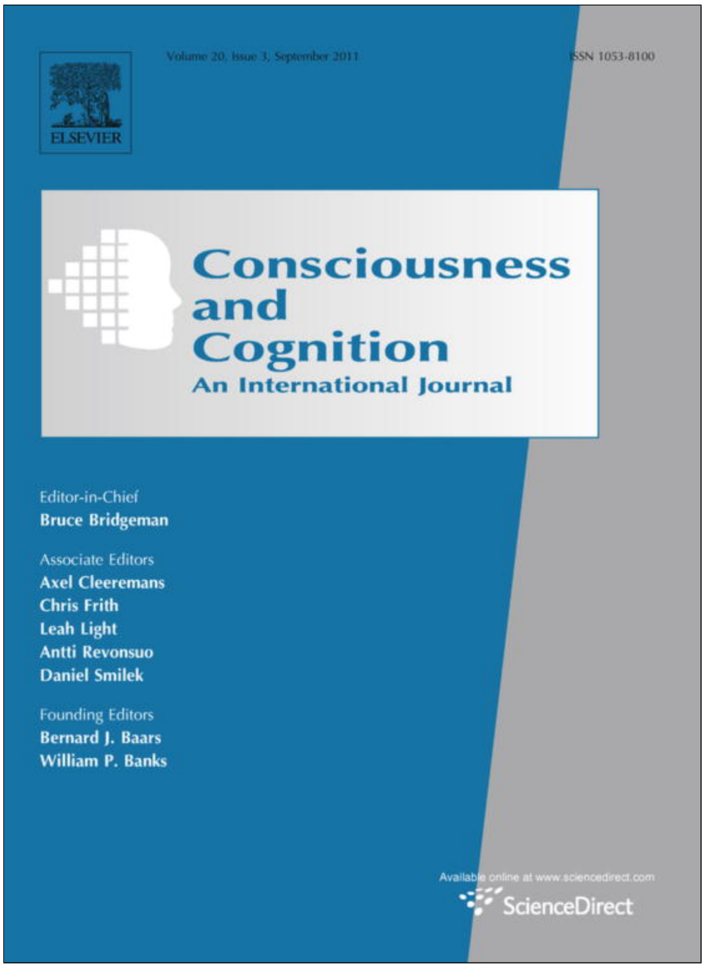

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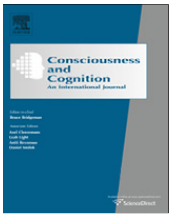

Scene congruency biases Binocular Rivalry

Liad Mudrik [a,*], Leon Y. Deouell [b], Dominique Lamy [a]

[a] *Department of Psychology, Tel Aviv University, Israel*
[b] *Department of Psychology, and Interdisciplinary Center for Neural Computation, The Hebrew University of Jerusalem, Israel*

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ABSTRACT

Contextual regularities, that is, objects' tendency to appear with certain other objects, facilitate the processing of visual scenes and confer contextually incongruent objects with a special attentional status. This study was aimed at investigating the mechanisms underlying this attentional advantage using Binocular Rivalry (BR). In two experiments, congruent and incongruent images (e.g., a man drinking from a glass vs. a man "drinking" from a hairbrush) were pitted against each other, yielding a version of BR in which two objects rival within a given scene. Incongruent objects predominated in awareness longer than congruent ones. This effect stemmed from the fact that their dominance epochs lasted longer on the average than those of congruent objects, suggesting a difficulty to disengage attention from such objects. On the other hand, no support was found for the notion that incongruent objects also attract attention.

1. Introduction

In a natural environment, objects tend to appear together with other objects: knives are usually encountered with forks, and both are more likely to appear in the kitchen or dining room rather than in the bathroom. These contextual regularities facilitate the processing of an otherwise overwhelming load of visual details: they enable us to perform fast judgments about the objects that make up a scene (e.g., Antes, Penland, & Metzger, 1981; Biederman, 1972; Boyce & Pollatsek, 1992; Friedman, 1979). Indeed, incongruent objects (i.e., objects with low probability of appearing in their current context) are identified slower (e.g., Bar & Ullman, 1996; Davenport & Potter, 2004; Palmer, 1975) and less accurately (e.g., Biederman, Rabinowitz, Glass, & Stacy, 1974; Boyce, Pollatsek, & Rayner, 1989; Underwood, 2005) than congruent objects (but see Hollingworth & Henderson, 1998).

Several findings suggest that attentional resources are preferentially allocated to incongruent objects. Eye fixation studies (for reviews about the relations between eye fixations and attention, see Liversedge & Findlay, 2000; Rayner, 1998) have shown that subjects fixate more often, for longer periods and in some studies also earlier on incongruent objects than on congruent ones (De Graef, Christiaens, & Dydewalle, 1990; De Graef, Detroy, & Dydewalle, 1992; Friedman, 1979; Loftus & Mackworth, 1978; Underwood & Foulsham, 2006; Underwood, Foulsham, van Loon, Humphreys, & Bloyce, 2006; Underwood, Templeman, Lamming, & Foulsham, 2008). In a similar vein, incongruent objects appear to resist change blindness better than do congruent ones (Hollingworth & Henderson, 2000). Change blindness, which refers to subjects' failure to notice even large changes in visual scenes that are alternately displayed and separated by a mask (Simons & Levin, 1997; Simons & Rensink, 2005) is attenuated for objects with high attentional priority (e.g., Kelley, Chun, & Chua, 2003; Rensink, Oregan, & Clark, 1997; Scholl, 2000). Thus, the finding of reduced change blindness for incongruent objects is compatible with the notion that these objects enjoy a special attentional status.

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* Corresponding author. Address: Department of Psychology, Tel Aviv University, Ramat Aviv, POB 39040. Tel Aviv 69978, Israel.
E-mail address: liadmu@gmail.com (L. Mudrik).

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Two different mechanisms have been suggested to account for this advantage of incongruent objects (Hollingworth & Henderson, 2000). According to the *attentional attraction hypothesis,* covert attention is drawn to an object when there is difficulty reconciling that object's identity with the overall meaning of the scene. During processing of a scene, the gist is rapidly extracted, together with first details about the scene's constituents (Carr, Mccauley, Sperber, & Parmelee, 1982; Oliva & Schyns, 1997, 2000; Oliva & Torralba, 2006). At that stage, partial recognition of the incongruent object is sufficient to determine that it violates the gist of the scene (Loftus & Mackworth, 1978; Underwood et al., 2008). Attention might be then directed to the suspicious object to gather finer details about it, or to ensure that no perceptual error was made during its partial recognition. The attentional attraction hypothesis is supported by the finding that incongruent objects are fixated earlier than congruent objects (e.g., Loftus & Mackworth, 1978). While failures to replicate this finding have been reported (De Graef et al., 1990; Henderson, Weeks, & Hollingworth, 1999), a well-controlled study by Underwood and his colleagues (2008) provides strong support for attentional attraction.

The *attentional disengagement hypothesis* (Henderson & Hollingworth, 1998, 1999; Mackworth & Morandi, 1967) suggests that once an incongruent object has been attended, either incidentally or because it is physically salient (due to differences in color, depth, etc...), it is more difficult to disengage one's attention from it because the resolution of the semantic inconsistency requires further scrutiny.

Although these accounts have been typically contrasted one against the other (e.g., Hollingworth & Henderson, 2000), they are not necessarily incompatible. Incongruent objects may both attract attention and hold it longer than objects that are compatible with the surrounding context. In this study, we used Binocular Rivalry (BR) in order to further examine this issue. During BR, two different stimuli are presented simultaneously but separately to each eye. This results in a subjective percept that alternates between the two stimuli, such that when one is fully perceived, the other is shunned from conscious awareness (see Blake & Logothetis, 2002; Leopold & Logothetis, 1999; Sterzer, Kleinschmidt, & Rees, 2009, for reviews). When the two stimuli are more or less equally salient, the alternations are unpredictable in duration, as if being generated by a stochastic process driven by an unstable time constant, with no dominant percept (Fox & Herrmann, 1967; Lehky, 1995; Levelt, 1965).

However, if one stimulus is ''stronger'' than the other, it will be perceived for a larger percentage of viewing time than the weaker stimulus (Blake & Logothetis, 2002). Effects of stimulus strength on dominance during BR have been demonstrated for perceptual saliency that results from physical characteristics such as brightness and contrast (Levelt, 1965; Mueller & Blake, 1989), luminance (Fox & Rasche, 1969; Kakizaki, 1960), motion (Breese, 1909; Wade, de Weert, & Swanston, 1984) or spatial frequency (Fahle, 1982). Dominance is also affected by higher-level variables such as emotional value (e.g., Alpers & Pauli, 2006; Alpers, Ruhleder, Walz, Muhlberger, & Pauli, 2005; Coren & Russell, 1992; Yoon, Joormann, Hong, & Kang, 2009), or personal value to the subject (Gilson, Brown, & Daves, 1982; Kohn, 1960). While early evidence for a familiarity advantage during BR (Bagby, 1957; Engel, 1956; Goryo, 1969) suffered from methodological shortcomings (for review, see Walker, 1978), more recent, well-controlled experiments showed that recognizable faces are indeed more dominant than unrecognizable ones during rivalry (Jiang, Costello, & He, 2007; Yu & Blake, 1992).

It has been suggested that dominance of a percept during BR indicates that this percept has gained attentional priority relative to the alternative percept (for a discussion of the similarities and differences between perceptual multistability and processes of selective attention, see Leopold & Logothetis, 1999; Logothetis, 1998), an idea that dates back to the time of Helmholtz (1867/1962). Consistent with this view, an fMRI study revealed parietal and frontal activations during perceptual alternations in BR (Lumer, Friston, & Rees, 1998), suggesting that attentional networks are indeed involved in biasing perception (see also Sheinberg & Logothetis, 1997).

Although recent behavioral studies demonstrated top-down, voluntary attention influence during initial (Chong & Blake, 2006) as well as ongoing rivalry (Ooi & He, 1999, 2005; Sasaki & Gyoba, 2002; van Ee, van Dam, & Brouwer, 2005; Walker, 1978), the role of endogenous attention in influencing BR predominance has been controversial (for reviews, see Fox, 1991; Lack, 1978), much like the relations of endogenous attention with awareness (Kentridge, Nijboer, & Heywood, 2008; Koch & Tsuchiya, 2007; van Boxtel, Tsuchiya, & Koch, 2009; Wyart & Tallon-Baudry, 2008). By contrast, bottom-up, data-driven factors that attract attention *exogenously* are more widely recognized as a powerful determinant of BR predominance (Duensing & Miller, 1979; Fox & Check, 1968; Mitchell, Stoner, & Reynolds, 2004; Ooi & He, 1999, 2005; Walker, 1975; Walker & Powell, 1979); attention cued by such exogenous factors is also a crucial forerunner of conscious perception in other paradigms (Chica, Lasaponara, Lupi ez, Doricchi, & Bartolomeo, 2010). It is thus reasonable to suggest that data-driven factors that bias BR predominance probably do so by exogenously attracting the observer's attention. Therefore, although BR predominance measures directly reflect subjects' *awareness*, they can shed light on the power of the rivaling stimuli in attracting/engaging attention in a bottom-up manner.

In this study, we sought to determine the attentional status of context-incongruent objects relative to congruent ones, by comparing their predominance during BR. We created an object-alternation version of rivalry where the alternations occur *between objects within a fixed background* shared by the two eyes, rather than between two whole images. In each trial, the same image of a real-life scene was presented to each eye, but in one eye the central object in the scene was congruent with it, and in the other this central object was incongruent. For example, in one eye a man would be drinking from a glass, while in the other the same man would be drinking from a hairbrush. The subjects reported seeing the whole image, and experiencing alternations between the congruent and incongruent objects only. They continuously indicated which object they perceived by key presses, throughout each trial. We expected incongruent objects to predominate over congruent objects, reflecting the former's presumed attentional advantage.

The commonly used *predominance score* of one percept during rivalry is defined as the dominance duration of this percept divided by the sum of the dominance durations of the two percepts, excluding the periods during which the two percepts are perceived as intermixed or fused (Alais & Blake, 1998; Yu & Blake, 1992). The predominance score, however, conflates the number of dominance events within a trial and their duration (see Kim & Blake, 2007; Sheth & Pham, 2008, for a similar distinction). A high predominance score may indicate: (1) that the predominant percept enjoys a larger number of dominance events (but any one of these events may be as long as the events in which the alternative percept dominates), (2) that it occupies the participants' awareness for longer stretches of time (without necessarily emerging into their awareness more often) or (3) both. Yet, these two indices have very different implications with regard to the distinction between the disengagement and attraction hypotheses. On the one hand, if it takes time to disengage one's attention from, or in other words attention is engaged for longer with, an incongruent stimulus, the corresponding percept should remain dominant for longer durations after it has gained access to awareness. This should be associated with longer average dominance duration for this percept, as indeed happens with stimuli which subjects endogenously try to attend to in rivalry situations (e.g. van Ee et al., 2005) or with arousing stimuli competing with non-arousing stimuli (Sheth & Pham, 2008). On the other hand, if incongruent stimuli attract attention, they can be expected to emerge into awareness faster than congruent stimuli. As a consequence, they should be more likely to be the first to gain dominance at the onset of trials (henceforward 'initial percept'), just as other stimuli that attract attention exogenously, irrespective of subjects' intentions, are more likely to gain dominance early on (Alpers & Pauli, 2006; Alpers et al., 2005; Mitchell et al., 2004; Yoon et al., 2009). Similarly, incongruent stimuli should more frequently gain dominance immediately after a fusion period than their congruent counterparts. Thus, we suggest that in the current context the distinction between initial or post-fusion percept and the mean duration (i.e. independent from the number of perceptual alternations during rivalry, (e.g., Kim & Blake, 2007; Sheth & Pham, 2008)), can be used to examine the relative contribution of later disengagement vs. early attraction mechanisms of stimulus predominance.

2. Experiment 1

On each trial of the first experiment, the same scene depicting a human action involving an object was presented to each eye, but in one eye, the object was congruent with the action performed on it, whereas in the other eye, it was incongruent with it (Fig. 1). The subjects were instructed to identify the object on which the action was performed and to continuously report perceptual alternations relative to this object as soon as these occurred. Subjects were not familiarized with the critical objects but first encountered them during the BR procedure.

2.1. Method

2.1.1. Participants

The participants were 14 healthy volunteers (nine females, four left handed), students of the Hebrew University of Jerusalem, aged 22–35 (mean = 25), with reportedly normal or corrected-to-normal sight and no psychiatric or neurological history. They participated in the experiment for payment (~5$ per hour). All experiments described in this paper were approved by the ethics committee of the department of psychology at the Hebrew University, and informed consent was obtained after the experimental procedures were explained to the subjects.

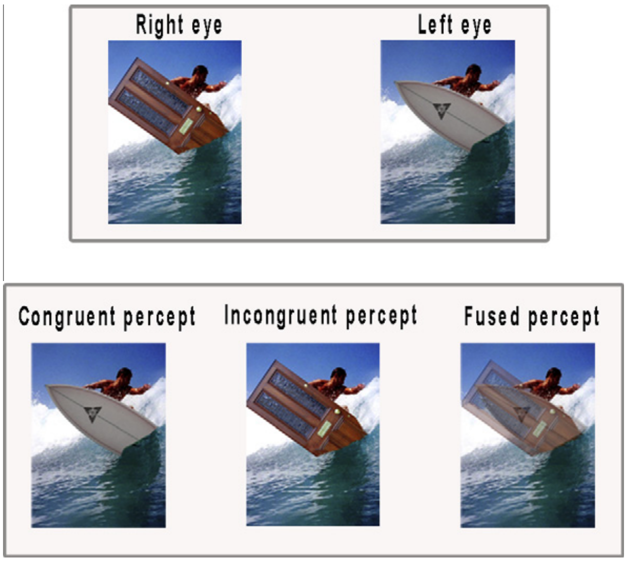

Fig. 1. Top: dichoptic stimulus presentation of a congruent scene to one eye and of an incongruent scene to the other eye. Bottom: examples of the possible visual percepts: a congruent scene, an incongruent scene or a mixture of both (i.e., the congruent and incongruent objects are perceived simultaneously, which is referred to as a fused percept).

2.1.2. Stimuli and apparatus

Subjects sat in a dimly lit room. The stimuli were presented on a 17″ CRT monitor with a 100-Hz refresh rate, using E-prime software. A mirror stereoscope was used to ensure that in each trial, the two images were presented separately to each eye. The screen was located 36 cm away from the stereoscope.

Forty-three pairs of colored pictures (viewing angle 10.68° × 7.71° through the stereoscope, see below) were designed for the experiment, using Adobe Photoshop software. Each pair included a congruent and an incongruent version of the same scene (Fig. 1). The scenes were real-life pictures taken from internet sources. They depicted a human action involving an object (e.g., a man playing a violin, a woman using a microscope). The incongruent scene was created by replacing the original object of the action with another, unrelated object (e.g., instead of a violin, the man was "playing" a broomstick). In order to equate the stimulus conditions prevailing in the congruent and incongruent scenes, congruent scenes were also digitally modified so that the original object was replaced by another exemplar of the same object category (e.g. one violin replaced by another violin, copied from another image). The pasted objects were also chosen from real-life pictures taken from internet sources. All the processed pictures were pre-tested in a separate experiment, and were rated by 24 subjects as being either highly incongruent or highly congruent (see Mudrik, Lamy, & Deouell, 2010 for the original set of stimuli).[1]

The pictures' luminance and RMS contrast were equated using in-house Adobe Photoshop script. For each object, 'Levels' and 'Contrast' adjustments (non-linear stretching and linear scaling, respectively) were applied to bring the mean luminance and the RMS contrast of each object to equal the average luminance and contrast, respectively, across objects. Because the background is identical for congruent and incongruent images, only isolated objects were equalized. This procedure resulted in a set of images with the same luminance and contrast values at the level of the background, object, and combined image.

In order to ensure that there were no other systematic differences in the low-level features of the two types of scenes, two analyses were conducted. First, all pairs were examined using the visual saliency model developed by Itti and Koch (2000). This computational model combines information across dimensions, namely orientation, intensity and color information, in a purely stimulus-driven manner, to create an explicit two-dimensional map that encodes the visual saliency or conspicuity of objects, and predict eye movements to different locations within the image based on this saliency. Such maps were prepared for all scenes and were visually compared to look for noticeable differences between the congruent and incongruent versions of a scene. We didn't find any such difference. Then, to get a more quantitative objective measure, the saliency values of all objects were determined according to the predicted number of eye fixations prior to fixating on the critical object – the more such fixations, the less salient the object was deemed to be. Objects were then divided to low (more than 7 fixations), medium (4–6 fixations) or high (1–3 fixations) saliency. No differences were found between the saliency levels of congruent vs. incongruent objects using a Chi square test ($p = .69$).

Second, we evaluated the images' perceived similarity in chromaticity and spatial frequency according to Neumann and Gegenfurtner's (2006) model. The model indices are constructed in accordance with some of the known properties of the early stages of human vision. The color codes in the "red–green" and "blue–yellow" channels are modeled using the color-opponent axes of a DKL color space and a logarithmic-radial scaling for the histogram bins. 2D discrete Fourier transform is used to create an orientation and spatial frequency histogram analogous to similar representations in the visual cortex. We applied the model to calculate similarity scores between every two images used in the experiment, and then compared the average similarity measures of all within-group pairs (congruent–congruent and incongruent–incongruent), to the similarity calculated between pairs of congruent and incongruent images, using Student's t-test. If congruent images systematically differ from incongruent images along these measures of chromaticity and spatial frequency, higher similarity measures should be found for within-group pairs, than across groups.

Under this assumption, we conducted a non-parametric bootstrap analysis, to assess whether the difference between within and between-group similarities was significant, without any assumption on the normality of the distributions. The rationale of this analysis was that under the null hypothesis of no difference between groups, the designation of an image as congruent or incongruent is immaterial. Thus, for 2500 iterations, we randomly permuted the similarity matrix so that a random number of similarity measures were designated 'between-' instead of 'within-' and vice versa. Thus, on each iteration we produced surrogate 'within-group' and 'between-group' similarity ratings and we compared their mean ratings using the Student's t-test. The frequency distribution of the t values thus obtained represents the distribution of t values under the null hypothesis of no difference. A t value in the true comparison (i.e. without mixing the similarity matrix) exceeding 95% of these values would be violating the assumption of no difference. In the spatial frequency domain, the comparison between the similarity scores within and between groups ($t(3158) = 1.28$) was not significantly different from the null distribution. In the chromaticity domain the images were in fact significantly more similar *between* groups than within ($t(3158) = 2.29$, $p = 0.02$). This result is in opposition to the hypothesis that congruent and incongruent images differed in chromaticity, and likely reflects the fact that each image had a comparable image in the other group but not within its own group. Note that similar qualitative results were obtained using parametric statistics (i.e., comparing the t values to the textbook t distribution assuming normality). Thus, congruent and incongruent images could not be discerned by luminance, contrast, chromaticity, spatial frequency, or object saliency as defined in the Itti and Koch model.

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[1] The pre-test was conducted on a larger set of stimuli ($N = 161$) used by us in a previous study (Mudrik et al., 2010). Out of these, in the present study, we chose the scenes that were rated as most congruent and most incongruent. Note that while in that previous study only the incongruent objects were pasted, while here both congruent and incongruent stimuli were digitally inserted into the picture.

2.1.3. Procedure

The experimental session included 40 experimental trials preceded by three practice trials. All trials started with a fixation cross presented to each eye, within a black frame. The subjects adjusted the mirrors of the stereoscope using two knobs so that each eye in isolation saw a fixation cross and a full frame, and with two eyes the fixation crosses and frames were fused.

After adjustment, subjects pressed the space bar of a keyboard. Then, a congruent scene and its incongruent counterpart were simultaneously presented, one to each eye, for 60 s. On half of the trials, congruent scenes were presented to the right eye, and in the other half – to the left. The two types of trials were intermixed, with the constraint that the same scene type (congruent/incongruent scene) was never presented to the same eye (right/left) in four or more consecutive trials.

At the beginning of each trial (in both the practice and experimental sessions), the experimenter explained that the perceived image might change several times during the trial. Then, subjects were instructed to press and hold the right-arrow key as soon as they saw the first image, while verbally describing what they saw, and specifically naming the object appearing in the scene. As soon as the percept changed (so that a different object was seen on the same background), subjects had to press and hold the left-arrow key, and again verbally name the object. The experimenter told the subjects that from then onwards, when they saw the first object they had identified they should press the right-arrow key, and when they saw the second object they should press the left-arrow key (without a verbal report). The subjects were instructed to press the up arrow key when they saw a fusion of the two objects.

2.1.4. Data analysis

The predominance scores (PS) in a trial were defined as:

$$\mathrm{PS_i} = d_\mathrm{i}/(d_\mathrm{c} + d_\mathrm{i}),\ \text{and}\ \mathrm{PS_c} = d_\mathrm{c}/(d_\mathrm{c} + d_\mathrm{i})$$

where $\mathrm{PS_i}$ and $\mathrm{PS_c}$ are the predominance scores for the incongruent and congruent images; d_c = total dominance duration of the congruent image in the trial; d_i = total dominance duration of the incongruent image in the trial. Fusion time is not included in this calculation; therefore $d_\mathrm{c} + d_\mathrm{i}$ are usually smaller than the total trial duration. $\mathrm{PS_i}$ was calculated in each trial and averaged across trials. Since $\mathrm{PS_c} + \mathrm{PS_i} = 1$ by definition and under the null hypothesis $\mathrm{PS_c} = \mathrm{PS_i}$, the average $\mathrm{PS_i}$ was tested for significant increase above 0.5 with a one-sample *t*-test across subjects.

The average dominance duration (ADD) was calculated in each trial as

$$\mathrm{ADD_c} = d_\mathrm{c}/N_\mathrm{c}\ \text{and}\ \mathrm{ADD_i} = d_\mathrm{i}/N_\mathrm{i}$$

where N_c and N_i are the numbers of congruent and incongruent dominance events in the trial, respectively. The average dominance duration was taken as a measure of disengagement.

The probability of percepts after a fusion (PAF) was calculated across trials in every subject, as

$$\mathrm{PAF_c} = N_\mathrm{c}/(N_\mathrm{c} + N_\mathrm{i})\ \text{and}\ \mathrm{PAF_i} = N_\mathrm{i}/(N_\mathrm{c} + N_\mathrm{i})$$

where N_c and N_i are the numbers of congruent and incongruent percepts that followed a fused percept throughout the session, respectively. Similar to the logic of the PS measure, the average $\mathrm{PAF_i}$ was tested for significant increase over 0.5 with a one-sample *t*-test across subjects.

The *number of initial percepts (IP)* for each percept type (congruent/incongruent) was calculated across trials in every subject. Trials that began with a fusion were not counted.[2]

The probability of percepts after a fusion and the number of initial percepts for one category relative to the other served as measures of attentional attraction.

2.2. Results

2.2.1. Predominance score

As expected, incongruent objects were predominant throughout rivalry. The $\mathrm{PS_i}$ (0.53, SD = 0.04) was significantly larger than 0.5 (the expected ratio if the congruent and incongruent objects had been perceived for equal durations; $t(13) = 2.68$, $p = .019$).

2.2.2. Disengagement measure

The average dominance duration of incongruent percepts (mean ADD = 10.40 s, SD = 7.02 s) was longer than the average dominance duration of congruent percepts (mean ADD = 8.37 s, SD = 6.58 s, $t(13) = 3.27$, $p = .006$).

2.2.3. Attraction measures

Following a period of fused percept, subjects did not perceive incongruent objects more often than congruent ones (mean $\mathrm{PAF_i} = 0.53$, SD = 0.08, not significantly different than 0.5, $t(13) = 1.32$, $p = .21$).

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[2] We also calculated this measure including trials that began with a fusion (i.e., we ignored the first press), and the results did not change.

Similarly, there was no difference between the number of trials in which subjects reported the incongruent object as their initial percept (mean $IP_i = 17.29$, SD = 3.36) and the number of trials in which they reported perceiving the congruent object first (mean $IP_c = 17.50$, SD = 4.42, $t(13) = 0.14$, $p = .89$).

2.3. Discussion

In Experiment 1, we used an object-alternation version of the Binocular Rivalry paradigm to unveil the mechanisms underlying the attentional advantage of incongruent objects over congruent ones. In this version of BR, the image remains constant, and two objects located at the same place in the scene compete for perceptual dominance. Subjects experienced perceptual alternations between the objects, so that, for instance, a person was perceived speaking over the phone and then speaking into a shoe, or vice versa.

The results provide clear support for contextual effects on the dominance pattern in BR. As low-level features were carefully held similar in the two competing images, the present experiment addressed the criticisms (Walker, 1978; Yu & Blake, 1992) that have been raised against older studies (Bagby, 1957; Engel, 1956; Gilson et al., 1982; Goryo, 1969; Kohn, 1960). Incongruent objects that did not differ in their visual properties from congruent ones predominated during BR presumably due to the lack of semantic correspondence between these objects and their context. Such predominance reflected a reluctance to disengage attention from incongruent stimuli, as indexed by the average dominance duration measure (disengagement hypothesis): dominance events were longer on the average for incongruent than for congruent objects. No support was found for the notion that incongruent objects can also attract attention: incongruent objects were as likely to be perceived after fusion as congruent ones, and as likely to emerge as the first percept at the beginning of rivalry.

One may argue that the predominance of the incongruent percept that we observed during Binocular Rivalry may reflect the widely established difficulty to identify out-of-context objects (e.g., Biederman, 1972; Biederman, Glass, & Stacy, 1973; Boyce & Pollatsek, 1992; Boyce et al., 1989; Kosslyn, 1994; Palmer, 1975). Since at the beginning of each trial subjects were asked to identify the objects as they gained dominance, they might have had to spend more time looking at objects that did not semantically match their context in order to reach identification. Accordingly, the longer average duration of incongruent relative to congruent percepts may simply reflect the difficulty to recognize incongruent objects at the beginning of each trial rather than the ability of incongruent objects to hold attention. To test this possibility, we recalculated the predominance scores and the average dominance duration excluding the first dominance periods of congruent and incongruent objects in each trial from the calculation. Incongruency predominance and longer dominance duration remained significant (mean $PS_i = 0.53$, SD = 0.05; $t(13) = 2.64$, $p = .02$, mean ADD = 5.49 s, SD = 4.73 s vs. 7.00 s, SD = 4.32 s for congruent and incongruent objects, respectively, $t(13) = 2.23$, $p = .04$). Although this finding weakens the argument that the predominance of the incongruent scenes resulted from difficulty to identify incongruent objects, Experiment 2 was performed in order to replicate the effect of incongruency on BR predominance, while avoiding the initial recognition caveat.

3. Experiment 2

In Experiment 2, subjects were familiarized with the objects before each rivalry trial in order to eliminate the added difficulty of identifying the incongruent object relative to the congruent one that may have prevailed in Experiment 1. We expected to replicate the results obtained in Experiment 1. Namely, we expected incongruent objects to predominate and to yield larger scores on the disengagement measure but not on the attraction measures.

3.1. Method

3.1.1. Participants

Eighteen healthy volunteers (15 females, one left handed), students of the Hebrew University of Jerusalem, aged 19–29 (mean = 23.5), with reportedly normal or corrected-to-normal sight and no psychiatric or neurological history, participated in the experiment for payment (~5$ per hour). Two additional subjects were excluded, because they reported very few alternations between percepts throughout the experiment (less than two alternations in each trial on average).

3.1.2. Stimuli, apparatus and procedure

The stimuli, apparatus and procedure were similar to those used in Experiment 1 except for the following changes. Before each trial, subjects viewed both the congruent-to-be and incongruent-to-be objects presented side by side, on either side of fixation, against a white background (with no context). Both objects were seen through both eyes, so that no rivalry occurred. The location of the objects (right/left to the fixation cross) was counterbalanced across trials, with the constraint that the same object type (congruent-to-be/incongruent-to-be) was never presented at the same location (right/left) in four or more consecutive trials. Subject viewed the objects for a few seconds, and named them. After identification, the congruent and incongruent objects remained on screen while the experimenter explained that during the next part of the trial, subjects should press the right-arrow key when they perceived the object presented now on the right, and the left-arrow key when they perceived the object on the left, or the up arrow key if their percept was a mixture of the two objects. Then, the complete scenes (including the objects within their context) were presented, such that rivalry between the objects began. The procedure thus became identical to that of Experiment 1. Because the addition of an object-identification phase on each trial made the trials longer than in Experiment 1, the number of trials was reduced from 40 to 30, to avoid fatigue. The 30 pairs used in Experiment 2 were the images rated as most congruent and most incongruent in the pre-test we conducted.

3.2. Results

3.2.1. Predominance score

As in Experiment 1, the predominance score of incongruent objects (mean $PS_i = 0.53$, SD = 0.05) was significantly larger than 0.5, $t(17) = 2.37$, $p = .03$.

3.2.2. Disengagement measure

Average dominance duration of incongruent percepts was again longer (mean ADD = 9.77 s, SD = 5.24 s) than the average dominance duration of congruent percepts (mean ADD = 7.23 s, SD = 4.76 s), $t(17) = 3.69$, $p = .002$.

3.2.3. Attraction measures

As in Experiment 1, the probability of congruent and incongruent percepts to be reported after a fusion did not significantly differ from 0.5 (mean $PAF_i = 0.50$, SD = 0.12, $t(17) = 0.04$, $p = .97$). In addition, the number of trials in which subjects reported the incongruent object as their initial percept (mean $IP_i = 11.00$, SD = 3.23) was actually lower than the number of trials in which they reported perceiving the congruent object first (mean $IP_c = 14.11$, SD = 3.95, $t(17) = 2.66$, $p = .016$).

Table 1 presents the results of both experiments on all measures.

3.3. Discussion

As in Experiment 1, incongruent objects predominated over congruent objects when potential differences in initial identification time of the congruent vs. incongruent objects were eliminated by familiarizing the subjects with the critical objects before each trial. Again, this finding resulted from the subjects' difficulty to disengage their attention from the incongruent percept, as indicated by the average dominance duration measure, and there was no evidence in favor of the attraction hypothesis. However, in contrast with the pattern observed in Experiment 1, the first percept in a trial was more often the congruent rather than the incongruent object. The latter finding likely resulted from contextual priming. As subjects were pre-exposed to the objects during the familiarization phase in this experiment, the context (viewed by both eyes without rivalry) was more likely to facilitate retrieval of the representation of the congruent than of the incongruent object (both held in working memory after the familiarization stage), thereby allowing the congruent object to be resolved first and gain dominance.

Thus, both experiments support the hypothesis that incongruent objects engage attention for a longer time than congruent objects. However, low-level differences have been widely shown to affect BR predominance (e.g., Breese, 1909; Fahle, 1982; Fox & Rasche, 1969; Levelt, 1965; Mueller & Blake, 1989). Could the effect we reported still be a result of some non-semantic, low-level differences between the images of congruent and incongruent objects which escaped the elaborate measures we employed (see Methods, Section 2.1.2) to eliminate such differences? Experiment 3 was conducted to empirically test this possibility. We pitted *isolated* congruent and incongruent objects against each other, thereby eliminating contextual influences on rivalry. We reasoned that if low-level differences rather than contextual congruity indeed accounted for our findings, the isolated objects in the present experiment should be associated with the same effects as when they were presented in context (as in Experiments 1 and 2).

Table 1

Predominance measures for congruent and incongruent objects, in Experiments 1 and 2. Predominance scores (PS_i, PAF) were tested for significant deviations from 0.5 with one-sample *t*-tests. All other measures were compared using paired sample *t*-tests. Significant results are marked with an asterisk.

Measure	Experiment 1		Experiment 2	
	Congruent	Incongruent	Congruent	Incongruent
Predominance score (PS_i)	0.53 (0.04)*		0.53 (0.05)*	
Disengagement measure				
Average predominance duration (APD)	8.37 s (6.58 s)*	10.40 s (7.02 s)	7.23 s (4.76 s)*	9.77 s (5.24 s)
Attraction measures				
Number of percepts after a fusion (PAF)	0.53 (0.08)		0.50 (0.12)	
Initial percept (IP)	17.50 (4.42)	17.29 (3.36)	14.11 (3.95)*	11.00 (3.23)

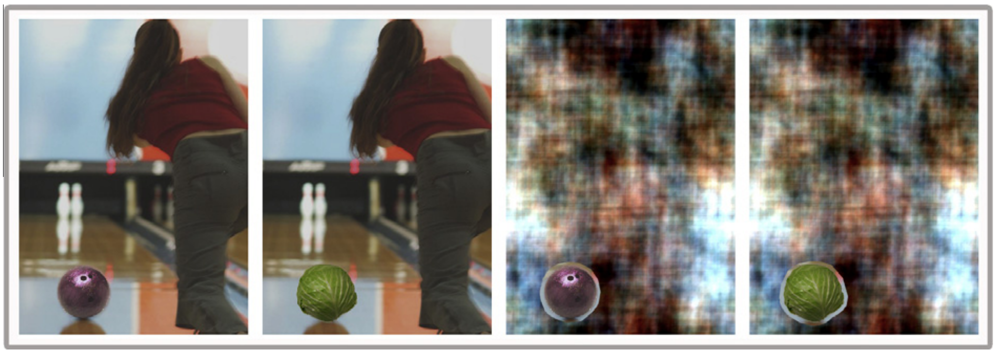

Fig. 2. Left pair: sample of a congruent and an incongruent image used in Experiments 1 and 2. Right pair: corresponding sample of stimuli used in Experiment 3. Incongruent (right) and congruent (left) objects and their near background, are pasted on the phase-randomized background.

4. Experiment 3

In Experiment 3, the objects used to create the congruent and incongruent conditions in Experiments 1 and 2 were pasted on meaningless backgrounds (Fig. 2) and presented to each eye. Thus, in this experiment there were no semantic relations between the objects and their backgrounds. To specifically examine the possibility that any distinctive low-level information resided in the contrast between object borders and their immediate background, the objects were cut from the stimuli used in Experiments 1 and 2 together with the immediately adjacent background. If the effects reported in Experiments 1 and 2 were truly caused by the level of congruency, they should disappear in Experiment 3. In contrast, if the effects were due to the objects themselves, or to the border zone between objects and the background into which they were digitally pasted, the difference should replicate despite the lack of a context.[3]

4.1. Method

4.1.1. Participants

Eighteen healthy volunteers (10 females, three left handed), students of the Hebrew University of Jerusalem, aged 21–30 (mean = 25.6), with reportedly normal or corrected-to-normal sight and no psychiatric or neurological history, participated in the experiment for payment (∼5$ per hour). One additional subject was excluded, because he failed to follow the experimenter's instructions and did not report perceptual alternations.

4.1.2. Stimuli, apparatus and procedure

The apparatus and procedure were similar to those used in Experiment 1. A new stimuli set was designed in the following way. As a first step, the congruent and incongruent objects were cut from the original images together with their immediately adjacent background. This ring (2–5 mm) surrounding the image did not include enough information to render the object congruent or incongruent (Fig. 2). Second, we filled the gap created in the image in step 1, with a segment copied from another area in the image. Consequently, the resulting image only included features of the background. Third, these background images were phase-randomized using Matlab. To this end we applied a 2-D discrete Fourier transform to the background image. At each spatial frequency, we maintained the amplitude constant and randomized the phase by adding a random phase shift between −pi and +pi (this was conducted on each of the three RGB layers separately, but using the same phase shift). We then applied a 2-D inverse Fourier transform to reconstruct a scrambled image. Finally, the cut objects (and surrounding rings) were pasted on the shuffled backgrounds at their original location.

4.2. Results

4.2.1. Predominance score

As opposed to Experiments 1 and 2, neither 'incongruent' nor 'congruent' objects predominated during rivalry (predominance score of exactly 0.50).

4.2.2. Disengagement measure

Similarly, no significant difference was found between the average dominance duration of incongruent percepts (mean ADD = 6.46 s, SD = 2.94 s) and the average dominance duration of congruent percepts (mean ADD = 7.29 s, SD = 3.59 s), $t(17) = 1.30$, $p = .21$.

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[3] We thank two anonymous reviewers for suggesting this control study.

4.2.3. Attraction measures

As in Experiments 1 and 2, the probability of congruent and incongruent percepts after a fusion did not significantly differ from 0.5 (mean $PAF_i = 0.48$, $SD = 0.06$, $t(17) = 1.19$, $p = .25$). In addition, no difference was found between the number of trials in which subjects reported the incongruent object as their initial percept (mean $IP_i = 13.33$, $SD = 6.49$) and the number of trials in which they reported perceiving the congruent object first (mean $IP_c = 14.83$, $SD = 7.29$, $t(17) = 1.13$, $p = .28$).

4.3. Discussion

When isolated objects (and their near background) rivaled against each other without any semantic relations to the scene's context, no difference was found in BR predominance, in all the measures used in Experiments 1 and 2. This finding strongly reduces the possibility that the differences seen in those experiments were caused by low-level differences between congruent and incongruent objects, or by differences in the contrast between objects' borders and the rest of the scene.

5. General discussion

Context is a powerful factor determining subjective perception. It can both facilitate recognition of context-congruent items, and allow attention to be directed to 'surprises', or context-incongruent items, which might require action. As we reviewed in the Section 1, previous evidence indeed suggests that attentional resources are preferentially allocated to incongruent objects. The main finding of the current study is that the attentional advantage of incongruent objects, demonstrated here in their predominance score during BR, results from attention dwelling on scene-incongruent objects, with no evidence for the notion that incongruent objects attract attention. That is, once an incongruent object has been perceived (even if partially) by chance, it is more difficult to disengage attention from it, as predicted by the attentional disengagement hypothesis (De Graef et al., 1990; Friedman, 1979; Henderson & Hollingworth, 1999). This difficulty to disengage was manifest in that incongruent scenes were perceived for longer periods than congruent scenes, as revealed by the average dominance duration measure (ADD). One may argue that the ADD measure can be interpreted in terms of attentional attraction: if incongruent scenes are more potent at breaking suppression and regaining dominance, they may shorten the congruent image dominance duration, rather than holding dominance for longer times, as was previously demonstrated for low-level features (Fox & Rasche, 1969; Levelt, 1965).[4] However, there was no indication from either of the direct attraction measures for such a possibility.

According to the disengagement hypothesis, attention is maintained on incongruent objects because they create conceptual "tension" (Hollingworth & Henderson, 2000), in line with the widely reported difficulty to identify such objects as compared with congruent objects (e.g., Antes et al., 1981; Bar & Ullman, 1996; Biederman, 1972, 1981; Boyce & Pollatsek, 1992; Davenport & Potter, 2004; Palmer, 1975). By this account, maintaining attention on the incongruent object allows further inspection that leads to the formation of a more complete representation of the incongruent object and of its relations with the background (i.e., its context). However, the need to form such complete representation can account for incongruency dominance only during the first stage of the rivalry. Yet our findings show that incongruent objects are perceived for longer durations even when excluding the first percepts from the analysis. Why then do incongruent objects more strongly engage attention even after their identity and relations with the background have been processed?

Two possible solutions rest on incongruent objects being both improbable and novel. First, even after identification, the conflict between the identified object and the scene persists. This requires further inspection (De Graef et al., 1990, 1992; Hamm, Johnson, & Kirk, 2002; Henderson & Hollingworth, 1999; Hollingworth & Henderson, 1998, 1999) that allows more information about the scene to be gathered or new interpretations to be formed. Second, scenes that include context violations are novel, since incongruent objects most likely had never been seen before within that particular context. Numerous studies have shown that subjects allocate increased attentional resources to novel images and displays (e.g., Berlyne, 1960; Daffner et al., 1998, 2000; Loftus & Mackworth, 1978; Mackworth & Morandi, 1967; Noton & Stark, 1971), even in infancy (Bomstein, 1985; Spelke, 1985), presumably due to prefrontal enhancement of the impact of such stimuli, together with inhibition of habitual reactions (Daffner et al., 1998; Leimkuhler & Mesulam, 1985). These novelty effects eventually decline (Sokolov, 1963), but they can endure for several repetitions (e.g., Clark, Fannon, Lai, Benson, & Bauer, 2000; Weizmann, Cohen, & Pratt, 1971). In our study, the novel arrangement of the incongruent scenes may have been responsible for their privileged attentional status lasting throughout the 1-min trial. This novelty effect may seem at odds with previous findings of a familiarity advantage in BR (Bagby, 1957; Goryo, 1969). However, the previous familiarity advantage during BR was found using stimuli that were personally relevant to subjects (i.e., religious symbols of one's own religion compared with others, or landscapes of subjects' homeland compared with foreign countries), while here, congruent stimuli did not pertain to subjects' personal interests or experience. Thus, both novelty and personal familiarity may be attentionally engaging.

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[4] Because in our study congruent and incongruent objects rivaled against each other, we could not determine if the predominance of incongruent objects stems from increased dominance durations or from decreased suppression durations. To perform such an analysis would require that both kinds of objects (congruent and incongruent) rival against a *neutral* one. This is of course impossible, since no object can serve as neutral in these terms; all objects are either congruent or incongruent with a given scene (even a non-object, i.e., for instance a scrambled object, would be likely to be perceived as incongruent – or at least as odd – in the context of a veridical scene).

Finally, this interpretation may also offer some reconciliation to the apparent conflict between the facilitated recognition of scene-congruent objects in object recognition tasks (e.g., Bar & Ullman, 1996; Biederman et al., 1974; Davenport & Potter, 2004; Palmer, 1975), and the advantage of scene-incongruent objects in maintaining attention found here. While full recognition is faster and more accurate for congruent objects, because of priming or redundancy effects, it is the novelty, or conceptual ambiguity, associated with incongruent objects (even if only partially or slowly recognized; see Mudrik et al., 2010; Underwood et al., 2008), which requires prolonged attentional engagement and awareness to resolve.

Our study provides the first evidence we are aware of for predominance related to semantic content during rivalry between two meaningful stimuli, when all low-level features (i.e., size, chromaticity, spatial frequency, luminance and contrast) are controlled for. Earlier reports of semantic effects during rivalry (e.g., Engel, 1956; Gilson et al., 1982; Kohn, 1960) suffered from methodological shortcomings (Walker, 1978). In particular, dominance of a certain semantic category was typically confounded with either its physical salience or a reporting bias in favor of that category. Other studies focused on the rivalry between a meaningful and a meaningless stimulus (Yu & Blake, 1992; see also Blake, 1988, for rivalry between words and non words, which showed no pattern of predominance). By showing effects of context on rivalry between two meaningful objects, our results are consistent with the idea that BR can be modulated by high-level processes such as attention, expectations and semantics (Leopold & Logothetis, 1999; Sterzer et al., 2009) and argue against strictly low-level accounts of BR (Blake, 1989; Blake & Boothroyd, 1985; Breese, 1909; Fahle, 1982; Fox & Rasche, 1969; Kakizaki, 1960; Levelt, 1965; Mueller & Blake, 1989; Wade et al., 1984).

Such high-level influences can also be described in terms of the traditional adaptation models of perceptual alternations (Kalarickal & Marshall, 2000; Kang & Blake, 2010; Laing & Chow, 2002; Lehky, 1995; Wilson, 2003, 2007), more commonly applied to low-level rivalry. The adaptation models are built around the notion of mutual-inhibition between pools of neurons representing possible alternative image interpretations. Once one image gains dominance while inhibiting the alternative, gradual adaptation processes commence, weakening the representation of the dominant percept while releasing the other representation from inhibition, eventually allowing the other perceptual representation to prevail (Alais, Cass, O'Shea, & Blake, 2010). The advantage of the incongruent object in the present case suggests that attentional effects might mitigate the adaptation processes, allowing the incongruent images to suppress the representation of the congruent image for a longer time (e.g., Chong & Blake, 2006; Kang & Blake, 2010; Klink et al., 2008; Mitchell et al., 2004).

Another implication of our study concerns the difference in the processes determining rivalry at the onset of a rivalry trial, and those determining ongoing BR. In Experiment 2, the first image to gain dominance was affected by contextual facilitation of congruent objects, while ongoing rivalry was shaped by the prolonged attentional engagement of incongruent objects, reflecting their novelty and the semantic conflict they entail. Similar dissociations between onset rivalry and predominance during the trial were also reported by others (Carter & Cavanagh, 2007; Sheth & Pham, 2008). The factors biasing dominance at these two distinct stages of BR require further research (Carter & Cavanagh, 2007; Chong & Blake, 2006), and should be acknowledged in BR studies.

In conclusion, relying on a fine-grained analysis of predominance measures during BR, the current study shows that attention lingers on scene-incongruent objects rather than being attracted to them. To uncover the attentional processes underlying context violation processing, we used the Binocular Rivalry paradigm, in such a way that rivalry occurred between objects within a given scene, and not between two images. This object rivalry upon a controlled background may prove useful in future investigations of the relations between objects and their backgrounds.

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