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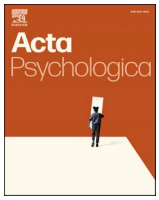

The effect of target-related and target-irrelevant novel stimuli on response behaviour

Julie M. Hall [a,c,*], Haeme R.P. Park [b], Ruth M. Krebs [a], Judith Schomaker [c]

[a] Department of Experimental Psychology, Ghent University, Belgium
[b] Neuroscience Research Australia, University of New South Wales, Australia
[c] Faculty of Social and Behavioural Sciences, Section Health, Medical & Neuropsychology, Leiden University, the Netherlands

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ABSTRACT

Novel events catch our attention, which can influence performance of a task. Whether this attentional capture by novelty benefits or impairs performance depends on several factors, such as the relevance of the stimulus, task requirements, and the timing of the event. Additionally, it has been argued that novel stimuli can hold intrinsic reward value, which may directly affect approach motivation, similar to positive valence stimuli. This link between novelty and approach/avoid behaviour has not been investigated directly. Here, we investigated whether stimulus novelty interacts with response behaviour in an approach/avoidance task, and whether these effects depend on the task relevance of novelty and stimulus timing. In experiment 1, participants gave an approach or avoid response dependent on a shape (diamond or square) presented at different stimulus onset asynchronies (SOA) following a novel or familiar scene (target-*irrelevant* novelty). In experiment 2, participants had to approach or avoid a novel or familiar image depending on the content (indoor/outdoor; target-*related* novelty). A shape was presented at different SOA. Results of a linear mixed model showed novelty-induced performance costs as demonstrated by longer RT and lower accuracy when novelty was target-relevant, likely due to attentional lingering at novel images. When images were target-irrelevant, approach but not avoid responses were faster for familiar versus novel images at 200 ms SOA only. Thus, novelty had a differentially pronounced detrimental effect on performance. These observations confirm that processing of novel stimuli generally depends on stimulus relevance, and tentatively suggests that differential processing of novel and familiar images is intensified by motivated approach behaviour.

1. Introduction

Valence-action biases facilitate quick responses for compatible compared to incompatible valence-action mappings (i.e., positive-approach/negative-avoid vs. positive-avoid/negative-approach; Carver & Scheier, 2001; Gray, 1990). This results in a behavioural advantage: quickly recognizing positive and negative stimuli in the environment is an essential regulatory mechanism to respond optimally to the current situation. Positively evaluated stimuli are associated with a response that decreases the distance between the individual and the stimulus, object, event or possibility (known as *approach* motivation), whilst negatively appraised stimuli are associated with a response that increases this distance (*avoid* motivation; Osgood, 1953). Thus, both approach and avoid motivation can energize and direct response behaviour (Elliot, 2006). In one of the first experimental studies that showed this valence-action effect, participants had to either pull cards towards themselves or push them away (Solarz, 1960). The cards contained words with pleasant or unpleasant meaning. Participants were quicker to pull pleasant words towards themselves as opposed to pushing them away, whilst the opposite was true for unpleasant words. These effects of "positive" and "negative" valences on responses have since been confirmed in other studies (for review, see Phaf et al., 2014) and extended to comparable dimensions, such as beneficial/harmful or rewarding/punishing (Elliot, 2006). Consistent with this, we recently showed that valence-action biases are also elicited by reward-predicting stimuli (Hoofs, Boehler, & Krebs, 2019), which is intriguing considering that this bias is not beneficial and goes against the task goal. Moreover, even target-irrelevant reward-associated stimuli bias actions (Hoofs, Carsten, et al., 2019) supporting the notion that valence-action biases are fairly automatic.

* Corresponding author at: Wassenaarseweg 52, 2333 AK Leiden, the Netherlands.
E-mail address: j.m.hall@fsw.leidenuniv.nl (J.M. Hall).

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Behaviourally, it has been shown that individuals spend more time viewing novel complex patterns compared to familiar ones when given a choice and both subjective 'pleasantness' and 'interestingness' increase with novelty (Berlyne, 1970; Park et al., 2010). Therefore, novelty may also elicit action biases, similar to stimuli with positive valences. Reward-encoding dopaminergic neurons in the midbrain and mesolimbic reward pathways also respond to novelty (Bunzeck & Düzel, 2006; Schultz, 1998; Wittmann et al., 2005). Given the importance of novelty detection in survival and learning, the overlap between reward and novelty processing in this brain structure could suggest that novelty itself may possess an intrinsic reward value (Reed et al., 1996). Indeed, novel rather than familiar images have been shown to selectively increase reward-anticipation in reward-processing structures of the midbrain (Krebs et al., 2011). Via these pathways novelty could potentially motivate exploration of new environments (Krebs, Schott, Schütze, & Düzel, 2009; Wittmann et al., 2007). This notion has been formalized in reinforcement learning models as exploration bonus or novelty bonus (Kakade & Dayan, 2002). Taken together, this suggests that novelty activates motivational pathways in the brain that could boost exploratory behaviour (Düzel, Bunzeck, Guitart-Masip, & Düzel, 2010).

The observation that novelty is associated with exploratory behaviour and mesolimbic reward pathways is suggestive of an association with positive valence, which in turn, could directly influence approach behaviour. However, there is also some evidence that individuals may be hesitant to approach something novel, as novel items contain a degree of uncertainty and are therefore associated with a possible risk (Crane et al., 2020). Animal studies have shown that in certain circumstances, innate neophobia is a sensible precaution to potentially dangerous environments or objects (Hughes, 2007; Mettke-Hofmann, 2017). Rats, for instance, are usually wary of unfamiliar foods and wild birds have been observed to avoid novel prey items (Hosey et al., 2009). In humans, a (pathological) fear of anything new also exists, and is most often reported in context of children encountering novel food (called food neophobia; Dovey et al., 2008). Furthermore, active judgement (or more broadly, task relevance) of novel stimuli may also influence preference. Liao et al. (2011) showed that participants only preferred novel over familiar scenes when they performed an objective judgement task, but not after mere passive exposure. Therefore, the first aim of this study is to investigate whether target-related and/or target-irrelevant novelty can elicit valence-action biases.

The second aim of this study is to explore the conditions in which novelty stimulates attention (orienting/alerting response) or distraction. Many studies have already shown that an orienting response, elicited by surprise or novelty, leads to distraction from ongoing tasks. For example, in the novelty oddball paradigm, sequences of repetitive stimuli are infrequently interrupted by novel or deviant stimuli that attract attention despite being target-irrelevant (Bendixen et al., 2010; Berti & Schröger, 2004; Näätänen et al., 1993; Parmentier & Andrés, 2010; Wetzel et al., 2013). Distraction by novelty is reflected by psychophysiological measures, such as the novelty P3 event-related potential component (Courchesne et al., 1975), but also by increases in response times (RT) and error rates (e.g. Parmentier et al., 2011). However, this distracting effect by target-irrelevant novel stimuli is not always observed (Parmentier et al., 2010). When novel stimuli are *target-related*, they can prolong RTs as well (Krebs, Schott, Schütze, & Düzel, 2009; Exp 1), possibly due to distraction, or more likely, the result of *attentional lingering* to promote stimulus encoding (Kafkas & Montaldi, 2011). Interestingly, in certain instances, novelty can even elicit a general facilitation effect. For example, previous work showed response speeding for novel vs. familiar cue stimuli in a monetary incentive task (Krebs, Schott, Schütze, & Düzel, 2009; Exp. 2). In this task, the stimuli were relevant, yet the novelty dimension was entirely implicit. Similarly, another study showed that visual perception on a two-alternative forced choice task was enhanced, when a target-irrelevant novel (vs. familiar) image was presented before the target (a Gabor patch; Schomaker & Meeter, 2012). The authors argued that the novel images increased visual sensitivity by eliciting a transient attentional response. The time between novel and target information may be a crucial factor in determining the consequence - either facilitation or distraction - of novelty. Specifically, target-irrelevant visual novelty has been shown to facilitate responses to an auditory target in a 0–200 millisecond time-window with effects disappearing at a longer 800 ms stimulus onset asynchrony (SOA; Schomaker and Meeter, 2014a). The authors suggested that these effects can be explained by the novel stimuli eliciting a brief alerting response, resulting in general response facilitation. This alerting response may be related to the phasic response in the noradrenergic locus coeruleus (LC; Sara & Segal, 1991; Vankov et al., 1995). Animal research has shown that the noradrenergic system augments processing of salient information, including novel stimuli, and attenuates processing of less relevant information (Aston-Jones et al., 1994; Oades, 1985). When a novel or salient image is presented, the LC neurons increase their firing rate (Aston-Jones & Bloom, 1981; Vankov et al., 1995). The timing of the response facilitating effects of novelty (~0–200 ms) is in line with the phasic LC response (Nieuwenhuis et al., 2005).

In summary, we investigated whether novel stimuli induce an action bias based on inherent valence associations, and whether this depends on task relevance. After a familiarization phase, participants performed a task in which novel and familiarized stimuli served as target-irrelevant primes (experiment 1) or as target-related target stimuli that indicated which action participant had to perform (i.e., approach = move forward vs. avoid = move backwards; experiment 2). Based on the notion that novel stimuli can promote exploratory behaviour via mesolimbic reward pathways (at least in some contexts), we expected that novel stimuli would promote approach behaviour through similar mechanisms as positive valence. Moreover, the tendency to explore a novel stimulus may be modulated by individual novelty seeking traits (Cloninger et al., 1991), with individuals scoring high on novelty seeking experiencing new images or situations as more rewarding compared to individuals with low novelty seeking (Krebs, Schott, Schütze, & Düzel, 2009). This difference could be reflected in a differential effect of novelty on global behavioral tendencies, such as approach vs. avoidance actions. Finally, we will explore the effect of task relevance in this context, as well as the effect of stimulus timing, as both have been shown to modulate performance in task involving novel stimuli. Task relevance was manipulated in a between-experiment fashion (target-irrelevant novelty in Exp. 1 vs. target-related stimuli in Exp. 2), with the broad hypothesis that target-related novel stimuli would have stronger impact on performance. To investigate the time-course of the effects, we varied the onset between the novel/familiar images and the target stimulus, with SOAs of 0, 200 and 800 ms (as in Schomaker and Meeter, 2014a). We specifically expected that novelty would promote approach behaviour around 0–200 ms post-stimulus, as this coincides with the latency of the LC phasic response (Aston-Jones et al., 1994), and has been shown to elicit a facilitation effect in a previous study (Schomaker and Meeter, 2014a).

2. Methods

2.1. Participants

One hundred and eighty-six participants were included in this study. Participants could subscribe to one of the two experiments via the online platform Prolific. Data of 19 participants were excluded due to a failure to finish the task or failure to respond to any trials ($n = 13$) or in case the accuracy was below 75 % ($n = 6$). Due to technical issues (i.e., failure to timely load the images), another 16 participants had to be excluded. As such, 151 participants were included in the final analyses (Experiment 1: $n = 72$, 27 females (37.5 %), mean age ± SD: 24.4 ± 4.9 y; Experiment 2: $n = 79$, 24 females (30.4 %), mean age ± SD: 24.2 ± 5.0 y). There was no overlap in participants across the two experiments. In both experiments, participants received a reimbursement of £5.63 for their

participation. The average time participants took to complete the task was approximately 40 min (£7.50/h). The inclusion criteria were age between 18 and 35 years, right-handedness, normal or corrected-to-normal vision, no (history of) diagnosed mental disorders or cognitive impairment, not taking any medication to treat symptoms of depression, anxiety or low-mood, proficiency in the English language and a minimal approval rate of 80 % for previous studies. The study was in accordance with the Declaration of Helsinki from 1964 and its later amendments. Informed consent was obtained from all participants in advance of participation.

2.2. Paradigms and procedures

2.2.1. Experiment 1 – target-irrelevant stimuli

In a *familiarization* phase the participants were familiarized with a set of 90 images depicting indoor and outdoor scenes. All images were presented on the screen for 1500 ms each in a randomized order. Every scene was shown four times to ensure familiarization. To make sure the images were attended, participants had to indicate whether they had seen the image before or whether the image was new with a key press ('z' or 'c'). In the second part of the experiment, participants performed an *approach/avoidance* task. An approach movement was accomplished by pressing the upwards arrow, whilst avoidance was accomplished by pressing the downwards arrow. A manikin jumped in the approach or avoid direction to simulate the movement. The required movement (approach/avoid) was indicated by a shape (square vs. diamond) and was counterbalanced across participants. A novel or familiar image was presented on the screen at different SOAs: 0 ms, 200 ms or 800 ms before the target shape appeared on the screen and remained on the screen during while the target was presented (1500 ms). Each image was only presented once during this phase. The target stimuli (diamond/square) were presented for 1000 ms and participants were instructed to respond as accurately and quickly as possible. If the response was correct and in time, a green check mark serving when a 'correct' response was made accompanied by a manikin animation that was presented below the stimuli, moved in the selected direction on the screen to simulate the approach/avoid movement. Participants were instructed to imagine they were the manikin. This simulation of approach/avoid movement using a manikin has been successfully validated in previous work (Krieglmeyer & Deutsch, 2010). If the response was incorrect or too late, a red coloured cross or a clock image was presented below the stimuli, signalling 'incorrect' and 'too late' response feedback, respectively. Feedback was presented for 300 ms. To complete this task successfully, participants did not need to process the novel and familiar images (i.e., only had to focus on the shape), therefore, we will refer to it as the *novelty irrelevant* target task (Fig. 1).

2.2.2. Experiment 2 – target-related novelty

Seventy-nine participants were included in Experiment 2. The familiarization phase and the procedure of the second part of the experiment were similar to Experiment 1. However, in the second part of this experiment, instead of responding to a shape, the participants had to respond to the scene of an image (indoor/outdoor) that determined the response movement (approach/avoid). These images contained the familiarized images of the familiarization phase of this experiment, as well as a set of novel images. A shape (diamond/square) was presented at 0 ms, 200 ms or 800 ms SOA before the target image appeared on the screen to ensure comparability between the experiments (as the pre-presentation of an image may have served as a warning signal for the upcoming target). In this experiment, the participant did not specifically classify whether the image was novel or familiar, however, the scene had to be processed (as indoor/outdoor) to select the correct approach/avoid response. Therefore, we will refer to this as the *novelty target-related* task.

2.2.3. Tridimensional Personality Questionnaire

All participants filled out the novelty seeking scale of the Tridimensional Personality Questionnaire (*TPQ-ns*; Cloninger et al., 1991). The novelty seeking scale is one of three subscales of the TPQ that seeks to measure different traits of an individual's personality: novelty seeking, harm avoidance and reward dependence. The novelty seeking scale includes 34 true/false questions.

2.3. Data analyses

All data from the first trial as well as premature responses (defined as RT <150 ms) were excluded. Analysis procedures were the same across the experiments. Accuracy rates and RT were analysed using a binominal generalized linear mixed model with a logit link function and linear mixed model respectively with action (approach/avoid), novelty (novel/familiar) and stimulus onset asynchrony (SOA; 0, 200, 800 ms) as fixed factors and subject (intercept) as random factor for each

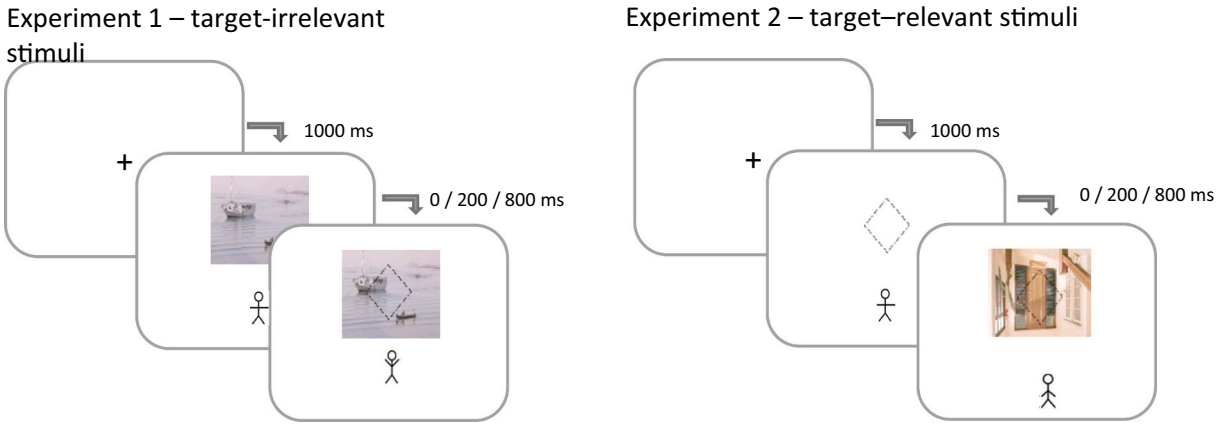

Fig. 1. Experimental paradigm of the target-irrelevant (experiment 1) and relevant stimuli (experiment 2). Subjects were first familiarized with a set of 90 images (not shown in the figure). In experiment 1 (left panel), subjects had to select an approach or avoid response based on a shape (diamond vs. square). The shape was preceded by a scene image which served as a prime and was irrelevant to the task. In experiment 2 (right panel), subjects had to select an approach or avoid response based on image content (indoor vs. outdoor). The image was preceded by a shape which served as a prime and was irrelevant to the task. In both cases, novelty/familiarity of the image was implicit, but in experiment 2 the image had to be attended to, which we refer to as target-related stimuli condition. In both experiments the SOA was varied randomly between trials (0, 200 or 800 ms), and a Manikin was shown to depict the chosen response (approach reflected by an upward- and avoid by a downward-moving Manikin). Feedback was presented to indicate whether participants gave the correct approach or avoid response, or whether the response was absent or too late.

experiment separately. In additional analyses, we combined the data of both tasks using similar models with experiment as an additional fixed factor. All data were analysed in *R* Statistical Software version 4.0.3 (The R Foundation for Statistical Computing) using the lme4 package (Bates et al., 2015). The reported *p* values for the fixed effects were based on a Type III ANOVA using a χ2-distribution as included in the R package *car*. Alpha was set at 0.05 for all statistical tests. The coefficient of determination (marginal and conditional R^2) was calculated using R package *MuMIn*. Pairwise post hoc analyses were performed using Tukey method for multiple comparison adjustment when a significant effect was found.

For each experiment, accuracy and RTs of the familiar condition were subtracted from the novel condition. These 'baseline' novel variables were then correlated with TPQ-ns using Spearman's rho and Pearson correlation coefficient depending on the distribution of the data. Furthermore, significant interaction effects were correlated to the TPQ-ns scores.

3. Results

3.1. Experiment 1 - target-irrelevant stimuli

3.1.1. Accuracy rates

To analyse accuracy rates, a generalized linear mixed model fit by maximum likelihood (Laplace Approximation; ['glmerMod']) was fitted (family: binomial (logit)); optimizer = "*nloptwrap*"). The mean and standard deviations of the accuracy rates and RT are displayed in Table 1. In Experiment 1 (*target-irrelevant stimuli*), the model showed a main effect of SOA on accuracy ($\chi^2(2) = 11.08$, $p = .004$, $R^2_{(marg)} = 0.002$, $R^2_{(cond)} = 0.044$). Tukey's test for post hoc analysis showed that accuracy rates were significantly lower for trials with SOA 0 compared to SOA 800 ($B = 0.61$, $SE = 0.20$, $Z = 3.11$, $p = .005$). Whilst accuracy rates for trials with SOA 0 ms were also lower than for trials with SOA 200 ms, this was not significant ($p = .053$). The difference between SOA 200 and SOA 800 ms was non-significant ($p = .703$). There was no main effect of novelty ($p = .360$) or action ($p = .244$). We observed a significant interaction between the two factors ($p = .046$), resonating from lower accuracy in novel as compared to familiar trials in the approach condition. No other interaction effects were observed ($p \geq .173$).

3.1.2. Response times (RT)

Table 1 and Fig. 3 provide an overview of the RT results of Experiment 1 (target-irrelevant stimuli). A main effect of action was observed, with faster approach responses as compared to avoid responses (approach: $M = 528$, $SD = 129$; avoid: $M = 544$, $SD = 129$; $p = .013$). There was no main effect of novelty on RT (familiar: $M = 528$, $SD = 129$; novel: $M = 544$, $SD = 129$; $p = .950$). A main effect of SOA was observed ($p < .001$). Tukey's test for post-hoc analyses showed that responses were slower at 0 ms ($M = 588$, $SD = 130$) versus 200 ms ($M = 534$, $SD = 122$; $B = -82.20$, $SE = 4.80$, $Z = -17.11$, $p < .001$) and 800 ms SOAs ($M = 485$, $SD = 114$; $B = -103.36$, $SE = 4.77$, $Z = -21.67$, $p < .001$). Additionally, responses for trials with 200 ms SOA were slower than with 800 ms SOA ($B = -21.15$, $SE = 4.77$, $Z = -24.43$, $p < .001$). Furthermore, we observed significant interaction between novelty and SOA ($p < .001$), as well as between action and SOA ($p = .001$). Finally, a three-way interaction effect between action, novelty, and SOA ($p < .001$) was found. These interaction effects all showed a similar pattern: participants were quicker to respond in the presence of familiar images with an SOA of 200 ms compared to novel trials. This effect was not present in avoid trials or in trials with 0 or 800 ms SOA.

Table 1
Overview of the fixed and random effects on RT in target-irrelevant stimuli (exp 1).

Fixed effects	Wald's χ^2(df)	*p*-Value	R^2 marginal	R^2 conditional
Novelty	0.004 (1)	**0.**950	0.004	0.194
Action	**6.202 (1)**	**0.013**	**0.004**	**0.195**
SOA	**521.289 (2)**	**< 0.001**	**0.111**	**0.306**
Novelty * Action	1.846 (1)	0.174	0.008	0.198
Novelty * SOA	**74.272 (2)**	**< 0.001**	**0.118**	**0.313**
Action * SOA	**13.477 (2)**	**0.001**	**0.115**	**0.310**
Novelty * Action * SOA	**16.22 (2)**	**< 0.001**	**0.123**	**0.318**

Random effects	Variance	Std. dev.	R^2 conditional
Subjects	3299	57.43	0.190
Residual	11,512	107.29	

Number of obs: 12132, subjects: 72.
REML criterion at convergence: 148090.3.

3.2. Experiment 2 – target-related stimuli

3.2.1. Accuracy

To analyse accuracy rates, a generalized linear mixed model (with the same formula as in experiment 1) was fitted. In Experiment 2 (target-related stimuli), a main effect for novelty was found with higher accuracy rates for familiar compared to novel scenes (novel $M = 0.84$, $SD = 0.34$; familiar $M = 0.89$, $SD = 0.31$; $\chi^2(1) = 15.56$, $p < .001$, $R^2_{(marg)} = 0.002$, $R^2_{(cond)} = 0.028$). Additionally, a main effect for action was found, with higher accuracy rates for approach compared to avoid trials (approach: $M = 0.88$, $SD = 0.32$; avoid: $M = 0.87$, $SD = 0.33$, $\chi^2(1) = 7.37$, $p = .007$, $R^2_{(marg)} < 0.001$, $R^2_{(cond)} = 0.027$). To check whether there was a response bias for approached images, a d' score was calculated. The average d' score for approach responses was 0.884 and 0.907 for avoid responses. T-tests showed that these scores did not significantly differ from each other ($p = .769$), and no differences in false alarm rates between approach and avoid trials were found ($p = .582$). The main effect of SOA was non-significant (SOA 0 ms $M = 0.86$, $SD = 0.35$; SOA 200 ms $M = 0.88$, $SD = 0.32$; SOA 800 ms $M = 0.89$, $SD = 0.31$; $p = .734$). No interaction effects were found (all $p \geq .099$).

3.2.2. Response times (RT)

Table 2 and Fig. 3 present an overview of the RT results in Experiment 2 (target-related stimuli). Responses following familiar targets were quicker than responses to novel targets (novel $M = 699$, $SD = 127$; familiar $M = 649$, $SD = 121$; $p < .001$) and approach responses were quicker than avoid responses (approach $M = 665$, $SD = 126$; avoid $M = 682$, $SD = 126$; $p < .001$). Furthermore, a main effect for SOA was found (SOA 0 ms $M = 695$, $SD = 122$; SOA 200 ms $M = 669$, $SD = 128$; SOA

Table 2
Overview of the fixed and random effects on RT in experiment 2.

Fixed effects	Wald's χ^2 (df)	*P*-value	R^2 *marginal*	R^2 *conditional*
Novelty	**153.95 (1)**	**< 0.001**	**0.040**	**0.150**
Action	**23.16 (1)**	**< 0.001**	**0.005**	**0.114**
SOA	**86.40 (2)**	**< 0.001**	**0.017**	**0.128**
Novelty * Action	1.88 (1)	0.170	0.044	0.156
Novelty * SOA	**9.21 (2)**	**0.010**	**0.059**	**0.170**
Action * SOA	**6.42 (2)**	**0.040**	**0.022**	**0.133**
Novelty * Action * SOA	5.47 (2)	0.065	0.064	0.176

Random effects	Variance	Std. dev.	R^2 *conditional*
Subjects	1804	42.47	0.109
Residual	13,230	115.02	

Number of obs: 12408, subjects: 79.
REML criterion at convergence: 153145.1.
Formula = lmer(RT ~ (1 | subject) + novelty * action * SOA).

800 ms $M = 657$, $SD = 126$; $p < .001$). Post-hoc analyses (Tukey's test) showed that RTs for SOA 0 were significantly longer compared to 200 ms ($B = -36.15$, $SE = 5.06$, $Z = -7.15$, $p < .001$) and 800 ms SOA($B = -43.92$, $SE = 5.01$, $Z = -8.77$, $p < .001$). SOA 200 and SOA 800 did not differ ($B = -7.76$, $SE = 4.97$, $Z = -1.56$, $p = .262$). Additionally, an interaction effect between novelty and SOA was found ($p = .010$; see Fig. 3). Here, familiar images showed shorter RTs at SOA 200 ms (compared to 0 ms) than novel images ($p = .002$). Furthermore, a two-way interaction between action and SOA was observed ($p = .040$). Avoid responses at SOA 800 ms were faster compared to approach responses ($p = .026$). The three-way interaction effect between novelty, action and SOA did not reach significance ($p = .065$).

3.3. Across-experiment analysis

In an additional analysis, we investigated the influence of the relevance of novel stimuli on task performance (Experiment 1: target-irrelevant stimuli; Experiment 2: target-related stimuli). We ran a (general) linear mixed model, evaluating the (fixed) effects of novelty, action, and SOA, as well as experiment (i.e., task relevance) on response behaviour, including subject as random effect. The main and interaction effects of experiment are discussed here. An overview of the full results can be found in Supplementary Materials Table S3 and S4.

3.3.1. Accuracy

Overall accuracy rates for experiment 1 (target-irrelevant; $M = 0.94$, $SD = 0.23$) were higher compared to experiment 2 (target-related; $M = 0.88$, $SD = 0.33$, $\chi^2(2) = 8.457$, $p = .004$, $R^2_{(marg)} = 0.020$, $R^2_{(cond)} = 0.057$). Additionally, we found a two-way interaction effect between novelty and experiment ($\chi^2(1) = 3.97$, $p = .046$, $R^2_{(marg)} = 0.021$, $R^2_{(cond)} = 0.058$). Accuracy was relatively lower for trials featuring novel as compared to familiar stimuli in experiment 2 compared to experiment 1. This difference is illustrated in Fig. 4. A two-way interaction effect between action and experiment ($\chi^2(2) = 6.28$, $p = .012$, $R^2_{(marg)} = 0.020$, $R^2_{(cond)} = 0.058$) was found, which showed that the difference between accuracy rates in approach versus avoid trials was greater in experiment 2 compared to experiment 1. A three-way interaction effect between novelty, action, and experiment ($\chi^2(2) = 6.07$, $p = .014$, $R^2_{(marg)} = 0.0208$, $R^2_{(cond)} = 0.058$) was observed (see Fig. 2). However, pairwise post hoc analysis showed that no significant effects after multiple comparisons correction ($ps \leq 0.255$).

3.3.2. Response times (RT)

As shown in Figs. 3 and 4, overall RTs were significantly shorter in experiment 1 (target-irrelevant stimuli), compared to experiment 2 (target-related stimuli; $\chi^2(1) = 78.48$, $p < .001$, $R^2_{(marg)} = 0.224$, $R^2_{(cond)} = 0.340$). A significant two-way interaction between novelty and SOA was found ($\chi^2(2) = 40.64$, $p < .001$), as well significant two-way interactions between novelty and experiments ($\chi^2(1) = 33.53$, $p < .001$) and SOA and experiment ($\chi^2(2) = 80.47$, $p < .001$). A significant three-way interaction between novelty, SOA, and experiment was found ($\chi^2(2) = 18.67$, $p < .001$, $R^2_{(marg)} = 0.292$, $R^2_{(cond)} = 0.411$). As shown in Fig. 3, in both experiments, we observed higher RTs for novel vs familiar stimuli. In experiment 1, this effect was specific to SOA 200 ms, whereas in experiment 2, this effect was present at 200 and 800 ms. The significant four-way interaction between novelty, action, SOA and experiment ($\chi^2(2) = 6.17$, $p = .046$, $R^2_{(marg)} = 0.296$, $R^2_{(cond)} = 0.415$) additionally showed that the action type also differed between experiments: results from experiment 1 showed that approach responses were quicker for familiar trials at SOA 200 ms. In experiment 2, familiar images showed quicker RTs compared to novel images at SOA 800 ms in experiment 2 for both approach and avoid movements.

3.3.3. Correlation analyses between novelty seeking traits and task performance

In Experiment 1, 64 participants completed the TPQ-ns and all participants of Experiment 2 completed the questionnaire ($M = 16.57$, SD = 4.42, range = 4–27). The difference scores between the novel and familiar condition ('baseline novelty') was calculated for accuracy rates and RTs across experiments. These scores did not correlate with TPQ-ns ($p \geq .097$; FDR corrected). No significant correlations were found between TPQ-ns scores and accuracy rates and RT baseline novelty score at 200 ms SOA for all trials, nor for the approach and avoid trials separately ($p \geq .798$; FDR corrected). The Cronbach's alpha for the TPQ-ns across experiments was 0.621.

4. Discussion

As novelty has been suggested to possess intrinsic reward value (Krebs et al., 2011; Wittmann et al., 2007) we hypothesized that novelty could directly influence action tendencies, similar to approach biases triggered by positive valence stimuli (Hoofs, Boehler, & Krebs, 2019). To investigate whether novel stimuli would promote approach responses, and whether this would depend on task relevance and the specific

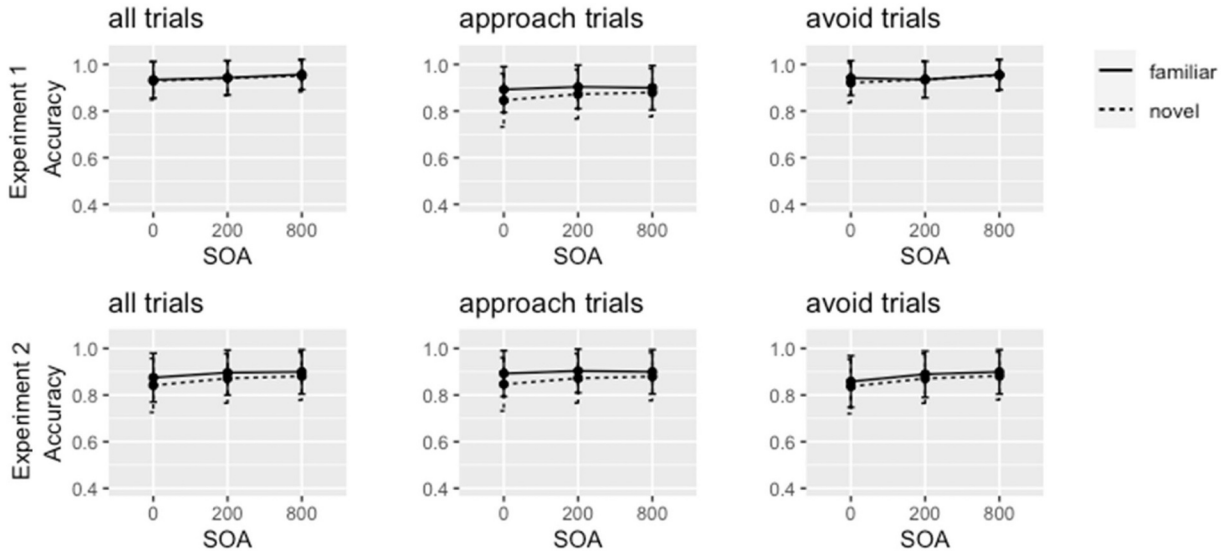

Fig. 2. Overview of mean accuracy rates for each condition. Top row: experiment 1; bottom row: experiment 2. Bars present the standard error of the mean. Note that the y-axis starts at 0.4 for a more detailed presentation of the effects.

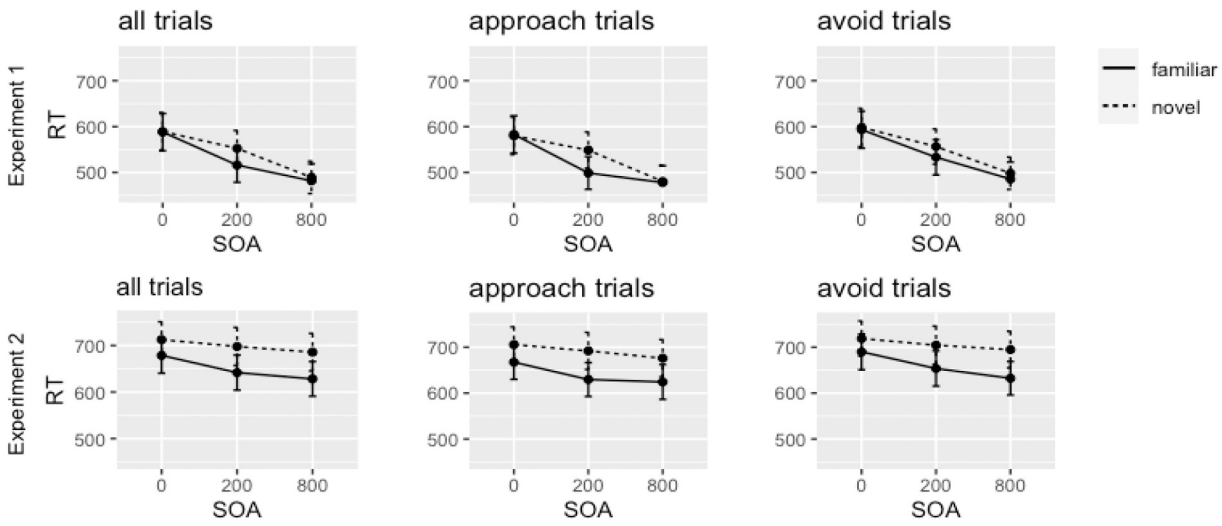

Fig. 3. Overview of mean RTs for each condition. Top row: experiment 1; bottom row: experiment 2. Interaction effects stimulus * SOA per experiment for all trials (left column), as well as for approach (middle column) and avoid trials (right column). Bars depict standard errors of the mean.

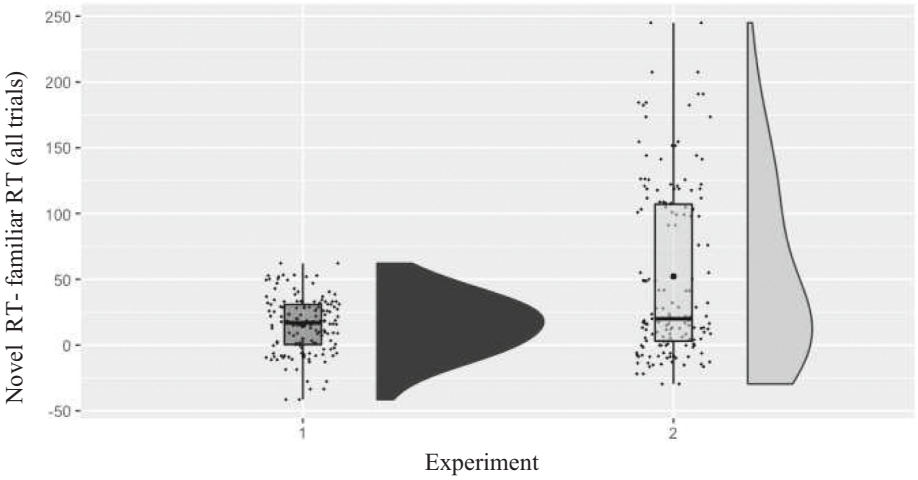

Fig. 4. Difference RTs between the novel and familiar condition for experiment 1 (left) and experiment 2 (right). Box plots indicate mean (dot) and median (line) and the variability outside the upper and lower quartiles. The dots represent the averaged data points per subject.

stimulus timing, we performed two online experiments. In Experiment 1 (target-irrelevant stimuli), novel and familiar images were presented as primes at different SOAs before a target shape (square/diamond) was presented that determined the approach or avoid response. In Experiment 2 (target-related stimuli), participants had to respond to the content of the novel and familiar images (indoor/outdoor), indicating the approach or avoid response, whilst the shapes (square/diamond) acted as irrelevant primes. Hence, in the latter task, the target image needed to be processed in order to perform the correct response. Overall, our results show poorer target-performance for avoid compared to approach trials and trials with lower versus higher SOAs. Moreover, we observed increased RT and lower accuracy rates following novel stimuli. This effect was most pronounced when novel stimuli were target-related (experiment 2). In what follows we discuss the observed performance patterns in light of the literature.

The selective performance detriments by target-irrelevant novel stimuli in approach trials (experiment 1) contrasts with our expectations. We expected that novelty (not familiarity) would promote approach behaviour, similar to an action-valence bias, but observed the opposite; faster and more accurate approach responses on familiar trials. Selective distraction by novelty on approach and not avoid trials could however also be explained by the information (relevance) hypothesis, as the approach rather than avoid response may have biased participants to process the novels to a higher level, leading to more distraction, than on avoid trials. Alternatively, whilst humans often show a preference for novelty compared to familiarity when viewing natural scenes (Berlyne, 1970; Park et al., 2010), this preference may vary with the frequency the familiar alternative is presented. Liking of an image increases after a small number of exposures and decreases again after many exposures (Zajonc et al., 1972). Furthermore, explicit judgement of a novel image increases its likability in contrast to simply viewing images (Liao et al., 2011). Active task engagement, such as an approach or avoid response in the current task, seems to be not sufficient to establish this preference. Other factors, such as complexity, also play a role in ascribing preference for a particular image (Berlyne, 1970). Repetition of a complex image increases the hedonic value whereas a repetition of a simple image may decrease its value. Images in our experiments consisted of complex natural scenes and repeated viewing may therefore have increased its valence. Additionally, the perceptual processing benefit for familiar images may also have contributed to its perceived positive value as less effort is needed to suppress the familiar in contrast to the novel information.

Notably, the differential approach bias triggered by target-irrelevant familiar stimuli only occurred when images were presented 200 ms before the target, which coincides with the activation of the LC-NA system after presentation of salient stimuli. As the firing rate of the noradrenergic neurons decreases as the stimulus becomes familiar (Aston-Jones & Bloom, 1981; Vankov et al., 1995), it may seem counterintuitive that a facilitation effect for familiar images is due to increased transient attention or an arousal effect. One could speculate that given both images are irrelevant, but act as alerting primes, novelty and familiar stimuli could *both* be salient when presented at SOA 200 ms. No additional cognitive resources are necessary to process familiar images, and thus the presentation of a familiar or known stimulus may benefit from the NA mediated increase in the state of vigilance. On the other hand, if familiar images were perceived as more positive, this could have facilitated by a dopaminergic response, which has a similar latency as the LC-NA system (Redgrave, Prescott & Gurney, 1999). Future studies using physiological measures (such as pupillometry) could shine light on these underlying mechanisms.

Although we found a similar tendency for an approach bias for familiar images at SOA 200 ms when the image was target-related (experiment 2), this effect was not significant. In fact, we observed an interaction between experiment, novelty, action, and SOA that suggested a differential response pattern for approach and avoid trials at SOA 800 ms between experiments. The paradigm with target-related images was generally more difficult than the one with target-irrelevant images as reflected in higher RT and lower accuracy rates. Participants had to judge more complex scenes as opposed to the simple shape in the former. These more complex perceptual effects in the target-related novel stimuli experiment could have overshadowed the possible positive valence of the familiar images observed in experiment 1. Previous work has shown that complex discrimination can engage focal attention similar to the processing of novel stimuli, and generates a strong P3a response (Polich & Comerchero, 2003). The interaction between task difficulty and novelty should be verified in future research, in which the target-unrelated images could differ in complexity.

The finding that novel images lead to performance costs when they were target-related (experiment 2) could be explained by distraction or (lingering) attention, which is in line with a large body of literature (Bendixen et al., 2010; Berti & Schröger, 2004; Näätänen et al., 1993; Parmentier & Andrés, 2010; Wetzel et al., 2013). Attentional resources are required to suppress target-irrelevant information. When these attentional resources are limited, as in the current time-pressured task, not all target-irrelevant information can be efficiency filtered. Target-irrelevant novel stimuli require more effort to be suppressed compared to familiar ones as indexed by the novelty-N2 component (Lv et al., 2010; Schomaker and Meeter, 2014b). Familiarization of stimuli could not be achieved without repetition. Thus, an alternative explanation is a more elaborate processing of novel images as compared to more efficient processing of familiar images. However, it is important to note that our findings of performance detriments on novel versus familiar trials cannot be explained by practice effects regarding the stimulus response contingencies, as the familiar stimuli were not repeated during the approach/avoid part of the task (only during the familiarization phase during which they made indoor/outdoor judgments, but not an approach/avoid distinction). As such, our findings of faster response times on familiar trials cannot be explained by a stronger stimulus-response association. This difference in repetition may have influenced general stimulus encoding principles in that novel inputs have to be compared with stored information, before they are encoded into long-term memory (Lisman & Grace, 2005). Consistent with this, it has been shown that responses to novel images were slower as compared to familiar images when an explicit novel/familiar judgement had to be made (Krebs, Schott, & Düzel, 2009, Exp. 1). Intriguingly, when the novelty dimension of the stimuli remained implicit, the pattern flipped with response facilitation for novel compared to familiar stimuli (Krebs, Schott, & Düzel, 2009, Exp. 2). However, the authors aimed to investigate interactions between novelty and reward information and can hence not be directly compared to the present study in which only one salient information source was presented.

Previous work has suggested that performance costs typically occur when novel stimuli are task relevant, and general facilitation may occur when it is target-irrelevant. For example, when a novel stimulus contains information about the timing of target appearance, even when presented in a different sensory field (e.g., auditory salient stimuli in a visual task; Parmentier et al., 2010; Wetzel et al., 2012; Wetzel et al., 2013). According to this *information hypothesis*, deviant/novel stimuli automatically produce a bottom-up salience signal which is suppressed by top-down control when it is irrelevant to the ongoing task (Parmentier et al., 2010), while facilitation by novelty may be observed when it is target-irrelevant (Schomaker and Meeter, 2014a; Wetzel et al., 2012). In line with this literature, we observed the most-pronounced performance detriments when novel stimuli were target-related (Experiment 2), when participants were required to process the novel scenes to select the correct response, while in our *target-irrelevant* stimuli task (Experiment 1) no main effect of novelty was observed. In this task, we only observed performance costs by novelty on approach trials at SOA 200 ms. Of note, our cross-experimental design did now allow us to test the same participants in both conditions.

We included a trait measure of novelty seeking in our experiments and expected that high novelty seeking would further promote a putative approach bias to novel stimuli, as the processing of novel stimuli has been associated with this trait in previous work (Koster et al., 2016; Krebs, Schott, Schütze, & Düzel, 2009). When the images were target-irrelevant (Experiment 1), a correlation was found between the difference novelty score (novel-familiar accuracy) and the novelty seeking scale of the TPQ, which could hint to such an association. However, this effect did not survive corrections for multiple comparisons. The impact of personality traits could have been obscured by the more prominent distracting effect - as opposed to energizing effect found in previous work (Koster et al., 2016). It should be noted that the internal validity of the TPQ-ns was lower compared to other studies (Otter et al., 1995), which may be due to the online nature of the study. It is possible this has influenced the results and future studies should be conducted to verify these (null) results.

The reference frame for approach and avoid responses has shown to be the representation of an individual self or object representing the self in space rather than their physical location (Markman & Brendl, 2005; Proctor & Zhang, 2010), which can be achieved with a manikin simulating responses (Krieglmeyer & Deutsch, 2010). Importantly, the manikin task has been shown to be a sensitive measure in mapping the valence-induced activation of approach–avoidance representations (Krieglmeyer & Deutsch, 2010) and has effectively been used to assess approach and avoidance tendencies towards different stimuli (e.g Hoofs, Carsten, et al., 2019; Mogg et al., 2003; Neumann et al., 2004; Rinck & Becker, 2007; Slepian et al., 2012). Therefore, we are confident the observed mappings in the current study can be classified as action-valence biases. However, future work should alternate the location of the manikin as such that the up and down arrow responses are random to fully eliminate any response bias.

In conclusion, in the target-irrelevant condition, we found faster responses on approach trials that feature familiar as compared to novel images at SOA 200 ms, which coincides with the activation of the LC-NA system. This finding may be explained by an increased hedonic value of familiar images or by an increased distraction of novel images when an approach response was required. We found an orienting response towards novelty, causing performance costs especially when novelty was target-related. This suggests that novelty especially leads to lingering of attention when actual processing of the target image is required. Alternatively, familiar images are processed more efficiently and thus facilitate quick and accurate response. Taken together, our results show that novel images lead to performance costs in an approach/avoidance task in general when they are target-related, but also selectively in

approach trials when they are target-irrelevant. This further demonstrates that the processing of novel stimuli may depend on the significance/relevance of novelty in a certain context, and tentatively suggests that differential processing of novel and familiar images is intensified by motivated approach behaviour.

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Human and animal rights

All procedures performed in studies involving human participants were in accordance with the ethical standards of the Ethical committee of Ghent University and with the 1964 Helsinki declaration and its later amendments.

CRediT authorship contribution statement

Julie M. Hall: Programming, Investigation, Statistical Analysis, Writing- Original draft preparation, Visualisation.

Haeme R. P. Park: Conceptualization, Writing- Reviewing and Editing.

Ruth M Krebs: Conceptualization, Writing- Reviewing and Editing.

Judith Schomaker: Conceptualization, Supervision, Writing- Original draft preparation.

Declaration of competing interest

None.

Data availability

https://osf.io/tvsf3

Preprint: https://psyarxiv.com/bzq9p/

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2022.103818.

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