



# Facilitation of responses by task-irrelevant complex deviant stimuli<sup>☆</sup>

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## ABSTRACT

Novel stimuli reliably attract attention, suggesting that novelty may disrupt performance when it is task-irrelevant. However, under certain circumstances novel stimuli can also elicit a general alerting response having beneficial effects on performance. In a series of experiments we investigated whether different aspects of novelty – stimulus novelty, contextual novelty, surprise, deviance, and relative complexity – lead to distraction or facilitation. We used a version of the visual oddball paradigm in which participants responded to an occasional auditory target. Participants responded faster to this auditory target when it occurred during the presentation of novel visual stimuli than of standard stimuli, especially at SOAs of 0 and 200 ms (Experiment 1). Facilitation was absent for both infrequent simple deviants and frequent complex images (Experiment 2). However, repeated complex deviant images did facilitate responses to the auditory target at the 200 ms SOA (Experiment 3). These findings suggest that task-irrelevant deviant visual stimuli can facilitate responses to an unrelated auditory target in a short 0–200 millisecond time-window after presentation. This only occurs when the deviant stimuli are complex relative to standard stimuli. We link our findings to the novelty P3, which is generated under the same circumstances, and to the adaptive gain theory of the locus coeruleus–norepinephrine system (Aston-Jones and Cohen, 2005), which may explain the timing of the effects.

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## 1. Introduction

In the 1920's, when Pavlov wanted to demonstrate conditioning in his trained dogs to colleagues, the animals let him down time and time again. The unfamiliar visitors would distract the dogs to such an extent that they failed to exhibit the expected conditioned response to the conditioned stimulus. Pavlov subsequently attributed this to an “investigatory reaction”, or a “What-is-it” reflex, having biological significance (Pavlov & Anrep, 1927). He argued that rapid detection and processing of novel stimuli is crucial to adapt to current demands and explore new possibilities. Task-irrelevant novel stimuli might thus attract attention at the expense of competing stimuli, even if those are task-relevant. Several lines of research have indeed shown that novelty reflexively attracts attention, evoking a rapid orienting response towards new things in our environment (Knight, 1996; Lisman & Grace, 2005). This is mostly known as the “orienting reflex/response” (Sokolov, 1963a,b).

In a situation in which an observer is engaged in a task, such an orienting response could impair the processing of important target information, resulting in slower response times and reduced accuracy when a target co-occurs with a novel, attention attracting, stimulus.

This was the case in Pavlov's conditioned dogs, who attended to the novel visitors instead of attending to the relevant conditioned stimulus.

However, task-irrelevant novelty might also have the opposite consequence, namely an enhancement of performance. In particular, the onset of a novel stimulus might evoke a general alerting response, which in turn would enhance performance on an ongoing task. Such alerting has been linked to norepinephrine (NE), a neurotransmitter mostly released from the locus coeruleus (LC). A theory of locus coeruleus–norepinephrine (LC–NE) function, the adaptive gain theory, suggests that LC–NE phasic activity selectively facilitates task-relevant behavioral responses (Aston-Jones & Cohen, 2005; Nieuwenhuis, Aston-Jones, & Cohen, 2005). This theory states that LC activity improves performance by facilitating task-related decision-making processes and suppressing non-target-related activity (Aston-Jones & Cohen, 2005). Such transient effects mediated by a noradrenergic response have been argued to underlie a related phenomenon, namely the accessory stimulus effect (Fernandez-Duque & Posner, 1997). This denotes the finding that unexpected or novel sounds can facilitate visual processing (e.g. Bernstein, Chu, Briggs, & Schurman, 1973; Hackley & Valle-Inclan, 1998; Valls-Sole et al., 1995; Wetzel, Widmann, & Schroger, 2012). Several studies have shown that visual stimuli can also act as warning signals but might be less potent in enhancing auditory perception (Bernstein et al., 1973; Bertelson & Tisseyre, 1969; Rodway, 2005; Posner, Nissen, & Klein, 1976).

Electrophysiological studies in rats have shown novelty to be one of the drivers of LC phasic activity. For example, in rats placed in a novel

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environment strong bursts of activity were seen in a large population of noradrenergic neurons of the LC (Sara, Vankov, & Herve, 1994; Vankov, Herve-Minvielle, & Sara, 1995) linking the LC phasic activity to novelty detection. It might thus be surmised that novelty, through its effects on the LC, may enhance task performance. Several effects suggestive of such an enhancement of performance have already been reported. Novelty can boost motivation to explore the environment, resulting in the so-called exploration bonus (Krebs, Schott, Schutze, & Duzel, 2009). In turn, long-term potentiation and learning have been reported to be enhanced in rats exploring new environments (Ballarini, Moncada, Martinez, Alen, & Viola, 2009; Dong et al., 2012; Moncada & Viola, 2007). Novel sounds can enhance visual target processing (SanMiguel, Morgan, Klein, Linden & Escera, 2010), for example when they are presented shortly before a target in a delayed recognition task (SanMiguel, Linden & Escera, 2010). Visual novelty has been reported to reduce behavioral interference on a Stroop task (Krebs, Fias, Achten, & Boehler, 2013) and to enhance visual perception – supposedly through the effects of transient attention (Schomaker & Meeter, 2012).

The above could lead to two opposing expectations of the effects of task-irrelevant novelty on task-related processes. On the one hand, novelty might induce impairment of performance on a task by evoking an orienting response and attracting attention away from the ongoing task. On the other hand, novelty might work like a potent accessory stimulus, leading to general alerting or a boost of transient attention and enhancing task performance. These responses might actually be two sides of the medallion. The orienting response has been suggested to be a call for processing resources (Filion, Dawson, Schell, & Hazlett, 1991; SanMiguel, Morgan et al., 2010; Zimmer, 1992), resulting in a general enhancement of attention. This enhancement could be allocated mostly to the novel stimulus that elicited the orienting response, or it may spill over to processing information presented in the close temporal vicinity to it. Indeed, both facilitating and distracting effects of novelty have been reported (SanMiguel, Linden et al., 2010; SanMiguel, Morgan, et al., 2010; Wetzels et al., 2012).

The event-related potential (ERP) component P3, taken as an index of the orienting response (Escera, Alho, Schroger, & Winkler, 2000; Escera, Alho, Winkler, & Näätänen, 1998), has been argued to reflect enhanced processing as a result of phasic NE release from the LC (Nieuwenhuis et al., 2005). Interestingly, the P3 component has been associated with both the distracting and facilitating effects of novelty (SanMiguel, Morgan, et al., 2010), suggesting a close relationship between the orienting response and the LC–NE response. LC–NE adaptive gain theory could thus be reconciled with both facilitating and distracting effects of novelty, but it does generate a specific prediction on the timing of possible effects. Nieuwenhuis et al. (2005) emphasize the potentiating effects of NE for a time-window of 100–200 ms post-stimulus. Accordingly, the LC–NE hypothesis would suggest that a novel visual stimulus would affect detection of auditory targets most when they are presented 100–200 ms after the onset of the visual stimulus.

The question we thus aimed to address is whether novelty facilitates or interferes with responses to unrelated, task-relevant stimuli, and which factors play a role in these processes. Novelty may be defined in several ways, and different types of stimuli have been referred to as novel in the literature. Possibly, different aspects of novelty exhibit either facilitating or distracting effects. We therefore set out to also investigate what effects different features of novelty have on task performance. Stimuli may deviate from everything stored in long-term memory or may deviate from their more immediate stimulus context. The first more long-term type of novelty has been called *stimulus novelty* (Courchesne, Hillyard, & Galambos, 1975), which refers to stimuli that were never encountered before. Stimulus novelty is a matter of degree: most visual input is novel in the sense that we usually have not experienced the exact configuration that we are experiencing right now. But most of the time the resemblance of the current visual input and past experiences is sufficient to readily categorize it.

Stimulus novelty thus refers to stimuli that cannot be recognized or easily categorized. Within an experiment this term implies that a stimulus is not repeated.

The second, more short-term aspect of novelty is *deviance*, which applies to an infrequent stimulus category that deviates from the current context. Deviant stimuli are not necessarily unique and could be repeated throughout the experiment, such as the infrequent deviant stimuli often used in mismatch negativity studies (see for example Czigler, Balazs, & Winkler, 2002; Liu & Shi, 2008). The counterpart of deviant stimuli is frequent ‘standard’ stimuli.

Another important concept is *relative complexity*, which refers to the complexity of a stimulus relative to the short-term stimulus environment. For example, high relative complexity refers to a stimulus that is more complex than most of the other stimuli in its context. A stimulus can be complex in multiple ways, but these will usually be highly correlated. Here, we operationalize image complexity by the amount to which images can be compressed without losing information.

Finally, we are interested in the notion of *surprise* by, or unexpectedness of, a stimulus. Although novel and deviant stimuli will always be surprising to some extent (a deviant stimulus breaks the mold set by frequent standard stimuli and a novel stimulus can by definition not be predicted), surprise can to some extent be manipulated independent of these other concepts.

In the present study we investigated the effects of all these factors on response accuracy and response speed in an adapted version of the visual novelty oddball paradigm. In this visual novelty oddball task participants saw two kinds of task-irrelevant visual stimuli presented in randomized order: A frequent repeated standard stimulus and infrequent, deviant novel stimuli. In addition to these visual stimuli, the task included an auditory target, a beep. Participants were required to give a speeded response whenever they heard the auditory target irrespective of the visual stimulus presented at that moment in time. In a first experiment, participants responded to the auditory target either in the presence of a complex task-irrelevant novel stimulus or a simple familiar standard stimulus, allowing us to investigate the effects of novelty on response speed and accuracy. In a second experiment we aimed to investigate whether any observed effects were due to deviance or relative stimulus complexity. Finally, in a third experiment we checked whether a combination of deviance and complexity could explain our findings. In the first experiment, we included one trial with a stimulus that was highly surprising but not novel (a rotating spiral) to investigate whether our results could be explained by surprise alone.

## 2. Experiment 1

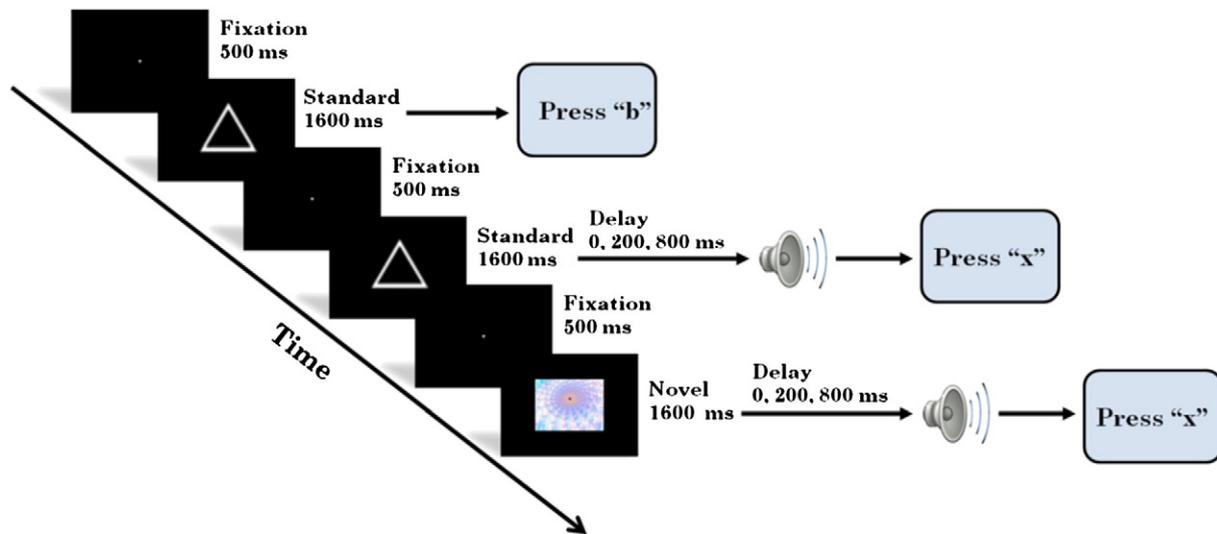
### 2.1. Methods

#### 2.1.1. Participants

15 volunteers (8 males; 14 right-handed; age = 18–26 years, mean = 20.7) with normal or corrected-to-normal vision participated in this experiment. The participants were either paid €5 as compensation or given course credit.

#### 2.1.2. Stimuli and apparatus

In the present study we used 240 fractal images, pictures newly generated by iterative mathematical computations using the open-source program ChaosPro 4.0 (<http://chaospro.de>). These fractals do not represent anything and are guaranteed to be new to the participants (similar to the fractal images used by Stoppel et al., 2009). The fractals covered  $10.2 \times 6.7^\circ$  of visual angle on the computer screen (see Fig. 1 for example fractal images). The standard stimulus was a triangle pointing either upwards or downwards, counterbalanced over participants. The triangle covered  $2.0 \times 2.0$  of visual angle. The auditory target was a 50 ms beep consisting of a 1000 Hz pure tone. At the end of the experiment an unexpected stimulus was presented. In this surprise trial a black



**Fig. 1.** Experimental paradigm. A) Example stimulus sequence and timing of one trial in Experiment 1. In Experiment 2 a complex standard (a fractal) and in Experiment 3 a simple standard was presented among a repeated or non-repeated complex stimulus such as the novel in Experiment 1.

and white spinning spiral was presented, rotating clockwise at a speed of 50 ms per discrete, 90° rotation.

### 2.1.3. Design and procedure

Participants were seated in a dimly lit cubicle. All images were presented on a CRT monitor (1024 × 768 pixels, 120 Hz refresh rate) at a viewing distance of about 75 cm. The task was a modified version of the visual oddball paradigm, requiring the participants to respond to a visual target with a specific button press (“b”) and to an auditory target with a different button press (“x”). In total, participants performed 600 trials. Participants could take breaks after every block of 100 trials. Each block had duration of about 5 min, and the entire session was finished in about 40 min.

Fig. 1 shows an example trial. Each trial started with a fixation cross that was presented for 500 ms, followed by a visual stimulus. The visual stimulus could be of two kinds. On 60% of all trials a simple repetitive standard stimulus, a triangle either pointing upwards or downwards (direction counterbalanced over subjects) was presented. On 40% of all trials a novel image was presented, a unique fractal randomly drawn from the set of 240 fractals. All 240 were presented in the experiment, each only once. Participants were instructed to look at the visual stimuli, even though these were task-irrelevant. The auditory target (a beep) occurred on 20% of the novel image trials and of the standard image trials. The beep was presented at one of three SOAs (0, 200, 800 ms) after the onset of the visual stimulus. The visual stimulus remained visible until the auditory target was played and the following 1600 ms. After presentation of the auditory target visual feedback about the accuracy of the response was presented. In case of a correct, incorrect, or no response within 2000 ms, visual feedback of ‘Correct’, ‘Incorrect’, or ‘Here, a response was required’ was shown for 1000 ms. The last trial was a surprise trial on which a rotating spiral was presented and the auditory target played at the 200 ms SOA. Accuracy was defined as the proportion of correct rejections together with the hits. That is, all trials when no response was given, when none was required and all correct responses to a target. Responses three standard deviations above or below the participants’ mean response time over all conditions were excluded from further analyses.

## 2.2. Results

Fig. 2A shows average response times to the auditory target per condition for each SOA (0, 200, 800 ms), and Table 1 lists the average response times and accuracy for every condition.

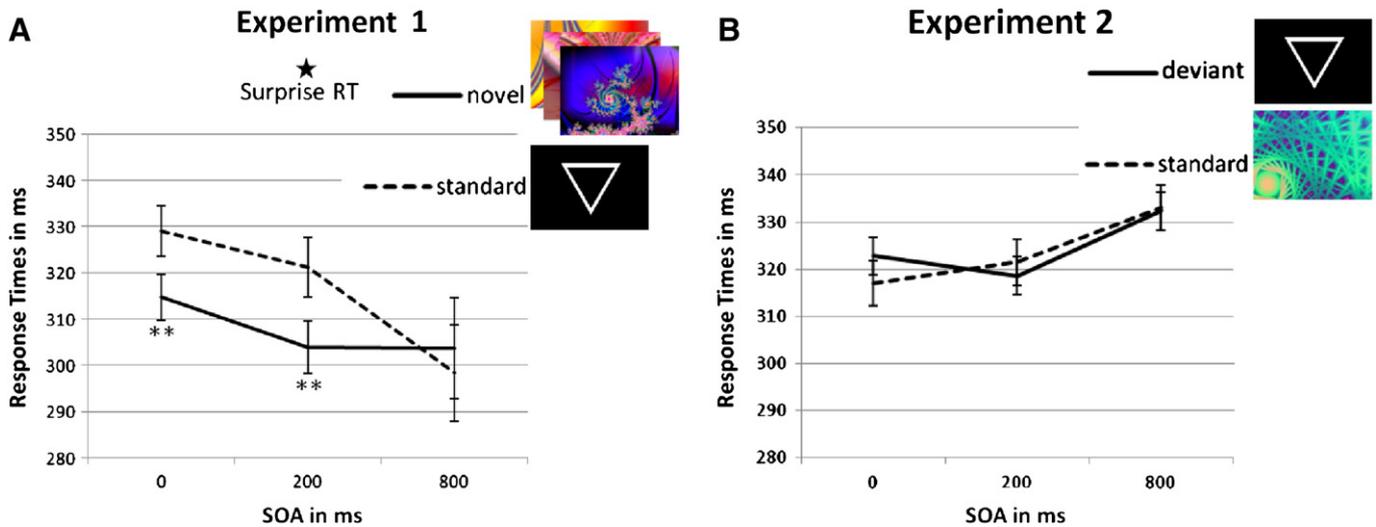
The average response times (RT) to the auditory target were subjected to a 2 × 2 repeated-measures ANOVA with [SOA (0, 200, 800) × Stimulus (Novel, Standard)] as factors. SOA had no main effect on average response times to the auditory target:  $F(1.15, 16.01) = 1.40$ ,  $p = .26$ ,  $\eta^2 = .09$ ; but stimulus type did. Responses were faster during presentation of a novel compared to a standard image,  $F(1, 14) = 19.86$ ,  $p < .001$ ,  $\eta^2 = .59$ . There was an interaction between visual stimulus type and SOA,  $F(2, 28) = 8.19$ ,  $p < .01$ ,  $\eta^2 = .37$ . Post-hoc comparisons showed that participants were faster in responding to the auditory target during the presentation of a novel compared to a standard image at the 0 ms SOA,  $t(14) = -4.03$ ,  $p < .001$ , and at the 200 ms SOA,  $t(14) = 4.15$ ,  $p < .001$ , but not at the 800 ms SOA,  $t(14) = 1.29$ ,  $p = .24$ . Accuracy was extremely high, with very few false alarms (see Table 1). No effects of either SOA,  $F(2, 28) = 1.56$ ,  $p = .23$ ,  $\eta^2 = .10$ , or visual stimulus type,  $F(1, 14) = 1.91$ ,  $p = .19$ ,  $\eta^2 = .12$ , for accuracy and no differences in false alarm rates for novel and standard stimuli,  $t(14) = 0.95$ ,  $p = .360$  were found.

The response time on the surprise trial was not different (mean = 399 ms,  $sd = 314$ ) from response times during the presentation of novel stimulus trials at the 200 ms SOA,  $t(11) = 1.01$ ,  $p = .333$ . Accuracy on the surprise trial was low (20% misses), with a trend for lower accuracy at the surprise trial compared to accuracy during the presentation of a novel stimulus at the same 200 ms SOA,  $t(14) = 1.87$ ,  $p = .082$ .

## 2.3. Discussion

To investigate whether the presence of novelty facilitates or impairs performance we combined the visual oddball task with an auditory stimulus detection task. Responses were faster during presentation of a task-irrelevant novel image than during presentation of a standard image. This effect was evident at the 0 and the 200 ms SOA, but not at the 800 ms SOA, suggesting that the effects of novelty were short-lived. This relative facilitation by novel images was not caused by a speed accuracy trade-off, since responses to the auditory target were not less accurate during the presentation of novel images, regardless of SOA. No evidence was found for the reverse possibility, namely that novel images would lead to an orienting response that would interfere with responding to auditory targets.

To test whether the effect of novel images was due to their unexpectedness we presented one surprise trial with a rotating stimulus at the end of the experiment, similar to the unexpected events used by Schutzwohl (1998). This stimulus was not novel, but it was highly



**Fig. 2.** Average response times to the auditory target for the three SOAs, during presentation of novel/deviant or standard stimuli. Graphs represent average response times for all participants for A) Experiment 1; B) Experiment 2. Error bars represent 1 within-subjects SEM. The average response time to the oddball can be found in the graphs as triangles, and the average response time on the surprise trial is depicted as a star. Stars under the error bars reflect contrasts between standard and novel (post-hoc paired *t*-tests). \**p* < .05; \*\**p* < .01.

unexpected as the only dynamic stimulus in the experiment. If the facilitatory effect of the novel images was caused by their unexpectedness, one would expect that the rotating stimulus would facilitate information processing as well. By contrast we found that people did not respond faster and were more inaccurate on the unanticipated surprise trial at the end of the experiment. This finding suggests that it is not the unexpectedness of the novel stimuli that facilitated response times.

**3. Experiment 2**

Results of the first experiment suggest that deviant, novel visual stimuli facilitate responses to auditory stimuli. In Experiment 2, we set out to test whether the high relative complexity of these deviant, novel stimuli is a requirement for facilitation, or whether facilitation also occurs for stimuli with low relative complexity. To test this we presented infrequent, simple deviants in a context of a repeated complex fractal image. If deviance from the context is the factor behind the facilitation of responses found in Experiment 1, responses to the auditory target would also be facilitated by the simple deviants. If complexity itself would be sufficient to facilitate responses to the auditory target, irrespective of their novelty, we would expect to find such

facilitation for the frequent, standard complex image. If the interaction between the two factors is important (i.e., images must be both complex and deviant to facilitate processing), facilitation is not expected in either condition.

**3.1. Method**

19 volunteers (7 males; 18 right-handed; age = 18–28 years, mean = 22.3) with normal or corrected-to-normal vision participated in the experiment. Compensation was €11 or course credit.

The design and apparatus were similar to those of Experiment 1, but now simple stimuli (repeated triangles) were infrequent deviants, while a repeated (non-novel) fractal functioned as the frequent standard image. The frequency of the deviant simple stimulus was 25%, and the frequency of the complex repeated fractal 75%. The frequency of the deviant stimulus was reduced compared to the 40% frequency of novel stimuli in Experiment 1, as now the effects of deviance were of specific interest. Auditory targets were again presented on 20% of trials. The total number of trials was 1600, and the experiment had duration of about 90 min. No surprise trial was presented.

**Table 1**  
Response times and accuracy for each SOA and every condition for Experiments 1, 2, and 3.

	Experiment 1		Experiment 2		Experiment 3			
	Standard	Novel	Standard	Deviant	Standard	Deviant	Standard	Novel
<i>Response times</i>								
0 ms	330 (42)	315 (38)	323 (56)	318 (51)	337 (67)	333 (69)	345 (46)	332 (48)
200 ms	322 (49)	304 (44)	319 (42)	322 (48)	344 (68)	329 (70)	346 (49)	331 (46)
800 ms	299 (81)	304 (84)	333 (44)	334 (42)	344 (65)	344 (68)	350 (47)	350 (54)
<i>Accuracy</i>								
0 ms	1 (0)	1 (0)	1.0 (.02)	.99 (.04)	1.0 (.01)	.99 (.03)	.99 (.02)	.99 (.03)
200 ms	1 (0)	1 (0)	1.0 (.01)	1.0 (.04)	.99 (.04)	1.0 (.00)	.99 (.03)	.99 (.04)
800 ms	1 (0)	.99 (.02)	.99 (.03)	1.0 (.02)	.99 (.05)	.99 (.03)	1.0 (.01)	1.0 (.03)
<i>False alarms</i>								
	.003 (.009)	.005 (.006)	.007 (.022)	.007 (.024)	.002 (.003)	.010 (.009)	.002 (.002)	.007 (.010)

Note. Average response time is given in milliseconds (ms). Accuracy as the proportion of trials that were “hits” or “correct rejections”. Standard deviations in parentheses.

### 3.2. Results

The same repeated measures ANOVAs as used in Experiment 1 were performed. Average response times to the auditory target per condition for each SOA (0, 200, 800 ms) can be found in Fig. 2B and average response times and accuracy for every condition in Table 1.

SOA had a main effect on average response times to the auditory target;  $F(1.48, 26.66) = 13.26$ ,  $p < .001$ ,  $\eta^2 = .42$ . Response times did not differ for the 0 ms and 200 ms SOA ( $F < 1$ ), but responses were faster at the 200 ms than at the 800 ms SOA,  $F(1, 18) = 49.67$ ,  $p < .001$ ,  $\eta^2 = .73$ . No effects of visual stimulus type or an interaction between visual stimulus type and SOA was found ( $F < 1.6$ ). Thus responses to the auditory target were equally fast during the presentation of a deviant simple stimulus or a frequent complex fractal stimulus. With regard to accuracy, again no effects of either SOA,  $F(2, 36) = 1.00$ ,  $p = .378$ ,  $\eta^2 = .05$ , or stimulus type,  $F(1, 18) = 1.00$ ,  $p = .331$ ,  $\eta^2 = .05$ , were found, nor were there any differences in the false alarm rate for deviant or standard stimuli,  $t(18) = 0.07$ ,  $p = .942$ .

### 3.3. Discussion

To investigate whether deviance from the context was sufficient to produce the facilitation of responses observed in Experiment 1, we presented an infrequent repeated simple image (simple deviant) in a context of frequent repeated complex images. No differences in response time were observed during the presentation of these two types of stimuli, suggesting that deviance is not a crucial factor in the facilitation found in the first experiment. Responses were also not facilitated by the more frequent complex image, which suggests that visual complexity on itself is not sufficient either. The remaining explanation of the facilitation found in Experiment 1 is a combination of both factors: That images must be both deviant and complex to produce facilitation of responses for the auditory target. We tested this conjecture in the next experiment.

## 4. Experiment 3

In Experiment 3 we tested whether a combination of deviance and complexity is sufficient to produce facilitation of responses or whether stimulus novelty also plays a role – i.e., whether a repeated deviant complex image will produce the same facilitation as the novel images in the first experiment. For this end, we presented deviant, infrequent complex stimuli in a context of frequent simple standard stimuli. In one condition the deviant stimuli consisted of one repeated fractal (Repeated Fractal condition), while in another non-repeated, novel fractals were used (Non-Repeated Fractal condition).

### 4.1. Method

14 volunteers (4 males; 12 right-handed; age = 20–29 years, mean = 24.7) with normal or corrected-to-normal vision participated in the experiment. Participants participated in this experiment as part of an experimental day for which they received a total compensation of 90 Euros.

The design and stimuli were similar to those of Experiment 2. Stimuli were now presented on a LCD monitor (1680 × 1050 pixels, 120 Hz refresh rate) with the same viewing distance of about 75 cm. There were two types of images: frequent simple images of a triangle and infrequent complex deviant fractals. The complex deviant images were repeated (Repeated Deviant condition) in one type of block, and trial-unique, thus novel, in another type of block (Non-Repeated Deviant condition). The order of these conditions was counterbalanced between subjects. Participants performed six blocks of each condition, each block consisting of 180 trials. In total the experiment consisted of 2160 trials and was finished in about 70 min. The frequency of deviant stimuli was 25% and of the simple standard stimulus 75%, while the

auditory target was presented on 20% of trials. No surprise trial was included.

### 4.2. Results

A repeated measures ANOVA with the factors [SOA (0, 200, 800) \* Stimulus (Deviant, Standard) \* Condition (Repeated Deviant; Non-Repeated Deviant)] was performed. Fig. 3 shows average response times to the auditory target per condition for each SOA (0, 200, 800 ms) and average response times and accuracy for every condition in Table 1.

There was a main effect of SOA on the average response times to the auditory target,  $F(2, 26) = 10.96$ ,  $p < .001$ ,  $\eta^2 = .46$ . No differences were found between the 0 ms and 200 ms SOAs ( $F < 1$ ). Responses were faster at the 200 ms compared to the 800 ms SOA,  $F(1, 13) = 16.38$ ,  $p = .001$ ,  $\eta^2 = .56$ . Responses were faster during the presentation of the deviant compared to the standard stimuli,  $F(1, 13) = 14.85$ ,  $p < .002$ ,  $\eta^2 = .53$ . Whether the deviant stimulus was repeated or not did make a difference ( $F < 1$ ). In addition, SOA and Stimulus interacted,  $F(2, 26) = 6.53$ ,  $p = .005$ ,  $\eta^2 = .33$ . Responses were faster for the deviant stimuli at the 0 ms SOA,  $F(1, 13) = 7.27$ ,  $p = .018$ ,  $\eta^2 = .36$ , and at the 200 ms SOA,  $F(1, 13) = 14.74$ ,  $p = .002$ ,  $\eta^2 = .53$ , but not at the 800 ms SOA ( $F < 1$ ). None of the other interactions was significant.

False alarm rates were higher during the presentation of a deviant than a standard in the Non-Repeated Deviant condition,  $t(13) = 4.42$ ,  $p = .001$  and the Repeated Deviant condition,  $t(13) = 2.55$ ,  $p = .024$ . For accuracy no effects of SOA ( $F < 1$ ), stimulus type,  $F(1, 13) = 1.34$ ,  $p = .269$ ,  $\eta^2 = .09$ , or condition ( $F < 1$ ) were found.

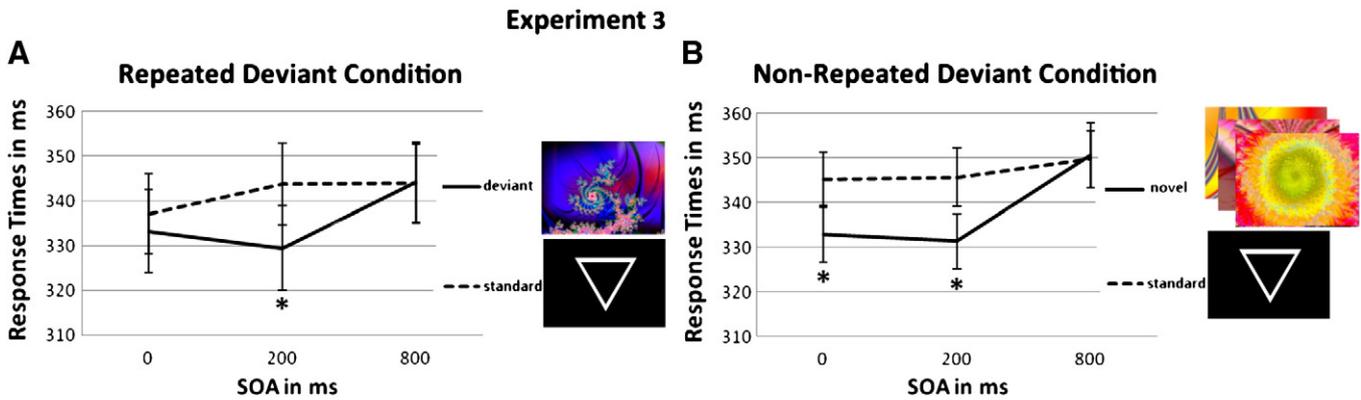
### 4.3. Discussion

In Experiment 3 we again found facilitation in the 0–200 ms post-stimulus time-window, both for complex deviant stimuli that were repeated and for those that were not repeated. These findings suggest that a combination of deviance and high relative complexity of task-irrelevant stimuli can facilitate response times to an unrelated auditory target, irrespective of whether they are novel.

## 5. General discussion

In the first experiment, we found facilitation of responses to an auditory target during the presentation of visual novel stimuli compared to repeated standard stimuli. In the next two experiments, we tested whether the facilitation was due to inherent stimulus novelty or to either deviance from the context or relative visual complexity. We found that novel stimuli only facilitate responses to auditory targets when they are infrequent and presented among simple standard stimuli – thus, when they are both deviant and relatively complex. Stimulus novelty, on the other hand, was not a requirement: the same facilitation was found whether an infrequent, deviant fractal was presented repeatedly, or whether each was presented only once (Experiment 3). We also tested whether any effect of novelty was due to surprise by including a non-novel but surprising stimulus at the end of the Experiment 1, but responses were not faster and accuracy was reduced on this surprise trial, suggesting that surprise cannot account for the facilitatory effect of the novel stimuli.

Novel stimuli have been reported to distract by involuntarily attracting attention (Escera et al., 1998; Naatanen, Teder, Alho, & Lavikainen, 1992), evoking the so-called orienting response. The allocation of attentional resources to novel information is reflected in an electrophysiological response commonly found to novel stimuli, the novelty P3 ERP component (Chong et al., 2008; Courchesne et al., 1975). The orienting response can distract from ongoing tasks, as reflected by increased response times and decreased accuracy on simple classification



**Fig. 3.** Average response times to the auditory target for the three SOAs, during presentation of deviant, novel or standard stimuli. Graphs represent average response times for A) the Repeated Fractal condition and B) the Non-Repeated Fractal condition of Experiment 3. Error bars represent 1 within-subjects SEM. Stars under the error bars reflect contrasts between standard and novel (post-hoc paired *t*-tests). \**p* < .05; \*\**p* < .01.

tasks (Berti & Schroger, 2003; Escera et al., 1998; Escera, Yago, & Alho, 2001; Escera, Corral, & Yago, 2002).

Bendixen et al. (2010) found distraction effects of irrelevant auditory stimuli on a visual primary task, in a design similar to the experiments in the present study, instead of improved performance as we found. The Bendixen et al. (2010) study, however, differed from our experiments on several crucial aspects that may explain the discrepancy in findings. First, auditory and visual stimuli were always presented at an expected SOA in their study, whereas in our study the target was presented with temporal uncertainty. It has been reported that novel and deviant stimuli do not have distracting effects when they are uninformative about the time and occurrence of a target (Wetzel et al., 2012), possibly explaining the discrepancy between our findings. Second, in the Bendixen et al. (2010) study participants had to respond on every trial, compared to only 20% of trials in the present study. A high event rate increases arousal and attentional demands (Kahneman, 1973); therefore, the Bendixen et al. (2010) task was probably more attentionally engaging than ours. Attentional demands of the task have been suggested to be a determining factor in whether novel stimuli have distracting or facilitating effects (SanMiguel, Linden et al., 2010): When the demands are high participants are already performing at an optimum, resulting in orienting costs to novel stimuli, while low attentional demands leave room for improvement; novel stimuli can then facilitate performance by refocusing attentional resources. Finally, their task consisted of stimuli of equivalent complexity within a sequence, while we only found facilitation by stimuli of high relative complexity in the current study. Each of these differences might explain the contrasting results between Bendixen et al. (2010) and the present study.

Our findings are in line with several studies that have suggested that distraction and facilitation are both aspects of novelty processing (Parmentier, Elsley, & Ljungberg, 2010; Ruhnau, Wetzel, Widmann, & Schroger, 2010; SanMiguel, Morgan, et al., 2010; Schomaker & Meeter, 2012; Wetzel et al., 2012). SanMiguel, Linden et al. (2010) and SanMiguel, Morgan, et al. (2010) found facilitated responses for visual targets during the presentation of novel sounds; the visual P300 to these visual targets was also enhanced. Interestingly, the novel sounds that led to this facilitation elicited the same electrophysiological responses typically elicited by distracting sounds, namely a novelty P3. The authors argued that the novelty P3 not only reflects orienting and distraction, but also signals an alerting response and executive control processes that could underlie facilitation (SanMiguel, Morgan, et al., 2010). Several studies have suggested that the novelty P3 is elicited under the same circumstances that we have linked to facilitation: the novelty P3 is elicited when a novel stimulus deviates from its context (Friedman, Cycowicz, & Gaeta, 2001), and is more complex than other stimuli in the experiment (Barkaszi, Czigler, & Balazs, 2013; Daffner, Mesulam, Scinto, Calvo, Faust & Holcomb, 2000; Daffner,

Scinto, Calvo, Faust, Mesulam, West, et al., 2000). If the facilitation observed in our Experiments 1 and 3 relies on the same alerting aspects of novelty processing as indexed by the novelty P3, facilitation would also depend on deviance and relative complexity. This is what we found: deviant stimuli facilitated response times only when their relative complexity was high (Experiments 1 and 3) and not when it was low (Experiment 2). Facilitation was only found when the stimuli had high relative complexity *and* were deviant.

Perhaps these same processes are also related to the so-called accessory stimulus effect. There have been many studies showing that auditory accessory stimuli can facilitate processing of concurrent visual stimuli (e.g. Bernstein et al., 1973; Hackley & Valle-Inclan, 1998; Valls-Sole et al., 1995). Several other studies have shown that visual stimuli can act as warning signals, but they might be less potent in enhancing auditory perception auditory stimuli in facilitating visual perception (Bernstein et al., 1973; Posner et al., 1976). Our experiments were very similar to an accessory stimulus paradigm, in that visual stimuli were entirely irrelevant to the task of the detection of auditory targets and were non-predictive about both presence and timing of the auditory stimulus. As in accessory stimulus studies, our visual stimuli speeded responses to the auditory target.

Posner (1978) argued that warning signals act by shifting the response criterion rather than enhancing information processing, allowing for faster but hasty decisions based on incomplete information. It is unlikely that our deviant stimuli acted as warning signals, since they were non-predictive of the auditory target. If the deviant stimuli nonetheless acted as warning signals that shifted the response criterion to a more liberal criterion, one would expect more false alarms during the presentation of deviants than during the presentation of standards. However, in Experiment 1 (in which we found facilitation for deviant novel stimuli) no differences in accuracy and false alarm rates were found. This suggests an improvement of either perception or decision processes and not just a shift of criterion. Findings were less clear for Experiment 3, where we also found facilitation, and participants had more false alarms during the presentation of deviant than of standard stimuli. This discrepancy might be due to the fact that most participants performed at ceiling (as evidenced by the large standard deviations, most participants did not exhibit any false alarms, and the means are therefore biased by the few participants with false alarms), making the results difficult to interpret. However, our results do not suggest that responses were faster due to a shift in response criterion alone.

Accessory stimulus effects have been argued to be mediated by a noradrenergic response leading to a transient and non-specific readiness state to perform (Fernandez-Duque & Posner, 1997). Also the P3 has been argued to reflect enhanced processing as a result of phasic NE release from the LC (Nieuwenhuis et al., 2005). The novelty P3 is elicited by novel stimuli that are more complex than the stimulus

environment in which they occur (Barkaszi et al., 2013), and interestingly, complexity has been suggested to play a role in the activation of LC neurons (Aston-Jones, Chiang, & Alexinsky, 1991). Especially complex stimuli can activate LC neurons in anesthetized monkeys (Grant, Aston-Jones, & Redmond, 1988) and cats (Rasmussen, Morilak, & Jacobs, 1986), whereas low-level simple stimuli failed to evoke such a response. On a behavioral level, more intense auditory accessory stimuli have been found to cause stronger facilitation than those with low intensity (Bernstein et al., 1973), and such stimuli also evoke LC phasic activity (Grant et al., 1988). The present study shows that when deviant stimuli have high relative complexity, they can enhance processing of an unrelated auditory target.

This suggests the following interpretation for our results: deviant stimuli with high relative complexity can activate the LC and elicit a novelty P3. This leads to a phasic release of NE, which in turn improves processing of unrelated stimuli, such as our auditory target. This effect is especially strong at the 0 and 200 ms SOAs that have previously been suggested to yield peak efficacy of phasic NE release (Nieuwenhuis et al., 2005).

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