Attentional control settings modulate susceptibility to the induced Roelofs effect

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Abstract When a visible frame is offset laterally from an observer's objective midline, the subjective midline is pulled toward the frame's center, causing the frame and any enclosed targets to be misperceived as being shifted somewhat in the opposite direction. This illusion, the Roelofs effect, is driven by environmental (bottom-up) visual cues, but whether it can be modulated by top-down (e.g., task-relevant) information is unknown. Here, we used an attentional manipulation (i.e., the color-contingency effect) to test whether attentional filtering can modulate the magnitude of the illusion. When observers were required to report the location of a colored target, presented within an array of differently colored distractors, there was a greater effect of the illusion when the Roelofs-inducing frame was the same color as the target. These results indicate that feature-based attentional processes can modulate the impact of contextual information on an observer's perception of space.

Keywords Perception · Attention · Illusion · Roelofs effect

Although one's percept of the world is seemingly flawless, manipulations of visual context can sometimes fool the visual system, revealing clues about the mechanisms used by the brain to organize our perceptual environment. In one such example, the presentation of a large rectangular frame that is offset from the observer's objective midline causes a distortion of the perceived, or subjective, midline (Roelofs, 1935). Under these conditions, when observers are asked to indicate the direction that is perceived to be straight ahead, they report their midline

as being shifted in the direction of the offset frame (Brecher, Brecher, Kommerell, Sauter, & Sellerbeck, 1972; Broscole, 1968; Dassonville & Bala, 2004a; Dassonville, Bridgeman, Bala, Thiem, & Sampanes, 2004; Werner, Wapner, & Bruell, 1953). In turn, this distortion of the observer's representation of visual space causes errors when judging the location of the frame (the *Roelofs effect*; Roelofs, 1935) or the location of a target presented inside the frame (the *induced Roelofs effect*; Bridgeman, Peery, & Anand, 1997; Dassonville & Bala, 2004a; Dassonville et al., 2004).

Although a distortion of the observer's subjective midline is understood to drive the Roelofs illusions (however, see also Dassonville & Bala, 2004b; de Grave, Brenner, & Smeets, 2002, 2004), the mechanism by which the offset illusion-inducing frame causes this distortion is unclear. One way to begin to dissect this mechanism is by investigating the level of visual processing at which the frame has its effect. Bridgeman and Lathrop (2007) demonstrated that the induced Roelofs effect can be obtained under conditions in which the inducing frame is not consciously perceived. In a version of the classic inattention blindness paradigm developed by Mack and Rock (1998), participants had to make a target location judgment in a paradigm that was made attentionally demanding by the presence of an additional perceptual task (a length discrimination judgment). On a small subset of the trials, an offset Roelofs-inducing frame was presented while participants were performing the two tasks. When questioned after the trial, more than half (54%) of participants reported that they did not perceive the frame; nonetheless, perception of the target's location was biased by the unperceived frame, suggesting that this contextual information is integrated even under circumstances in which it never reaches perceptual awareness. Indeed, Bridgeman and Lathrop's analysis indicated that awareness of the

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frame was insufficient to even modulate the magnitude of the effect. In sum, these results suggest that the contextual information of the Roelofs-inducing frame exerts its effects early in sensory processing.

Similar to the findings of Bridgeman and Lathrop (2007) with the induced Roelofs effect, Moore and Egeth (1997) demonstrated that the Ponzo and Müller-Lyer illusions could be evoked even without awareness of the illusion-inducing contextual information (see also Chan & Chua, 2003; Lamy, Segal, & Ruderman, 2006). However, other studies have typically indicated that, in spite of these findings, the magnitude of illusory phenomena can be modulated by attention within the visual display. For example, the magnitude of the Müller-Lyer illusion can be modulated using paradigms that cause observers to focus their attention on one of two sets of illusion-inducing wings that are presented simultaneously (Coren & Porac, 1983; Goryo, Robinson, & Wilson, 1984; Predebon, 2004; Tsal, 1984). Furthermore, Predebon (2006) demonstrated that the common finding of illusion decrement in the Müller-Lyer illusion, or the decrease in illusion magnitude over the course of an experiment, is best accounted for by the observer's adoption of an attentional set to ignore the illusion-inducing context, indicating that an observer's internal goals can modulate susceptibility to the illusion. These studies, and others that have examined the rod-and-frame (Daini & Wenderoth, 2008) and Ebbinghaus illusions (Shulman, 1992), indicate that attentional selection is capable of modulating the illusory effects of contextual elements within the visual image.

The report by Bridgeman and Lathrop (2007) that the magnitude of the Roelofs effect was not modulated by awareness of the inducing frame seems to run counter to the many reports that attention can modulate the effect sizes in a wide range of illusions. It may be that the Roelofs effect is truly different from these other illusions, with its effects driven solely within levels of visual processing that are immune to attentional modulations. Alternatively, it is possible that the Roelofs effect can in fact be modulated by attention, but that this effect escaped detection due to the low statistical power inherent in the type of between-subjects comparison of single-trial measures of illusion susceptibility that Bridgeman and Lathrop performed. In the present study, we performed a more direct test of the ability of attention to modulate the magnitude of the induced Roelofs effect.

Experiment 1

If top-down attentional selection does in fact play a role in the Roelofs effect, we might expect the magnitude of the illusion to be modulated by manipulations known to affect

spatial attention. As an example, the contingent-involuntary-orienting hypothesis suggests that involuntary shifts of attention are contingent on top-down control settings that are created based on task expectancies and/or demands (Folk, Remington, & Johnston, 1992). Indeed, a number of paradigms have been used to demonstrate that an attentional distractor has a much larger impact when it is of the same color as the expected target (Folk, Leber, & Egeth, 2002, 2008; Folk & Remington, 1999, 2006; Folk et al., 1992).

In the present study, we modified the standard induced Roelofs task to determine whether the magnitude of the illusion could be modulated by feature-based attentional selection. Participants were instructed to search for and report the location of a target (e.g., a red dot) presented inside an offset rectangular frame. The target item was presented among three distractor items of different colors, so that, in order to achieve optimal performance, participants would be required to maintain an attentional set that would filter out the irrelevant colored items. The color of the offset, Roelofs-inducing frame was manipulated so that on some trials it matched the participants' top-down attentional settings. If the Roelofs effect can be modulated by attentional filtering, the magnitude of the illusion should be larger on those trials in which the target and frame colors match, but smaller on trials in which the frame is of a different color.

Method

Participants A total of 20 University of Oregon undergraduates with normal or corrected-to-normal vision volunteered to participate for course credit. Participants provided informed consent prior to their participation, and all procedures were approved by the Institutional Review Board of the University of Oregon.

Apparatus Participants were seated in a dark room with their heads steadied by a chin-and-forehead rest positioned approximately 90 cm from the plane of a translucent projection screen (137 × 102 cm). The stimuli were back-projected (Electrohome Marquee 8500 projector with a refresh rate of 60 Hz) onto the screen, and centered at eye level. Eye position was monitored continuously during the experimental trials using an EyeLink 1000 eyetracking system (SR Research Systems), operating at a 250-Hz sample rate. Manual responses were collected as button-presses on a game pad connected to the host computer.

Stimuli At the start of each trial, a white fixation point (RGB values 255, 255, 255; 0.9° in diameter) appeared 10° above eye level at the center of the screen. A large rectangular frame (25° horizontal × 12.5° vertical, 1° thick), was positioned so

that it was centered at eye level, 5° to the left or right of the participants' midsagittal plane. Inside the frame, one target (defined by color; see below) and three distractors (0.5° in diameter) appeared at random locations within an invisible 7×3 array of possible locations (Fig. 1). The positions within this array were -4.5° , -3° , -1.5° , 0° , 1.5° , 3° , and 4.5° from the participant's midsagittal plane, and -1.5° , 0° , and 1.5° from eye level. Targets and distractors appeared in randomly selected locations within the array with equal probabilities, such that any small display imbalances (and any resulting Roelofs-like effects) caused by their presentation would cancel out over the course of the experiment.

Participants were asked to report only the location of the target, which could be distinguished by its red color (RGB: 255, 0, 0) for half of the participants (randomly assigned), or by blue color (RGB: 0, 200, 255) for the others. The distractors were green (RGB: 0, 210, 0), yellow (RGB: 196, 196, 0), and purple (RGB: 218, 121, 255) on each trial. The color of the Roelofs-inducing frame varied randomly from trial to trial, either red (RGB: 255, 0, 0), blue (RGB: 0, 200, 255), or yellow (RGB: 196, 196, 0). All frame, target, and distractor colors were matched for luminance (0.2 cd/m^2).

For participants searching for a red target, the red, blue, and yellow frames comprised the *set*-, *different*-, and *distractor-color* conditions, respectively. Specifically, when searching for a red target, the red frame was the same color as the to-be-reported target (set-color condition). Likewise, the yellow frame comprised the distractor-color condition because yellow was one of the three distractor colors, whereas blue never appeared as a distractor color and constituted the different-color condition. Conversely, for

participants that searched for a blue target, the red frame constituted the different-color condition, the blue frame constituted the set-color condition, and the yellow frame constituted the distractor-color condition. Equal numbers of set-, distractor- and different-color trials appeared in the experimental trials.

Procedure Each trial began with the presentation of the fixation point. Participants initiated the trial by moving their eyes to the fixation point and then pressing a button on the game pad with the left thumb. The fixation point was extinguished immediately, and after a 400-ms delay, the rectangular frame was illuminated, followed 100 ms later by the target/distractor array. The frame and the target/distractor array were then simultaneously extinguished, with a total frame duration of 200 ms and a target/distractor duration of 100 ms. Participants were instructed to report the location of the target while ignoring the irrelevant frame and distractors. Participants responded with a buttonpress to indicate the target's location with respect to straight ahead, with a press of the left index finger indicating a target to the left, and a press of the right index finger indicating a target to the right.

Throughout each trial, participants were required to maintain fixation within an invisible, circular fixation zone (2.5° radius)¹ that surrounded the fixation point in the center of the screen. Trials during which blinks occurred, or during which the eyes moved outside of the fixation zone (even after the fixation point was extinguished), were discarded and repeated at the end of the experimental block. This resulted in a total of 504 valid experimental trials completed by each participant. Prior to the experimental trials, participants performed 40 practice trials, for which performance was not analyzed.

Data analysis For each combination of target location, frame location, and frame color, the perceived location of the target was quantified as the proportion of trials on which the participant reported the target as being located to the right of straight ahead (Fig. 2). Since the induced Roelofs effect caused by a frame shifted to the left or right of midline is known to affect only a target's perceived azimuth, trials were collapsed across the different target elevations. Psychometric functions were then fit to these data to determine the point of subjective equality (PSE, the location at which the targets were equally likely to be

Fig. 1 Spatial schematic of the visual display; while the display is drawn to scale, the cartoon observer is not. The array of possible target/distractor locations (gray circles) was not visible to participants, and the fixation point was extinguished before frame, target, and distractors onset. In this set-color trial, the participant had the task of reporting the location of the red target (left or right of straight ahead) presented amid yellow, purple, and green distractors within a red frame (here offset to the participant's right)

¹ To prevent the fixation point from serving as a possible allocentric cue to target location, it was extinguished 500 ms before target presentation. The larger-than-typical fixation zone was required to offset the increased task difficulty that resulted from the requirement to maintain fixation even after the fixation point was extinguished. Possible effects of small eye movements away from the fixation point are examined in the Results section of [Experiment 1](#).

Fig. 2 Typical results from a single participant in [Experiment 1](#). Best-fit psychometric functions are plotted for each frame offset (e.g., left and right) and each color condition. The point at which each function surpasses a proportion of .5 indicates the point of subjective equality (PSE) for that condition

judged as to the left or right of straight ahead), using the equation:

Proportion "Right" responses

$$= (1 - \text{amp})/2 + \left[\text{amp} \times e^{[(\text{tarpos} - \text{PSE})/\tau]} / (1 + e^{[(\text{tarpos} - \text{PSE})/\tau]}) \right]$$

where tarpos was the actual target location, PSE was the point of subjective equality, τ was the slope of the psychometric function, and amp was the amplitude of the psychometric function (the best-fitting PSE, τ , and amp values were determined iteratively using a least-squares algorithm in Microsoft Excel). The amplitude parameter was included to account for the finding that the floor and the asymptote of the psychometric functions often did not reach 0 and 1 in some participants. This effect may have occurred because of an occasional inability of the participant to correctly isolate the target from the distractors. To quantify the magnitude of the Roelofs effect in each color condition, the PSE for the left-frame condition was subtracted from that of the right-frame condition, with this total effect size statistically compared across color conditions.

Results

Figure 2 shows the typical pattern of results from a single participant, with left-shifted frames increasing the likelihood that particular targets will be reported as being to the right of straight ahead, and vice versa. Although the overall magnitude of the induced Roelofs effect in each color condition (Fig. 3, Table 1) differed significantly from zero [set color, $t(19) = 6.024$, $p < .0001$; different color, $t(19) = 4.609$, $p < .0001$; distractor color, $t(19) = 5.043$, $p < .0001$], a repeated measures ANOVA revealed a significant main

effect of frame color [$F(2, 38) = 6.751$, $p = .003$]. Planned comparisons indicated that the Roelofs effect for the set-color condition was significantly larger than those for the different-color [$t(19) = 3.485$, $p = .002$] and distractor-color [$t(19) = 3.191$, $p = .005$] conditions, while the effects for the different- and distractor-color conditions did not significantly differ [$t(19) = -0.651$, $p = .523$].

To test for differences in the slope (τ) and amplitude (amp) values across the psychometric functions for the different color conditions, separate repeated measures ANOVAs were conducted with frame color as the sole factor, and slope and amplitude (collapsed across the right- and left-frame conditions) as the dependent variables (Table 1). The main effect of frame color was not

Fig. 3 Mean induced Roelofs effect size (calculated by subtracting the PSE for the left-frame condition from that of the right-frame condition) for each of the three frame color conditions in [Experiment 1](#). Asterisks indicate $p < .05$

Table 1 Roelofs magnitude, slope, and amplitude parameters (mean $\pm$ SE) for different trial conditions in Experiments 1 and 2

Experiment	Condition	Roelofs (°)	Slope (°/°)	Amplitude (°)
1	Set color	2.80 $\pm$ 0.44	12.90 $\pm$ 1.41	0.90 $\pm$ 0.03
	Different color	2.13 $\pm$ 0.45	10.09 $\pm$ 1.25	0.84 $\pm$ 0.04
	Distractor color	2.30 $\pm$ 0.45	12.20 $\pm$ 1.59	0.92 $\pm$ 0.03
2	Distractors present			
	Set color	2.53 $\pm$ 0.59	11.46 $\pm$ 0.95	0.97 $\pm$ 0.01
	Different color	2.26 $\pm$ 0.63	10.83 $\pm$ 0.95	0.96 $\pm$ 0.01
	Distractors absent			
	Set color	2.77 $\pm$ 0.59	7.71 $\pm$ 0.90	0.99 $\pm$ 0.01
	Different color	2.30 $\pm$ 0.56	6.56 $\pm$ 1.01	0.99 $\pm$ 0.01

significant for slope [$F(2, 38) = 1.38, p = .262$] but did reach significance for the amplitude [$F(2, 38) = 5.08, p = .01$], with a smaller overall amplitude in the different-color frame condition. Planned comparisons indicated that the amplitude was significantly smaller in the different-color than in the set-color and distractor-color conditions [$t(19) = 2.26, p = .03$; $t(19) = -2.99, p = .007$, respectively]. The amplitudes in the set-color and distractor-color conditions did not significantly differ [$t(19) = -0.79, p = .439$].

Eye-tracking analyses To ensure that the patterns of mislocalization seen for the various color conditions were not caused by differing tendencies to break fixation and make small eye movements within the invisible fixation zone, we compared the eye position at target onset for each combination of frame position and color using a fully factorial ANOVA. Importantly, eye position was unaffected by frame position, frame color, or their interaction [$F(1, 18) = 2.89, F(2, 36) = 0.35$, and $F(2, 36) = 0.005$, respectively; all n.s.].

Discussion

The results of Experiment 1 demonstrate that a top-down attentional set, in this case an attentional set tuned to color based on a contingent task, can modulate the magnitude of the induced Roelofs effect. Specifically, when participants searched for a target item of a certain color, the presentation of a frame of that same color caused a larger shift in perceived straight ahead, as compared to the significantly smaller shift that occurred when the frame color did not match the participants' attentional set (e.g., yellow frame when searching for a red target). These findings are consistent with a contingent-capture account of attention, as proposed by Folk et al. (1992), with the attentional set serving to enhance the effects of frames with colors that match the expected target, or diminish the effects of non-target-colored frames through attentional filtering.

In the paradigm of the present study, the target item for which participants searched was always presented among three distractor items, defined by their yellow, purple, and green colors. Given this limited range of distractor colors, one might expect that if feature-based filtering did occur, the filter might be specifically tuned to filter out those colors. On the other hand, it is possible that the attentional set served to filter out all nontarget colors, including those that were not typically included among the distractors. In the latter possibility, one would expect the magnitude of the Roelofs effect for the different-color condition to resemble that of the distractor-color condition. Indeed, the effect in the different- and distractor-color conditions did not differ significantly, while both were smaller than that for the set-color condition, indicating that the attentional set acted broadly by filtering all nontarget colors, enhancing only the target color, or both.

Is it possible that different rates of guessing could account for the difference in the magnitude of the induced Roelofs effect measured in the various color conditions? One could argue that in the set-color trials, the frame would serve as a potent distractor due to its color. This would then draw attentional resources away from the target, causing participants to “miss” the target and base their responses on guesswork. If that was the case, one would expect psychometric functions with decreased slopes (i.e., greater τ values) and smaller amplitudes for the set-color trials. However, this pattern of results was not seen in the data (Table 1), indicating that a higher rate of guessing could not account for the results.

Although our findings are consistent with an attentional set that can modulate the perceptual consequences of the Roelofs-inducing frame, an alternative explanation should be considered. Specifically, it is possible that the similar target and frame colors in the set-color condition might have led to an enhancement of the Roelofs effect due to a perceptual grouping of the target and frame. Experiment 2 was designed to address this alternative, perceptual grouping account of the results.

Experiment 2

In order to argue that feature-based attentional processing can modulate the magnitude of the induced Roelofs effect, it is important to rule out the possibility that the findings of [Experiment 1](#) were the result of the visual system's tendency to perceptually group objects of the same color. The Gestalt psychology principle of *similarity* suggests that when objects have similar characteristics—for example, color or shape—they tend to be grouped together at a perceptual level (Koffka, 1935). Previous work has demonstrated that this Gestalt grouping tendency is capable of modulating illusory effects in, for example, the Müller-Lyer illusion, where the illusion is strongest when the horizontal segment of the figure is of the same color as the illusion-inducing wings (Goryo et al., 1984).

To dissociate these two possibilities, in [Experiment 2](#) we employed a color-contingent paradigm similar to that of [Experiment 1](#), but included occasional probe trials in which only a single target is presented (i.e., distractors-absent trials), with the participant required to report the location of this solitary target *regardless of its color*. Because the distractors-present trials were more numerous than the relatively rare distractors-absent trials, and because the sequence of trial types was unpredictable, the attentional set maintained by the participant to assist in the distractors-present trials should be operational during the distractors-absent trials as well. If this attentional set concomitantly modulated the effects of a Roelofs-inducing frame, this effect should also be apparent in the distractors-absent trials, regardless of the actual color of the target. On the other hand, if the results from [Experiment 1](#) indicated a tendency for a larger Roelofs effect to occur when the target and frame could be perceptually grouped due to like colors, one would similarly expect a larger effect in the distractors-absent trials only when the target and frame were the same color and not when they were different colors.

Methods

Participants A total of 21 University of Oregon undergraduates with normal or corrected-to-normal vision volunteered to participate for course credit. Participants provided informed consent prior to their participation, with all procedures approved by the Institutional Review Board of the University of Oregon.

Apparatus The apparatus was identical to that used in [Experiment 1](#).

Stimuli and procedure The majority of trials (75%, dubbed here *distractors-present trials*) were identical to those described in [Experiment 1](#), with participants asked to report

the locations of red targets presented among green, yellow, and purple distractors, in the presence of frames that were either red (set color) or blue (different color). In the remaining 25% of trials (*distractors-absent trials*), the stimulus contained only a solitary blue target within a red (set color) or blue (different color) frame, with no distractors present. Participants were instructed that when a lone target appeared inside the frame, regardless of color, they were to report the location of the target just as they did in distractors-present trials.

In the experiment, participants performed four blocks of 224 trials each, resulting in 896 total trials (672 distractors-present trials and 224 distractors-absent trials, presented in random order). Participants were informed that the majority of the trials would be distractors-present trials, and they were instructed to report the location of the red target item in these trials. When no distractors were present, participants were told to report the location of the single target item, regardless of its color. Prior to performing the experimental trials, participants performed 40 practice trials. All eyetracking and rejection procedures were identical to those in [Experiment 1](#).

Data analysis The analysis methods were identical to those of [Experiment 1](#).

Results

A significant induced Roelofs effect was evident in all task conditions (Fig. 4, Table 1): set color/distractors present, $t(20) = 4.404$, $p < .0001$; different color/distractors present, $t(20) = 3.69$, $p = .001$; set color/distractors absent, $t(20) = 4.819$, $p < .0001$; different color/distractors absent, $t(20) = 4.183$, $p < .0001$. A repeated measures ANOVA, including Frame Color and Distractor Presence as factors, revealed a significant main effect of frame color [$F(1, 20) = 15.406$, $p = .001$], indicating a larger Roelofs effect when the frame color matched the attentional set. However, there was no significant main effect of distractor presence [$F(1, 20) = 0.984$, $p = .333$], nor any interaction between frame color and distractor presence [$F(1, 20) = 0.785$, $p = .386$]. Planned comparisons revealed that the effect in the set-color/distractors-present trials was larger than that in the different-color/distractors-present trials [$t(20) = 2.618$, $p = .016$], replicating the results of [Experiment 1](#). Importantly, a similar difference was seen in the distractors-absent trials, with a larger Roelofs effect for the set-color condition than for the different-color condition [$t(20) = 2.768$, $p = .012$].

As in [Experiment 1](#), we analyzed the slope (τ) and amplitude (amp) values of the psychometric functions using a repeated measures ANOVA, with Frame Color and Distractor Presence as factors (Table 1). The main effect

Fig. 4 Mean induced Roelofs effect size for each of the four trial conditions in [Experiment 2](#). Asterisks indicate $p < .05$

of frame color was not significant for slope [$F(1, 19) = 1.51$, $p = .235$] or amplitude [$F(1, 19) = 0.01$, $p = .917$]. However, there was a significant main effect of distractor presence for both slope and amplitude [$F(1, 19) = 24.36$, $p < .001$; $F(1, 19) = 9.88$, $p = .005$, respectively], but frame color and distractor presence did not significantly interact for either parameter [$F(1, 19) = 0.11$, $p = .744$]; $F(1, 19) = 0.08$, $p = .776$].

Discussion

In the distractors-present trials, a larger Roelofs effect was found when the color of the frame matched the participants' attentional set (i.e., set-color/distractors-present trials, where the frame was red, since participants anticipated having to search for a red target), as compared to trials in which the frame was of a different color (i.e., different-color/distractors-present trials). This replicates the findings from [Experiment 1](#), but does not itself resolve the confound that prompted [Experiment 2](#), since this difference in effect sizes could be attributed either to the fact that the frame matched the color of the attentional set or that it matched the color of the target, allowing for an enhanced perceptual grouping of the two.

The distractors-absent trials are key in resolving this confound, since the targets on these trials were of a different color (blue) than that of the attentional set (red). Thus, on set-color/distractors-absent trials, the frame matched the color of the attentional set but did not match the color of the target; the opposite pattern was true for the different-color/distractors-absent trials. The finding that the Roelofs effect was significantly larger for the set-color/distractors-absent trials indicates that it was the match between the frame color and the attentional set that allowed

for an enhanced Roelofs effect, not the match between frame and target colors.

Given the expected effects of the distractors, it was not surprising to see an increased rate of guessing in the trials in which they were present, as indicated by significant decreases in amplitude and slope (i.e., increased τ values) of the psychometric functions in the distractors-present, as compared to the distractors-absent, conditions. However, there were no main effects of frame color on the amplitude and slope, nor were there any interactions involving frame color, indicating that the differences in the Roelofs effect across the color conditions were not caused by different rates of guessing.

General discussion

Our results demonstrate that feature-based attentional processes are capable of modulating the magnitude of the induced Roelofs effect—when participants were instructed to search for a specific target color among distractor items, an offset frame with a color that matched the participants' attentional set caused a larger Roelofs effect than one with a different color. Thus, although the Roelofs effect can be obtained without a conscious awareness of the inducing frame (Bridgeman & Lathrop, 2007), it is possible to modulate the effect with top-down processes in the form of attentional set. Given this, it is somewhat surprising that Bridgeman and Lathrop found no significant difference in the magnitude of the illusion when comparing participants who did perceive the frame with those who did not. However, this null result in their analysis can possibly be attributed to a lack of statistical power in their test—given large individual differences in susceptibility to the illusion (Walter, Dassonville, & Boschler, 2009), a between-subjects test (using only a single measure of susceptibility from each participant) would lack the desired sensitivity.

The present findings demonstrate that the Roelofs effect is similar in some respects to the Müller-Lyer illusion, which is also not completely reliant on conscious awareness of the contextual elements that evoke the illusion (Chan & Chua, 2003; Lamy et al., 2006; Moore & Egeth, 1997), but has been shown to be modulated by attentional effects (Coren & Porac, 1983; Goryo et al., 1984; Predebon, 2004, 2006; Tsal, 1984). Although the phenomena of visual illusions are often regarded as windows into the low-level processes of the visual system, later stages of visual processing, such as feature- and space-based attentional selection, can influence illusion susceptibility. Conceptual and semantic information has also been shown to modulate the magnitude of the Ebbinghaus illusion (Coren & Enns, 1993; Coren & Miller, 1974; Rose & Bressan, 2002; but see also Choplin & Medin, 1999), providing further

evidence of the extent to which top-down processing can affect the impact of contextual information in perception. However, the effect of top-down processing is not without limits: Observers trained to recognize line segments as being fragments of intact rectangular frames viewed earlier nonetheless showed an induced Roelofs effect appropriate for the line segment rather than for the intact frame that it represented (Walter & Dassonville, 2006).

An aspect of this work that remains unclear is the manner in which the attentional modulation of the Roelofs effect is brought about. Under a filtering account, attention would serve to decrease the impact of distractors and frames that have colors that do not match the attentional set (i.e., an attentional cost to unattended stimuli), while a frame with a color matching the attentional set would pass through the filter and have its normal impact. In contrast, it is also possible that the perceptual salience of a frame that matches the attentional set may actually be exaggerated by its ability to capture attention (i.e., an attentional benefit to attended stimuli), giving it a larger-than-normal impact relative to frames with different colors. Of course, it is also possible that both costs and benefits play important roles. Undoubtedly, the relative sizes of these costs and benefits will be just as difficult to tease apart in the realm of contextual processing as they have been in other aspects of attentional processing.

The findings of the present study indicate that the magnitude of the induced Roelofs effect (Bridgeman et al., 1997; Dassonville & Bala, 2004a; Dassonville et al., 2004) can be modulated by attentional processing, but it remains to be shown whether the same can be said of the original Roelofs effect (in which the frame itself is mislocalized; Roelofs, 1935). We have argued elsewhere (Dassonville & Bala, 2004b) that the induced and original effects are driven by the same mechanism; if this is true, we would expect similar attentional modulations for both. However, de Grave et al. (2002, 2004) have argued that different mechanisms underlie the two effects. If that is the case, there is the possibility that our present findings will not hold for the original Roelofs effect.

The Roelofs effect demonstrates the brain's tendency to use the locations of salient objects in the visual scene as cues to the structure of perceptual space. Although, in the limited viewing conditions used to demonstrate the Roelofs effect, these cues can lead to illusory perceptions, it can be conjectured that, when viewing a well-lit scene, the sum of these cues provide generally accurate information for the construction of a reasonably faithful representation of space. Given this, the present finding that top-down attentional processing can modulate the effects of contextual cues can be inferred to apply not only to the illusory conditions associated with the Roelofs effect, but also to the more typical use of contextual information for constructing a representation of space while viewing well-lit scenes.

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