**Perception of semantic relations in scenes:
a registered report study of attention hold**

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Abstract

To what extent the semantic relations present in scenes guide spatial attention automatically remains a matter of debate. Considering that spatial attention can be understood as a sequence of shifts, engagements, and disengagements, semantic relations might affect each stage of this process differently. Therefore, we investigated whether objects that violate semantic rules engage attention for longer than objects that are expected in a given context. The experiment involved a central presentation of a distractor scene that contained a semantically congruent or incongruent object, and a peripheral presentation of a small target letter. We found that incongruent scenes did not delay responses to the peripheral target, which indicates that they did not hold attention for longer than congruent scenes. Therefore, by showing that violations of semantic relations do not engage attention automatically, our study contributes to a better understanding of how attention operates in naturalistic settings.

Introduction

A scene can be defined as a view of the environment that comprises both background elements and discrete objects, all arranged according to certain spatial and semantic rules (Henderson and Hollingworth, 1999). Thus, in real-world scenes, objects always occur in relation to other scene elements, and these relations (both spatial and semantic) play a key role in the object recognition process (Bar, 2004; Kaiser et al., 2019; Võ et al., 2019). This role has been convincingly shown by studies investigating perception of semantically incongruent objects, which are defined as those with a very low probability of occurring in a given context and which therefore violate observers' expectations regarding a scene's composition (Biderman, 1982). A robust body of evidence indicates that semantically incongruent objects are recognized more slowly and less accurately than congruent ones (Boyce et al. 1989; Davenport and Potter 2004; Rieger et al. 2008; Leroy et al., 2020; Furtak et al., 2022). These findings are taken as evidence that contextual information in the form of gist or global scene statistics is computed first, and that it facilitates subsequent recognition of congruent objects by pre-activating their representations (Hochstein and Ahissar, 2002; Bar, 2004; Oliva and Torralba, 2006).

Contextual information is also known to guide further exploration of a scene by directing spatial attention to locations and objects expected to be most informative (Peelen and Kastner, 2014; Wu et al., 2014; Kaiser et al., 2019; Wolfe and Horowitz, 2017; Võ et al., 2019). In line with the assumption that unexpected stimuli are most informative, some studies have found that incongruent objects attract attention automatically. For instance, participants directed their initial saccades to incongruent objects in eye-tracking studies (Loftus and Mackworth 1978; Underwood and Foulsham 2006; Becker et al. 2007; Underwood et al. 2007, 2008; Bonitz and Gordon 2008) and detected a change more quickly if a scene contained an incongruent object in the change-blindness paradigm (Hollingworth and Henderson 2000; LaPointe et al. 2013; Mack et al. 2017; LaPointe and Milliken 2017; Ortiz-Tudela et al. 2017, 2018). If confirmed, this would suggest that semantic relations in real-world scenes are analyzed pre-attentively and are used to guide the deployment of spatial attention. However, numerous other studies did not find evidence supporting automatic attention capture by incongruent objects (e.g., De Graef et al. 1990; Gareze and Findlay 2007; Rayner et al. 2009; Võ and Henderson 2009, 2011; Cornelissen and Võ 2017). Therefore, we recently conducted a study in order to address this controversy (Furtak et al., 2020). To provide conclusive evidence for or against automatic attention capture by incongruent objects, the aforementioned study was designed in the

following way. First, we employed a set of congruent and incongruent scene images which had been validated in several previous studies (Mudrik et al. 2010, 2011, 2014; Mack et al., 2017; Biderman and Mudrik 2018; Moors et al., 2018; Faivre et al. 2019; Shir et al., 2021). Second, we employed a well-established methodology based on the dot-probe task and N2pc ERP component analysis that has been used to investigate attention capture by threatening real-world scenes (Kappenman et al., 2014, 2015). Third, we also included the threatening scene images from the study by Kappenman and colleagues in a ‘positive control’ condition in our experiment. These steps were taken to strengthen our conclusions, particularly in the case of a null result in the incongruent condition (i.e., no attention capture). Specifically, we reasoned that demonstrating attention capture caused by threatening scenes in the “positive control” condition of our experiment would mitigate the concern that our procedure was not sensitive enough, or concerns about any other general factors that potentially explain the lack of the effect in the incongruent scenes would also be mitigated. This was indeed what we found: we replicated the original result of Kappenman and colleagues (2015) by showing that threatening images did attract attention; however, we found no evidence for attention shifts to semantically incongruent scenes.

Even though our study demonstrated that incongruent objects did not capture attention automatically (Furtak et al., 2020), such objects might still be prioritized by attention in other ways. The classic theory of attention proposed by Posner (1987) differentiates two independent functionalities of spatial attention orienting: attention shifts, defined as movement of attention from its current location to a new one; and attention engagement, described as involvement in processing of a stimulus in the present location and a transient inability to disengage and shift to a new one. Two lines of research have suggested that semantically incongruent objects engage and hold attention for longer than congruent ones. First, eye-tracking studies have demonstrated that participants fixate on incongruent objects more frequently and for longer in comparison to congruent ones when they are exploring a scene freely (Võ and Henderson, 2009, 2011). However, in eye-tracking studies, covert attention orienting cannot be dissociated from overt eye movements (e.g., Hunt and Kingstone, 2003; Juan et al., 2004), which prevents identification of the specific mechanisms that contribute to longer fixations. Moreover, in these previous eye-tracking studies, participants were allowed to explore a scene freely and for a relatively long time, thus it is not known to what extent the effect was indeed automatic and involuntary (but see Cornelissen and Võ, 2017). Second, in the binocular rivalry paradigm, incongruent objects did not enter awareness preferentially, but once they were perceived, their

dominance lasted longer (Mudrik et al., 2011). Yet, while such an observation indicates greater involvement of attentional resources in the processing of incongruent objects, it does not inform us about spatial attention orienting (i.e., patterns of shifts and engagements). Therefore, whether or not semantically incongruent objects hold spatial attention requires further study.

The holding of spatial attention can be specifically measured using a paradigm that involves simultaneous presentations of a central distractor image and a peripheral target stimulus. It can be inferred that the central distractor holds attention if a response to the target is delayed. Such a paradigm has been used in several previous studies. For instance, when a centrally presented simple distractor shape exhibits task-relevant features (i.e., the same color as a target), it holds attention and delays shifts to a peripheral target stimulus (Folk et al., 2009; but see Zivony & Lamy, 2014). Additionally, faces are considered to benefit from general attentional prioritization and, indeed, a face image displayed centrally delays reaction to a peripheral target in comparison to images of other non-face stimuli (Bindemann et al., 2005). Finally, two studies conducted by van Hoff and colleagues (2013, 2014) found that disgust-evoking images hold attention and impair recognition of peripherally presented letters. The effect was specific to disgust-evoking images, as other emotional categories, such as fear, sadness, or happiness, did not cause a similar effect.

The present study tested the hypothesis that semantically incongruent objects hold spatial attention for longer than congruent ones. To provide robust evidence in favor of either the null or the alternative hypothesis, the study was guided by the same logic as our previous work on attention capture (Furtak et al., 2020). First, we used the scene images developed by Mudrik et al. (2010), which made it possible to compare the results of the present study to the previous work of our and other groups using the same stimuli set (e.g., Mudrik et al. 2011, 2014; Mack et al., 2017; Biderman and Mudrik 2018; Moors et al., 2018; Faivre et al. 2019; Bola et al., 2021; Shir et al., 2021). Second, we employed a procedure developed specifically to investigate automatic holding of spatial attention by real-world scene images (van Hooff et al., 2013, 2014). Third, to establish a ‘positive control’ condition, we included disgust-evoking images in our study and aimed to replicate the main result of van Hooff and colleagues (2014). Successful replication would indicate that the paradigm established in our experimental setting is sensitive enough to reveal an attention-hold effect, which would facilitate the interpretation of results from the semantically incongruent condition, particularly in the case of a null result in the latter.

There were four possible outcomes of the experiment with respect to the main hypothesis:

1) both disgust-evoking and incongruent scenes hold attention for longer (in comparison to control conditions of happy and congruent scenes): this would replicate and generalize the results of van Hooff et al. (2013, 2014) and reveal that the same effect is caused by incongruent scenes.

2) disgust-evoking scenes hold attention, but incongruent scenes do not: this would replicate and generalize the results of van Hooff et al. (2013, 2014) and demonstrate that the procedure is sensitive, which would allow the conclusion that incongruent scenes do not cause the same effect.

3) disgust-evoking scenes do not hold attention, but incongruent scenes do: this would demonstrate that the procedure is, in principle, sensitive, and that incongruent scenes hold attention; however, it would indicate that the results of van Hooff et al. (2013, 2014) do not generalize or replicate.

4) neither disgust-evoking nor incongruent scenes hold attention: this outcome would suggest that incongruent scenes do hold attention and that the results of van Hoff et al. (2013, 2014) do not generalize or replicate. Importantly this outcome does not allow any conclusions about the sensitivity of the procedure, thus any interpretations should be treated with caution.

Method

1. Participants and sample-size estimation

For the present study, 46 healthy individuals (3 left-handed; age: $M = 26.4$, $SD = 4.5$, range = 18–35 years) were recruited via social media. The sample was gender balanced (23 females). Exclusion criteria were any diagnosed neurological or neuropsychiatric disorders, and deviating from normal, uncorrected vision. Participants signed an informed consent form and were financially compensated for their time. All experimental procedures were approved by the Research Ethics Committee at Nicolaus Copernicus University (KB 447/2020).

The sample size necessary for the planned 2x2x3 repeated-measures ANOVA analysis (see the Planned Analyses section) was estimated using a simulation-based power analysis conducted with the ANOVA_exact Shiny app (Lakens & Caldwell, 2021; <https://arcstats.io/shiny/anova-exact/>). In the simulations, we used the mean reaction times (RT) reported by van Hoff et al. (2014), who observed mean RT equal to 534 ms, 522 ms, and 500 ms in the disgust-evoking condition (for 100, 200 and 300 ms SOAs, respectively), and 518 ms, 502 ms, and 490 ms in the happiness-evoking control condition. Common standard

deviation was set to 60 ms in the simulation, a value that was calculated based on the SEM displayed in Figure 3 in van Hoff et al (2014). The correlation between factors was estimated on the basis of our previous RT data (Furtak et al., 2020) and was set to 0.8.

Using these parameters, we conducted simulations of two extreme scenarios. In the first one, we assumed that incongruent scenes compared to congruent ones would evoke an identical RT effect as disgust-evoking images compared to happiness-evoking ones. In the second one, we assumed that incongruent scenes would not evoke any RT effect at all (mean RT for incongruent scenes would be the same as for congruent and happiness-evoking scenes). In both simulations the alpha value was set to 0.05, and the desired power level was set to 0.9. The first simulation indicated that 14 participants would be enough to achieve the desired level of statistical power for the main effect of interest (*saliency*, see the Operationalization section); in the second simulation, a sample size of 46 participants resulted in the desired power of both the *saliency* effect and the *saliency* x *stimulus type* interaction.

We thus stopped collecting data once 46 valid datasets had been acquired. No data analysis was conducted prior to collecting all the datasets, except for checking the exclusion criteria described in section 6.

2. Apparatus

Stimuli were displayed on a DELL AW2518HF LCD monitor (24.5”) with 1920*1080 resolution and 120 Hz refresh rate. The experimental procedure was programmed and presented using Presentation® software (Version 20.1, Neurobehavioral Systems, Inc., Berkeley, CA). Participants were seated in a dimly lit, sound-attenuated room. The viewing distance of 60 cm was maintained by an adjustable chinrest.

3. Stimuli

Two sets of stimuli were used. The first was a subset of 50 pairs of scenes from the set developed by Mudrik et al. (2010) and recently validated by Shir et al. (2021). In each pair, the congruent version of a scene presents a person performing an action with an object that is highly probable in a given context (e.g., a man playing a violin), whereas in the incongruent version the key object has a very low probability of occurring in the given context (e.g., a man “playing” a broomstick). In both versions, the critical object was pasted onto the scene to avoid any confounds that could result from pasting an object in the incongruent version only. Low-level image properties, like contrast and luminance, were digitally equalized within each stimuli pair. The stimulus set has been validated and used in several previous studies (e.g., Mudrik et al. 2011, 2014; Mack et al., 2017; Biderman and Mudrik 2018; Moors et al., 2018; Faivre et al. 2019; Furtak et al., 2020).

The study of van Hooff et al. (2014) demonstrated that disgust-evoking images hold attention, but neutral, happy and sad images do not. However, an important limitation of the study of van Hooff and colleagues is that they selected and used only 10 images per emotional category from the International Affective Picture System (IAPS) stimulus set (Lang et al., 2008). Using only 10 images per category might have been the reason for the observed rapid habituation effect. Therefore, in the present study we aimed to replicate and generalize their findings by using 50 disgust-evoking and 50 happiness-evoking images. Images were selected from the Nencki Affective Picture System (NAPS), which is a set of modern, high-quality images that are suitable for use in different cultures (Marchewka et al., 2014). Happy images were used as a control condition as, in comparison to neutral images, they are better matched to disgust-evoking images in terms of content and arousal. Selection of images was based on their characteristics in terms of the discrete emotional categories provided by Riegel et al. (2016) and was conducted in the following way: first, we aimed to achieve maximal homogeneity of emotion categories within each subset (by selecting images that were assigned to one emotion category only); second, we aimed to maintain diversity of the presented content within the disgust- and happiness-evoking subsets (i.e., people, faces, animals, objects, landscapes) while keeping the number of images representing each content type equal between subsets. Thus, the chosen disgust-evoking images depict unpleasant or disturbing scenes that convey negative emotional content (e.g., cockroach, spoiled food, mutilated bodies), while happiness-evoking images present cheerful, positively loaded scenes (e.g., puppy, appetizing food, people playing sports)¹. During the selection process, we intended to keep the means of the arousal scores in both stimuli conditions as close as possible, but disgust-evoking stimuli were in general more arousing (**Fig. 1**, $M_{\text{disgust}} = 6.26$; $M_{\text{happy}} = 4.46$; $t(98) = 13.15$; $p < .001$).

¹ NAPS ids of disgust-evoking pictures: Animals_018_h, Animals_027_h, Animals_032_h, Animals_033_h, Animals_037_h, Animals_041_h, Animals_043_h, Animals_047_h, Animals_062_h, Animals_065_h, Animals_078_h, Animals_221_h, Faces_156_h, Faces_264_h, Faces_266_h, Faces_366_h, Landscapes_007_h, Objects_006_h, Objects_007_h, Objects_010_h, Objects_011_h, Objects_013_h, Objects_019_h, Objects_022_h, Objects_053_h, Objects_060_h, Objects_088_h, Objects_109_h, Objects_122_h, Objects_125_h, Objects_126_h, Objects_154_h, Objects_206_h, People_057_h, People_058_h, People_087_h, People_164_h, People_198_h, People_202_h, People_216_h, People_217_h, People_220_h, People_222_h, People_223_h, People_228_h, People_230_h, People_233_h, People_239_h, People_240_h, People_241_h.
Happiness evoking pictures: Animals_100_h, Animals_117_h, Animals_122_h, Animals_131_h, Animals_158_h, Animals_173_h, Animals_177_h, Animals_183_h, Animals_184_h, Animals_186_h, Animals_187_h, Animals_220_h, Faces_001_h, Faces_079_h, Faces_122_h, Faces_134_h, Landscapes_180_h, Objects_049_h, Objects_056_h, Objects_069_h, Objects_077_h, Objects_078_h, Objects_086_h, Objects_192_h, Objects_209_h, Objects_211_h, Objects_258_h, Objects_260_h, Objects_276_h, Objects_278_h, Objects_295_h, Objects_306_h, Objects_319_h, People_026_h, People_030_h, People_044_h, People_055_h, People_067_h, People_068_h, People_096_h, People_103_h, People_116_h, People_176_h, People_179_h, People_180_h, People_183_h, People_185_h, People_188_h, People_190_h, People_192_h.

We confirmed that the disgust-evoking and happy subsets did not differ in terms of low-level properties like luminance, contrast, and entropy.

It is noteworthy that images from the congruent/incongruent subset have a vertical orientation, while NAPS images have a horizontal orientation, but they all maintain the same proportion between the long and the short edges. Therefore, they could be presented in a way that equalizes the area covered on the screen without any image distortions. Importantly, low-level properties (e.g., luminance and contrast) were not equalized between sets as this would have changed the properties of the stimuli and prevented comparisons of our results with results of previous studies using these images. Because the properties of the stimuli were not matched between sets, stimuli from both sets were presented in separate blocks (as described in the Procedure section).

Figure 1. Scatter plot demonstrating arousal and valence ratings of the disgust- and happiness-evoking NAPS images chosen for the present study (Riegel et al., 2016).

4. Procedure

The experimental procedure used in the present study was developed by van Hoff et al. (2013, 2014). In our study, the procedure comprised 1,200 trials in total and lasted approximately 1h 10 min. A short break was provided after each 75 trials, and its duration was controlled by the participant. Trials were arranged in 8 blocks, each of 150 trials. Congruent/incongruent stimuli were presented in half of the blocks; in the other half, the

pictures came from the NAPS set. Blocks comprising congruent/incongruent and disgust-evoking/happy images were presented alternately, with the first block type counterbalanced across participants. Within blocks, each stimulus category (i.e., congruent vs. incongruent scene, or disgust- vs happiness-evoking) appeared in an equal number of trials. Furthermore, for each stimulus category, the target letter was presented with one of three stimulus onset asynchronies (SOA) with respect to the scene image (100 ms, 200 ms, 300 ms), and each SOA occurred in $\frac{1}{3}$ of trials. Therefore, there were 100 trials per each image category and the SOA condition. The order of trials of different conditions was randomized within blocks.

All stimuli were presented against a gray background (RGB [128, 128, 128]; **Fig. 2**). Each trial began with a white fixation cross ($0.85^\circ \times 0.85^\circ$ of visual angle) displayed in the center of the screen for a random duration between 1500 and 2500 ms. The fixation cross was followed by a scene ($4.10^\circ \times 6.87^\circ$ for congruent/incongruent images, and $6.87^\circ \times 4.10^\circ$ for disgust-evoking/happy images) presented centrally and remaining on the screen for 1200 ms or until the participant's response to the target letter. A white target letter 'N' or 'Z' (Arial, 15pt, $0.37^\circ \times 0.37^\circ$) was displayed 100 ms, 200 ms, or 300 ms after the scene onset in one of four peripheral locations (on the left, on the right, above or below the scene), 5.04° from the center of the screen. The target letter was presented for 50 ms.

The participants' task was to identify the peripheral letters 'N' or 'Z' and respond accordingly with a button press as quickly and accurately as possible. Letters and their locations were pseudorandomized across trials (with the control for the frequency of each letter/location condition for each stimulus category and display time condition). The trial ended after either a valid response (after the letter onset), or 5000 ms after the letter onset if there was no response. Participants responded by pressing one of two response buttons (using their left and right index fingers). The location of the response buttons in relation to the target letters was counterbalanced across participants (i.e., half of participants responded with the left button to "N" and the right button to "Z", while the other half responded with the left button to "Z" and the right button to "N").

In relation to van Hooff et al.'s (2013, 2014) studies, our procedure was characterized by the following changes. First, we included only the short SOAs (100, 200, 300 ms) that were used by van Hooff and colleagues, but we did not include the longer ones (500, 800 ms). Second, we increased the number of trials per condition (from 40 to 100) in order to increase the precision of within-subjects estimates. Third, the duration of the fixation cross was randomly selected in order to minimize the influence of learned reflexive behavior on the effect of interest.

5. Operationalization

Independent variables: The following three variables were included in the analysis as factors: *stimulus type* (semantic vs affective stimuli); *stimulus saliency* (salient, potentially attention-holding stimuli [semantically incongruent or disgust-evoking images] vs. control stimuli [semantically congruent or happiness-evoking images]); and *SOA* (short [100 ms], medium [200 ms], long [300 ms]). All independent variables were introduced in a within-subject design.

A) TRIAL SCHEME

B) STIMULI

Figure 2. Schematic presentation of a trial sequence (A) and representative stimuli used in the four conditions of the experiment (B).

Dependent variables: *Reaction times* (RT) of correct responses to the target letters were defined as a primary measure. We aggregated RT data for each condition by calculating the median, which is the most appropriate statistic to describe variables that deviate from the normal distribution. *Accuracy* of responses to the target letters, defined as the proportion between correct responses and all valid responses (correct or incorrect), served as a secondary measure.

Hypothesis: We expected salient stimuli (semantically incongruent or disgust-evoking images) to cause an attention-hold effect which would be reflected by longer RTs and lower accuracy of responses to target letters when compared to control stimuli (semantically congruent or happiness-evoking).

6. Exclusion criteria

Participants: A participant was excluded if he/she failed to complete the experimental procedure or exhibited a letter discrimination accuracy lower than 70% in any of the stimulus category/SOA conditions.

Trials: For the RT analysis, we excluded trials with no response or an incorrect response, and correct trials in which reaction times were shorter than 200 ms or longer than 1600 ms with respect to the target letter onset. For the accuracy analysis, we excluded no-response trials and trials in which reaction times were shorter than 200 ms or longer than 1600 ms with respect to target letter onset.

7. Planned analyses

All statistical analyses were conducted using the SciPy package (Virtanen et al., 2020) and JASP 0.9.1.0 software (JASP Team, 2018) and cross-checked with the Statcheck web app (Rife et al., 2016, <http://statcheck.io>).

We conducted confirmatory analyses of the RT and accuracy effects related to the following factors: *stimulus type* (2 levels), *stimulus saliency* (2 levels), and *SOA* (3 levels). Therefore, we used a 2 x 2 x 3 repeated-measures ANOVA. Our main focus was on the influence of *stimulus saliency* on RT and accuracy in the letter-classification task as this made it possible to verify whether semantically incongruent or disgust-evoking stimuli held attention. The following interactions of *stimulus saliency* with other variables were also examined:

- 1) The interaction of *stimulus saliency* with *stimulus type* factor and follow-up simple main effects; this allowed verification of our hypothesis concerning the attention-holding properties of semantically incongruent and disgust-evoking scenes (in comparison to control stimuli) and revealed potential differences between these two stimulus types.

2) The interaction of *stimulus saliency* and *SOA*, which demonstrated the time course of the attention-hold effect.

8. Data and materials

All data (raw and aggregated) and materials (scripts used to present the procedure and analyze data) used in the study are freely available from the Open Science Framework (OSF; <https://osf.io/7a8jt/>).

Results

Participants' performance in the designed procedure was very accurate, thus the percentage of trials that were valid and entered the analysis was high ($Mdn = 99.6\%$, $range = [92.4\%, 100\%]$). All participants discriminated target letters with accuracy higher than 70% in all of the conditions (pooled accuracy from all conditions: $Mdn = 95.1\%$, $range = [86.6\%, 98.7\%]$). Therefore, none of the recruited participants were excluded from the sample.

Primary measure: reaction times

Median RT values were analyzed using a three-way repeated-measures ANOVA, with *stimulus type*, *stimulus saliency*, and *SOA* as factors (**Fig. 3**). The *stimulus saliency* factor is crucial for conducted analysis, as it reflects attention hold properties of semantically incongruent and disgust-evoking stimuli, and therefore only effects and interactions comprising this factor are reported. Results were interpreted according to the highest-order significant interaction (Meyers et al., 2006) and followed up by the analysis of simple effects (Howell, 2009) or post-hoc tests necessary to fully understand the outcome. RT values observed at different levels of *SOA* violated the sphericity assumption, thus all effects that involved *SOA* were corrected using the Greenhouse-Geisser correction. The analysis revealed a significant three-way interaction between *stimulus type*, *stimulus saliency*, and *SOA* ($F(1.94, 87.45) = 9.05, p < .001, \eta^2_p = 0.17$). Such an interaction means that the attention-hold effect, as indicated by RT, depends differently on *SOA* in both stimuli sets (semantic and affective). We also found a significant 2-way interaction between *stimulus saliency* and *stimulus type* ($F(1, 45) = 28.10, p < .001, \eta^2_p = 0.38$) and a significant main effect of *stimulus saliency* ($F(1, 45) = 38.51, p < .001, \eta^2_p = 0.46$). The two-way interaction between *stimulus saliency* and *SOA* did not reach the significance level ($F(1.91, 85.88) = 1.88, p = 0.159$). Therefore, further analysis steps were performed to explore and interpret the highest-level, three-way interaction.

To examine simple interactions and main effects which can reveal the exact relations between the three factors (*stimulus type*, *stimulus saliency*, and *SOA*), a two-way repeated-measures ANOVA with *stimulus saliency* and *SOA* was conducted separately for each level of *stimulus type* (semantic and affective stimuli). In the semantic condition we obtained non-significant two-way interaction between *stimulus saliency* and *SOA* ($F(2, 90) = 1.25, p = 0.291$), and non-significant main effect of *stimulus saliency* ($F(1, 45) = 2.00, p = 0.165$). Therefore, we conclude that the RT attention-hold effect was not caused by incongruent stimuli in any of the *SOA* conditions.

The same analysis performed on affective stimuli revealed a significant two-way interaction between *stimulus saliency* and *SOA* ($F(2, 90) = 11.31, p < .001, \eta^2_p = 0.20$), which suggests that *SOA* affected RT differently for the presentation of disgust-evoking images than for happiness-evoking ones. Follow-up analysis of the simple main effects provided evidence for a significant *stimulus saliency* effect in all *SOA* conditions (100 ms: $F(1, 45) = 38.46, p < .001$; 200 ms: $F(1, 45) = 42.41, p < .001$; 300 ms: $F(1, 45) = 10.75, p = 0.002$) meaning that the attention-hold effect was present in all *SOA* conditions. Finally, we conducted 3 contrasts with Holm corrections for multiple comparisons on the differences in RT effects induced by disgust-evoking stimuli between 3 *SOA* levels. These tests revealed that the RT effects in the 100 ms and 200 ms *SOA* conditions did not differ from each other ($t(45) = 0.18, p_{holm} = 0.859$), but both were higher than the effect for the 300 ms *SOA* condition (100 ms vs 300 ms: $t(45) = 4.20, p_{holm} < .001, d = 0.62$; 200 ms vs 300 ms: $t(45) = 4.03, p_{holm} < .001, d = 0.59$). Thus, we conclude that the attention-hold effect for disgust-evoking images was stronger for short *SOAs* in comparison to the 300 ms *SOA*.

Secondary measure: response accuracy

A similar three-way repeated measures ANOVA was conducted on response accuracy scores (**Fig. 3**). We obtained a significant two-way interaction between *stimulus saliency* and *stimulus type* ($F(1, 45) = 10.61, p = 0.002, \eta^2_p = 0.19$), which means that the relation between accuracy scores for salient vs control stimuli differed between semantic and affective sets of images. Neither of the other effects concerning *stimulus saliency* factor was significant (*stimulus saliency*: $F(1, 45) = 1.16, p = 0.288$; *stimulus saliency* x *SOA*: $F(2, 90) = 0.03, p = 0.971$; *stimulus saliency* x *stimulus type* x *SOA*: $F(2, 90) = 2.22, p = 0.115$). Analysis of simple main effects of *stimulus saliency* on different levels of *stimulus type* revealed that a significant attention-hold effect was present for disgust-evoking ($F(1, 45) = 12.38, p = 0.001$) but not for

semantically incongruent scenes ($F(1, 45) = 0.73, p = 0.40$). Therefore, results of the accuracy scores analysis are in line with results of the RT analysis.

A)

B)

Figure 3. Reaction times (A) and response accuracy scores (B) obtained for semantic (left plot) and affective (right plot) sets of stimuli. Dots represent means, while whiskers designate 95% confidence intervals calculated using the Cousineau–Morey method for within-subjects designs (Morey, 2008)

Unplanned analyses

Bayesian repeated measures ANOVA and targeted Bayesian comparisons were conducted to provide further support for the null result obtained in the planned frequentist analysis in the semantic condition. Bayesian ANOVA analysis was performed with Cauchy priors ($r = 0.5$)

for fixed effect, while for Bayesian t-tests Cauchy priors ($r = 0.707$) were used. Bayes factors were interpreted according to the guidelines proposed by Wetzels et al. (2011).

The Bayesian ANOVA indicated that the observed RT data are most likely under the model comprising *stimulus saliency*, *stimulus type*, *SOA*, and the interaction between *stimulus saliency* and *stimulus type* ($P(M) = 0.053$; $P(M|data) = 0.845$; $BF_{10} = 0.023$ for a full model and $BF_{10} < 1e-5$ for a model comprising only main effects, compared to the best model). Thus we concluded that the effect of saliency differs between affective and semantic stimuli. The analysis of the prediction power of effects across matched models revealed extreme evidence in favor of inclusion of *stimulus saliency* x *stimulus type* interaction ($BF_{incl} > 1e+5$), strong evidence against the inclusion of *stimulus saliency* x *SOA* interaction ($BF_{incl} = 0.095$) and substantial evidence for the inclusion of 3-way *stimulus saliency* x *stimulus type* x *SOA* interaction ($BF_{incl} = 3.903$). Therefore, although the best model does not account for 3-way interaction, there is evidence that this interaction occurs in the data.

Furthermore, we conducted 6 Bayesian paired-sample t-tests to compare the RT effect for each combination of *stimulus set* and *SOA*. For semantic stimuli Bayes factors indicated that there is substantial evidence against the difference between salient and control stimuli for 100 ms SOA ($BF_{10} = 0.131$) and 200 ms SOA ($BF_{10} = 0.279$), and anecdotal evidence for the effect for 300 ms SOA ($BF_{10} = 2.211$). Bayes factors obtained for affective stimuli implied extreme evidence of saliency effect for 100 ms SOA ($BF_{10} > 1e+5$) as well as for 200 ms SOA ($BF_{10} > 1e+5$), and very strong evidence for 300 ms SOA ($BF_{10} = 31.330$). Thus, Bayesian analysis provided further support for the conclusions that attention is held by disgust-evoking but not by semantically incongruent stimuli.

An analogous analysis was conducted for accuracy scores. The model under which our data occurred to be most probable was the one containing *stimulus saliency*, *stimulus type* and 2-way interaction between these two factors ($P(M) = 0.053$; $P(M|data) = 0.574$; $BF_{10} = 0.004$ for a full model and $BF_{10} = 0.024$ for a model comprising main effects of *stimulus saliency* and *stimulus type*, compared to the best model). Further, we found very strong evidence for inclusion of *stimulus saliency* x *stimulus type* interaction ($BF_{incl} = 42.628$), strong evidence against the inclusion of *stimulus saliency* x *SOA* interaction ($BF_{incl} = 0.040$), and anecdotal evidence against a 3-way interaction of *stimulus saliency*, *stimulus type* and *SOA* ($BF_{incl} = 0.392$). Pairwise comparisons between salient and control stimuli from the semantic set revealed strong evidence against the effect for 100 ms SOA ($BF_{10} = 0.058$) and substantial evidence against the effect for 200 ms SOA ($BF_{10} = 0.109$) as well as for 300 ms SOA ($BF_{10} = 0.232$). Evidence for attention hold effect elicited by affective stimuli was very strong for 100

ms SOA ($BF_{10} = 74.124$) and substantial for 200 ms SOA ($BF_{10} = 3.041$). But for 300 ms SOA we found anecdotal evidence against the effect ($BF_{10} = 0.692$). In summary, Bayesian analysis of accuracy scores confirmed that semantically incongruent stimuli do not hold attention, while disgust-evoking stimuli elicit a robust attention hold effect.

Discussion

Mechanisms of selective attention are typically investigated with stimuli defined by simple physical features and presented in arrays of mutually independent items. Such basic studies provide crucial insights into the mechanisms of attention, but how their findings translate into more naturalistic settings is not well understood. While naturalistic environments are inherently more complex and crowded, they are also characterized by spatial and semantic regularities that, by introducing expectations regarding the location and identity of objects, might effectively facilitate attentional selection (Peelen and Kastner, 2014; Wu et al., 2014; Kaiser et al., 2019; Wolfe and Horowitz, 2017; Võ et al., 2019).

The present study was therefore designed to investigate how the semantic relations present in real-world scenes affect the functioning of spatial attention. Importantly, while the majority of previous studies focused on identifying features that *attract* attention in scenes, here we investigated attention engagement, which is a different and relatively under-researched mechanism. Specifically, we tested whether spatial attention is automatically engaged and held by violations in the semantic composition of real-world scenes. However, we found no such effect: objects that were semantically incongruent did not hold attention for longer than congruent ones. Conducted Bayesian analysis confirmed that collected data support lack of effect in the semantically incongruent condition. What proves that our procedure was, in principle, effective and sensitive – and thus further strengthens the interpretation of the observed null result – is the results from the “positive control” condition, in which both the reaction times and accuracy scores indicate that the disgust-evoking scenes did hold attention (in line with van Hooff et al., 2013, 2014). Below we discuss both the null effect in the semantic condition and the attention-hold effect in the affective condition in light of previous research.

Semantically incongruent scenes do not hold spatial attention

Comparing the perception of semantically congruent and incongruent objects is one of the most informative ways of investigating the role of contextual relations in natural scenes (Biederman et al., 1982). It is now well established that objects which are semantically incongruent and do not benefit from contextual facilitation (Bar, 2004) are recognized more

slowly and less accurately in comparison to congruent ones (Boyce et al., 1989; Davenport and Potter, 2004; Davenport, 2007; Joubert et al., 2008; Fize et al., 2011; Mack et al., 2017; Leroy et al., 2020; Furtak et al., 2022). Furthermore, perception of incongruent objects is associated with greater amplitude of ERP components (Mudrik et al., 2010; Võ and Wolfe, 2013; Truman and Mudrik, 2018) and stronger activity of several brain regions, including visual and cognitive-system areas, as assessed with fMRI (Remy et al., 2014; Faivre et al., 2019). The results of these neuroimaging studies are taken as evidence that greater involvement of neural and cognitive resources is necessary in order to resolve the semantic conflict and eventual recognition of incongruent objects. Accordingly, it has been proposed that incongruent objects preferentially engage attention and hold it for longer. Several eye-tracking studies have indeed found that once participants fixated on a semantically incongruent object, they maintained their gaze for longer in comparison to a congruent object (Henderson et al., 1999; Underwood et al., 2008; Võ and Henderson 2009, 2011; Cornelissen and Võ, 2017). However, our data tell a different story and challenge the conclusions of these previous studies: by using an experimental paradigm designed to measure an automatic hold of covert spatial attention and analyzing both reaction times and accuracy scores, we found no evidence that semantically incongruent objects hold attention for longer than semantically congruent ones. Conducted Bayesian analysis revealed that our data provide strong evidence against such an effect.

When discussing the results of previous eye-tracking studies, it is important to point out that in many of them the presented objects were not completely task-irrelevant (as discussed by Cornelissen and Võ, 2017). Consequently, it is unclear whether the observed gaze-hold effect was truly automatic. To address this, Cornelissen and Võ (2017) designed a study in which participants were tasked with searching for a target letter overlaid on a centrally presented image of a scene. Even though the scene image was completely task-irrelevant, participants still exhibited prolonged gaze duration when fixating on incongruent objects in comparison to congruent ones. How can this difference in results and conclusions between Cornelissen and Võ's study (2017) and our study be explained? First, by differences in the spatial arrangement of the presented stimuli. In Cornelissen and Võ's paradigm (2017), the scene image was bigger than in our study and provided a reference frame for the main search task. Conversely, in our experiment a relatively smaller scene image was displayed centrally, whereas targets were presented peripherally and did not overlap spatially with the scene. Second, the temporal aspect also differs between both studies. In Cornelissen and Võ's paradigm (2017), participants searched through an array of targets at their own pace, which might have provided them with more time to recognize the structure of the scene and generate expectations regarding the

locations and identities of objects (even though the scene was presented in the background). In contrast, in our experiment the targets appeared shortly after the scene's onset (SOA between 100 ms and 300 ms), thus the time available to recognize the scene was limited. However, recognition of both the gist of the scene and the main objects present in it is very rapid and automatic (e.g., Joubert et al., 2007, 2008; Furtak et al., 2022), thus short inspection times are unlikely to affect these processes. Finally, an important difference is that Cornelissen and Võ (2017) investigated markers of overt attention in the form of eye movements. In contrast, our experimental paradigm was designed to capture the covert aspect, as participants were asked to maintain their gaze on the centrally presented fixation cross at all times (and the target presentation time was short in order to prevent eye movements to the target). The overt and covert aspects of attention are typically strongly correlated, but in principle they can be dissociated (e.g., Hunt and Kingstone, 2003), which might potentially contribute to the different patterns of results observed between these studies.

The paradigm used in the present study was designed by van Hoff and colleagues (2013, 2014) to investigate the automatic and covert component of attentional selection. However, one might argue that the features introduced to test automaticity (i.e., short SOAs, task-irrelevance of a scene) might limit the procedure's sensitivity to detect the attention-hold effect. This concern is mitigated, first, by the fact that the procedure was validated by van Hoff and colleagues (2013, 2014), who across two studies found this paradigm to be suitable for the investigation of attention hold by complex scenes. Second and most importantly, this concern is mitigated by data from the "positive control" condition included in our study, in which we found that the disgust-evoking scenes did hold attention. This strongly indicates that the procedure was, in principle, effective and sensitive enough. However, one could still argue that the effect in the semantic condition exists but is much weaker than in the affective condition. While such an argument cannot be completely refuted, in order to detect even a potentially very subtle effect of incongruence (i.e., much weaker than in the emotional condition) we included more trials per condition and tested a bigger sample of participants in comparison to the original studies by van Hooff and colleagues (2013, 2014). Thus, we were able to obtain better estimates of the within-subject effect with respect to the between-subjects variance. Another potential concern might be that the effect of affective stimuli is indeed rapid and automatic, but more time is required to recognize semantic incongruence. To test for such a possibility we included the 300 ms SOA condition. In the planned frequentist analysis we did not find a significant effect in the semantically incongruent condition, neither in RT, not in accuracy scores. The Bayesian analysis of accuracy scores supported the null effect, but analysis of RT provided

anecdotal evidence that incongruent scenes do hold attention for longer than the congruent ones. Therefore, future studies might investigate attentional prioritization of incongruence using longer SOAs, which we did not use here in line with our aim to focus on the automatic aspect of attention hold. Overall, our study provides robust evidence that attention is preferentially engaged by disgust-evoking scenes, but no such effect is caused by semantically incongruent scenes.

What further strengthens our conclusion that incongruent objects do not hold attention is that we employed scene images from the most commonly used and well-tested set of stimuli, which was developed by Mudrik and colleagues (2010). All images from this set present a subject performing an action with either a congruent or an incongruent object. Notably, the action-based context creates strong expectations, as typically very few objects are congruent with the presented action. This is confirmed by the results of previous studies which found that incongruent scenes included in the set cause robust effects in behavioral (e.g., Biderman and Mudrik, 2018), ERP (e.g., Mudrik et al., 2010; Truman and Mudrik 2018), and fMRI measures (Faivre et al., 2019), and that participants were able to detect and recognize the incongruence easily (Mudrik et al., 2010; Furtak et al., 2020). Therefore, the null effect we observed cannot be explained by excessively subtle semantic manipulations in the images used. Future studies investigating attention might also test other stimuli sets, for instance those in which congruence is manipulated by presenting natural or artificial objects (animals or furniture) on either natural or artificial (outdoors or indoors) backgrounds (e.g., Remy et al., 2014; Leroy et al., 2020).

Disgust-evoking scenes hold spatial attention

While the main goal of our study was to investigate the effect of semantic relations in scenes, the results of the “positive control” condition provide important information regarding the involvement of attention in the perception of emotional content. Specifically, we demonstrate that disgust-evoking images engage and hold attention for longer than happiness-evoking images. This effect was found for all SOAs used in our study, but it was in fact stronger at 100 ms and 200 ms SOAs in comparison to the 300 ms SOA. This indicates that the observed attention hold was rapid and automatic. Therefore, our study closely replicated the results reported by van Hooff and colleagues (2013, 2014).

What can be considered a main limitation of van Hooff and colleagues’ (2013, 2014) work is that in their studies only 10 images per emotional category were used (images were selected from the IAPS set; Lang et al., 2008). In contrast, for our study 50 images per emotional category were selected from the NAPS set, which provides a bigger pool of modern and

culturally neutral emotional scene images (Marchewka et al., 2014; Riegel et al., 2016). Thus, by revealing the same effect using a bigger subset of images from a different set, we not only replicated van Hooff and colleagues' findings (2013, 2014) but also confirmed their robustness and generalizability.

In the “positive control” condition of our study, the disgust-evoking scenes were compared to happiness-evoking scenes, as the latter were not found to hold attention in previous studies and thus constituted an appropriate baseline (van Hooff et al., 2013, 2014). We did not include other emotional categories, like fearful or neutral images, as investigating the specificity of disgust-related effects was not the main goal of our work. Previous studies suggest that disgust indeed exhibits a specific behavioral and neural signature in comparison to all other basic emotions. More specifically, disgust is associated with a tendency to narrow attention and inspect the disgust-evoking object more closely (Gable & Harmon-Jones, 2010; Carretié et al., 2011). This hypothesis is supported by the attention-hold effect observed in our study, and by studies showing that disgust-evoking stimuli are remembered better in comparison to other emotional categories (Chapman et al., 2013, Croucher et al., 2011; Riegel et al., 2022). Furthermore, ERP studies found that disgust-evoking images evoke a larger frontal P2 ERP component (Carretié et al., 2011) and a larger early posterior negativity (EPN; Wheaton et al., 2013) in comparison to fear-evoking images. Both ERP components occur early, around 200 ms post-stimulus, therefore they could be related to early attentional engagement. Importantly, a potential limitation when interpreting the results of the “positive control” condition is that the disgust- and happiness-evoking images differed not only in valence but also in arousal. However, this problem is not specific to our study as disgust-evoking images are typically rated as most arousing, therefore matching them to control stimuli in this dimension is difficult to do.

Finally, the block design can be considered as another limitation of our work: the affective (disgust-evoking/happy) and semantic (congruent/incongruent) images were presented in two separate blocks, the order of which was counterbalanced between participants. While presenting all images in random order might potentially strengthen the investigated effects, the block design was used because both sets differed in terms of low-level properties (luminance, contrast). These properties were not normalized between sets, as changing them would have made comparison to other studies using the same stimuli problematic and would prevent referring to the subjective evaluations collected for NAPS images in validation studies (Marchewka et al., 2014; Riegel et al., 2016).

Conclusions

In conclusion, our recently published study revealed that semantically incongruent objects do not capture attention automatically (Furtak et al., 2020), while the present study provides evidence that such objects do not hold attention either. Therefore, by showing that violation of semantic relations is not preferentially selected by spatial attention, our work imposes important constraints on existing and future theoretical models that describe how attention operates in complex naturalistic settings.

References

- Bar, M. (2004). Visual objects in context. *Nature Reviews Neuroscience*, 5(8), 617–629.
- Becker, M. W., Pashler, H., & Lubin, J. (2007). Object-intrinsic oddities draw early saccades. *Journal of Experimental Psychology: Human Perception and Performance*, 33(1), 20.
- Biderman, N., & Mudrik, L. (2018). Evidence for implicit—but not unconscious—processing of object-scene relations. *Psychological Science*, 29(2), 266–277.
- Biederman, I., Mezzanotte, R. J., & Rabinowitz, J. C. (1982). Scene perception: Detecting and judging objects undergoing relational violations. *Cognitive psychology*, 14(2), 143–177.
- Bindemann, M., Burton, A. M., Hooge, I. T., Jenkins, R., & De Haan, E. H. (2005). Faces retain attention. *Psychonomic bulletin & review*, 12(6), 1048–1053.
- Furtak, M., Mudrik, L., & Bola, M. (2022). The forest, the trees, or both? Hierarchy and interactions between gist and object processing during perception of real-world scenes. *Cognition*, 221, 104983.
- Bonitz, V. S., & Gordon, R. D. (2008). Attention to smoking-related and incongruous objects during scene viewing. *Acta psychologica*, 129(2), 255–263.
- Boyce, S. J., Pollatsek, A., & Rayner, K. (1989). Effect of background information on object identification. *Journal of Experimental Psychology: Human Perception and Performance*, 15(3), 556.
- Carretié, L., Ruiz-Padial, E., López-Martín, S., & Albert, J. (2011). Decomposing unpleasantness: Differential exogenous attention to disgusting and fearful stimuli. *Biological psychology*, 86(3), 247–253.
- Chapman, H. A., Johannes, K., Poppenk, J. L., Moscovitch, M., & Anderson, A. K. (2013). Evidence for the differential salience of disgust and fear in episodic memory. *Journal of Experimental Psychology: General*, 142(4), 1100.
- Charash, M., & McKay, D. (2002). Attention bias for disgust. *Journal of anxiety disorders*, 16(5), 529–541.
- Cornelissen, T. H., & Võ, M. L. H. (2017). Stuck on semantics: Processing of irrelevant object-scene inconsistencies modulates ongoing gaze behavior. *Attention, Perception, & Psychophysics*, 79(1), 154–168.

Croucher, C. J., Calder, A. J., Ramponi, C., Barnard, P. J., & Murphy, F. C. (2011). Disgust enhances the recollection of negative emotional images. *PloS one*, 6(11), e26571.

Davenport, J. L., & Potter, M. C. (2004). Scene consistency in object and background perception. *Psychological science*, 15(8), 559–564.

De Graef, P., Christiaens, D., & d'Ydewalle, G. (1990). Perceptual effects of scene context on object identification. *Psychological research*, 52(4), 317–329.

Faivre, N., Dubois, J., Schwartz, N., & Mudrik, L. (2019). Imaging object-scene relations processing in visible and invisible natural scenes. *Scientific reports*, 9(1), 1–13.

Faul, F., Erdfelder, E., Buchner, A., & Lang, A.-G. (2009). Statistical power analyses using G*Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods*, 41, 1149–1160.

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, 39, 175–191.

Folk, C. L., Ester, E. F., & Troemel, K. (2009). How to keep attention from straying: Get engaged!. *Psychonomic Bulletin & Review*, 16(1), 127–132.

Furtak, M., Doradzińska, Ł., Ptashynska, A., Mudrik, L., Nowicka, A., & Bola, M. (2020). Automatic attention capture by threatening, but not by semantically incongruent natural scene images. *Cerebral Cortex*, 30(7), 4158–4168.

Gable, P., & Harmon-Jones, E. (2010). The blues broaden, but the nasty narrows: Attentional consequences of negative affects low and high in motivational intensity. *Psychological Science*, 21(2), 211–215.

Gazeze, L., & Findlay, J. M. (2007). Absence of scene context effects in object detection and eye gaze capture. In *Eye Movements* (pp. 617–637). Elsevier.

Henderson, J. M., & Hollingworth, A. (1999). High-level scene perception. *Annual review of psychology*, 50(1), 243–271.

Henderson, J. M., Weeks Jr, P. A., & Hollingworth, A. (1999). The effects of semantic consistency on eye movements during complex scene viewing. *Journal of experimental psychology: Human perception and performance*, 25(1), 210.

Hochstein, S., & Ahissar, M. (2002). View from the top: Hierarchies and reverse hierarchies in the visual system. *Neuron*, 36(5), 791–804.

Hollingworth, A., & Henderson, J. M. (2000). Semantic informativeness mediates the detection of changes in natural scenes. *Visual Cognition*, 7(1–3), 213–235.

Howell, D. C. (2009). Statistical methods for psychology, Toronto. ON: Nelson Education.

Hunt, A. R., & Kingstone, A. (2003). Inhibition of return: Dissociating attentional and oculomotor components. *Journal of Experimental Psychology: Human Perception and Performance*, 29(5), 1068.

JASP Team (2020). JASP (Version 0.14.1)[Computer software]

Joubert, O. R., Fize, D., Rousselet, G. A., & Fabre-Thorpe, M. (2008). Early interference of context congruence on object processing in rapid visual categorization of natural scenes. *Journal of Vision*, 8(13), 11–11.

Joubert, O. R., Rousselet, G. A., Fize, D., & Fabre-Thorpe, M. (2007). Processing scene context: Fast categorization and object interference. *Vision research*, 47(26), 3286–3297.

Juan, C. H., Shorter-Jacobi, S. M., & Schall, J. D. (2004). Dissociation of spatial attention and saccade preparation. *Proceedings of the National Academy of Sciences*, 101(43), 15541–15544.

Kaiser, D., Quek, G. L., Cichy, R. M., & Peelen, M. V. (2019). Object vision in a structured world. *Trends in cognitive sciences*, 23(8), 672–685.

Kappenman, E. S., Farrens, J. L., Luck, S. J., & Proudfit, G. H. (2014). Behavioral and ERP measures of attentional bias to threat in the dot-probe task: Poor reliability and lack of correlation with anxiety. *Frontiers in psychology*, 5, 1368.

Kappenman, E. S., MacNamara, A., & Proudfit, G. H. (2015). Electrocortical evidence for rapid allocation of attention to threat in the dot-probe task. *Social Cognitive and Affective Neuroscience*, 10(4), 577–583.

Lang, P.J., Bradley, M.M., & Cuthbert, B.N. (2008). International affective picture system (IAPS): Affective ratings of pictures and instruction manual. *Technical Report A-8*. University of Florida, Gainesville, FL.

LaPointe, M. R., & Milliken, B. (2017). Conflicting effects of context in change detection and visual search: A dual process account. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, 71(1), 40.

LaPointe, M. R., Lupianez, J., & Milliken, B. (2013). Context congruency effects in change detection: Opposing effects on detection and identification. *Visual Cognition*, 21(1), 99–122.

Leroy, A., Faure, S., & Spotorno, S. (2020). Reciprocal semantic predictions drive categorization of scene contexts and objects even when they are separate. *Scientific reports*, 10(1), 1–12.

Loftus, G. R., & Mackworth, N. H. (1978). Cognitive determinants of fixation location during picture viewing. *Journal of Experimental Psychology: Human perception and performance*, 4(4), 565.

Mack, A., Clarke, J., Erol, M., & Bert, J. (2017). Scene incongruity and attention. *Consciousness and cognition*, 48, 87–103.

Marchewka, A., Żurawski, Ł., Jednoróg, K., & Grabowska, A. (2014). The Nencki Affective Picture System (NAPS): Introduction to a novel, standardized, wide-range, high-quality, realistic picture database. *Behavior research methods*, 46(2), 596–610.

Meyers, L. S., Gamst, G., & Guarino, A. J. (2006). *Applied Multivariate Research: Design and Interpretation*. London: Sage.

Moors, P., Boelens, D., Van Overwalle, J., & Wagemans, J. (2016). Scene integration without awareness: no conclusive evidence for processing scene congruency during continuous flash suppression. *Psychological science*, 27(7), 945–956.

- Morey, R. D. (2008). Confidence intervals from normalized data: A correction to Cousineau (2005). *Tutorials in Quantitative Methods for Psychology*, 4(2), 61–64.
- Mudrik, L., Deouell, L. Y., & Lamy, D. (2011). Scene congruency biases binocular rivalry. *Consciousness and cognition*, 20(3), 756–767.
- Mudrik, L., Lamy, D., & Deouell, L. Y. (2010). ERP evidence for context congruity effects during simultaneous object–scene processing. *Neuropsychologia*, 48(2), 507–517.
- Mudrik, L., Shalgi, S., Lamy, D., & Deouell, L. Y. (2014). Synchronous contextual irregularities affect early scene processing: Replication and extension. *Neuropsychologia*, 56, 447–458.
- Oliva, A., & Torralba, A. (2006). Building the gist of a scene: The role of global image features in recognition. *Progress in brain research*, 155, 23–36.
- Ortiz-Tudela, J., Martín-Arévalo, E., Chica, A. B., & Lupiáñez, J. (2018). Semantic incongruity attracts attention at a pre-conscious level: evidence from a TMS study. *cortex*, 102, 96–106.
- Ortiz-Tudela, J., Milliken, B., Botta, F., LaPointe, M., & Lupiañez, J. (2017). A cow on the prairie vs. a cow on the street: Long-term consequences of semantic conflict on episodic encoding. *Psychological Research*, 81(6), 1264–1275.
- Peelen, M. V., & Kastner, S. (2014). Attention in the real world: toward understanding its neural basis. *Trends in cognitive sciences*, 18(5), 242–250.
- Posner, M. I., Inhoff, A. W., Friedrich, F. J., & Cohen, A. (1987). Isolating attentional systems: A cognitive-anatomical analysis. *Psychobiology*, 15(2), 107–121.
- Rayner, K., Castelhana, M. S., & Yang, J. (2009). Eye movements when looking at unusual/weird scenes: Are there cultural differences?. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 35(1), 254.
- Rémy, F., Vayssière, N., Pins, D., Boucart, M., & Fabre-Thorpe, M. (2014). Incongruent object/context relationships in visual scenes: Where are they processed in the brain?. *Brain and cognition*, 84(1), 34–43.
- Riegel, M., Wierzba, M., Wypych, M., Ritchey, M., Jednoróg, K., Grabowska, A., ... & Marchewka, A. (2020). Distinct medial-temporal lobe mechanisms of encoding and amygdala-mediated memory reinstatement for disgust and fear. *Neuroimage*.
- Riegel, M., Żurawski, Ł., Wierzba, M., Moslehi, A., Kłócek, Ł., Horvat, M., ... & Marchewka, A. (2016). Characterization of the Nencki Affective Picture System by discrete emotional categories (NAPS BE). *Behavior research methods*, 48(2), 600–612.
- Rieger, J. W., Köchy, N., Schalk, F., Grüşchow, M., & Heinze, H. J. (2008). Speed limits: orientation and semantic context interactions constrain natural scene discrimination dynamics. *Journal of Experimental Psychology: Human Perception and Performance*, 34(1), 56.
- Rife, S. C., Nuijten, M. B., Epskamp, S. (2016). Statcheck: Extract statistics from articles and recompute p-values [web application]. Retrieved from <http://statcheck.io>.

Shir, Y., Abudarham, N., & Mudrik, L. (2021). You won't believe what this guy is doing with the potato: The ObjAct stimulus-set depicting human actions on congruent and incongruent objects. *Behavior Research Methods*, 1–15.

Truman, A., & Mudrik, L. (2018). Are incongruent objects harder to identify? The functional significance of the N300 component. *Neuropsychologia*, 117, 222–232.

Underwood, G., & Foulsham, T. (2006). Visual saliency and semantic incongruity influence eye movements when inspecting pictures. *The Quarterly journal of experimental psychology*, 59(11), 1931–1949.

Underwood, G., Humphreys, L., & Cross, E. (2007). Congruency, saliency and gist in the inspection of objects in natural scenes. In *Eye Movements* (pp. 563–VII). Elsevier.

Underwood, G., Templeman, E., Lamming, L., & Foulsham, T. (2008). Is attention necessary for object identification? Evidence from eye movements during the inspection of real-world scenes. *Consciousness and cognition*, 17(1), 159–170.

Van Hooff, J. C., Devue, C., Vieweg, P. E., & Theeuwes, J. (2013). Disgust-and not fear-evoking images hold our attention. *Acta psychologica*, 143(1), 1–6.

Van Hooff, J. C., van Buuringen, M., El M'rabet, I., de Gier, M., & van Zalingen, L. (2014). Disgust-specific modulation of early attention processes. *Acta psychologica*, 152, 149–157.

Virtanen, P., Gommers, R., Oliphant, T. E., Haberland, M., Reddy, T., Cournapeau, D., ... & van Mulbregt, P. (2020). SciPy 1.0: fundamental algorithms for scientific computing in Python. *Nature methods*, 17(3), 261–272.

Võ, M. L. H., & Henderson, J. M. (2009). Does gravity matter? Effects of semantic and syntactic inconsistencies on the allocation of attention during scene perception. *Journal of Vision*, 9(3), 24–24.

Võ, M. L. H., & Henderson, J. M. (2011). Object–scene inconsistencies do not capture gaze: evidence from the flash-preview moving-window paradigm. *Attention, Perception, & Psychophysics*, 73(6), 1742–1753.

Võ, M. L. H., & Wolfe, J. M. (2013). Differential electrophysiological signatures of semantic and syntactic scene processing. *Psychological science*, 24(9), 1816–1823.

Võ, M. L. H., Boettcher, S. E., & Draschkow, D. (2019). Reading scenes: how scene grammar guides attention and aids perception in real-world environments. *Current opinion in psychology*, 29, 205–210.

Wetzels, R., Matzke, D., Lee, M. D., Rouder, J. N., Iverson, G. J., & Wagenmakers, E. J. (2011). Statistical evidence in experimental psychology: An empirical comparison using 855 t tests. *Perspectives on Psychological Science*, 6(3), 291–298.

Wheaton, M. G., Holman, A., Rabinak, C. A., MacNamara, A., Proudfit, G. H., & Phan, K. L. (2013). Danger and disease: electrocortical responses to threat-and disgust-eliciting images. *International Journal of Psychophysiology*, 90(2), 235–239.

Wolfe, J. M., & Horowitz, T. S. (2017). Five factors that guide attention in visual search. *Nature Human Behaviour*, 1(3), 1–8.

Wu, C. C., Wick, F. A., & Pomplun, M. (2014). Guidance of visual attention by semantic information in real-world scenes. *Frontiers in psychology*, 5, 54.

Zivony, A., & Lamy, D. (2014). Attentional engagement is not sufficient to prevent spatial capture. *Attention, Perception, & Psychophysics*, 76(1), 19–31.