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What's new? The interaction between novelty and cognition

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CHAPTER 3

Facilitation of responses by task-irrelevant complex deviant stimuli

This chapter is an adaptation from Schomaker, J., & Meeter, M. (2014a). Facilitation of responses by task-irrelevant complex deviant stimuli. Acta Psychologica, 148, 74-80. Experiments 1 and 3 were not reported in the paper.

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 effect 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 (Experiments 1 and 2). Facilitation was diminished when the standard stimuli were as complex as the novels (Experiment 3), and was absent for both infrequent simple deviants and frequent complex images (Experiment 4). However, repeated complex deviant images did facilitate responses to the auditory target at the 0 and 200 ms SOA (Experiment 5). These findings suggest that task-irrelevant deviant visual stimuli can facilitate responses to an unrelated auditory target in a short 0-200 milliseconds 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 & Cohen, 2005b), which may explain the timing of the effects.

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, 1963b).

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, 2005b; Nieuwenhuis et al., 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, 2005b). 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 (eg. Bernstein, Chu, Briggs, & Schurman, 1973; Hackley & Valle-Inclan, 1998; Valls-Sole et al., 1995; Wetzels et al., 2012). Several studies have shown that visual stimuli can also act as warning signals but might be less potent in enhancing auditory perception (Bertelson & Tisseyre, 1969; Bernstein et al., 1973; 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 environment strong bursts of activity were seen in a large population of noradrenergic neurons of the LC (Sara et al., 1994; Vankov et al., 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 et al., 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). In humans, novel sounds can enhance visual target processing (SanMiguel, Morgan, et al., 2010), for example when they are presented shortly before a target in a delayed recognition task (SanMiguel, Linden, et al., 2010). Visual novelty has been reported to reduce behavioral interference on a Stroop task (Krebs et al., 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 et al., 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; Wetzel et al., 2012).

The event-related potential (ERP) component P3, taken as an index of the orienting response (Escera, Alho, Winkler, & Näätänen, Escera et al., 2000; Escera, Alho, Winkler, & Näätänen, 1998; 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 et al., 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 et al., 2002; Liu & Shi, 2008). The counterpart of deviant stimuli are 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 expectations set by frequent standard stimuli and a novel stimulus can by definition not be predicted), surprise can be 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 a visual novelty oddball task participants typically see three kinds of visual stimuli presented in randomized order: 1. A frequent standard stimulus that does not require a response; 2. An infrequent target that requires a speeded response; 3. Infrequent, thus deviant, novel stimuli that are task-irrelevant and do not require a response. However, in some versions of the paradigm no visual target was presented, but only deviants (either novel or familiar) and standards were presented. In addition to these visual

stimuli, in all experiments the task included an additional auditory target, a beep. Participants were required to give a speeded response whenever they heard the auditory target irrespective of the visual stimuli presented at that moment in time (beeps were never presented during a visual target stimulus, so that participants never had to give two responses at the same time). In a first experiment, participants responded to the auditory target either in the presence of a visual, task-irrelevant novel stimulus or a familiar standard stimulus, allowing us to investigate the effects of novelty on response speed and accuracy. In a second experiment no visual target was presented to rule out the possibility that the effects observed in the first experiment were due to standard/visual target similarity. In a third experiment we controlled for relative complexity, by keeping the complexity of all stimuli equal. In a fourth experiment we aimed to investigate whether any observed effects were due to deviance or relative stimulus complexity. In a final fifth experiment we checked whether a combination of deviance and complexity could explain our findings. In the first three experiments, 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.

Experiment 1

Method

Participants

25 volunteers (8 male; 23 right-handed; age 17-27 years, mean = 20.8) with normal or corrected-to-normal vision participated in this experiment. The participants were paid either €8,50 as compensation or given course credit.

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 10.2x6.7° of visual angle on the computer screen (see Figure 1 for example fractal images). The standard stimulus was a triangle pointing

either upwards or downwards, counterbalanced over participants, while the other triangle functioned as target stimulus (the 'oddball'). The triangle covered $2.0^{\circ} \times 2.0^{\circ}$ 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 and white spinning spiral was presented, rotating clockwise at a speed of 50 ms per discrete, 90 degree rotation.

Design and procedure

Participants were seated in a dimly lit cubicle. All images were presented on a CRT monitor (1024x768 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 960 trials. Participants could take breaks after every block of 100 trials. Each block had a duration of about 5 minutes, and the entire session was finished in about 70 minutes.

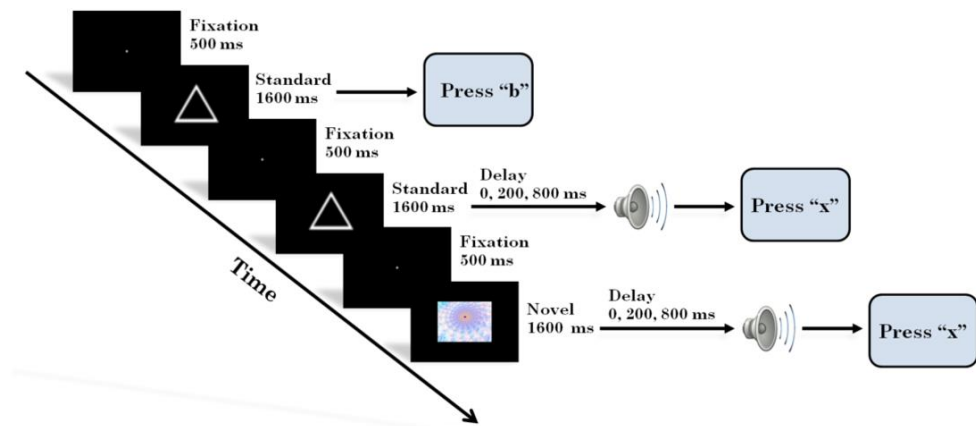


Figure 1. Experimental Paradigm. A) Example stimulus sequence and timing of one trial in Experiment 1. In Experiments 2 and 3 simple standards were presented among a repeated or non-repeated complex stimulus such as the novel in Experiment 1.

Figure 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 three kinds: (1) On 37.5%

of all trials a simple repetitive standard stimulus, a triangle either pointing upwards or downwards (direction counterbalanced over subjects) was presented; (2) On 37.5% of all trials an infrequent visual target stimulus was presented, which was a triangle pointing in the opposite direction as the standard; (3) On 25% 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. The beep occurred on 20% of the novel image trials, and of the standard image trials. Participants had to respond on 50% of all trials (37.5% responses to the visual target and 12.5% to the auditory target). 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 a target (both visual and auditory) 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. There was a surprise trial at the end of the experimental task. In this trial participants were presented with a rotating spiral and after an SOA of 200 ms the auditory target played. 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.

Results

Responses to the visual target were fast (mean = 409 ms) and mostly correct (mean = 99%); they were not further analyzed. Figure 2A shows average response times to the auditory target per condition, and Table 1 lists the response times and accuracy per 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 (0, 200, 800 ms) had a main effect on RT; $F(1.30,31.01) = 4.96, p < .05$. Post hoc comparisons showed that responses were slower at the 0 ms SOA (mean = 472 ms; sd = 72 ms) than at the 200 ms SOA (mean = 440 ms; sd = 72 ms), $t(25) = 5.97, p < .001$. There were no differences between the 200 and 800 ms SOA or the 0 and 800 ms SOA. Responses were faster during the presentation of a novel image than of a standard image, $F(1,24) = 17.86, p < .001$. There was no interaction between visual stimulus type and SOA ($F < 1$). Responses were much slower on the surprise trial (mean = 525, sd = 142) than on the novel image trials (mean = 430, sd = 73; see Figure 2A) at the same 200 ms SOA, $t(20) = 2.46, p < .05$.

Responses to the auditory target were generally correct (mean = 96.4 %). Average accuracy per condition can be found in Table 1. Accuracy was higher at the 800 ms compared to the

0 and 200 ms SOA, $t(24) = -2.08, p < .05$ and $t(24) = -3.09, p < .01$ respectively. Responses were more accurate during presentation of novel compared to standard images, $F(1,24) = 4.46, p < .05$. SOA and visual stimulus type interacted, $F(2,48) = 3.94, p < .05$. Responses at the 0 ms SOA were more accurate during presentation of novel compared to standard images, $t(24) = 2.80, p < .01$. There was a trend in the same direction at the 200 ms SOA, $t(24) = 1.78, p = .09$. In contrast, accuracy did not differ at the 800 ms SOA ($t < 1$). There were more false alarms during the presentation of standard than of novel images, $t(24) = 3.40, p = .002$. Many participants did not respond to the auditory target on the surprise trial (76.9% misses).

Table 1. Response Times and Accuracy for Each SOA and Every Condition for Experiments 1, 2, 3, 4, and 5.

	Experiment 1		Experiment 2		Experiment 3		Experiment 4		Experiment 5	
	Standard	Novel	Standard	Novel	Standard	Novel	Standard	Novel	Standard	Novel
<i>Response Times</i>	Non-Repeated									
<i>0 ms</i>	483 (90)	456 (65)	330 (42)	315 (38)	477 (112)	482 (86)	323 (56)	318 (51)	345 (46)	332 (48)
<i>200 ms</i>	450 (77)	427 (70)	322 (49)	304 (44)	444 (99)	439 (87)	319 (42)	322 (48)	346 (49)	331 (46)
<i>800 ms</i>	462 (86)	441 (101)	299 (81)	304 (84)	436 (132)	440 (131)	333 (44)	334 (42)	350 (47)	350 (54)
<i>Accuracy</i>										
<i>0 ms</i>	.94 (.06)	.97 (.04)	1 (0)	1 (0)	.96 (.05)	.95 (.06)	1.0 (.02)	.99 (.04)	.99 (.02)	.99 (.03)
<i>200 ms</i>	.96 (.05)	.98 (.04)	1 (0)	1 (0)	.96 (.08)	.95 (.05)	1.0 (.01)	1.0 (.04)	.99 (.03)	.99 (.04)
<i>800 ms</i>	.98 (.04)	.97 (.04)	1 (0)	.99 (.02)	.96 (.06)	.96 (.07)	.99 (.03)	1.0 (.02)	1.0 (.01)	1.0 (.03)
<i>False Alarms</i>										
	.016 (.003)	.003 (.020)	.003 (.009)	.005 (.006)	.004 (.005)	.002 (.003)	.007 (.022)	.007 (.024)	.002 (.003)	.010 (.009)

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

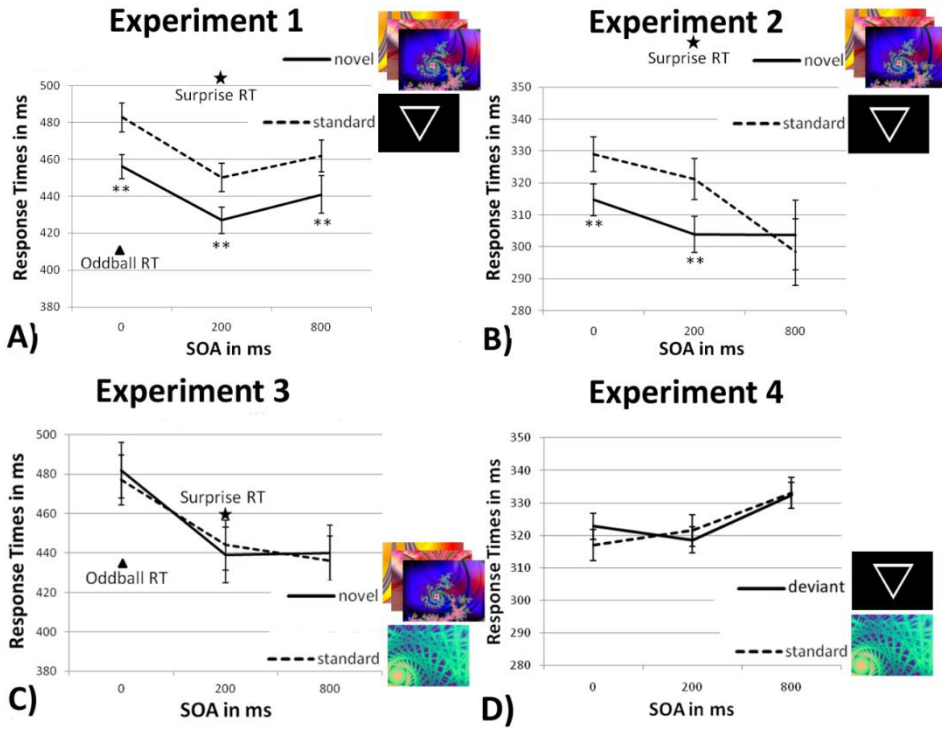


Figure 2. Average response times to the auditory target for the three SOAs, during presentation of novel/deviant or standard stimuli. Graphs represent average response times for all participants for A) Experiment 1; B) Experiment 2; C) Experiment 3; D) Experiment 4. Error bars represent 1 within-subjects 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 are depicted as a star. Stars under the error bars reflect contrasts between standard and novel (post-hoc paired t-tests). * $p < .05$; ** $p < .01$.

Discussion

To investigate whether the presence of novelty facilitates or impairs performance we combined the visual oddball task with an auditory stimulus detection task. We found relatively slow responses to the auditory target at the 0 ms SOA relative to the 200 ms SOA, both during the presentation of standard and novel images. This suggests that the onset of visual stimuli attracted attention, thereby

slowing responses to the auditory target when it co-occurred with the stimulus onset (0 ms SOA). This could either be an overshadowing of the auditory target by the visual onset, or it could be a result of the necessity to evaluate whether the visual stimulus was a target. Whichever it was, the capture of attention by visual onsets was short-lived: At the 200 ms SOA, responses were as fast as at the 800 ms SOA.

On top of the effect of SOA, responses were also faster during presentation of a task-irrelevant novel image than during presentation of a standard image. This relative facilitation by novel images was not caused by a speed accuracy trade-off, since responses to the auditory target were more 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 unexpected as the only dynamic stimulus in the experiment. If the 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 responded slowly and inaccurately on the unanticipated surprise trial at the end of the experiment. This finding suggests that it is not the unexpectedness of the novels that facilitated response times in Experiment 1.

Experiment 2

In Experiment 1, standard stimuli were very alike to visual targets (both triangles), while novels (fractals) were obviously different in terms of physical stimulus characteristics. This suggests a confound in Experiment 1, namely of similarity to the visual target. Possibly the novels were not facilitating processing, but the standards were interfering with stimulus processing because of their resemblance to the visual target. Because novels were very different from the visual target, they could allow participants to disengage attention easily. To rule out this explanation for the results in Experiment 1, we conducted a new experiment in which no visual targets were presented.

Methods

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

The stimuli, apparatus, and design were the same as in Experiment 1, except that no visual targets were presented in this experiment. Therefore the number of trials was reduced to 600, and the experiment had a duration of about 40 minutes.

The frequency of novels was 40% and of standards 60%, which is the same as the relative frequencies of novels and standards in Experiment 1. Participants were told to look at the visual stimuli, even though these were task-irrelevant, and to react to the auditory target (present on 20% of trials). The last trial was again a surprise trial with a rotating spiral.

Results

Figure 2B 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 same repeated measures ANOVA as used in Experiment 1 was performed. SOA had no main effect on average response times to the auditory target; $F(1,15,16.01) = 1.40, p = .26$, but stimulus type did: As in Experiments 1, responses were faster during presentation of a novel compared to a standard image, $F(1,14) = 19.86, p < .001$. There was an interaction between visual stimulus type and SOA, $F(2,28) = 8.19, p < .01$. Post-hoc comparisons showed that 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) and no differences in false alarm rates for novels and standards, $t(14) = 0.95, p = .360$. No effects were found of either SOA, $F(2,28) = 1.56, p = .23$ or visual stimulus type, $F(1,14) = 1.91, p = .19$.

The response time on the surprise trial was not different (mean = 399 ms, sd = 314) from response times during the presentation of a novel stimulus trials at the 200 ms SOA ($t < 1.50, p = .33$). Accuracy on the surprise trial was relatively low (80% correct).

Discussion

In Experiment 2, we tested whether the facilitation of responses found for the novels in the first experiment were caused by the fact that the novels did not resemble the visual target as much as

the standard stimulus (both being triangles). Although now no visual targets were presented, we again found facilitation during the presentation of novels compared to standards. This suggests that it is not the similarity of standards to the visual target that explains the facilitation of responses by the novels in Experiment 1.

Experiment 3

In Experiments 1 and 2, novels were not only novel but also had high relative complexity and were deviant; that is, they were more complex and less frequent than standards. In Experiment 3 we investigated whether novelty without high relative complexity and deviance would be sufficient to create facilitation of responses. We therefore used randomly drawn fractals as novel, standard, and target stimuli. Standard and target stimuli were repeated throughout the experiment while novels were presented just once. They thus remained novel, but did not deviate as a category from standards and targets. We used the stimulus probabilities of Experiment 1.

Method

38 volunteers (8 male; 38 right-handed; age 17-30 years, mean = 21.5) with normal or corrected-to-normal vision participated in the experiment. The participants were paid €8,50 or given course credit.

The stimuli and apparatus were mostly the same as in Experiment 1. However, now one fractal stimulus, randomly chosen for each participant, served as target stimulus, and another randomly chosen fractal served as a standard stimulus. Participants were familiarized with these stimuli before the start of the experiment by showing both fractals for at least 30 seconds. The number of trials was the same as in Experiment 1. Again a surprise trial with a rotating spiral was presented at the end of the experiment, and 200 ms after its presentation the auditory target sounded, signaling that a response was required.

Results

The same repeated measures ANOVA as used in Experiment 1 and 2 was performed. Figure 2C shows average response times to the auditory target per condition for each SOA (0, 200, 800 ms) in Experiment 3, and Table 1 lists the average response times and accuracy for every condition.

SOA (0, 200, 800 ms) had a main effect on average response times to the auditory target; $F(1.26, 46.36) = 16.93, p < .001$. Post hoc comparisons showed that participants were slower at the 0 ms SOA (mean = 472 ms; sd = 80 ms) than at the 200 ms SOA (mean = 435 ms; sd = 81 ms), $t(38) = 8.45, p < .001$, and at the 800 ms SOA (mean = 428, sd = 118), $t(37) = 4.18, p < .001$. No effects of visual stimulus type, or an interaction between visual stimulus type and SOA was found ($F < 1.5$). There were thus no differences between responses to the auditory target during presentation of a novel, relative to a standard stimulus. With regard to accuracy, again no effects were found of either SOA, $F < 1$, or stimulus type, $F < 1$. There were fewer false alarms during the presentation of a novel than during the presentation of a standard stimulus, $t(37) = 3.16, p = .003$.

Responses to the unexpected surprise trial were slow (mean = 459 ms, sd = 115 ms; see Figure 2C) compared to responses on the novel stimulus trials at this 200 ms SOA, $t(22) = 1.75, p < .05$. Accuracy on this trial was very low (60.5% correct).

Analysis over Experiments 1, and 3

To confirm that differences between experiments were not chance fluctuations, we performed an omnibus ANOVA for Experiments 1 and 3 with stimulus type and SOA as within subjects factors, and complexity of the standards (low in Experiment 1, high in Experiment 3) as a between subjects factor. We did not include Experiment 2 in this analysis, since the task in this experiment differed from the other two in that there only was an auditory and no visual target.

Responses to the auditory target were affected by SOA, $F(1.28, 77.46) = 17.32, p < .001$, Greenhouse-Geisser corrected, and by stimulus type, $F(1, 61) = 9.18, p = .004$. Stimulus type interacted with complexity of the standards, in that novels facilitated responses only when complexity of the standards was low (high relative complexity), $F(1, 61) = 16.09, p < .001$. Neither the two-way interactions nor any interaction involving SOA was significant ($F < 2.2$). There was no main effect of stimulus complexity, $F < 1$.

Discussion

In Experiment 3 we used stimuli from the same category as the novel, target and standard images. In Experiment 3 novels therefore did not deviate from their context in terms of complexity. Now, no differences in response times to the auditory target were found for standards and novels. Novels thus facilitate responses only when they are presented among frequent simple stimuli, as in Experiment 1 and 2, and not when they are presented among stimuli from the same category of fractals.

It may be that novels must deviate from their context to facilitate responses. It may also be that for facilitation to occur stimuli must be more complex than their context, as was the case in Experiments 1 and 2. Finally, it may be that complex fractals always facilitate responses to auditory stimuli relative to simple stimuli, irrespective of their novelty. If that were the case, average response times would be lower for standards in Experiment 3, relative to those in Experiment 1. Our between-experiment comparison suggested that this was not the case. However, we tested whether complexity per se, deviance, or relative complexity were causing the facilitation in the next experiment.

An alternative explanation for the differences between Experiment 1 and 3 might be that the complex standard and target stimuli were still perceived as novel during part of Experiment 3; however, when we analyzed performance over individual blocks (not shown here) there was no trace of a change of the data pattern over the course of the experiment.

Experiment 4

Results of the first two experiments suggest that deviant, novel visual stimuli facilitate responses to auditory stimuli. In Experiment 4, 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 Experiments 1 and 2, 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 both be complex and deviant to facilitate processing), facilitation is not expected in either condition.

Method

19 volunteers (7 male; 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 a duration of about 90 minutes. No surprise trial was presented.

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 Figure 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 were found of either SOA, $F(2, 36) = 1.00$, $p = .378$, $\eta^2 = .05$, or stimulus type, $F(1, 18) = 1.00$, $p = .331$, $\eta^2 = .05$. Nor were there any differences in the false alarm rate for deviant or standard stimuli, $t(18) = 0.07$, $p = .942$.

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 both be deviant and complex to produce facilitation of responses for the auditory target. We tested this conjecture in the next experiment.

Experiment 5

In Experiment 5 we tested whether a combination of deviance and complexity is sufficient to produce facilitation of responses, or whether stimulus novelty also play 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).

Method

14 volunteers (4 male; 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 (1680x1050 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 minutes. 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.

Results

A repeated measures ANOVA with the factors [SOA(0, 200, 800)*Stimulus(Deviant, Standard)*Condition(Repeated deviant; Non-repeated deviant)]. Figure 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 SOA ($F < 1$). 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 were found of SOA ($F < 1$), stimulus type, $F(1,13) = 1.34, p = .269, \eta^2 = .09$, or Condition ($F < 1$).

Experiment 5

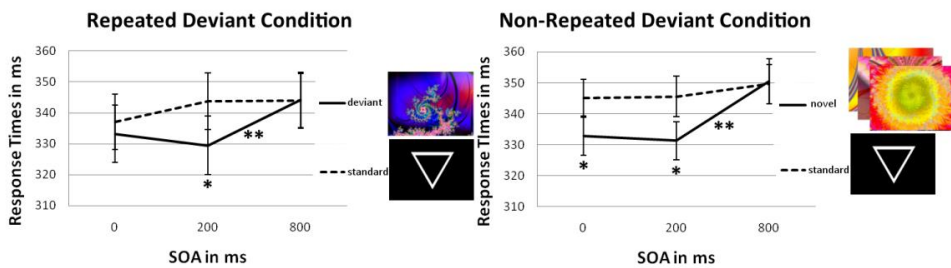


Figure 3. Average response times to the auditory target for the three SOAs, during presentation of deviant, novel or standard stimuli. Graphs represent average response times for A) the Repeated Fractal condition and B) the Non-Repeated Fractal condition of Experiment 5. Error bars represent 1 within-subjects SEM. Stars under the error bars reflect contrasts between standard and novel (post-hoc paired t -tests). * $p < .05$; ** $p < .01$.

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 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.

General Discussion

In a first experiment, we found facilitation of responses to an auditory target during the presentation of visual novel stimuli compared to repeated standard stimuli. These findings were replicated in a second experiment, in which no visual target was presented ruling out the possibility the effects reflected slowing by the standard stimuli rather than facilitation by the novels, due to standard and visual target similarity. We also tested whether any effect of novelty was due simply to surprise by including a non-novel but surprising stimulus at the end of the experiment, but responses were slow and accuracy reduced on this surprise trial. In the next three 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 novels 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 5). The facilitation was not caused by surprise. An unexpected, surprising stimulus at the end of the experiments resulted in missed auditory targets and slower response times - did not facilitate but rather distracted participants. Novel stimuli have been reported to distract by involuntarily attracting attention (Escera, Alho, Winkler, & Näätänen, 1998; Näätänen et al., 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 event-related potential 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 tasks (Berti & Schröger, 2003; Escera, Alho, Winkler, & Näätänen, 1998; Escera et al., 2002; Escera et al., 2001).

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 on 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 et al., 2010; Ruhnau, Wetzel, Widmann, & Schröger, 2010; SanMiguel, Morgan, et al., 2010; Schomaker & Meeter, 2012; Wetzel et al., 2012). SanMiguel, 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). Interestingly, 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 et al., 2013; Daffner, Mesulam, Scinto, Calvo, et al., 2000; Daffner, Scinto, et al., 2000). If the facilitation observed in our Experiments 1, 2 and 5 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, 2 and 5), and not when it was low (Experiment 3). 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 (eg. 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 Our Experiments 2, 4, and 5 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. [45] 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 Experiments 2 and 5 where we also found facilitation, participants had: no differences in false alarms were found in Experiment 2, and more false alarms for deviant compared to standard stimuli in Experiment 5. 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 anaesthetized 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, which is in line with the timing of the LC phasic response, as it has been measured in rodents (Pineda, et al., 1993; Aston-Jones, Segal, & Bloom, 1980; Foote, Aston-Jones, & Bloom, 1980; Aston-Jones, & Bloom, 1980).

