotheses under investigation. All three were right-handed and had 20/20 Snellen acuity, with (EET and KMR) or without correction.

2.2. Apparatus

Stimuli were created with an image processing system (Data Translation, DT 2861) which was housed in a personal computer (High Tech, 486). Images were presented on a high resolution monitor (Sony, PVM-1343MD). The luminance output of the monitor was linearized with look-up tables containing the inverse of the monitor's gamma functions. The screen subtended 11° of visual angle (VA) in height and 14° of VA in width. Viewing was binocular and subjects were positioned 105 cm from the monitor.

2.3. Stimulus conditions

During all judgments, the inducing stimuli were 0.5 c/d sinusoidal gratings with a contrast of 25% presented in rectangular areas (subtending 14° of VA horizontally by 5° of VA vertically) above and below the inspection area (which subtended 0.5° of VA vertically and 14° of VA horizontally). A circular fixation point, 3′ VA in diameter, was centered in the display. The inspection area was either gray (40 cd/m^2—the space average luminance of the inducing stimuli) or black (30 cd/m^2—the lowest luminance in the inducing grating).

In stationary Experiments (1 and 2), five stimulus conditions (CO, RI, RO, AI, and AO) with gray and black inspection areas were tested. Each trial in each condition consisted of three frames: the first conditioning frame; the second conditioning frame; and the final judgment frame. The duration of the frames was 6, 2 and 6 s, respectively. Two tones were sounded near the beginning (0.5 s after onset) and end (5.5 s after onset) of the judgment frame and subjects were instructed to respond with regard to their perceptions immediately after both of these tones (R1 and R2). Condition CO was the baseline condition and involved 14 sec. of stimulation with either a gray or black inspection area (see Fig. 1—top row for an example with a gray inspection area). Conditions RI and RO were the same except that low contrast (3% relative to the inspection area average luminance) sinusoidal gratings were inserted into the inspection areas during the two judgment frames. These conditions are depicted in the second and third rows of Fig. 1. These trials were designed to assess the reliability of the subject's criteria for in- and out-of-phase judgments (see criteria below). For Experiment 1, conditions AI and AO involved the presentation of a 25% contrast, 0.5 c/d grating in the inspection area during the second conditioning frame, in- or out-of-phase with the inducing grating. These trials were intended to create afterimages that were in- and out-of-phase with the inducing gratings. Thus,

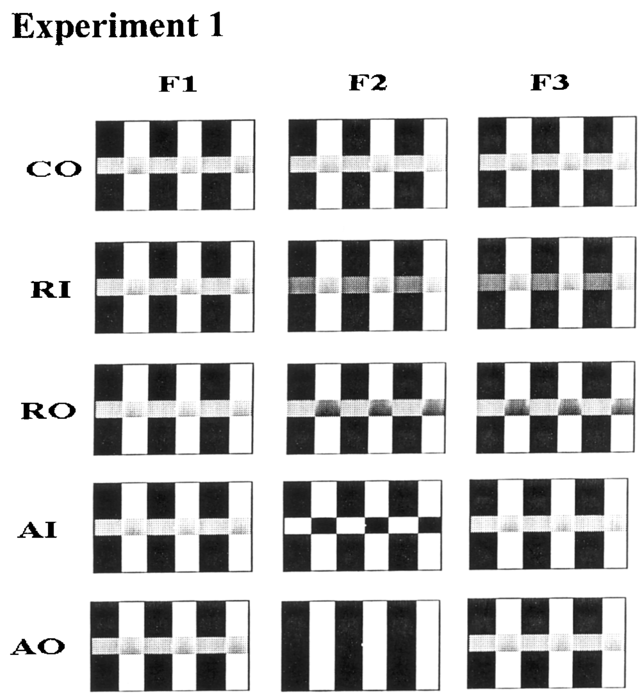

Fig. 1. The stimulus order on trials in the various conditions of Experiment 1 are depicted in three frames (F1–F3). In the control condition (CO) all three frames were the same. In the RI and RO condition low contrast gratings were inserted in the inspection area either in- (RI) or out-of-phase (RO) during the last two frames. In the AO and AI conditions high contrast gratings, either in-phase (AO) or out-of-phase (AI) with the inducing gratings, were inserted in frame two.

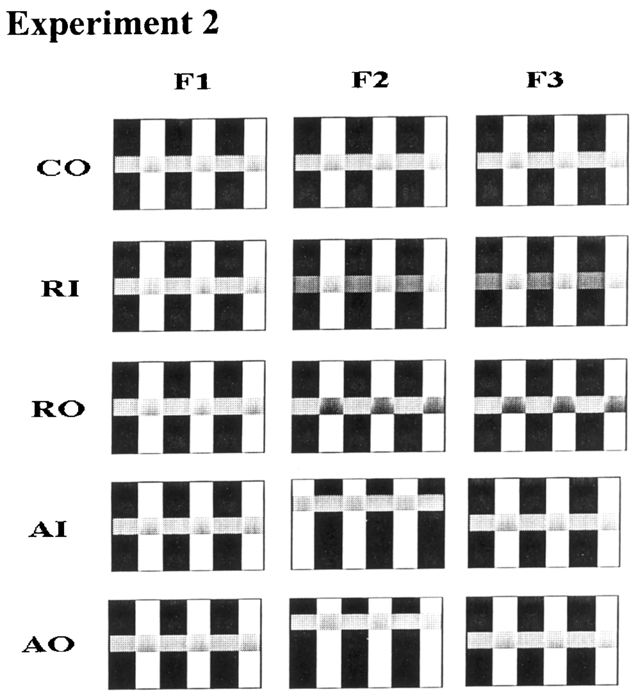

Fig. 2. The stimulus order on trials in the various conditions of Experiment 2 is depicted in three frames (F1–F3). In the control condition (CO) all three frames were the same. In the RI and RO condition low contrast gratings were inserted in the inspection area either in- (RI) or out-of-phase (RO) during the last two frames. In the AO and AI conditions the inspection area was shifted upward to expose the area near fixation to high contrast gratings that were out-of-phase (AI) or in-phase (AO) relative to the inducing gratings in frames 1 and 3.

condition AI involved a real out-of-phase grating during the second conditioning frame to create an in-phase afterimage (AI) during the final judgment frame. Likewise, condition AO involved a real in-phase grating during the second conditioning frame to create an out-of-phase afterimage (AO) during the final judgment frame. These conditions are depicted in the fourth and fifth rows of Fig. 1. In Experiment 2, conditions CO, RI, and RO were exactly the same as Experiment 1 (i.e. rows 1–3 are identical in Figs. 1 and 2). Conditions AI and AO involved shifting the inspection area up 0.5° and exposing the area under fixation to the sinusoidal luminance profile. Note that in the AI condition, the inducing gratings in the second conditioning frame were 180° out-of-phase with those in the first and third frames. In the AO condition, all inducing gratings were in the same phase. These conditions are depicted in the fourth and fifth rows of Fig. 2. During the second conditioning frame in the AI and AO conditions the fixation point stayed at center screen when the inspection area shifted up. Subjects were instructed to maintain fixation on the fixation point at all times. These conditions were again intended to simulate afterimages that might be created during vertical scanning eye movements across the inducing gratings. In Experiment 3, the inducing gratings were drifted at a rate of 2 c/s. The stimulus conditions were the same as Experiment 2, except that only two frames were presented (see Fig. 3). The duration of the first frame was 8 s and that of the second was 2 s. Only one tone was presented 0.5 s after the onset of the second frame.

2.4. Criteria

In order to establish uniform criteria for reporting perceptual responses, extensive discussions were held with each subject. They were shown numerous examples of stationary and moving gratings with gray and black inspection areas. Various criteria for defining phantoms and induced gratings were discussed and the criteria to be used in the experiment were defined. They were told that when viewing static displays (Experiments 1 and 2), if they perceived the region to the left of fixation as darker than the area to the right of

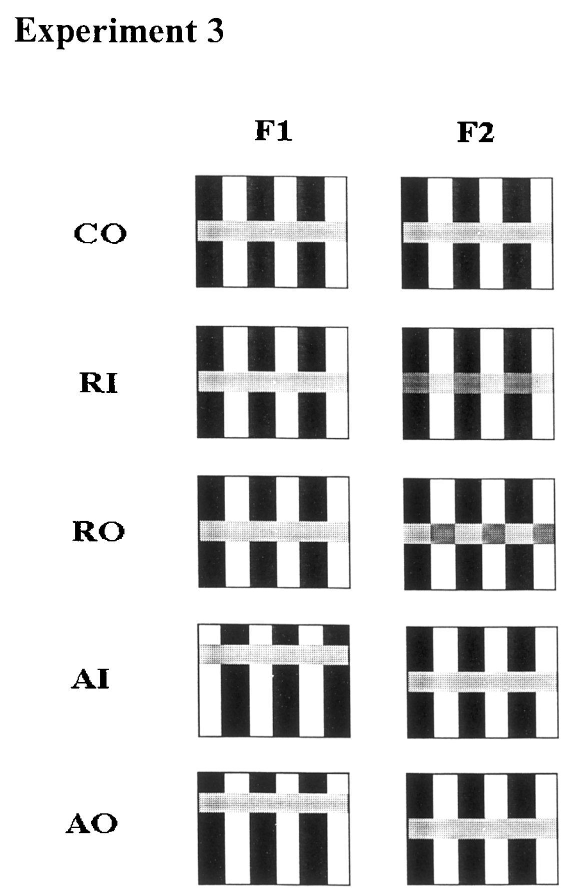

Fig. 3. The stimulus order on trials in the various conditions of Experiment 3 is depicted in two frames (F1–F2). In the control condition (CO) both frames were the same. In the RI and RO condition low contrast gratings were inserted in the inspection area either in- (RI) or out-of-phase (RO) during the last frame. In the AO and AI conditions the inspection area in frame 1 was shifted upward to expose the area near fixation to high contrast gratings that were out-of-phase (AI) or in-phase (AO) relative to the inducing gratings in frame 2.

fixation, they were to respond in-phase, since these areas would always be between dark and light inducing bars, respectively. If they perceived the opposite possibility (brighter to the left and darker to the right), they were to respond out-of-phase, because in this case brighter and darker areas would be between dark and light inducing bars, respectively. They were told not to use continuation of the dark bars as a criterion for in-phase judgments and that illusory depth phenomena were also to be ignored. If no brightness differences were seen, they were to respond none. When viewing moving stimuli, these criteria could not be used. Instead they were to indicate what the brightness relationships were relative to the light and dark inducing bars. Finally, they were tested with low contrast gratings inserted between the inducing gratings (conditions RI and RO above), in both static and moving displays to determine if they understood the criteria.

2.5. Procedure

All subjects served in Experiment 1 first, then 2 and 3. There were 24 trials for each of the ten conditions (two inspection area luminances × five stimulus conditions) in Experiments 1 and 2, and 28 trials for each of the ten conditions in Experiment 3. Within each experiment the order of trials was completely randomized. Subjects looked at the fixation point, initiated a trial and responded at the tones using one of three keys to indicate the response categories outlined in the criteria described above. Experiments 1 and 2 required three 30 min sessions to complete and Experiment 3 required two 40 min sessions.

3. Results

3.1. Experiment 1

The results of Experiment 1 are presented in Fig. 4. Mean response frequency for each stimulus condition is plotted as a function of response category (none, in-phase, or out-of-phase) for gray and black inspection areas for the first (R1) and second (R2) responses. The smaller the standard error bars, the greater the agreement between subjects. For the first response in the CO condition with gray inspection areas, all three subjects reported out-of-phase illusory bars on a high proportion of the trials. This pattern of responses may be considered the baseline against which to judge the effects of conditions AI and AO. All three subjects were highly successful at detecting the real in- and out-of-phase gratings in the RI and RO conditions, indicating that they were employing the criteria correctly. The afterimage conditions biased their judgments such that the frequency of in-phase R1 judgments increased following conditions intended to produce in-phase (AI) afterimages and the frequency of out-of-phase R1 judgments increased following conditions intended to produce out-of-phase afterimages (AO). For the AI condition, subjects KMR and MLB reported illusory bars on fewer trials ($N=15$, $I=5$, $O=4$; $N=9$, $I=10$, $O=4$, respectively) than did subject EET ($N=2$, $I=22$, $O=0$). Inspection of the R2 data indicates that the subjects recovered from the afterimage manipulations after 5.0 s and the baseline (CO) pattern of results was re-established. A similar pattern of results for R1 and R2 were obtained with the black inspection area, but it is clear from the baseline condition (CO) that illusory bars were seen on fewer trials for this condition compared to the gray inspection area and subject variability was higher. In addition, the R2 data for the AI and AO conditions showed less complete recovery for the black relative to the gray inspection area.

3.2. Experiment 2

The results of Experiment 2 are presented in Fig. 5. The pattern of results is quite similar to those obtained in Experiment 1. For the R1, out-of-phase illusory bars were seen most often by all three subjects in the baseline (CO) condition with a gray inspection area. They were again quite successful at detecting real in- and out-of-phase bars with both gray and black inspection areas. The after image manipulations were more successful at biasing judgments in the AO condition than the AI condition, and there was less subject agreement in the AI condition. Less in-phase judgments were reported by subjects KMR ($N=9$, $I=11$, $O=4$) and EET ($N=7$, $I=16$, $O=1$), while subject MLB saw only in-phase bars ($I=24$). The results for R1 with the black inspection area followed a similar pattern, but less illusory gratings were seen overall and the afterimage conditions were somewhat less successful and more variable across subjects. Consideration of the R2 data indicates that there was less complete recovery after 5.0 s for the RI condition than was observed in Experiment 1.

3.3. Experiment 3

The results of Experiment 3 are presented in Fig. 6. For the gray baseline condition (CO), only one subject (EET) reported in-phase illusory gratings on two trials. The rest of the judgments fell into the none or out-of-phase categories. All three subjects were successful at detecting gratings in the RI and RO conditions. The afterimage conditions produced very few in-phase or out-of-phase responses. With the black inspection area, few in-phase responses were observed in the baseline condition, and fewer out-of-phase judgments occurred relative to the gray condition. The AI and AO condi-

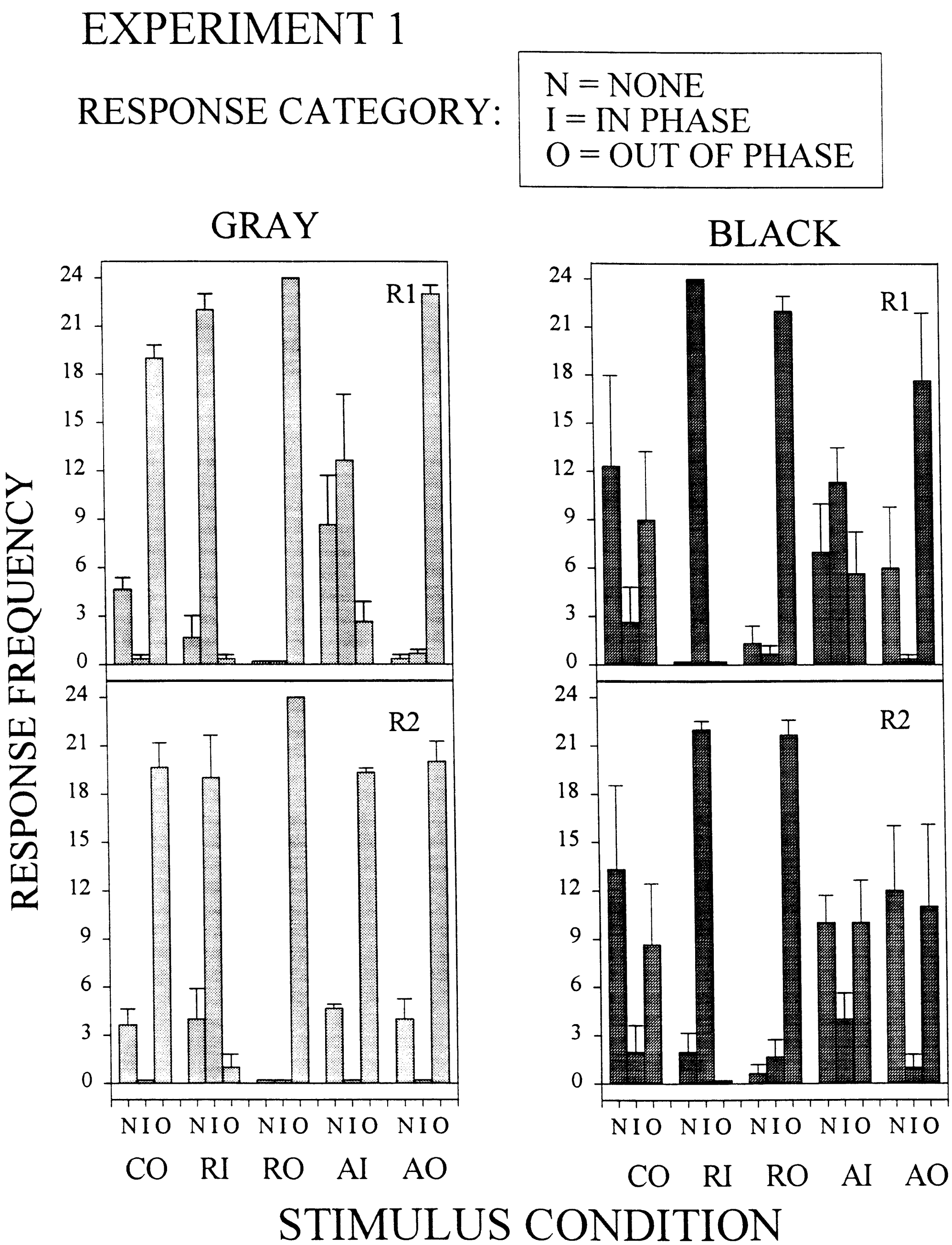

Fig. 4. The average number of responses in each response category as a function of stimulus condition for gray and black inspection areas for both the first (R1) and the second (R2) responses in Experiment 1. Vertical error bars = ± 1.0 S.E.

tions yielded results quite similar to the baseline condition, indicating that few afterimages were produced.

4. Discussion

It is clear from these data that the brightness judgment technique and the criteria employed resulted in a predominance of grating induction responses, even with the black inspection area and drifting inducing stimuli, which have been reported to favor phantoms. This result is in agreement with McCourt (1994) and indicates that when subjects are asked to attend to local luminance differences within the inspection area, out-of-phase luminance differences are perceived most often. It also highlights the importance instructional set may have in determining the relative prevalence of grating induction and phantoms. It is possible, that in most previous phantom experiments, instructions and stimulus conditions (dark or light inspection areas and/or moving inducing stimuli) lead the subjects to attend to the more global aspects of the scene and emphasize

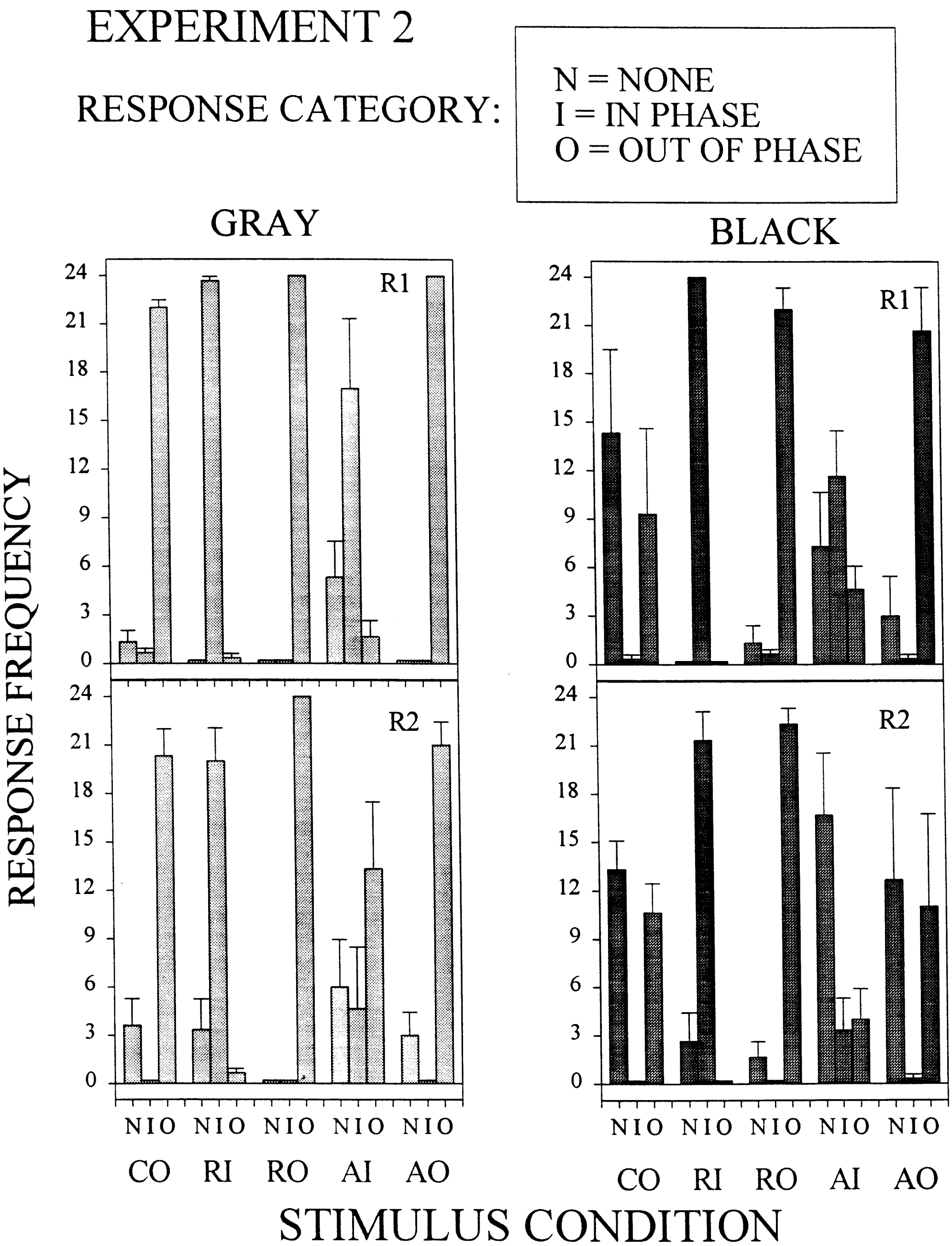

Fig. 5. The average number of responses in each response category as a function of stimulus condition for gray and black inspection areas for both the first (R1) and the second (R2) responses in Experiment 2. Vertical error bars = ±1.0 S.E.

the continuity of the inducing stimuli through the inspection area. Using such criteria, subjects often report a figure/ground organization with the illusory grating appearing in front of the inspection area. Drifting inducing stimuli might be expected to facilitate attention to this more global perspective. Another possibility is that in-phase phantom judgments are elicited by misleading instructions to the subjects. However, until these methodological issues are examined more closely, it is perhaps best to consider the stimulus used for the elicitation of illusory gratings as a bistable illusory opportunity in which in- or out-of-phase gratings may be viewed, depending on the perceptual set adopted.

The notion that successive brightness contrast could have accounted for McCourt's (1994) results did not receive support from the present results. While the afterimage manipulations did bias judgments in the predicted directions for the static conditions, out-of-phase judgments were more predominant even when inducing gratings were moving. While grating induction

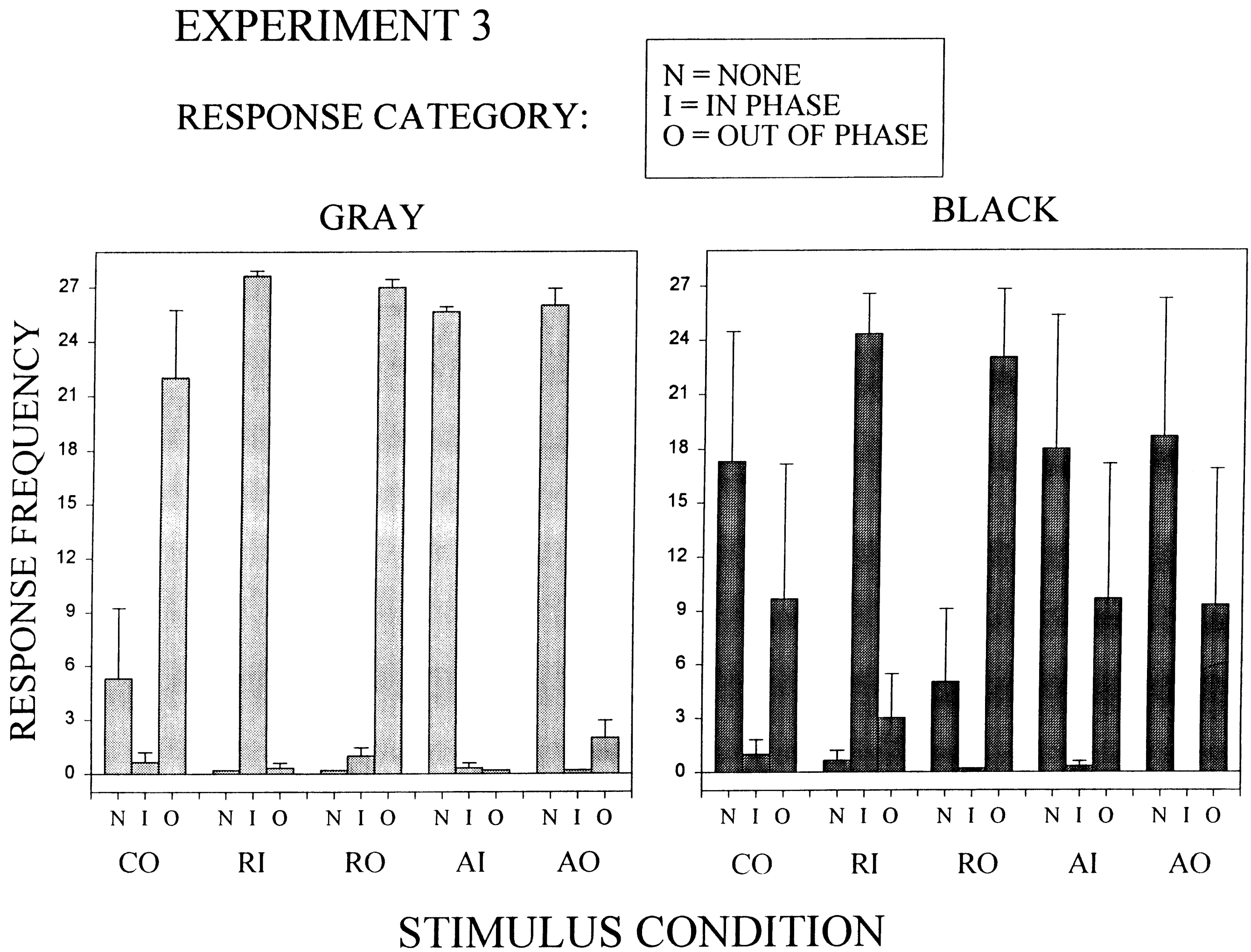

Fig. 6. The average number of responses in each response category as a function of stimulus condition for gray and black inspection areas in Experiment 3. Vertical error bars = ± 1.0 S.E.

does share a number of common properties with simultaneous brightness contrast (Blakeslee & McCourt, 1997), it is also true that it can be biased by successive brightness contrast (Foley & McCourt, 1985). Illusory phantoms appear to derive from different mechanisms.

McCourt (1990) has suggested that grating induction might be mediated by parvocellular neurons since the luminance range in which grating induction is observed is similar to that found to excite such cells. Gyoba (1994), on the other hand, argues that phantom gratings might derive from the activation of magnocellular neurons since phantoms are produced at much lower luminances and do not appear at isoluminance. These notions, taken together with the present results, suggest that the technique employed and the criterion adopted by subjects in illusory grating studies can influence which perceptual responses predominate.

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