

Reversible-figure perception: Mechanisms of intentional control

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Observers can exert a degree of intentional control over the perception of reversible figures. Also, the portion of the stimulus that is selected for primary or enhanced processing (focal-feature processing) influences how observers perceive a reversible figure. Two experiments investigated whether voluntary control over perception of a Necker cube could be explained in terms of intentionally selecting appropriate focal features within the stimulus for primary processing. In Experiment 1, varying observers' intentions and the focus of primary processing produced additive effects on the percentage of time that one alternative was perceived. In Experiment 2, the effect of varying the focus of primary processing was eliminated by the use of a small cube, but the effect of intention was unaltered. The results indicate that intentional control over perception can be exerted independently of focal-feature processing, perhaps by top-down activation or priming of perceptual representations. The results also reveal the limits of intentional control.

Reversible figures such as the Necker cube, Rubin's face/vases, and Boring's young girl/old woman are ambiguous visual patterns that support at least two markedly different perceptual organizations or interpretations. During a period of continuous viewing, observers experience fluctuating perceptions that alternate between the possible interpretations of the figure even though the stimulus pattern itself remains unchanged. Interest in this class of illusions can be traced at least as far back as a paper published by Necker in 1832 (cited in Boring, 1942). Continued interest in these figures stems from the belief that understanding their multistable nature will provide insights into the operation of fundamental perceptual mechanisms.

Traditionally, theoretical accounts of figural reversals have fallen into one of two categories, depending on whether they emphasize the influence of bottom-up or of top-down processes. In the bottom-up camp, most researchers have favored an explanation based on the operation of relatively passive, local processes of neural adaptation and recovery that influence perception in a bottom-up manner (e.g., Spitz & Lipman, 1962; von Grünau, Wiggin, & Reed, 1984). Although this view originated in the context of discredited Gestalt assumptions about underlying physiology (Kohler & Wallach, 1944), more recent formulations have related adaptation effects to the fatigue and recovery of localized neural "channels" that often are hypothesized to play a major

role in the visual system (e.g., Anstis, Verstraten, & Mather, 1998; Braddick, Campbell, & Atkinson, 1978; Regan, 1982).

Contemporary versions of this hypothesis have received impressive support from selective-adaptation experiments designed to assess the effects of fatiguing particular cortical structures on subsequent perception of reversible figures (e.g., Howard, 1961; Toppino & Long, 1987). For example, selectively adapting one underlying cortical structure through extended viewing of an unambiguous version of a reversible figure increases the likelihood that the opposite organization will be perceived when an ambiguous version of the same figure is subsequently presented (e.g., Long, Toppino, & Mondin, 1992; Virsu, 1975). The localized nature of the underlying processes is revealed by the finding that the magnitude of adaptation effects declines markedly with the extent to which the adaptation and test stimuli are presented to different retinal locations (Toppino & Long, 1987; von Grünau et al., 1984).

From the top-down theoretical perspective, perception is often conceptualized as a hypothesis-testing or problem-solving process (e.g., Gregory, 1970; Rock, 1975). Figural reversals are assumed to occur when the perceptual system alternates between equally acceptable "solutions" to the perceptual puzzle, and emphasis is placed on the role of active, relatively global processes that exert their effects in top-down fashion. The influence of such processes has been demonstrated in the results of numerous studies. These include, to name just a few, findings that observers may fail to perceive reversals if they do not know that the stimuli are reversible (Girgus, Rock, & Egatz, 1977; Rock & Mitchener, 1992), that the rate at which reversals are perceived increases as a function of learning (Long, Toppino, & Kostenbauder, 1983), and

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that observers can exert intentional control over the perception of reversible figures (e.g., Liebert & Burk, 1985; Pelton & Solley, 1968).

Finally, a number of investigators (e.g., Hochberg, 1968; Long et al., 1992; Palmer & Bucher, 1981; Toppino & Long, 1987) have adopted a hybrid theoretical framework based on the assumption that the perception of reversible figures is influenced by numerous factors including both local, bottom-up processes and global, top-down processes. In this view, the important theoretical and empirical challenges are to identify the contributing processes, to determine when and how they operate, and to describe how they may be interrelated.

The present research was conceived within the hybrid framework and was designed to clarify the manner in which observers voluntarily control the perception of reversible figures. In particular, interest was centered on the degree to which voluntary control could be explained in terms of a more general account of figural reversals that will be referred to as the *focal-feature hypothesis*.

The fundamental assumption underlying the focal-feature hypothesis is that different focal regions or areas within an ambiguous figure favor different global interpretations of the stimulus. Which interpretation is experienced is assumed to depend on which focal area is selected for primary or enhanced processing. Figural reversals are assumed to reflect shifts in primary processing from one focal area to another. One of the earliest versions of the focal-feature hypothesis appears to have been proposed by Necker himself. According to Boring (1942), Necker believed that eye movements were critical in producing figural reversals. As the locus of fixation was shifted from one area of an ambiguous cube to another, the currently foveated region was assumed to appear closer and, thus, to bias the perceived orientation of the figure.

Fixation at different focal areas has been demonstrated to promote different perceptual interpretations with a variety of reversible figures (e.g., Gale & Findlay, 1983; García-Pérez, 1992; Georgiades & Harris, 1997; Kawabata, 1986; Ruggieri & Fernandez, 1994). However, a necessary role for eye movements has been questioned. Although correlations have been reported between eye movements and reversals (e.g., Ellis & Stark, 1978), eye movements often seem to follow rather than precede reversals (e.g., Pheiffer, Eure, & Hamilton, 1956). Furthermore, fluctuating perceptions occur with stabilized images, for which the effect of eye movements are neutralized (Pritchard, 1958).

More recently, García-Pérez (1989, 1992) has proposed a version of the focal-feature hypothesis that may account for the inconsistent role of eye movements by considering the effects of both eye movements and shifts in visual attention. Noting the relationship between acuity and fixation, he observed that "the perceptual image is sharp and clean around the fixation location, but . . . gradually blurs and loses detail with increasing distance to that location" (García-Pérez, 1992, p. 90). Thus, the

interpretation favored by the foveated area will strongly bias interpretation of the figure as a whole. Although the focus of visual attention typically coincides with the locus of fixation, it is well known that attention can be shifted independently of eye movements (e.g., Posner, 1980). With large figures and normal viewing conditions, García-Pérez (1989) proposed that eye movements and shifts in attention coincide in selecting the focal area that is fixated and receives enhanced processing. It can be inferred that the selection of focal areas in large figures is unlikely to reflect a shift of attention without an accompanying eye movement because alternate focal areas in these stimuli will be difficult to resolve without a concomitant shift of fixation. However, García-Pérez (1989) suggested that eye movements may be less important with somewhat smaller figures, for which acuity may be relatively good in all competing focal areas. In the latter case, selection of the focal area to receive enhanced processing may reflect a shift in attention that occurs independently of eye movements.¹ It is important to keep in mind, however, that the crux of the focal-feature hypothesis is selective processing. That is, the current perception of a reversible figure is presumably determined by the single area or subset of features that is selected to receive preferential processing, regardless of whether that selectivity reflects the locus of fixation or the focus of attention alone.

Exactly what causes these shifts in the focus of primary or preferential processing remains unclear. In some cases, shifts may be relatively involuntary, triggered either by data-driven processes such as neural fatigue, higher order processes such as a search or exploration algorithm (e.g., Leopold & Logothetis, 1999), or both. In other cases, the shifts are clearly intentional and under top-down control.

With respect to intentional control, several investigators have shown that observers can voluntarily speed up or slow down their reversal rates by complying with instructions to switch as rapidly as possible between perceptual alternatives or to maintain for as long as possible whichever alternative is currently dominant (e.g., Pelton & Solley, 1968; Seth & Reddy, 1979; Struber & Stadler, 1999). Also, observers who have been instructed to hold or maintain a particular perceptual interpretation are able to increase the proportion of time that they perceive the designated alternative (e.g., Hochberg & Peterson, 1987; Liebert & Burk, 1985; Peterson & Gibson, 1991; Peterson & Hochberg, 1983; Phillipson & Harris, 1984). Thus, it is well established that observers can exert intentional control over the perception of reversible figures.

Intention and enhanced processing of focal areas have similar effects in the sense that both are selective, leading to one interpretation of a reversible figure rather than the other. However, the degree to which intention and focal-feature processing may be related is unclear. One suggestion has been that the same underlying process may be involved in both cases, with the focal-feature hy-

pothesis accounting for the effects of intention. That is, observers may exert voluntary control by intentionally switching or maintaining the focus of primary processing on those areas within the stimulus that are biased toward the desired global organization (e.g., Gale & Findlay, 1983; Hochberg & Peterson, 1987).

A competing hypothesis is that the effects of intention may be “mediated cognitively by summoning and fitting one central interpretation rather than another to the stimulus array” (Hochberg & Peterson, 1987, p. 379). This implies a form of priming that enhances the activation of one underlying perceptual representation relative to the other (e.g., Peterson & Gibson, 1991; Peterson, Harvey, & Weidenbacher, 1991; Suzuki & Peterson, 2000). Priming might be achieved through activation of the desired representation, inhibition of the alternative, or both. The main point, however, is that the effect of intention is thought to be exerted directly via a centrally mediated, top-down influence on the activation of underlying global representations rather than indirectly via selective processing of local stimulus cues.

The present research was designed to assess predictions derived from the aforementioned two hypotheses regarding how intention exerts its effect on the perception of reversible figures. The locus of fixation within a Necker cube and the intention to perceive a particular interpretation of the cube were varied. To the extent that the effects of both variables are mediated by enhanced processing of critical focal areas, the effects of intention and fixation location were expected to be interrelated. However, to the extent that intention effects are mediated by a relatively independent process (e.g., direct, top-down priming of underlying representations), the locus of fixation and observers' intentions were expected to yield independent effects.

EXPERIMENT 1

Several previous investigators have identified the location of two focal areas within a Necker cube (Figure 1) that seem to favor perception of the cube in opposite orientations (e.g., Ellis & Stark, 1978; Kawabata, 1986; Kawabata, Yamagami, & Noaki, 1978). Fixating location A in Figure 1 seems to favor seeing the cube in a down-to-the-left orientation whereas location A' presumably favors an up-to-the-right orientation. The fixated area tends to be seen as being relatively closer to the observer.

In a series of experiments designed to explore a constructivist account of form perception, Peterson and her colleagues (Hochberg & Peterson, 1987; Peterson & Gibson, 1991; Peterson & Hochberg, 1983) used altered Necker cubes to investigate the joint effects of instructing observers to hold one orientation of the cube and of instructing them to fixate or attend to local regions of the cube. The cubes were modified so that the area surrounding one interior vertex (either B or B' in Figure 1) was unambiguous, strongly biasing perception toward a particular interpretation. Observers' fixation or attention was focused on either the unambiguous vertex (e.g., B)

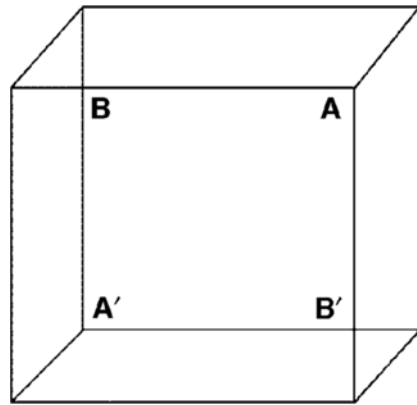


Figure 1. An example of a Necker cube with interior vertices labeled.

or the opposite, ambiguous, vertex (e.g., B'), and they were instructed to maintain a perception of the cube that was either consistent or inconsistent with the biased region. Results indicated that intentional control over the perceived orientation of the cube was severely restricted when observers focused on the unambiguous vertex but not when they focused on the ambiguous vertex.

These findings provide strong evidence that observers' global interpretation of a stimulus is influenced by the local region that is the focus of primary processing. These results also indicate that voluntary control can be limited by the presence of unambiguous stimulus cues. However, these findings do not directly address the question of whether voluntary control over the processing of focal features may mediate the effects of intention on the perception of ambiguous stimuli. When observers nominally focused on the ambiguous vertex in the work of Peterson and her colleagues, instructions to hold one or the other orientation may have caused attention to shift toward a focal area (i.e., A or A' in Figure 1) that favored the desired interpretation. However, it is also plausible that intentional control was exerted by means of direct, top-down activation of the desired representation and that it occurred independently of the area of the cube receiving focal processing.

In the present experiment, observers viewed a large Necker cube. In an effort to demonstrate an effect of focal-feature processing, observers were directed to maintain their gaze on a fixation point that could occur in focal area A, focal area A', or the center of the figure. In addition, half of the observers (hold condition) were instructed to hold one of the two interpretations of the cube, whereas the remaining observers (no-hold condition) viewed the cubes under neutral (unbiased) instructions. In all cases, observers reported perceived reversals during the viewing session. The main predictions concerned the percentage of the viewing period that each alternative was perceived.

In the no-hold conditions, it was assumed that the focus of attention and primary processing generally would correspond to the locus of fixation that observers

were instructed to maintain. Although fixation or attention might fluctuate spontaneously, this condition should not be affected by any experimenter-induced bias and, therefore, should provide a baseline condition against which performance in the hold conditions could be compared. In accordance with predictions of the focal-feature hypothesis, we expected the percentage of time that each interpretation of the cube was perceived in the no-hold condition to vary with fixation.

If focal-feature processing also accounts for voluntary control over figural reversal, one of two results was expected. First, if hold instructions induce observers to divert processing from the designated fixation location to an area biased toward the instructed orientation of the cube, the effects of fixation location should be reduced in the hold condition relative to the no-hold condition.² Second, if observers strictly maintain the focus of processing on the fixation location regardless of hold instructions, then hold instructions should have little or no effect on performance. In contrast, if intention is mediated by a relatively independent process such as top-down priming of the designated representation, the effects of fixation location and hold instructions should be additive.

Method

Observers and Design. Twenty-four observers were randomly assigned to each of four between-subjects conditions generated by a 2 (report instructions) \times 2 (hold instructions) \times 3 (fixation location) mixed factorial design with the last factor manipulated within subjects. All 96 observers were students at Villanova University and participated for partial fulfillment of the requirements of a general psychology course.

Materials and Procedure. Observers were seated with their heads restrained by a chinrest so that they viewed a computer monitor from a distance of 50.8 cm. Stimuli were black Necker cubes presented on a white background. Fixation was maintained on a cross (+) located within the boundaries of the cube.

At the beginning of the experiment, the nature of reversible figures was explained to observers and a demonstration Necker cube (subtending $8.18^\circ \times 8.53^\circ$ of visual angle) was used to explain the different orientations in which the cube could be perceived (i.e., facing down to the left or up to the right). Then observers received four practice trials using the demonstration cube during which they gained experience with seeing reversals while practicing the requirements of their particular experimental conditions. At the outset of a trial, a fixation cross appeared alone for 2 sec. Then a cube was added to the display for 1 min. Observers viewed the cube while maintaining fixation and reporting on their perceptions. The importance of maintaining fixation was stressed throughout the practice and experimental trials. Practice trials were separated by 1-min rest periods.

In the first two practice trials, observers practiced the procedures of their particular report-instruction conditions. In all cases, observers were instructed to press a button located in front of them whenever they perceived the cube to be in a particular designated orientation and to hold the key down as long as they continued to perceive that alternative. When the alternate percept was experienced, they were to release the button. Depending on their report-instruction condition, observers were told to depress the button either when they perceived the cube in the down-to-the-left orientation or when they perceived it in the up-to-the-right orientation.

The next two practice trials incorporated the demands of the hold-instruction conditions. In one of these two trials, the fixation cross was located just inside of the upper left interior vertex (B in

Figure 1). In the other, it was located just inside of the lower right interior vertex (B' in Figure 1). Observers were instructed to keep their gaze fixated on the cross while they simultaneously tried to hold or maintain one of the two perceived orientations of the cube. Depending on their hold-instruction condition, observers were told to maintain either the down-to-the-left orientation or the up-to-the-right orientation. The orientation they were instructed to hold always corresponded to the orientation they were instructed to report with their buttonpress responses. It was thought that mixing report and hold instructions (e.g., report down-to-the-left while trying to maintain up-to-the-right) would create confusion and interference.

Two minutes after the last practice trial, observers received final instructions and began the first of 12 1-min experimental trials. Stimuli on these trials were Necker cubes with horizontal and vertical dimensions subtending 15.6° and 16.2° of visual angle, respectively. Depending on the fixation-location condition, a fixation cross appeared in the center of the cube, just inside the upper right interior vertex (i.e., A in Figure 1) or just inside the lower left interior vertex (i.e., A' in Figure 1). Within each three-trial block of experimental trials, each of the three fixation-location conditions occurred once. The order of trials within each block was determined randomly for each observer. Procedures for experimental trials were identical to those introduced during practice for each of the four combinations of report instructions and hold instructions. To minimize the possibility that neural satiation or fatigue built up on one trial would affect performance on the next trial, experimental trials were separated by a 2-min rest period. Previous research has indicated that this interval should be sufficient to allow dissipation of neural fatigue effects (e.g., Magnussen & Johnsen, 1986).

Results

Statistical significance was set at $p = .05$ for all analyses in both Experiment 1 and Experiment 2.

Percentage of time reporting down to the left. A millisecond timer recorded the cumulative amount of time within each trial that observers pressed the response button to indicate perception of the orientation they were instructed to report. For observers in the report-up-to-the-right condition, the data were converted into the time that the cube was perceived in a down-to-the-left orientation by subtracting from 1 min. For the purpose of analysis, the time that the down-to-the-left orientation was perceived was converted to a percentage of the 1-min viewing period for all observers. The mean percentage of time reporting the down-to-the-left orientation is presented in Figure 2.

A 2 (report instructions) \times 2 (hold instructions) \times 3 (fixation location) analysis of variance (ANOVA) with repeated measures on the last factor revealed only three significant effects. The main effect of fixation location was reliable [$F(2,184) = 31.37$, $MS_e = 107.21$]. The down-to-the-left orientation was perceived for the greatest percentage of time on trials involving a top-right fixation (65.4%). It was perceived less often with a center fixation (55.5%) and slightly, but not significantly, less often with a bottom-left fixation (54.8%). There also was a significant main effect of report instructions [$F(1,92) = 30.87$, $MS_e = 814.44$] that was qualified by a significant hold-instructions \times report-instructions interaction [$F(1,92) = 18.48$, $MS_e = 814.44$].

Simple effects analyses revealed that in the no-hold conditions, the effect of report instructions was not reli-

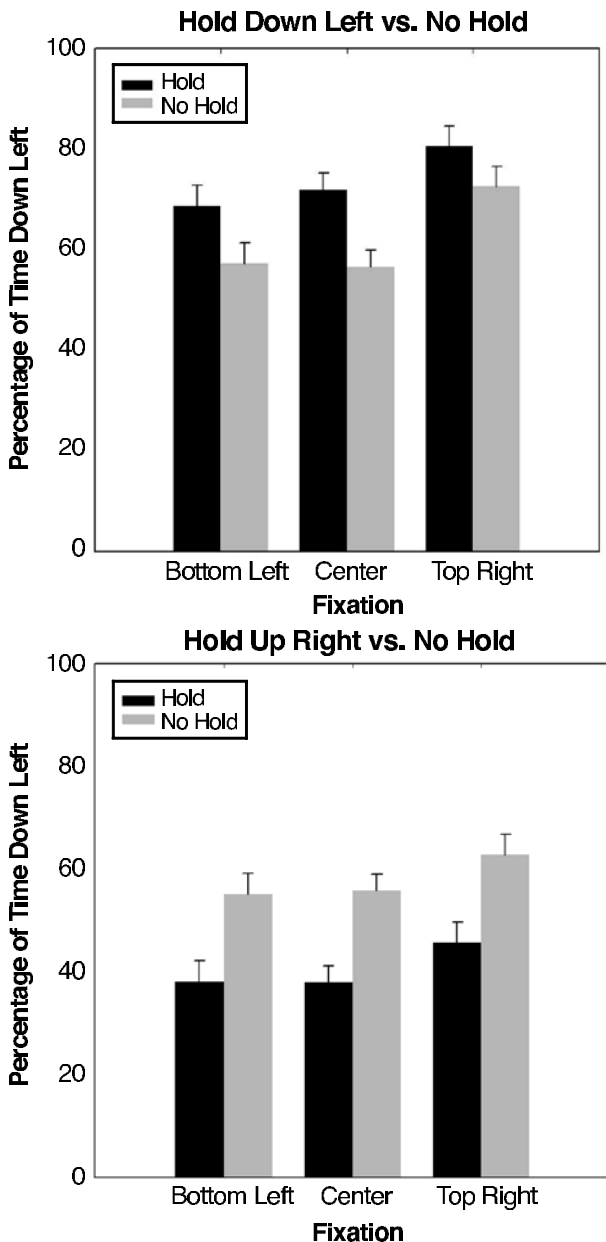


Figure 2. Means and standard errors of the means for the percentage of time that a cube was perceived to be in the down-to-the-left orientation in Experiment 1 as a function of fixation location and hold instructions. The top panel depicts data for observers who reported (and held in the hold condition) whenever they perceived the cube in the down-to-the-left orientation. The bottom panel contains the data for observers who reported (and held in the hold condition) the up-to-the-right orientation.

able [$F(1,92) < 1.00$, $MS_e = 814.44$]. Overall, the down-to-the-left orientation was perceived 60% of the time in the no-hold conditions, and the percentage of time was not significantly affected by whether observers were reporting the up-to-the-right orientation or the down-to-the-left orientation. This contrasts with results obtained in the hold

conditions, for which down to the left was perceived for a significantly greater percentage of the time when observers were reporting and trying to hold a down-to-the-left orientation (73.7%) than when they were reporting and trying to hold an up-to-the-right orientation (40.6%). Another set of simple effects analyses indicated that hold instructions differed from no-hold instructions in both the report-up-to-the-right and report-down-to-the-left conditions [$F_s(1,92) = 13.26$ and 5.94 , respectively ($MS_e = 814.44$)].

Number of reversals. A reversal was indicated each time an observer released the response button and each time he/she pressed it again. Thus, each buttonpress represented a “reversal cycle” in which an observer’s perception switched and then switched back again to the percept he/she was reporting. The number of buttonpresses (or reversal cycles) was used as a measure of the number of reversals. It approximates one half of reversals to which an observer actually responded by controlling the buttonpress response.

A 2 (report instructions) \times 2 (hold instructions) \times 3 (fixation location) ANOVA with repeated measures on the last factor revealed that only the effect of fixation location was significant [$F(2,184) = 24.27$, $MS_e = 2.74$]. Tukey HSD paired comparisons indicated that more reversals occurred with a central fixation ($M = 7.54$) than with either a top-right fixation ($M = 5.64$) or a bottom-left fixation ($M = 6.23$). The latter two fixation conditions did not differ significantly from each other.

Discussion

Consistent with predictions of the focal-feature hypothesis, fixating near the upper-right interior vertex (focal area A in Figure 1) increased the percentage of time that the cube was perceived to be in the down-to-the-left orientation in comparison with results obtained with the relatively neutral central fixation. Curiously, fixating near the lower-left interior vertex (focal area A' in Figure 1) did not significantly decrease down-to-the-left perceptions relative to the central fixation condition. It is unclear why the latter result was obtained. If replicable, the finding would underscore the need for further research on factors that may influence the effectiveness of focal-feature processing, such as, for example, its relationship to processing asymmetries that are known to exist in the visual field (e.g., He, Cavanagh, & Intriligator, 1996; Previc, 1990). However, for the purposes of the present experiment, the important point is simply that an effect of focal-feature processing on the perception of a Necker cube was manifested in the finding that the total time for which a particular perspective was perceived was significantly determined by the location within the figure to which observers directed their gaze.

The effect of instructing observers to hold or maintain a particular perception of the Necker cube was reflected in the interaction between report instructions and hold instructions. Relative to no-hold conditions, instructing observers to hold (and report) a down-to-the-left or an

up-to-the-right orientation led, respectively, to a major increase or a major decrease in the percentage of time that a down-to-the-left perspective was perceived. Observers clearly were able to exert intentional control over their perceptions.

The most interesting aspect of the findings was that both fixation location and hold instructions produced substantial effects, but there was no hint of an interaction between the variables. The additive nature of their effects is clearly apparent in Figure 2. This pattern of findings is inconsistent with the proposal that the focal-feature hypothesis accounts for the effects of hold instructions as well as the effects of fixation location. If the effects of both variables depended on the set of features that are selected to receive enhanced processing, their effects should be redundant when both lead to processing of the same focal area, and the effects of one variable or both should be reduced when they are in conflict. The obtained pattern of results is consistent with the hypothesis that intentional control over perception is mediated by some largely independent process such as direct, top-down priming or activation of underlying representations, as has been suggested by Peterson and her colleagues (e.g., Hochberg & Peterson, 1987; Peterson & Gibson, 1991; Suzuki & Peterson, 2000).³

Consideration of the findings involving the number of reversals (reversal cycles) and their implications will be postponed until the General Discussion section.

EXPERIMENT 2

This experiment further explored whether the focal-feature hypothesis might account for both the effects of fixation location and the intentional effects of hold instructions. Observers were instructed either to hold a down-to-the-left or an up-to-the-right orientation. (No hold instructions were not included.) They fixated either on the top-right or the bottom-left interior vertices (i.e., focal area A or A', respectively). And, finally, cube size was varied. Some trials involved relatively large stimuli that were the same size as the experimental stimuli of the previous experiment. Other trials involved very small stimuli for which critical focal areas were separated by less than 1° of visual angle.

We reasoned that the reduction in cube size might reduce the degree to which competing focal areas would be differentially processed.⁴ In this case, the focal-feature hypothesis would predict that the effect of fixation location observed with large cubes should be reduced when the small cubes are viewed. If the intentional influence of hold instructions is also mediated by focal-feature processing, the use of the small cube should in addition reduce the effect of hold instructions. If, however, the effect of hold instructions is mediated by relatively independent processes, such as top-down activation or priming, it may be unaffected by cube size.

Method

Observers and Design. Fifty-six observers from the same population as in Experiment 1 participated in the experiment. Twenty-

eight observers were randomly assigned to each of two between-subjects conditions generated by a 2 (hold instructions) × 2 (fixation location) × 2 (cube size) mixed factorial design with the last two factors varied within subjects.

Materials and Procedures. Materials and procedures were the same as in Experiment 1 with the following exceptions. Only two fixation locations were used (near the top-right and bottom-left interior vertices). All observers were instructed to hold or maintain a perception of the cube. Half of the observers were instructed to hold a down-to-the-left orientation whereas the remaining observers were instructed to hold an up-to-the-right orientation. As in Experiment 1, observers responded by holding down a button to indicate the time during which they perceived the particular orientation they had been instructed to maintain. Finally, trials involved either the same relatively large cube that was used in Experiment 1 or a small cube for which the horizontal and vertical dimensions subtended 1.5° and 1.7° of visual angle, respectively. Following instructions and practice sessions that corresponded with those in Experiment 1, observers participated in 12 experimental trials. Within each four-trial block of experimental trials, there was one trial representing each of the four types of stimuli that could be generated from crossing two fixation locations with two cube sizes. The order of trials within each block was determined randomly for each observer.

Results

Percentage of time reporting down to the left. As in Experiment 1, the time data from all observers was converted to the percentage of time that they perceived the cube in a down-to-the-left orientation. The mean percentages are presented in Figure 3. A 2 (hold instructions) × 2 (fixation location) × 2 (cube size) ANOVA with repeated measures on the last two factors revealed three significant effects. There was a strong effect of hold instructions [$F(1,54) = 37.13$, $MS_e = 936.92$]; the mean percentage of time that observers perceived the down-to-the-left orientation was 64.8% when they were instructed to hold the down-to-the-left perspective and only 39.9% when they were instructed to hold the up-to-the-right perspective. There also was a main effect of cube size [$F(1,54) = 4.74$, $MS_e = 87.21$] that was qualified by a significant cube size × fixation-location interaction [$F(1,54) = 4.49$, $MS_e = 51.72$]. Simple effects analyses indicated that on trials involving the small cube, there was no effect of fixation location [$F(1,54) < 1.00$, $MS_e = 51.72$]. However, on trials involving the large cube, the percentage of time that observers reported the cube to be in a down-to-the-left orientation was significantly greater when fixation location was at the top right as opposed to the bottom left [$F(1,54) = 11.43$, $MS_e = 51.72$].

Number of reversals. A 2 (hold instructions) × 2 (fixation location) × 2 (cube size) ANOVA with repeated measures on the last two factors was conducted on the number of reversal cycles. Only the effect of cube size was reliable [$F(1,54) = 19.71$, $MS_e = 4.37$]. Small cubes produced significantly more reversals ($M = 8.00$ reversal cycles) than large cubes ($M = 6.76$ reversal cycles).

Discussion

The results of Experiment 2 provide additional evidence that the focal-feature hypothesis accounts for the effect of fixation location but not the effect of the intent

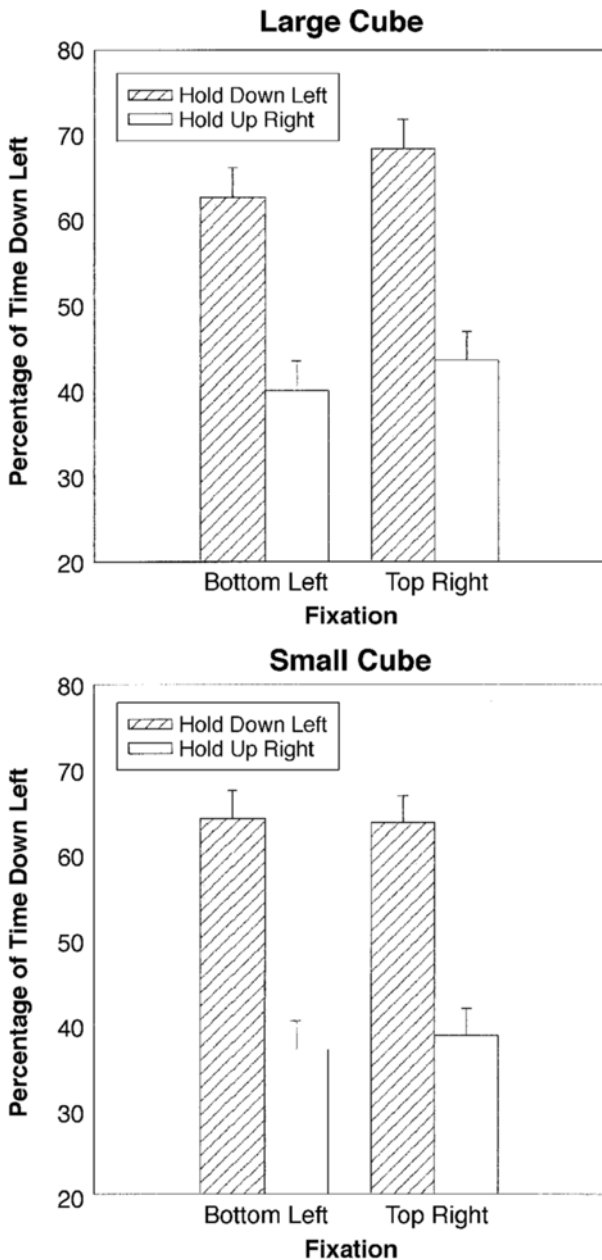


Figure 3. Means and standard errors of the means for the percentage of time that a cube was perceived to be in a down-to-the-left orientation in Experiment 2 as a function of fixation location, cube size, and hold instructions.

to maintain a particular interpretation of a Necker cube. When a large cube was used, the present results replicated the effect of fixation location that was obtained in Experiment 1. That is, the percentage of time that the cube was perceived in a down-to-the-left orientation was greater with a top-right fixation than with a bottom-left fixation. However, as predicted on the basis of the focal-feature hypothesis, the effect of fixation location was reduced when a small cube used. This finding provides

strong evidence that the selective processing of focal features is responsible for the effects of fixation location. However, cube size had no discernible effect on the effects of hold instructions. Observers exerted intentional control over their perceptions equally well with both large and small cubes. This pattern of findings strongly suggests that the effect of intentionally maintaining a particular interpretation of a Necker cube is mediated by processes other than focal-feature processing.

GENERAL DISCUSSION

The results of both experiments support the selective processing of focal features as a contributing factor in the perception of a Necker cube. The overall percentage of time that each interpretation of the cube was perceived was influenced by the location within the cube on which observers were supposed to fix their gaze. When selective processing of different points within the cube was discouraged by the use of very small cubes, the effect of fixation location was eliminated. Thus, in accordance with the focal-feature hypothesis, enhanced processing of parts of a figure that favor one interpretation over the other seems to affect how an observer perceives the entire stimulus. This is consistent with the findings of several previous reversible-figure studies (e.g., Kawabata, 1986; Peterson & Gibson, 1991; Tsal & Kolbet, 1985), and, more generally, with interpretations of perception that emphasize the role of local cues in determining global perceptual organization (e.g., Hochberg, 1968).

Of greater interest in the present experiments, however, was the observers' ability to voluntarily control their perception of one or the other organization of a Necker cube. When instructed to hold or maintain one interpretation of the cube, observers reported seeing that alternative for a greater proportion of the viewing period than they did when they received unbiased or neutral instructions. This finding is consistent with the results of several previous studies that have demonstrated intentional control over the perception of reversible figures (e.g., Liebert & Burk, 1985; Peterson & Hochberg, 1983; Phillipson & Harris, 1984; Suzuki & Peterson, 2000).

The primary concern of the present research was whether intentional control should be construed as simply another manifestation of the mechanism described by the focal-feature hypothesis. That is, one explanation of the effectiveness of instructions to hold a particular organization of a reversible figure is that observers may voluntarily select for primary processing areas of the stimulus favoring the desired interpretation (e.g., Gale & Findlay, 1983; Hochberg & Peterson, 1987). However, the present results provide no support for this hypothesis.

In Experiment 1, fixation location and hold instructions produced substantial effects that were additive. This should not have occurred if the effect of both variables could be explained in terms of the focal-feature hypothesis, according to which observers select, and give enhanced processing to, one area of the stimulus at a

time (e.g., García-Pérez, 1989, 1992). In no-hold conditions, fixation location was the only factor systematically affecting the area to which observers attended. However, if the focal-feature hypothesis also accounts for the effects of intention, instructions to hold a particular perception would place potentially competing demands on the selection of a focal area. To the extent that observers diverted processing from fixation to an area favoring the intended orientation of the cube, the effect of fixation would have been reduced relative to the no-hold condition, but it was not. Alternatively, if observers strictly maintained their gaze and attention on the fixation location regardless of instructions, sizable effects of intention should not have been obtained, but they were.

In Experiment 2, cube size was varied. The small cube was expected to reduce the degree to which competing focal areas would be selectively processed. Consistent with this expectation, the fixation effect observed in Experiment 1 was replicated with a large cube in Experiment 2 but was reduced, and actually eliminated, when the small cube was used. Importantly, however, the size of the cube had no measurable influence on the effect of hold instructions. Observers were able to voluntarily maintain a designated perception equally well with both large and small cubes, even though they apparently did not differentially process focal areas with the latter stimuli. These findings seem very difficult to reconcile with the focal-feature processing explanation of intentional control over the perception of reversible figures.

The present results should not be interpreted to mean that shifts in the focus of primary processing never contribute to successful efforts to voluntarily control the perception of reversible figures. Such a possibility would be highly surprising in view of the fact that the area of a figure to which one attends clearly influences the interpretation of reversible figures and the fact that both eye movements and attention are at least partially under voluntary control. In addition, differences among reversible figures in the degree to which their perceptions can be regulated voluntarily (e.g., Struber & Stadler, 1999) may reflect some variation in the mechanisms underlying intentional control. Nevertheless, the additive effects of hold instructions and fixation location in the Necker cube (Experiment 1) and that fact that a small cube eliminated the fixation-location effect while not influencing the effect of hold instructions (Experiment 2) strongly indicate that the effects of intention can be mediated by processes that are relatively independent of focal-feature processing.

The present findings suggest that intentional control over the perception of reversible figures may be mediated by central processes as opposed to mechanisms that influence perception by altering stimulus input to the visual system. Although future research will be needed to explore fully the nature of the central processes that may be involved, the present results are consistent with the hypothesis of Peterson and her colleagues (e.g., Hochberg & Peterson, 1987; Peterson & Gibson, 1991; Peterson

et al., 1991; Suzuki & Peterson, 2000) that intentional control can be exerted by means of top-down priming of perceptual representations. In this view, visual processing of a reversible figure is thought to activate at least two structural representations that compete for dominance. Intention is assumed to have a top-down effect on perception via central processes that influence the relative activation of these competing representations, with the alternative receiving greater activation being consciously perceived.

Regardless of the mechanism(s) involved, an important question concerns what exactly observers are able to control when they intentionally control their perceptions of a Necker cube. In the present experiments, observers were instructed to hold and maintain a designated interpretation of the stimulus. This implies that they should prolong the periods in which the ambiguity of the Necker cube is resolved in favor of the desired orientation and should avoid reversals to the extent possible. It is interesting, therefore, that observers were successful in extending the desired perception but not in avoiding reversals. The intention to hold a particular perception produced a substantial effect on the percentage of time that the desired interpretation was perceived. However, the effects of intention on the number of reversals were comparatively small, inconsistent, and unreliable. Although there may be conditions under which hold instructions have a stronger influence on the number of reversals (e.g., Phillipson & Harris, 1984), the effect of intention on the number of reversals in the present experiments seemed to be considerably weaker than its effect on the time that each alternative was perceived. A similar pattern of results was obtained by Liebert and Burk (1985), who instructed observers to hold one interpretation of a reversible screen, or a Schröder staircase.⁵

The relative lack of an effect of intention on the number of reversals underscores the limitations of intentional control and suggests that reversals were strongly influenced by involuntary processes in the conditions of the present experiments. This also implies that the number of reversals and the duration of the percepts may be controlled at least partially by different underlying processes. Additional support for this possibility comes from two other apparent dissociations in the data. First, cube size in Experiment 2 affected the number of reversals but had no systematic effect on the proportion of time that each alternative was perceived. Finally, fixation location influenced both the temporal distribution of perceptions and the number of reversals, but the two sets of effects seem to be largely uncorrelated. That is, a down-to-the-left orientation of the cube was perceived for significantly more time with the top-right fixation than with the bottom-left fixation in Experiment 1, but the two fixation conditions did not differ in terms of the number of reversals. Also, the central fixation and the bottom-left fixation did not differ in terms of the temporal measure of perception, but the central fixation led to a significantly greater number of reversals.

The present experiments were not designed to assess the nature of the involuntary processes that seem to influence reversal rate. However, the data may have some preliminary implications for candidate processes. One possibility, recently proposed by Leopold and Logothetis (1999), is that reversals are the consequence of top-down control processes that involuntarily initiate reevaluations of the sensory input on a random schedule. Although this mechanism is consistent with many findings reviewed by Leopold and Logothetis, it is unclear how such a mechanism could account for the finding in Experiment 2 that the use of a small cube increased the frequency of reversals (see also Dugger & Courson, 1968; Toppino & Long, 1987; Washburn, Mallay, & Naylor, 1931). That is, it is not obvious how or why the refresh or reevaluation rate would change as a function of stimulus size.

A second possibility is based on the focal-feature hypothesis. The findings that the frequency of reversals was elevated by the use of a centrally located fixation point in Experiment 1 and by the use of a small cube in Experiment 2 are potentially consistent with the hypothesis that shifts in the focus of primary processing may induce, or at least influence, reversals. Assuming that the focus of processing wanders, perhaps involuntarily, for unspecified reasons, deviations of processing from a central point of fixation are more likely than deviations from other fixation locations to approach opposing focal areas at different times, thereby leading to relatively more reversals. For similar reasons, smaller figures, for which opposing focal areas are relatively close to one another, should produce more reversals than larger stimuli. However, the plausibility of this explanation is undermined by the finding in Experiment 2 that a very small cube eliminated the effect of fixation location on the percentage of time that one interpretation was perceived. That is, a direct manipulation of the focus of primary processing (fixation location) became less effective when a small cube, rather than a large cube, was used, presumably because the small cube reduced the degree to which focal areas would be differentially selected for primary processing. This finding seems difficult to reconcile with the hypothesis that the reversal rate is higher for small than for large cubes because the former stimuli increase the frequency with which primary processing is shifted between focal areas.

The final hypothesis is based on an adaptation-fatigue mechanism that generally is assumed to reflect data-driven, involuntary processes. Furthermore, some theorists (e.g., Attneave, 1971) have proposed a system in which the two organizations of a stimulus have a mutual and reciprocal inhibitory relationship such that strengthening one organization results in a proportional weakening of the other. Such a mechanism is potentially consistent with the possibility that asymmetries in the relative strengths of the organizations produced by intentional processes would result in different durations of dominance for the competing organizations but would not have as strong an effect on the number of reversals. In

addition, the hypothesis is potentially consistent with the findings that more reversals are reported with a central fixation point and with a small cube. Both of these conditions cause a greater proportion of the stimulus figure to fall in the central portion of the visual field, where acuity is greater. Babich and Standing (1981) found that the reversal rate was faster for Necker cubes that were centrally, rather than peripherally, located. They considered this finding to be one of several ways in which higher quality sensory input seems to lead to faster reversal rates, which, in turn, they attributed to more rapid neural "satiation." Other related results reported by Babich and Standing include the findings that reversal rate is faster with complete as opposed to incomplete cubes and with higher luminance as opposed to lower luminance figures.

In summary, the present results indicate that the area of the stimulus receiving primary processing and an observer's intentions both influence the perception of reversible figures. Importantly, the effects of intention seem to be independent of focal-feature processing and are more likely to be caused by centrally mediated, top-down priming of the intended perceptual representation. The results also indicated significant limits on the degree of intentional control that can be exerted over the perception of reversible figures and suggested that somewhat different processes may underlie (1) the proportion of time during which each organization of a reversible figure is perceived and (2) the number of reversals that are perceived within a fixed viewing period. Observers' intentions seem to influence the former more strongly than the latter.

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NOTES

1. An implication of this hypothesis is that the effect of focal-feature processing would be reduced or eliminated if figures were small enough to discourage or prevent selective processing of different focal features.
2. We expected any shifts in the focus of primary processing to involve altered fixation because, with large cubes, the effectiveness of shifts in attention without eye movements would be restricted by the reduction in acuity that accompanies increasing eccentricity (García-Pérez, 1989, 1992). However, this was not regarded as a critical consideration because the predictions of the focal-feature hypothesis depend on the area of the stimulus that is selected for primary processing and not on whether that selection reflects a redirection of fixation or a change in the focus of attention that occurs independently of eye movements.
3. It is worth considering whether the effect of fixation location might be attributed to the foveation of the set of features at the designated location whereas the effect of hold instructions might be attributed to spatial attention being directed to the set of features favoring the intended percept. This possibility is somewhat awkward for the focal-feature hypothesis because it complicates the meaning of "selective" visual processing, but it is unable to account for the results of Experiment 1 in any case. In the no-hold conditions, there is every reason to assume that, aside from unsystematic variation, the area of fixation and the focus of attention coincide. For example, if the fixation point were in the area of the bottom-left vertex in the no-hold condition, both fixation and attention would be directed to that area. Exactly the same thing should happen in the hold conditions when the intended orientation of the cube and the fixation location requires processing of the same subset of features. That is, for example, if observers intended to hold or maintain the up-to-the-right orientation of the cube and the fixation point were in the

area of the bottom-left vertex, both fixation and attention would be directed to the latter area. It follows that there should be no difference between hold and no-hold instructions under these circumstances. However, contrary to this prediction, a clear and significant difference was obtained.

4. Given the size of our small cubes, differences in acuity were expected to be negligible for different focal areas. Although the minimum size of the so-called attentional spotlight has been investigated in several contexts (e.g., B. A. Eriksen & C. W. Eriksen, 1974; C. W. Eriksen & Hoffman, 1972; Intriligator & Cavanagh, 2001), it was unclear whether observers would be capable of selectively processing different focal areas within our small cubes. However, the distance between focal areas seemed sufficiently small to warrant the expectation that the degree of selective processing would be smaller with our small cubes than with our large stimuli.

5. In contrast to the weak effect of hold instructions on the number of reversals in the present experiments, a substantial effect of volition on the number of reversals is demonstrated when observers are instructed to continually switch their intentions so that they are, respectively, always contrary to or always in agreement with the current perception (e.g., Pelton & Solley, 1968; Seth & Reddy, 1979; Struber & Stadler, 1999). However, the different results are not necessarily incompatible. They may simply reflect the influence of different procedures. In addition, it should be noted that even when observers are encouraged to repeatedly switch their intended percept, the findings indicate significant limitations on voluntary control in that observers do not come close to completely regulating reversals.

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