Research Article

Psychological Science
21(12) 1886–1893
© The Author(s) 2010
Reprints and permission:
sagepub.com/journalsPermissions.nav
DOI: 10.1177/0956797610389190
http://pss.sagepub.com
SAGE

Task Usefulness Affects Perception of Rivalrous Images

Adrien Chopin and Pascal Mamassian
Laboratoire Psychologie de la Perception, Université Paris Descartes

Abstract

In bistable perception, several interpretations of the same physical stimulus are perceived in alternation. If one interpretation appears to help the observer to be successful in an auxiliary task, will that interpretation be seen more often than the other? We addressed this question using rivalrous stimuli. One of the elicited percepts presented an advantage for a separate visual search task that was run in close temporal proximity to the rivalry task. We found that the percept that was useful for the search task became dominant over the alternate percept. Observers were not aware of the manipulation that made one percept more useful, which suggests that usefulness was learned implicitly. The learning influenced only the first percept of each rivalrous presentation, but the bias persisted even when the useful percept was no longer useful. The long-lasting aspect of the effect distinguishes it from other documented attentional effects on bistable perception. Therefore, using implicit learning, we demonstrated that task usefulness can durably change the appearance of a stimulus.

Keywords

vision, learning, visual search, visual attention

Received 3/15/10; Revision accepted 7/4/10

The visual world is ambiguous, and the visual system has multiple functional resources to resolve these ambiguities: It can use prior knowledge (Mamassian & Landy, 1998), auxiliary measures (Kersten, Mamassian, & Yuille, 2004), or combinations of different cues (Ernst & Banks, 2002). In the study reported here, we tested the extent to which a task can influence the disambiguating process and, consequently, the appearance of the stimulus (Carrasco, Ling, & Read, 2004). Can perception be modified to allow observers to be successful in a task?

To investigate a possible task influence on perception, we showed participants rivalrous stimuli. Images are rivalrous if they are too different to be fused when each is displayed in front of one eye (DuTour, 1760). Eventually, observers experience bistability, which means they perceive an irrepressible alternation of the elicited percepts. This experiment allowed us to address the following question: If one of the rivalrous images makes an auxiliary task easier, will that image be perceived more often than the other image?

Factors Already Known to Affect Bistability Dynamics

Because bistability is an alternation between percepts, studying bistability implies measuring its dynamics. Moreover, understanding bistability involves answering the key question of what can influence its dynamics. Many factors are known to affect bistability dynamics (Blake & Logothetis, 2002; Leopold & Logothetis, 1999; Walker, 1978). One of the main factors is stimulus driven. Levelt (1966) discovered that rivalry dynamics strongly depend on the stimulus's contour contrast, a phenomenon he called *stimulus strength*. It is now known that changing the contrast ratio between the images presented to the eyes mainly alters the phase durations of the higher-contrast image (Brascamp, van Ee, Noest, Jacobs, & van den Berg, 2006). Observers' past history has also proved to be an important factor in bistability. For example, in multistable rivalry (in which observers perceive combinations of parts of the images presented to the eyes), participants are usually "trapped" between pairs of complementary patterns (Suzuki & Grabowecky, 2002a). Percepts of ambiguous stimuli can easily survive across blank periods (Leopold, Wilke, Maier, & Logothetis, 2002) or interposed patterns (Maier, Wilke, Logothetis, & Leopold, 2003). In short, what has been previously perceived can be used to predict the next percept. Finally, bistability is influenced by prior beliefs (Mamassian & Landy,

---

Corresponding Author:
Adrien Chopin, Laboratoire Psychologie de la Perception, CNRS UMR 8158, Université Paris Descartes, 45 rue des Saints-Pères, Paris 75006, France
E-mail: adrien.chopin@gmail.com

1998; Sundareswara & Schrater, 2008) and expectation in response series (Maloney, Martello, Sahm, & Spillmann, 2005).

In parallel with stimulus-driven and past-history influences, attention plays a critical role in binocular rivalry dynamics. Attentional effects can be split between exogenous and endogenous effects (Posner, Nissen, & Ogden, 1978; Schneider & Shiffrin, 1977). Exogenous effects correspond to the automatic deployment of attention, whereas endogenous effects are voluntary. One example of exogenous attention is the pop-out phenomenon (Treisman & Gelade, 1980). In a study by Ooi and He (1999), a stimulus that exhibited a pop-out in the image presented to one eye made that image dominant over the other image. Exogenous attentional effects can be object based: Two studies (Chong & Blake, 2006; Mitchell, Stoner, & Reynolds, 2004) demonstrated that when two transparent surfaces were displayed dichoptically, cuing one surface made it dominant.

Endogenous attention is also able to affect bistability dynamics. Early work focused on the reversal rate of rivalry and indicated that observers can voluntary modulate it (Lack, 1971). Several authors (Meng & Tong, 2004; van Ee, van Dam, & Brouwer, 2005) broadened Lack's results by showing that the rivalrous house-face stimulus, the Necker cube, the slant rivalry stimulus, and gratings in rivalry could be selectively attended. In others words, observers were able to voluntarily make the desired interpretation dominant. Ooi and He (1999) provided a clear demonstration that drawing endogenous attention to one eye's location with a central cue (Posner et al., 1978) helps the observer resist a reversal triggered by a perturbation in the image viewed by the other eye. These results were extended to object-based voluntary control (Chong & Blake, 2006).

These studies suggest several general comments. Researchers studied bistability as an event isolated from the task in which participants were involved (and therefore from the task's purposes). Nevertheless, task-driven influences on perception were found. For example, a study about face perception (Schyns & Oliva, 1999) used hybrid-face stimuli composed of a female and a male face, one embedded in low spatial frequencies and the other in high spatial frequencies. The results showed that participants based expressiveness judgments on the information embedded in high frequencies more than on the information embedded in low frequencies, whereas they based expression identifications on the information embedded in low frequencies more than on the information embedded in high frequencies. Participants used high- and low-frequency information equally when making gender categorizations. Participants' selectivity in attending certain frequency bands (i.e., frequency intake) was long lasting: A previous categorization of a face biased perceptive behavior even during a different categorization task.

Investigating the Role of Percept Usefulness in Bistability

In the study reported here, we focused on a task-driven influence on rivalry dynamics. We define a percept as more useful than another percept if it allows observers to be more successful in a task. To our knowledge, no previous study has specifically addressed the role of percept usefulness in perception of ambiguous stimuli. The specific purpose of this experiment was to determine whether people could learn percept usefulness defined by a task and whether that learning would influence the bistability process.

The importance of the usefulness of an event in automatically capturing attention has been emphasized in a previous study (Lambert, Naikar, McLachlan, & Aitken, 1999). In that study, pairs of cue letters were presented before a target. The relative locations of the letters (*W* to the right side of a screen and *S* to the left side, or the opposite presentation) correctly predicted the spatial location of the target in 80% of the trials. As a result, valid trials triggered faster responses than invalid ones. The relationship between the cue letters and target location was learned implicitly. Although this spatial cuing experiment demonstrated that usefulness could influence the deployment of attention, it did not reveal whether perception itself or the bistability process can be affected.

Researchers typically measure only the first few seconds of bistable episodes, yet effects could vary over time. Mamassian and Goutcher (2005) noted that when bistability was finally measured over longer trials, an average measure was computed across the whole duration of the trial, without examination of the temporal variations in the trial. In the experiment reported here, the full dynamics of a rivalrous episode were studied. Our procedure associated task success with rivalry dynamics and produced task-driven dominance in bistability.

Participants were presented with a set of eight Gabor patches whose orientation was rivalrous between the two eyes. They were given two tasks to perform alternately: In the search task, they had to localize the Gabor whose contrast was lower than the contrast of the other Gabors in the display (monocular target), and in the rivalry-report task, they had to report the perceived orientation of the Gabor patches (rivalry measure) for a prolonged duration. After a given number of trials, and unbeknownst to participants, all search targets had the same orientation. In this context, the visual system would be rewarded for making that orientation dominant because searching within that orientation would raise the chance of success in the search task. Therefore, we predicted that in the rivalry-report task, participants would report perceiving the orientation that was always associated with the target in the search task more than they would report the other orientation.

Method

Stimuli

The stimuli consisted of eight Gabor patches embedded in a background grating. The background grating was an oriented sinusoidal variation in luminance (spatial frequency = 3 cycles/deg) covering the whole area of the stimulus (a square with side length equal to 3.9° of visual angle). Each Gabor was generated by increasing the luminance contrast of the background grating within a Gaussian window (0.2° at half height). The Gabors were distributed evenly around a virtual circle (diameter = 2.64°) centered on the background grating. The target was a single Gabor with contrast lower than that of the others, and this lower-contrast Gabor was present only during the search task. Binocular rivalry was induced by presenting to the two eyes gratings with orthogonal orientations. In a given trial, all the Gabors and the background grating presented to a given eye had the same orientation. Orientations could be either right tilted or left tilted (either 45° to the right or 45° to the left of vertical, respectively).

Because the stimulus was relatively large, there was a risk that participants would experience a piecemeal perception of the rivalrous images. We significantly decreased this tendency by presenting the images in flicker (5-Hz flicker rate) and out of phase between the two eyes (e.g., Suzuki & Grabowecky, 2002b). This manipulation is known to affect the dynamics of rivalry only slightly (Logothetis, Leopold, & Sheinberg, 1996). The flicker always began by displaying the image to the right eye. To help maintain vergence, we designed the display so that the background grating was surrounded by a frame of small squares, half of them black; the other squares were yellow during the search task and blue during the rivalry-report task (Fig. 1). The frame was identical in the two eyes (zero disparity).

Apparatus

A modified Wheatstone stereoscope was used to present the binocular stimuli, and a chin rest was used to maintain participants' head position. Observers viewed the stimuli from a distance of 100 cm in a darkened room. The stimuli were generated on an Apple Mac G4 with the PsychToolBox library (Brainard, 1997; Pelli, 1997) and displayed on a 21-in. CRT monitor at a frame rate of 75 Hz. The screen resolution was 1,280 × 960 pixels.

Observers

Nine observers (4 women and 5 men) participated in the experiment. Three other observers were excluded because they failed a calibration procedure and began the experiment with a strong preference to report either a particular orientation or the orientation presented to a particular eye on the first percept of the first block of trials (> 76%, statistically different from a 50% frequency of giving a particular answer on the rivalry-report task at $p < .01$). Participants' ages ranged from 20 to 29 years.

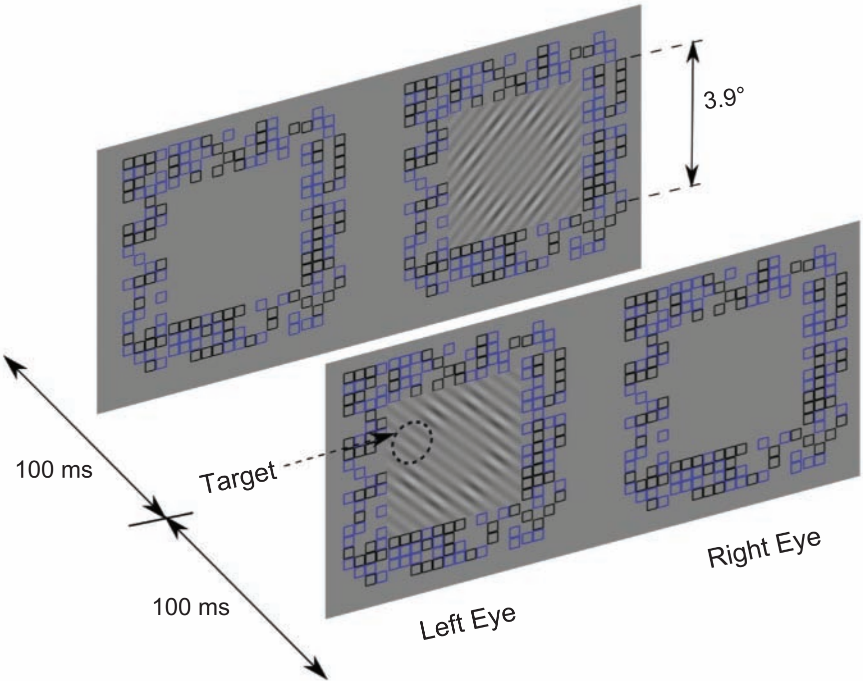

Fig. 1. Example of the rivalrous stimuli used in the experiment. In each frame, the display on the left was presented to the left eye, and the display on the right was presented to the right eye. The two frames depicted were alternated at 5 Hz. The target was a monocular Gabor patch with contrast lower than that of the other Gabor patches (the dashed circle that demarcates the target in this illustration was not present in the experiment). Stimuli were identical during the visual search task and the rivalry-report task, except that the target was absent in the latter and the squares in the frame were either black and yellow (search task) or black and blue (rivalry-report task).

Procedure

Observers alternated between the two tasks on different trials. Each trial lasted up to 15 s. The first task was the search task. The target was the Gabor that had a lower contrast than the others; it was present in only one of the two eyes' images (i.e., the target was monocular). The trial ended as soon as observers found the target or after 15 s if the target was not found within that time. In both cases, observers were asked to indicate the target's location by moving a circle to it with the arrow keys on the keyboard. Feedback about the correct location was provided.

The other task was a traditional binocular rivalry task: Observers had to report the perceived orientation of the Gabors by pressing one of two keys. Participants made multiple responses throughout the trial as their perception of the orientation changed. The first response had to be made within the first second; otherwise, the trial stopped and was administered again. If participants were uncertain, they were asked to choose the orientation percept that appeared the strongest. No target was present during this rivalry-report task. A blank screen appeared between successive trials and lasted until the observer pressed a button to begin the next trial.

The experiment consisted of four consecutive blocks of trials. Each block included 24 target-search trials and 24 rivalry-report trials. In the first block, the target was presented equally often in the right-tilted orientation and the left-tilted orientation. In contrast, in the two middle blocks, the target was always in the same orientation (whether this orientation was right tilted or left tilted was randomized across observers), which made the orientation of the image predictive of the presence of the target: We refer to this manipulation as *the orientation bias*. Observers were not told about this bias, nor did they become aware of it. As in the first block, the last block presented no bias.

In a calibration session conducted with each participant prior to starting Block 1, the contrast of the right-eye image was varied while the contrast of the left-eye image was fixed to 50% in the center of a Gabor and 20% in the background grating (mean luminance = 15 cd/m^2). The contrast for which the grating orientation presented to the right eye was reported for 50% of stimuli (no eye preference) was selected for the experiment. Target contrast was adjusted after each trial throughout the experiment in order to maintain a constant level of search performance. The performance goal was 83% correct in Block 1. For participants who did not achieve 83% correct on Block 1, the participants' actual performance on Block 1 was selected to be the performance goal for subsequent blocks. The adjustment procedure was an adaptive staircase with a step size asymmetric and proportional to the deviation between demonstrated and desired performance.

The significance of the difference in temporal dynamics between the first block and each subsequent one was analyzed with a nonparametric permutation test (Efron & Tibshirani, 1993). The specific test we used was a maximal suprathreshold cluster-size permutation test with t statistics (Nichols & Holmes, 2002). This test is appropriate for multiple comparisons: It finds the significant time clusters while avoiding Type I errors. To increase statistical power, we conducted a step-down procedure (Holmes, Blair, Watson, & Ford, 1996) in which significant clusters were identified and cut out, and the remaining data were tested again.

Results

We set the target's orientation to be the same in Blocks 2 and 3 but to be random in Blocks 1 and 4. Dominance in the first block therefore served as a baseline for analyzing the effects of the biased orientation introduced in the subsequent blocks. We performed an analysis of the orientation dominance measured during the rivalry-report task, as well as an analysis of the duration for which each consecutive percept was perceived.

Dominance

We defined the *biased orientation* as the orientation that was consistently associated with the target in Blocks 2 and 3. The dominance of a percept at time t was defined as the probability of seeing that particular percept at time t across all trials. We computed *biased-orientation dominance* as the probability of reporting a percept whose orientation was this biased orientation. *Biased-orientation dominance on the first percept* is biased-orientation dominance computed for the very first percept of each trial. Given our hypothesis, if the search task affected the rivalry dynamics, biased-orientation dominance should have increased between the first block and the next two. As a control, we also tested for dominance of the image presented to the right eye. Because the eye to which the target was presented was always random, we did not expect any change in right-eye dominance between blocks.

As we expected, biased-orientation dominance on the first percept was greatly increased in the two middle blocks relative to the first block (Fig. 2a)—Block 2 vs. Block 1: Wilcoxon $W = -31$, $p < .05$, Cohen's $d = 0.93$, odds ratio = 1.78; Block 3 vs. Block 1: Wilcoxon $W = -45$, $p < .005$, Cohen's $d = 1.56$, odds ratio = 2.04. In other words, the biased orientation was seen significantly more often than the unbiased one on the first percept. This increase was also significant in the last block, when the target's orientation was no longer biased, Wilcoxon $W = -31$, $p < .05$, Cohen's $d = 0.99$, odds ratio = 1.7. No statistical difference in the right-eye dominance on the first percept was found between the first block and the other blocks (Fig. 2b)—Wilcoxon $W = 5$, -27, and -8, respectively, for comparisons of Blocks 2 through 4 with Block 1; $p > .12$ for each comparison.

In the next analysis, we tested whether the orientation-dominance effect found on the first percept was present throughout the trial. We divided each 15-s trial into small temporal bins and computed the orientation dominance over each of these bins. Each bin was 0.6 s long, except for the first bin, which lasted 1 s. For this analysis, biased-orientation dominance was computed as the fraction of the temporal bin

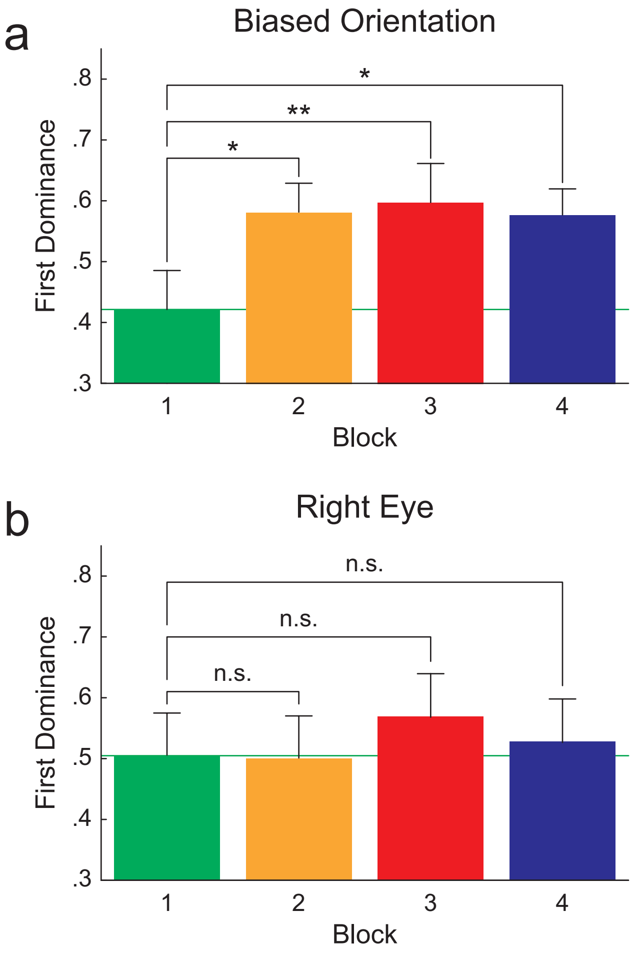

Fig. 2. Mean dominance on the first percept as a function of block. The graph in (a) shows biased-orientation dominance, and the graph in (b) shows right-eye dominance. By design, the biased orientation was the useful orientation in the search trials of Blocks 2 and 3. Dominance was measured in the rivalry-report trials. Asterisks indicate statistically significant comparisons (*$p < .05$, **$p < .005$). Error bars indicate standard errors of the mean.

during which the biased orientation was perceived (averaged across all trials), and it therefore could vary between 0 and 1. Biased-orientation dominance hovered around .5, which corresponds to equal probabilities of seeing the biased orientation and the orthogonal orientation (Fig. 3). However, at the beginnings of the trials, there was a significant increase in biased-orientation dominance in Blocks 2 through 4, compared with Block 1, and this increase lasted up to 2.2 s ($p < .05$, using the nonparametric permutation test described in the Method section). This result is consistent with the previous analysis on biased-orientation dominance on the first percept. A similar analysis was performed on right-eye dominance, and no difference between the first block and any other block was significant (*p*s > .47).

Phase-duration means and percept order

The strong dominance in favor of the biased orientation at the beginning of a trial could have multiple origins. We have shown that the biased orientation was more likely to be reported in the first percepts of Blocks 2 through 4 than in the first percepts of Block 1 (Fig. 2). Two additional effects could complement this first-percept bias: an increase in the duration of the biased percepts and a decrease in the duration of the nonbiased percepts. To determine whether there was any effect on phase duration, we performed an analysis of the mean phase durations (Fig. 4). A repeated measures analysis of variance with factors of orientation (biased or nonbiased), percept (consecutive ordinal rank), and block did not reveal a significant Block × Percept × Orientation interaction, $F(9, 72) = 1.39$, $p > .05$. This result suggests that introducing the orientation bias did not change the initial phase duration.

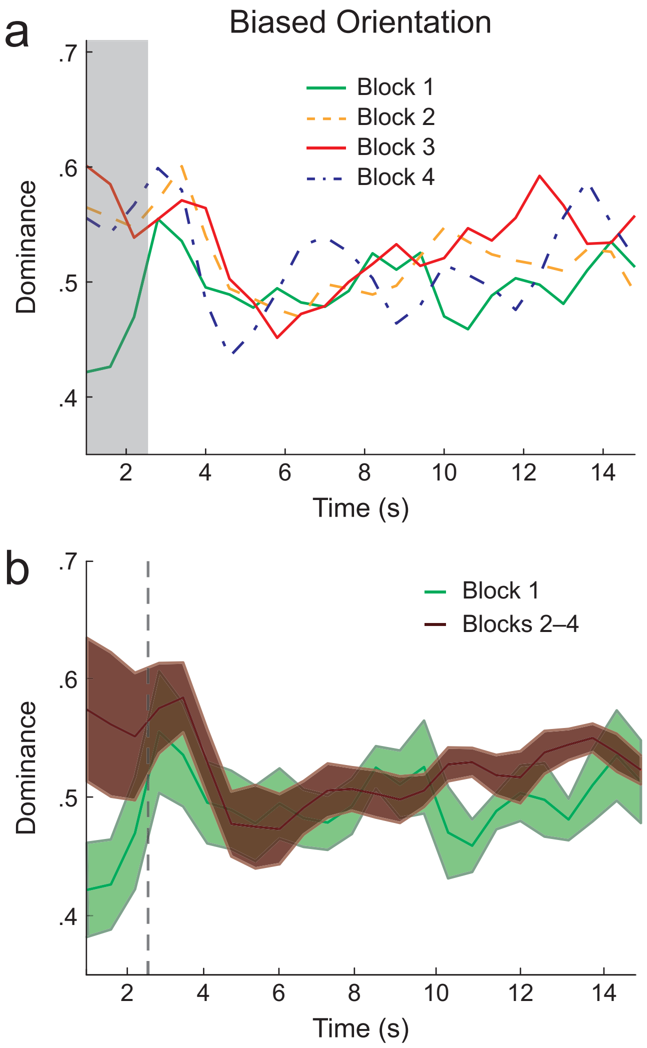

Fig. 3. Mean dominance of the biased orientation over the course of each trial. The graph in (a) plots biased-orientation dominance against trial time for each block. The shaded area indicates the period during which there were significant differences between Block 1 and the other blocks ($p < .05$). In (b), Blocks 2 through 4 are collapsed together for comparison with Block 1. Standard error is shown by the shaded areas around the lines. The area to the left of the gray dashed line is the period during which dominance differed significantly between Block 1 and the other blocks ($p < .05$).

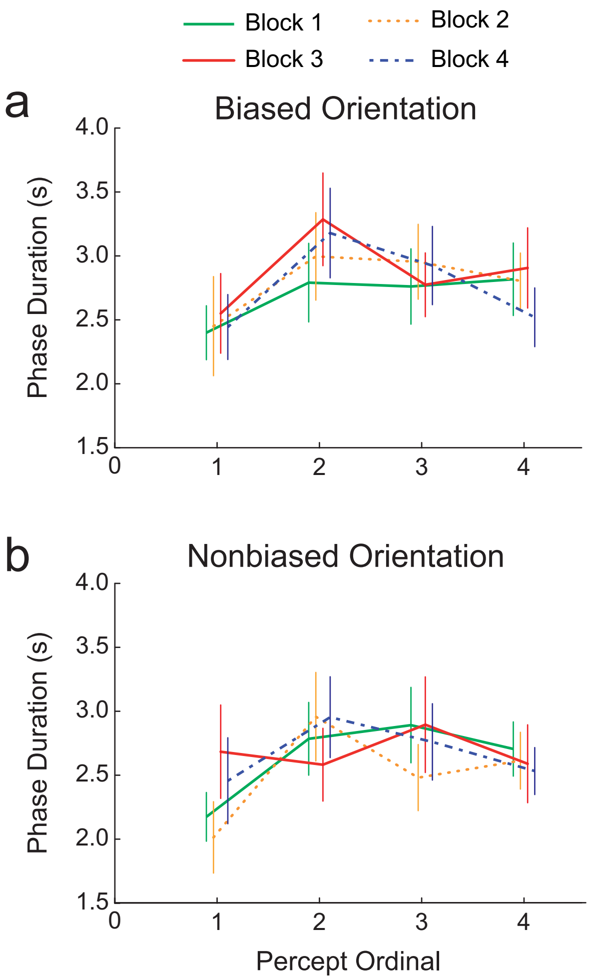

Fig. 4. Mean phase duration as a function of percept ordinal for each block. Phase durations were computed separately for the (a) biased and (b) nonbiased orientations and averaged within each block. Error bars indicate standard errors of the mean.

Discussion

We designed a novel paradigm to investigate the extent to which the task that observers are engaged in can affect the intake of useful information by changing the appearance of a stimulus. Under binocular rivalry, observers searched for a monocular, low-contrast target. Unbeknownst to them, during the middle blocks of the experiment, the target was always presented in the same orientation, but could be presented to either eye. Observers could be more successful in the search task if they were able to implicitly learn the regularity of the target orientation and to make the image containing objects with that orientation dominant. We decided to bias the target orientation because the rivalry literature tends to favor the idea that rivalry involves competition between oriented units rather than between preferred-eye units (i.e., units coding for information coming from one eye only; Andrews, 2001; Kovacs, Papathomas, Yang, & Feher, 1996; Logothetis et al., 1996).

In the rivalry task, we found a bias to perceive the image containing the target whenever a new stimulus was presented. This first-percept bias occurred early in Block 2 and was sustained even after the target resumed having a random orientation, in Block 4. The bias was due almost completely to an increase in the percentage of first percepts in the biased orientation (Fig. 2) and not to a change in phase durations (Fig. 4). This result confirms that important differences exist between initial and average bistable dynamics (Hupé & Rubin, 2003; Mamassian & Goutcher, 2005). In summary, observers were able to change the initial appearance of a rivalrous stimulus to help themselves perform an auxiliary search task.

In the following sections, we consider alternative explanations of our results based on stimulus strength, attention, and perceptual stabilization. We then discuss issues related to the need to postulate statistical learning to explain our findings and consider the relation of our findings to other task-driven effects.

Levelt's stimulus strength

As reviewed in the introduction, Levelt's (1966) stimulus strength is related to the contrast in the stimulus. In our experiment, a difference of stimulus strength was created because the target's contrast was lower than the contrast of the rest of the stimulus. However, it is important to keep in mind that our target was presented only during the search task, and not during the rivalry-report task. It is therefore difficult to see how the difference in contrast could have had any influence on the rivalry dynamics. In addition, we were careful to set the target to a lower contrast than the distractor objects. Therefore, if the binocular rivalry dynamics were influenced by a long-lasting effect of stimulus strength, the image that did not contain the target would have become dominant. We found the opposite pattern: The dynamics were changed such that the dominance of the image containing the target, rather than of the image with the largest overall contrast, was increased. Therefore, our results cannot be attributed to a difference in strength between the two rivalrous images.

Endogenous or exogenous attention

An explanation of our results in terms of exogenous attention is unsatisfactory for a very simple reason: The search task and the rivalry-report task took place in different trials. Thus, any potential effect would have had to survive at least 15 s to carry over to the next trial. However, exogenous effects are usually very short: In Ooi and He's (1999) experiment, for example, the pop-out effect disappeared after 3 s.

Similarly, an explanation in terms of endogenous attention is improbable. Because we asked our participants to report the target's location, not its orientation, in the search task, none of them noticed the orientation bias and reported it when asked about it at the end of the experiment. As a consequence, they could not have voluntarily controlled the dynamics of their binocular rivalry in a meaningful way because they had no reason to give an advantage to one particular percept. Finally, the effect we observed remained unchanged in Block 4, in which no orientation bias was present. Thus, explanations linked to short-lasting attention or voluntary control are unsatisfactory.

Perceptual stabilization

Perceptual stabilization (Leopold et al., 2002) could partially explain the first-percept bias. Let us assume that successful search trials ended with the target percept and that this last percept survived the blank interval before the rivalry-report trial (stabilization). Because the successful trials would have ended with the biased percept in Blocks 2 and 3, stabilization would have yielded a bias on the first percept in these blocks. If this hypothesis is correct, first-percept dominance should have differed between successful and failed trials. However, no significant difference was found (Wilcoxon $W = -12$, -23, -13, and -7 on Blocks 1–4, respectively; $p > .05$ for each comparison). Therefore, stabilization did not occur in our experiment. In addition, such an explanation would not account for the bias found in Block 4.

The long-lasting effect observed in this study demonstrates that some implicit learning occurred. Because the main alternative explanations have been addressed, we review some of the implications of this finding.

Statistical learning

To explain the effects we observed, we have to accept that statistical learning occurred during the biased blocks. Several studies have established that statistical learning can happen in perception. The first such experiments used a serial reaction time paradigm (Jimenez & Mendez, 1999; Schneider & Shiffrin, 1977) and showed that repetitions of temporal patterns can decrease the reaction time in a go/no-go task. Another surprising finding is that repeating the context (e.g., the location of the target relative to a set of distractors) enables observers to find the target more quickly (Chun & Jiang, 1998). The same reduction in reaction time occurred when context was defined as the association between the shapes of the target and the distractors independent of their location or as the association of the displacements of the target and distractors (Chun, 2000). Here, we showed that statistical associations resulting from task demands can directly affect what is perceived, revealing task-driven influences in binocular rivalry.

Relation to other task-driven effects

In the introduction, we reviewed Schyns and Oliva's experiment (1999). In their experiment, the frequency intake depended on the task. In light of our findings, frequency intake could depend on the usefulness of the frequency bandwidth for the task. If that is the case, a higher percentage of correct responses would be expected when only the preferred bandwidth was available for performing the task than when only the nonpreferred bandwidth was available. However, a higher percentage of correct responses was not found in Schyns and Oliva's control experiment (in which only the preferred bandwidth was available), meaning that usefulness probably had only a weak influence in their data.

Our results suggest that the first percept of binocular rivalry benefited from a mechanism that computes usefulness on the basis of previous experience with the task. This finding is surprising because binocular rivalry is often seen as mainly stimulus driven (Meng & Tong, 2004; van Ee et al., 2005). We think the result could be well described using the concept of gain function in a Bayesian framework (Kersten et al., 2004).

In conclusion, we believe that the observed effect (i.e., first-percept bias) on bistability dynamics reflects long-lasting learning resulting from the visual search task. The visual system learns implicitly the probability of being rewarded in the search task when one of the two rivalrous interpretations is perceived. The more useful a percept is, the more the visual system makes it dominant at the first perceptual decision.

Acknowledgments

We are grateful to Tomas Knapen for useful ideas about the design of the experiment and to Patrick Cavanagh for relevant pointers to the attention literature.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interest with respect to their authorship or the publication of this article.

References

Andrews, T.J. (2001). Binocular rivalry and visual awareness. *Trends in Cognitive Sciences*, *5*, 407–409.

Blake, R., & Logothetis, N.K. (2002). Visual competition. *Nature Reviews Neuroscience*, *3*, 13–21.

Brainard, D.H. (1997). The Psychophysics Toolbox. *Spatial Vision*, *10*, 433–436.

Brascamp, J.W., van Ee, R., Noest, A.J., Jacobs, R.H., & van den Berg, A.V. (2006). The time course of binocular rivalry reveals a fundamental role of noise. *Journal of Vision*, *6*(11), Article 8. Retrieved October 11, 2010, from http://www.journalofvision.org/content/6/11/8.full

Carrasco, M., Ling, S., & Read, S. (2004). Attention alters appearance. *Nature Neuroscience*, *7*, 308–313.

Chong, S.C., & Blake, R. (2006). Exogenous attention and endogenous attention influence initial dominance in binocular rivalry. *Vision Research*, *46*, 1794–1803.

Chun, M. (2000). Contextual cueing of visual attention. *Trends in Cognitive Sciences*, *4*, 170–178.

Chun, M., & Jiang, Y. (1998). Contextual cueing: Implicit learning and memory of visual context guides spatial attention. *Cognitive Psychology*, *36*, 28–71.

DuTour, É.F. (1760). Discussion d'une question d'optique [Discussion on a question of optics]. *l'Académie des Sciences: Mémoires de Mathématique et de Physique Présentés par Divers Savants*, *3*, 514–530.

Efron, B., & Tibshirani, R.J. (1993). *An introduction to the bootstrap* (Monographs on Statistics and Applied Probability 57). New York, NY: Chapman & Hall.

Ernst, M.O., & Banks, M.S. (2002). Humans integrate visual and haptic information in a statistically optimal fashion. *Nature*, *415*, 429–433.

Holmes, A.P., Blair, R.C., Watson, J., & Ford, I. (1996). Nonparametric analysis of statistic images from functional mapping experiments. *Journal of Cerebral Blood Flow & Metabolism*, *16*, 7–22.

Hupé, J.M., & Rubin, N. (2003). The dynamics of bi-stable alternation in ambiguous motion displays: A fresh look at plaids. *Vision Research*, *43*, 531–548.

Jimenez, L., & Mendez, C. (1999). Which attention is needed for implicit sequence learning? *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *25*, 236–259.

Kersten, D., Mamassian, P., & Yuille, A. (2004). Object perception as Bayesian inference. *Annual Review of Psychology*, *55*, 271–304.

Kovacs, I., Papathomas, T.V., Yang, M., & Feher, A. (1996). When the brain changes its mind: Interocular grouping during binocular rivalry. *Proceedings of the National Academy of Sciences, USA*, *93*, 15508–15511.

Lack, L.C. (1971). The role of accommodation in the control of binocular rivalry. *Perception & Psychophysics*, *10*, 38–42.

Lambert, A., Naikar, N., McLachlan, K., & Aitken, V. (1999). A new component of visual orienting: Implicit effects of peripheral information and subthreshold cues on covert attention. *Journal of Experimental Psychology: Human Perception and Performance*, *25*, 321–340.

Leopold, D.A., & Logothetis, N.K. (1999). Multistable phenomena: Changing views in perception. *Trends in Cognitive Sciences*, *3*, 254–264.

Leopold, D.A., Wilke, M., Maier, A., & Logothetis, N.K. (2002). Stable perception of visually ambiguous patterns. *Nature Neuroscience*, *5*, 605–609.

Levelt, W. (1966). The alternation process in binocular rivalry. *British Journal of Psychology*, *57*, 225–238.

Logothetis, N.K., Leopold, D.A., & Sheinberg, D.L. (1996). What is rivalling during binocular rivalry? *Nature*, *380*, 621–624.

Maier, A., Wilke, M., Logothetis, N.K., & Leopold, D.A. (2003). Perception of temporally interleaved ambiguous patterns. *Current Biology*, *13*, 1076–1085.

Maloney, L.T., Martello, M.F.D., Sahm, C., & Spillmann, L. (2005). Past trials influence perception of ambiguous motion quartets through pattern completion. *Proceedings of the National Academy of Sciences, USA*, *102*, 3164–3169.

Mamassian, P., & Goutcher, R. (2005). Temporal dynamics in bistable perception. *Journal of Vision*, *5*(4), Article 7. Retrieved October 11, 2010, from http://www.journalofvision.org/content/5/4/7.full

Mamassian, P., & Landy, M.S. (1998). Observer biases in the 3D interpretation of line drawings. *Vision Research*, *38*, 2817–2832.

Meng, M., & Tong, F. (2004). Can attention selectively bias bistable perception? Differences between binocular rivalry and ambiguous figures. *Journal of Vision*, *4*(7), Article 2. Retrieved October 11, 2010, from http://www.journalofvision.org/content/4/7/2.full

Mitchell, J.F., Stoner, G.R., & Reynolds, J.H. (2004). Object-based attention determines dominance in binocular rivalry. *Nature*, *429*, 410–413.

Nichols, T.E., & Holmes, A.P. (2002). Nonparametric permutation tests for functional neuroimaging: A primer with examples. *Human Brain Mapping*, *15*, 1–25.

Ooi, T.L., & He, Z.J. (1999). Binocular rivalry and visual awareness: The role of attention. *Perception*, *28*, 551–574.

Pelli, D.G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision*, *10*, 437–442.

Posner, M.I., Nissen, M.J., & Ogden, W.C. (1978). Attended and unattended processing modes: The role of set for spatial location. In H. Pick & E. Saltzman (Eds.), *Modes of perceiving and processing information* (pp. 137–157). Hillsdale, NJ: Erlbaum.

Schneider, W., & Shiffrin, R.M. (1977). Controlled and automatic human information processing: 1. Detection, search, and attention. *Psychological Review*, *84*, 1–66.

Schyns, P.G., & Oliva, A. (1999). Dr. Angry and Mr. Smile: When categorization flexibly modifies the perception of faces in rapid visual presentations. *Cognition*, *69*, 243–265.

Sundareswara, R., & Schrater, P.R. (2008). Perceptual multistability predicted by search model for Bayesian decisions. *Journal of Vision*, *8*(5), Article 12. Retrieved October 11, 2010, from http://www.journalofvision.org/content/8/5/12.full

Suzuki, S., & Grabowecky, M. (2002a). Evidence for perceptual "trapping" and adaptation in multistable binocular rivalry. *Neuron*, *36*, 143–157.

Suzuki, S., & Grabowecky, M. (2002b). Overlapping features can be parsed on the basis of rapid temporal cues that produce stable emergent percepts. *Vision Research*, *42*, 2669–2692.

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive Psychology*, *12*, 97–136.

van Ee, R., van Dam, L.C.J., & Brouwer, G.J. (2005). Voluntary control and the dynamics of perceptual bi-stability. *Vision Research*, *45*, 41–55.

Walker, P. (1978). Binocular rivalry: Central or peripheral selective processes. *Psychological Bulletin*, *85*, 376–389.