Expecting the unexpected: The effects of deviance on novelty processing

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Abstract

The brain has an innate interest in the new. Novelty is detected automatically, and often attracts attention – eliciting the orienting response. However, novelty is not a unitary concept, and the extent to which the orienting response is elicited depends on several factors. In the present study we investigated how stimulus novelty, deviance from the context, and complexity of the stimulus context contribute to the anterior N2 and novelty P3 event-related potential components, using the visual novelty oddball paradigm. In the first experiment, the novelty P3 was drastically reduced when the stimulus context was complex compared to simple and in a second experiment when novels were frequent rather than deviant. No such effect was found for the anterior N2, suggesting it is a function of stimulus characteristics, not deviance. In contrast, the novelty P3 depended on deviance and contextual complexity.

Keywords: Novelty; Psychophysiology; Event-Related Potentials; Novelty P3; Anterior N2; Deviance; Stimulus Context

New stimuli often receive priority in processing; they elicit an orienting response (Sokolov, 1963) and automatically attract attention (Escera, Alho, Schroger, & Winkler, 2000). This has been known for a long time (Pavlov, 1927), but it remains somewhat of an open question in what way a stimulus must be novel to elicit such an orienting response. Most people have probably never seen a picture of an axolotl, making it novel. If presented among pictures of well-known animals, the axolotl will also stand out – it will deviate from its context. If the axolotl elicits an orienting response, would that be a reaction to its novelty, or to its deviance from the context? Here, we set out to investigate to what extent the brain's responses to newness are a function of deviance relative to the context, or of stimulus-based novelty (e.g. would an axolotl presented amongst all unfamiliar animals still elicit an orienting response?).

Electrophysiological Responses to Novelty

The brain's responses to novelty have been investigated for decades using a variety of oddball paradigms and the event-related potential (ERP) technique. The ERP technique has a high temporal resolution, allowing to disentangle several aspects of the orienting response over time. A task that is often used to investigate the neural correlates of novelty processing is the three-stimulus oddball paradigm in which frequent standard, infrequent task-irrelevant nontargets, and infrequent target stimuli are presented in a random sequence. In such a task, the infrequent, deviant nontarget stimuli are known to elicit a frontally peaking negative component between 250 and 350 ms post-stimulus, which has been called the anterior N2, sometimes also referred to as N2b (Folstein & Van Petten, 2008; Naatanen & Picton, 1986; Szucs, Soltesz, Czigler, & Csepe, 2007), it is believed to reflect the relatively automatic detection of novelty (Chong et al., 2008). The anterior N2 is typically followed by a frontocentrally oriented component peaking around 300-550 ms post-stimulus, that has been termed the P3a (Squires, Squires, & Hilyard, 1975), believed to reflect the orienting or switching of attention – the orienting response (Escera, Alho, Winkler, & Naatanen, Escera et al., 2000; Escera, Alho, Winkler, & Naatanen, 1998; 1998).

In the Courchesne, Hillyard, & Galambos' (1975) novelty oddball paradigm, the task-irrelevant stimuli consisted of bizarre and novel stimuli, that were shown to elicit a positive component in the same time-range and with the same frontal topography as the P3a, which they termed the novelty P3. The novelty P3 has been suggested to reflect a conscious evaluation of unexpected or unusual events impacting subsequent behavior, rather than the mere detection of deviance (Folstein & Van Petten, 2008; Friedman, Cycowicz, & Gaeta, 2001), a process believed to take place in the frontal lobes (Daffner, Mesulam, Holcomb, et al., 2000; Daffner, Mesulam, Scinto, Acar, et al., 2000; Schroger, Giard, & Wolff, 2000; Verbaten, Huyben, & Kemner, 1997). Although the P3a and novelty P3 were originally seen as two separate components, more recent studies have found little reason to distinguish them (Combs & Polich, 2006; Goldstein, Spencer, & Donchin, 2002; Polich & Comerchero, 2003; Simons, Graham, Miles, & Chen, 2001). Since we are here concerned with the processing of novel stimuli, we will refer to this frontocentrally-oriented component as the novelty P3.

The novelty P3 has been functionally dissociated from the P3b (or P300), which is elicited by task-relevant target information (He, Lian, Spencer, Dien, & Donchin, 2001; Spencer, Dien, & Donchin, 2001). It has a later latency than the novelty P3 and typically has the largest amplitude over temporal/parietal electrodes (Soltani & Knight, 2000). The target P3b component has been suggested to index the updating of working memory (Donchin, 1981; Donchin & Coles, 1988) and memory processing in general (Polich, 2007). In addition, it has been argued that events must be task-relevant and involve a decisional process to evoke the P3b component (Friedman et al., 2001; Verleger, 2008); however, task-irrelevant novel stimuli are also known to elicit a P3b component, sometimes overlapping with the novelty P3 (Dien, Spencer, & Donchin, 2003, 2004; He et al., 2001; Spencer, Dien, & Donchin, 1999; Spencer et al., 2001).

Types of Novelty

As suggested above, novelty may be defined in several ways, and different types of stimuli have been referred to as novel in the literature. Stimuli may be unexpected, or deviate from the immediate context, such as the other stimuli in the experiment; or may deviate from everything in memory – i.e., never have been encountered by the observer. The last, more long-term aspect is what has been called (1) *stimulus novelty* (Courchesne, Hillyard, & Galambos, 1975), which applies to stimuli that have never been experienced before. The stimulus itself is truly novel and differs from anything stored in long-term memory. Stimulus novelty is a matter of degree: most visual input is novel in the sense that we usually have not experienced the exact combination of lighting, perspective, and distance to the stimulus that we are experiencing right now. However, usually the current visual input will resemble past experiences enough to readily be categorized. Stimulus novelty thus refers to stimuli that cannot be recognized and categorized from memory.

A second concept is (2) *contextual novelty*, referring to stimuli that might be familiar, but differ substantially from other stimuli experienced within the context; in an experiment, this usually means that a stimulus differs in a recognizable way from all other stimuli in the experiment (for examples see Barkaszi, Czigler, & Balazs, 2013; Cycowicz & Friedman, 2007; Polich & Comerchero, 2003). Contextually novel stimuli are thus non-repeated throughout an experiment, but they may belong to a well-known category (such as animals or geometric forms). By definition, stimulus novelty implies contextual novelty; stimulus novelty is thus a subcategory of contextual novelty.

A third concept related to novelty is (3) *deviance* at the level of the category. *Deviant stimuli* are those from a category of stimuli that is rare and physically stands out from the other stimuli within the experimental context. Whether a stimulus stands out depends on the variance within those other stimuli: A circle may stand out and thus be deviant if all other stimuli are squares, but not if the other stimuli are all sorts of simple forms. Deviant stimuli are not necessarily unique, and may be repeated throughout the experiment. An example of such stimuli are the infrequent deviant stimuli typically used in mismatch negativity studies (see for example Czigler, Balazs, & Winkler, 2002; Liu & Shi, 2008). Deviance is relatively independent from the other two types of novelty, as stimuli can be deviant but not novel (as in mismatch negativity studies), or can be novel but not deviant (as when participants are shown a series of frequent impossible 3D-figures).

A fourth concept is that of (4) *expectedness* and its corollary, *surprise.* Deviant and (contextually) novel stimuli will all be somewhat surprising, in that they cannot be predicted from the immediately preceding stimuli (examples of unexpected but non-novel stimuli can be found in Iwanaga & Nittono, 2010; Waszak & Herwig, 2007).

Finally, a concept that is relevant is *stimulus context complexity*. Complex visual stimuli are those that contain a large variety of visual features, resulting in that they cannot be compressed much (see Rigau, Feixas, & Sbert (2005) for an information-theoretical approach to complexity). Stimulus context complexity refers to the complexity of the immediate context in which a stimulus occurs. This complexity of the stimulus context has been suggested to play a crucial role in the generation of the novelty P3 (Barkaszi et al., 2013). Note, this concept does not imply any stimulus characteristics, but is about the context in which the stimulus occurs.

Table 1 summarizes the concepts described above. Figure 6 in the Discussion summarizes their relations, and how ERP components may be related to each. Notably, we did not aim for completeness; there may be other concepts of novelty and expectation that are omitted in Table 1 and Figure 6.

Table 1.

Concepts related to novelty, with a description and examples of stimuli.

Concept	Description	Example	Condition in Present Study
1. Stimulus Novel	Unfamiliar, never experienced before. Different from anything stored in long-term memory. *Non-repeated*	Unfamiliar stimuli, like fractals or difficult to categorize objects (Courchesne, et al., 1975; Daffner, Mesulam, et al., 2000; Daffner, Scinto, et al., 2000; Stoppel, et al., 2009; Schomaker, & Meeter, 2012;)	Novels in Normal Novels in Scrambled Novels in Novels
2. Contextually Novel	Differs from context (such as the experiment), but might be familiar. *Non-repeated*	Non-repeated letters or well-known symbols (Polich, & Comerchero, 2003; Friedman, & Cycowicz, 2007; Barkaszi, et al., 2013	Novels in Normal Novels in Scrambled Novels in Novels
3. Deviant	Infrequent category that is dissimilar to other stimuli. *Repeated or Non-repeated*	vMMN stimuli such as infrequent grating patterns (Czigler, Balázs, Winkler, 2002; Liu,& Shi, 2008)	Novels in Normal Novels in Scrambled
4. Unexpected	Violates expectancies, due to deviations from explicit predictions *Repeated or Non-repeated*	Unanticipated stimulus sequence, such as unpredicted action effects (Waszak, Herwig, 2007; Iwanaga, & Nittono, 2010)	Novels in Normal Novels in Scrambled Novels in Novels Standards in Scrambled
Stimulus context complexity	Complex stimuli contain a large variety in stimulus features. Stimulus context complexity is defined by the average complexity of all stimuli already presented	Complex stimuli: fractals, impossible line drawings, detailed photographs Simple stimuli: geometric shapes, symbols, cartoon figures	**High stimulus context complexity:** Novels condition Scrambled condition **Low stimulus context complexity:** Normal condition

The Influence of Stimulus Context

The concepts set out above may be useful in discerning the circumstances that elicit novelty responses, as suggested by the findings from two studies in which several aspects of novelty were manipulated. In two studies, Daffner et al. (Daffner, Mesulam, Scinto, Calvo, et al., 2000; Daffner, Scinto, et al., 2000) investigated how different types of novelty contribute to the anterior N2 and novelty P3. They employed three visual oddball tasks in which infrequent target and rare nontarget stimuli, and frequent standard stimuli (which they referred to as background stimuli) were either simple, easily recognizable stimuli, or complex, unfamiliar line-drawings. In their "all simple" task, all stimuli were simple geometric forms. The standard and target stimuli were repeated in this task, while the rare nontargets were not. The rare nontargets were thus contextually novel, but since all types of stimuli were drawn from the same set of simple stimuli were not a deviant category, and had low complexity. In a second "all unusual" task, all stimuli were complex and unfamiliar. Again

standard and target stimuli were repeated and the rare nontarget stimuli were not; since in this task the rare nontargets were unfamiliar and unrepeated; they possessed stimulus novelty, but as a category were again not deviant. In the third "mixed" condition, standard and target stimuli were repeated unfamiliar pictures, and the rare nontargets were nonrepeated simple shapes that were both contextually novel and deviant since they belonged to a different stimulus category, but did not possess stimulus novelty. An anterior N2 for rare nontargets was only found in the "all unusual task", suggesting that it depends mainly on stimulus novelty. In contrast, deviance had little effect: in the "mixed" task, the frequent unfamiliar standard stimuli elicited a larger anterior N2 than the simple rare nontargets. The novelty P3, on the other hand, showed the opposite pattern: it was larger for the simple rare nontargets when these were deviant, as in their "mixed" task, than for the unfamiliar standard stimuli, and it was not found in the two conditions in which the rare nontargets were not deviant as a category. These findings suggest that the anterior N2 is driven by stimulus novelty and not deviance or contextual novelty, whereas the novelty P3 is driven by deviance and/or contextual novelty rather than stimulus novelty.

However, one aspect of the Daffner, Mesulam, et al. (2000) and Daffner, Scinto, et al. (2000) studies complicates the interpretation of the results. The task-irrelevance and unexpectedness of the rare nontarget stimuli was reduced, since stimulus duration and the onset of the next stimulus depended on a self-paced response, which could reduce the anterior N2 and novelty P3 through anticipation. In addition, the simple rare nontarget stimuli in these studies were not repeated, therefore they were also contextually novel; deviance and contextual novelty were thus confounded - was the novelty P3 larger for simple rare nontargets than for unfamiliar standards because they were deviant, or because they were contextually novel?

This last question was addressed in a study by Barkaszi, Czigler, & Balázs (2013), in which the effects of stimulus complexity of the standard, target and deviant nontarget visual stimuli on the orienting response was investigated while varying the contextual novelty of the rare nontargets between conditions. More precisely, they employed an oddball task in which the rare nontarget category either consisted of one complex stimulus (the "identical" condition) or complex trial-unique contextually novel stimuli (the "variable" condition), presented among repeated simple standards and targets. Only in the "variable" condition the nontargets were novel – contextually and not stimulus novel, since the complex stimuli consisted of butterfly pictures that would have been familiar to most participants. Against expectations Barkaszi, et al. (2013) found a smaller novelty P3 for the rare nontargets when these were contextually novel compared to when they were not. In a third condition, a simple deviant nontarget was presented repeatedly among complex standard and target stimuli. Between the first two and the third condition the complexity of the stimulus context varied, with low complexity in the first two compared to high complexity in the third. In all three conditions, rare nontargets deviated from the context provided by the other stimuli, however, only when the stimulus context was simple, and not when it was complex an anterior N2 and novelty P3 were evoked, suggesting that the combination of contextual complexity and deviance is sufficient to evoke both components. These findings seemingly contradict the findings of the Daffner, et al., (2000a; 2000b) studies. Barkaszi et al. (2013) argue that the self-initiated response in the Daffner studies may have reduced the task-irrelevance of all stimuli, possibly underlying the generation of the P3 for the simple rare nontargets

The Effects of Task Difficulty

Another interpretation of the results discussed in the previous paragraph is that a novelty P3 is elicited when rare nontargets are more complex and require more processing resources than the target stimuli, which was the case in all conditions in which a novelty P3 was found. This is in fact what Barkaszi and colleagues suggested: the novelty P3 is only elicited when a stimulus requires elaborate processing, which was thought to depend on the complexity of the task-irrelevant stimuli

relative to the task-relevant stimuli. There is currently no way to discriminate between such an account focusing on the target-nontarget relation, and one focusing on the deviance between standard and nontarget stimuli, since target and standard stimuli were always from the same category in the studies discussed above.

Target stimuli affect processing of nontargets also in another way. In oddball paradigms, the task is to discriminate targets from standard and rare nontarget stimuli. Task difficulty, as defined by target/standard discriminability, is known to affect novelty P3 amplitude and topography (Comerchero & Polich, 1999; Jeon & Polich, 2001; Katayama & Polich, 1998; Nittono & Ullsperger, 2000). When targets are difficult to discriminate from standards the task demands more attention than when the discrimination is easy. It has been found that when the task is difficult, this extra attention results in a larger novelty P3 to all nontargets, while the P3b to targets is decreased (Frank, Yee, & Polich, 2012; Katayama & Polich, 1998; Sawaki & Katayama, 2006; Verbaten et al., 1997). Moreover, it has been argued that the topographic scalp location of the novelty P3 to infrequent nontargets is mainly determined by task demands rather than stimulus novelty (Comerchero & Polich, 1999; Polich, 2007; Polich & Comerchero, 2003): in an easy task the P3 peaks more parietally, and in a difficult task a more frontal novelty P3 is generated, even for rare non-novel stimuli. In both Daffner et al. (2000) studies and the Barkaszi, et al. (2013) study, discrimination was probably more difficult when target and standard were both complex than when they were both simple (this is also apparent from large differences in accuracy between conditions). This suggests that any differences observed between conditions could be due to differences in task difficulty.

Present Study

Taken together, the studies discussed suggest that stimulus context plays an important role in the generation of the novelty P3. However, in the Daffner et al.(2000) studies deviance and contextual novelty were confounded, while in both those and the Barkaszi et al. (2013) study the effect of nontarget-standard deviance cannot be disentangled from the effects of the nontarget-target contrast. Moreover, Barkaszi et al. (2013) used stimuli that were only contextually novel, which leaves open whether their results generalize to stimuli that possess stimulus novelty. In the current study, we therefore set out to vary the stimulus context. For that we varied the deviance of novel nontargets and the complexity of the stimulus context, and investigated how these two variables and stimulus novelty interact in the generation of the anterior N2 and novelty P3 components.

Concretely, we compared ERPs generated by nontarget stimuli that were stimulus novel (line drawings of impossible figures and fractals) under different stimulus context conditions. In two experiments we compared the typical "novelty" visual oddball task with simple standards (Normal condition) to one in which the experimental context was set by either frequent complex standards (Experiment 1) or novel stimuli (Experiment 2). In each experiment novel and target stimuli were the same in both conditions, which means that target-novel nontarget contrast did not vary between conditions (although target difficulty may have – we will return to this issue in the General Discussion).

In all conditions, the nontarget novel stimuli possessed stimulus novelty. In the Normal condition in both experiments, they were additionally deviant with respect to the context (the simple standards), and relatively complex. In the Scrambled condition of Experiment 1, standard stimuli were complex, scrambled versions of the novels. In this condition novels were still deviant, but they were now not more complex than the standard stimuli (at least when defined in information-theoretic terms, though perhaps not in other ways). In the Novels condition of Experiment 2, no standard stimuli were presented, and instead nontarget novels were frequent. Now novels were neither deviant (since they themselves were the stimulus context), nor relatively complex. By

keeping the novels the same between conditions but varying the context in which they occur we aimed to investigate the effects of deviance and the complexity of the stimulus context on the processing of stimulus novelty.

To the extent that stimulus novelty is sufficient for the generation of an anterior N2 and novelty P3, we should not see differences for these components between the conditions. When deviance from the context is a prerequisite for the elicitation of novelty responses, no effects of condition should be found in Experiment 1 (where novels deviate from the context in both conditions), but condition effects should be seen in Experiment 2 (where novels are frequent in one and deviant in another condition). If, on the other hand, complexity of the stimulus context plays a role in the generation of the novelty responses, differences between conditions should be evident in both experiments.

Experiment 1

Methods

Participants

22 Adults (9 male; age 18-42, mean = 22.6, sd = 4.7; 12 right-handed) with normal or corrected to normal vision participated in this study. Participants either received course credit or 18 Euros of compensation.

Stimuli

There were three types of stimuli, standard, target and novel stimuli. Novel stimuli were randomly drawn from a set of 80 new, difficult to categorize, line-drawings from a set of pictures that also have been used by others (Kosslyn et al., 1994; Kroll & Potter, 1984). Standard stimuli varied in complexity and size between two conditions; they either consisted of a simple triangle (Normal condition), or of a scrambled picture (Scrambled condition). The scrambled pictures were produced by scrambling 50 of the novel stimuli by randomly moving every white pixel 30 positions in left or right horizontal (X) and then in an up or down vertical (Y) direction. This created stimuli that resemble dot clouds. See Figure 1 for example of a scrambled picture. The 50 scrambled pictures created in this way were equivalent in luminance and contrast to novel pictures while being clearly distinguishable from them, and were more complex than the original novels when this was measured by the size of compressed files (Rigau, et al., 2005). In both conditions the target was a triangle (pointing in opposite direction as the standard in the Normal condition). All stimuli were presented in the center of the screen in a randomized sequence. Standards in the Normal condition and targets were presented at a viewing angle of about 4°, the novel stimuli and standards in the Scrambled condition covered a viewing angle of about 6.7x6.7°.

Procedure & Design

Participants were seated in a Faraday-shielded, sound-attenuated, and dimly lit room. The visual stimuli were presented on a 21 inch CRT computer screen using E-Prime programming software (Psychology Software Tools Inc., Pittsburgh, PA, USA) at a viewing distance of about 80 cm. The refresh rate of the screen was 120 Hz. The task was a visual oddball paradigm in which participants observed a sequence of visual stimuli.

The first 21 trials were part of a practice block. Stimuli in the practice block were from the Normal condition. Thereafter participants performed eight blocks of 70 trials (about 4.5 minutes per block), of which four consisted of the Normal condition and four of the Scrambled condition,

presented in a mixed design. Between blocks participants could take self-paced breaks. The condition alternated between blocks. Because of a programming mistake, the first block was always of the Normal condition (we will come back to this in the Discussion). The 560 experimental trials were completed in about 30 minutes.

Figure 1A and 1B show example stimulus sequences for the Normal and the Scrambled condition respectively. A trial started with the presentation of a central fixation cross. The presentation duration of the fixation was jittered between 800-1820 ms. Subsequently a visual stimulus was presented for 2 seconds, which could be of three kinds: (1) A standard stimulus on 71.4% of all trials. In the Normal condition the standard was an up- or downwards pointing triangle (direction counterbalanced across participants) and in the Scrambled condition it was one of 50 scrambled figures (each presented once in each block); (2) An infrequent target stimulus on 14.3% of all trials, which was a triangle pointing in the opposite direction as the standard triangle. Participants had to press 'b' in response to the target; (3) A novel stimulus on 14.3% of all trials, a unique line-drawing that was randomly drawn from a set of 80 pictures. All novel stimuli were presented only once. The task was the same between conditions; participants were told to give a speeded response (pressing 'b') to the target either with their left or right index finger, counterbalanced over participants.

Insert Figure 1 around here

EEG Recordings

The EEG was recorded using the 128 channel Biosemi system (Biosemi, Amsterdam, the Netherlands) with sintered Ag/AgCl electrode tips, that were plugged into an elastic cap (Electro-Cap International Inc. Eaton, OH, USA). For encephalic electrode locations of the Biosemi system see www.biosemi.com. Data are reported from electrodes that approximately correspond to Fz, Cz, Pz and Oz midline electrodes from the 20-10 system. The electrode equivalents for the Biosemi 128 system are: Fz = C21, xy(46,90); Cz = A1, xy(0,0); Pz = A19, xy(46,-90). In the rest of the text the 10-20 system electrode names will be used for the Biosemi electrode equivalents.

EEG signals were digitized with a sampling rate of 500 Hz and a gain setting of 1000. During recording electrode offset was kept below 20 μV. Raw EEG data were digitally filtered offline using a 0.1 Hz basic finite impulse response 1000-point high-pass filter with a transition bandwidth of 0.01 Hz (roll-off 24 dB per octave), and a 30 Hz low-pass filter with a transition bandwidth of 5 Hz (roll-off 6 dB per octave).

The recordings were offline referenced to the average of electrodes on the left and right mastoids. Horizontal eye movements were measured using bipolar electrodes placed at the outer corners (the canthi) of the eyes and vertical eye movements, including blinks, were measured by electrodes placed above and below the mid of the orbital sockets in order to control for eye movements during data analysis.

EEG Analysis

ERPs were computed from -200 to stimulus onset to 800 ms post-stimulus. Amplitudes were computed relative to a 200 ms pre-stimulus baseline. Noisy channels were detected on basis of visual inspection, and were replaced by the average signal of three and if possible by four surrounding electrodes. Independent component analysis (ICA) decomposition of the data was performed using the logistic infomax ICA algorithm (Bell & Sejnowski, 1995) with a natural gradient feature using the EEGlab toolbox in Matlab (Delorme & Makeig, 2004). The results of the decomposition were used for

the rejection of eye movements and blink components on basis of visual inspection (0.8-4% of data were rejected per participant using ICA). ERPs were derived from the remainder of the data using standard signal averaging procedures (Luck, 2005). Epochs containing muscle or movement artifacts were rejected on basis of trial-by-trial visual inspection by a trained individual (rejected trials < 11%). Minimally 36 and maximally 40 epochs contributed to the individual average ERPs for novel and target stimuli for both the Normal and the Scrambled condition. A minimum of 178 and a maximum of 200 epochs to the individual average ERPs for standards for both conditions.

The novelty P3 and P3b were not clearly distinguishable as evidenced by the grand-average ERPs (see Figure 2), both peaking posteriorly and at around the same time. A posterior peak is usually found for the P3b, but not for the novelty P3, which usually peaks more frontally. Since the novelty P3 and P3b overlap in the time, the novelty P3 component possibly became masked by the P3b. To investigate this possibility a temporospatial principal component analysis (PCA) was used to decompose the data, and to identify the underlying components that contributed to the grand-average ERP signal. A two-step spatiotemporal PCA (Dien, 2012) was conducted using the ERP PCA Toolkit (EP Toolkit; Dien, 2010) in order to dissociate the novelty P3 and P3b. In addition, we aimed to identify the anterior N2, to be able to analyze it independently from the other components. PCA was done on the subject-averaged data for all conditions for -200 to 800 ms epochs, including all EEG channels. Separate PCAs were performed to analyze the data for Experiment 1 and 2. A covariance matrix was used, using time information for a temporal PCA and channel information for a spatial PCA. In the first step a temporal PCA was performed, making use of the high temporal resolution of EEG, as recommended by Dien (1998; 2012), using a Promax rotation (Kayser & Tenke, 2003) with Kaiser correction. A rotation parameter of three kappa was used (Dien, 2010) to rotate the data to an oblique simple structure (Hendrickson & White, 1964). For data reduction purposes a scree plot using a parallel test (Cattell, 1966; Horn, 1965) was used to display the variance accounted for by the factors, and to determine how many factors to retain in the temporal PCA. In the second step a separate spatial PCA was computed for the temporal factors using an Infomax rotation (Dien, Khoe, & Mangun, 2007). Again a scree plot and parallel test were used to determine how many spatial factors to retain in this second step. The EP Toolkit converts the factors back to microvolt scaling by multiplying the factor loadings and factor scores, thereby allowing for easy interpretation of the results. A threshold for the variance accounted for by the factors was set at 0.50%. The factors reported on were selected on basis of previous findings in the latency and topography of the anterior N2, novelty P3 and P3b components. The anterior N2 was expected to peak between 225-275 ms having a frontal orientation. The novelty P3 was expected to have a frontal/frontocentral orientation peaking in a broad 300-550 ms time-window. The P3b was expected to peak in a bit later, between 450-600 ms and to have a more posterior orientation. First factors were selected on basis of timing, and then a selection was made based on topography. Because we were primarily interested in the anterior N2, novelty P3, and P3b, other ERP components were not identified or analyzed.

Statistical Analyses

The PCA covariance factor loadings (that is, the factors rescaled in microvolt scaling for ease of interpretation) corresponding to the components of interest (anterior N2, novelty P3, and P3b) were subjected to repeated measures ANOVAs 2*3 ANOVAs: [Condition (Normal, Scrambled)]*[Stimulus(Standard, Novel, Target)]. A significant effect of Stimulus was followed up by three 2*2 ANOVAs with [Condition (Normal, Scrambled)]*[Stimulus(Standard vs. Novel, Novel vs. Target, Target vs. Standard)] as factors. A significant interaction effect was followed up by *t*-tests investigating the effects of condition per stimulus. To rule out a task difficulty account of the data the P3b for targets and novels was compared per condition using paired-samples *t*-tests. When the sphericity assumption was violated, the Greenhouse-Geisser correction was used to reduce the degrees of freedom. Where multiple comparisons were made, Bonferroni correction was applied.

Note, since the temporospatial PCA converts recordings into factors spanning all electrodes, the analyses did not include an electrode site factor was included in this analysis.

Response times, accuracy, and false alarm rates were compared between conditions using *t*-tests. False alarms were defined as a response on a no-response trial; when participants responded with 'b' when no target was presented.

Results

Figure 2 shows the grand-average ERPs for the Normal and Scrambled condition per stimulus type. The anterior N2 had a mainly frontal distribution, while a positive peak in the P3 time-window was found to peak at more posterior parietal electrode sites.

Insert Figure 2 around here

Principal Component Analysis

The temporospatial PCA led us to identify a factor presumed to reflect the anterior N2. Two PCA factors contributing to the positive peak in the P3 time-window were identified. The first peaking frontally, the second posteriorly and somewhat later. These factors were presumed to reflect the novelty P3 and P3b. Figure 3 shows the mean PCA factors for all components and conditions as subjected to the statistical analyses. Figure 4 shows the PCA waveforms and topoplots for these three factors and the corresponding grand-average ERPs.

In the first step a temporal PCA was performed using Promax rotation. The scree test indicated to retain twelve factors in the temporal PCA. These factors accounted for 94.48% of the variance. In the second step a spatial PCA using Infomax rotation was performed. Thirteen spatial factors were retained as suggested by a new scree test, explaining 89.26% of the variance. The spatial PCA was performed, using these spatial factors, for all twelve temporal factors separately, which resulted in a total of 156 temporospatial factors.

Thirty-eight out of 156 temporospatial factors met the threshold size of 0.5%. One of these factors consisted of a frontally negative peak in the anterior N2 time-window. This temporospatial factor consisted of a temporal factor that peaked at 248 ms and a spatial factor that peaked frontally. This factor was interpreted as the anterior N2, and accounted for 3.90% of the total variance. Two different temporospatial factors showed a positive peak in the P3 time-window. The first factor peaked frontally at 422 ms, and the second peaked posteriorly and somewhat later at 486 ms. Based on a priori knowledge on the latency and topography the frontally oriented and peaking at 422 ms was interpreted as the novelty P3 and explained 1.00% of the variance. This PCA factor also consisted of two negative peaks (see Figure 4), suggesting some contribution of other ERP components: A negative peak around the time of the anterior N2, and some late negativity, after the novelty P3 peak. The latter may reflect reorienting negativity (RON). Especially the anterior N2 has been associated with the novelty P3, and sometimes both components together are referred to as the N2/P3 complex (Folstein & Van Petten, 2008); here, part of the anterior N2 seemed to load on the same factor as the novelty P3, whereas a larger (and slightly earlier) portion loaded on the separate factor described earlier. Also RON been argued to be closely related to the anterior N2 and novelty P3 (Bendixen et al., 2010), which may explain why PCA did not distinguish them entirely and took them together into one factor. The last PCA factor that was selected was posteriorly oriented and peaked somewhat later at 486 ms, and was presumed to reflect the P3b. The P3b factor explained 7.33% of the variance. These factors were subjected to the analyses reported below, and will be referred to as the components that they are believed to reflect.

Insert Figure 4 around here

Anterior N2 Component

The anterior N2 PCA factor was larger in the Scrambled than in the Normal condition, $F(1,21)$ = 7.49, p = .012, η^2 = .26. Stimulus affected the anterior N2, $F(1.58, 33.26)$ = 29.32, p < .001, η^2 = .58. The novels elicited a larger anterior N2 than the targets, $F(1,21)$ = 37.58, p < .001, η^2 = .64, and than standards, $F(1,21)$ = 31.40, p < .001, η^2 = .60. Standards elicited a larger anterior N2 than targets, $F(1,21)$ = 9.47, p = .006, η^2 = .31, which was mainly driven by the larger anterior N2 for standards in the Scrambled condition, $t(21)$ = 4.36, p < .001. No differences were found between standard- and target-elicited anterior N2 in the Normal condition (p = .77).

In addition, Stimulus and Condition interacted, $F(2,42)$ = 13.78, p < .001, η^2 = .43. Post-hoc comparisons showed that the effect of condition was mainly driven by the standard stimuli, $t(21)$ = 5.79, p < .001, the only stimuli that were physically different between conditions - with a larger anterior N2 in the Scrambled than in the Normal condition. No effects of condition were found for novels or targets (p > .665).

Novelty P3

The temporospatial PCA factor corresponding to the novelty P3 was larger in the Normal compared to the Scrambled condition, $F(1,21)$ = 15.55, p = .001, η^2 = .43.

Stimulus affected the novelty P3, $F(2,42)$ = 7.05, p = .002, η^2 = .25. This effect was further investigated with 2*2 ANOVAs. The novelty P3 was larger for novels than for standards in both conditions, $F(1,21)$ = 7.52, p = .012, η^2 = .26, and larger for targets than for standards, $F(1,21)$ = 13.54, p = .001, η^2 = .39. It did not differ between targets and novels, $F(1,21)$ = 1.83, p = .191, η^2 = .08. Condition and Stimulus did not interact, $F(1.41, 29.66)$ = 2.03, p = .160, η^2 = .09.

P3b Component

The P3b did not differ between conditions, $F(1,21)$ = 1.17, p = .292, η^2 = .05. Stimulus did affect the P3b, $F(1.23, 25.84)$ = 25.62, p < .001, η^2 = .55. The targets elicited a larger P3b than novels, $F(1,21)$ = 18.15, p < .001, and than standards, $F(1,21)$ = 36.52, p < .001, η^2 = .64. Novels elicited a larger P3b than standards, $F(1,21)$ = 12.48, p = .002, η^2 = .37. Stimulus and Condition interacted, $F(2,42)$ = 16.03, p = .001, η^2 = .43. This effect was further investigated with post-hoc comparisons. Novels elicited a larger P3b in the Normal compared to the Scrambled condition, $t(21)$ = 4.62, p < .001. No effects of condition were found for standards (p = .416) or targets (p = .057).

Behavioral Data

Table 2 lists the behavioral results. No differences between conditions were found for response times, $t(21)$ = .54, p = .59, nor for accuracy, $t(21)$ = 1.00, p = .33. False alarm rates were very low: 0.09% in the Scrambled condition and 0.16% in the Normal condition. This difference was not significant, $t(21)$ = .89, p = .38.

Table 2

Mean Response Times and Accuracy

Condition	Normal standards	Scrambled standards
Experiment 1		
Response Times	543.23 (51.28)	538.72 (55.70)
Accuracy	99.77 (0.74)	99.89 (0.53)
Experiment 2	Normal standards	Novels
Response Times	516.39 (72.17)	498.31 (67.06)
Accuracy	99.83 (0.65)	99.84 (0.65)

Note: Response times in milliseconds and accuracy in percentage correct. Standard deviations in parentheses.

Discussion

In both conditions of Experiment 1, novels possessed stimulus novelty and were deviant with respect to the context. In the Normal condition the stimulus context was simple, whereas it was complex in the Scrambled condition, due to the manipulation of the standards. In information-theoretical terms standards in this condition were even somewhat more complex than novels. Though in other ways (i.e., semantic) they may have been less complex than the novels, they were clearly more complex than the triangles in the Normal condition.

We anticipated to find a novelty P3 and P3b distinguishable on basis of differences in peak latency and topography, but in the grand-average ERPs no clear distinction was evident. Using temporospatial PCA we decomposed the data, revealing two positive components in the P3 time-window, and a separate negative component in the N2 time-window. We further analyzed these PCA factors, which both contributed to the P3 peak observed in the grand-average ERP signal.

The novel-elicited anterior N2 did not differ between the two conditions. This suggests that novelty detection as reflected by the anterior N2 component is not affected by complexity of the stimulus context, extending previous findings that it is relatively automatic (Chong et al., 2008; Tarbi, Sun, Holcomb, & Daffner, 2011). In contrast, the further processing of novelty was qualitatively affected by the complexity of the stimulus context. A large novelty P3 was elicited in the Normal condition, whereas it was almost absent in the Scrambled condition. These results suggest that the novelty P3 is very sensitive to the complexity of the stimulus context in addition to task difficulty or inherent stimulus novelty. In addition, the novelty P3 was larger for novel than for standard stimuli, suggesting that it is also affected by another aspect of the novel stimuli. No differences were found for novel and target stimuli, suggesting either that targets were also deviant in the experiment, or that the novelty P3 factor also contained target processing that occurred in the same time range and with a similar scalp topography as the novelty P3. This second alternative is supported by the results of Experiment 2 discussed below, in which the novelty P3 occurred earlier and no target loading on this factor was found.

Behavioral performance was not affected by the context manipulation, suggesting that the tasks between conditions were of similar difficulty (Comerchero & Polich, 1999). There was a trend, however, for a larger target P3b in the Normal compared to the Scrambled condition. A smaller P3a

to targets might also reflect increased task difficulty (Katayama & Polich, 1998); therefore, we will return to possible effects of task difficulty in the General Discussion.

Experimental Design

One concern in Experiment 1 is that all participants started with a block of the Normal condition. It is known that stimuli presented for the first time evoke more pronounced novelty responses. Could this drive the reported novelty P3 differences between conditions throughout the experiment? This question could not be addressed using the PCA factors, since single trial information is lost in the individual subject averages subjected to the PCA analyses. To test this we compared the original ERP data measured in the first block with those in the third, fifth, and seventh block (all Normal condition). The novelty P3 (mean peak for 375-450 ms) was found to be smaller in the first compared to following blocks. The differences are of opposite direction as those between the Normal and Scrambled condition (novelty P3: Normal > Scrambled). The P3b (mean peak for 400-500 ms) targets did not differ between the first and later blocks. The lack of counterbalancing thus cannot explain the findings reported here, and if anything only acted to decrease the size of the effects condition.

Experiment 2

In Experiment 2, we replicated Experiment 1 with different stimuli and a slightly different design. First, novels were now colorful computer-generated fractals (as in Schomaker & Meeter, 2012; Stoppel et al., 2009) instead of monochrome line drawings. Moreover, we replaced the Scrambled condition with the Novels condition in which there were no standards; instead, only frequent novel and infrequent target stimuli were presented. In this condition, participants thus could expect to see stimuli that were stimulus novel on most trials, and the novels as a category were not deviant. In this way we aimed to investigate whether the anterior N2 is unaffected by deviance relative to the context, and to replicate our finding that the novelty P3 depends on the complexity of the stimulus context, rather than of stimulus novelty, which was the same between conditions. The Normal condition again consisted of a typical visual oddball task, including infrequent trial-unique novels (now fractals), infrequent targets (triangles) and frequent standards (also triangles).

Methods

Subjects

15 Participants (4 male; age 18-32, mean = 23.5, sd = 4.0; all right-handed) with normal or corrected to normal vision volunteered in the experiment. Participants were paid 16 Euros or were given course credits.

Stimuli

The target stimuli were the same as in Experiment 1. The novel stimuli in both the Novels and Normal condition were randomly drawn from a set of 280 unique, fractal figures generated by an open-source program using iterative mathematical computations (ChaosPro 4.0; http://chaospro.de). The fractals were colorful, complex figures that were difficult to categorize. The standard stimuli in the Normal condition were the same as in Experiment 1. In contrast, in the Novels condition, no standard stimuli were presented, leaving only two types of stimuli in this condition (frequent novels and infrequent targets). The target and standard stimuli had a viewing angle of about 4°. The novel

stimuli covered a viewing angle of about 10.2x6.7°. Stimuli were now presented on an LCD (instead of a CRT) screen with a refresh rate of 120 Hz and a resolution of 1680x1050.

Procedure & Design

See Figure 1C and 1D for example trials of the Normal standards and Novels condition in Experiment 2. The procedure and task were almost the same as in Experiment 1, with some changes as outlined below. Again, participants performed a practice block of 21 trials, and eight blocks of 70 trials. The first four blocks (or last four, counterbalanced over participants) were of the Normal conditions, the other four were of the Novels condition. In the Novels condition two types of stimuli were presented: (1) A non-repeated novel fractal stimulus occurring on 85.7% of the trials; (2) An infrequent target presented on 14.3% of trials. In the Normal condition there were three types of stimuli (novels, standards, and targets) presented with the same probability as the stimuli in the Normal condition of Experiment 1, but novels were now fractals. The target and standard were again triangles either pointing upwards or downwards. In both conditions participants had to respond to the target by pressing 'b'. The stimulus sequence and duration was the same as in Experiment 1. Figure 1C and 1D show an example stimulus sequence for a trial in a Normal and a Novels block respectively.

EEG Recordings and analysis

The EEG was recorded using the same procedures as in Experiment 1. ICAs, data cleaning and ERP calculation were done in the same way as in Experiment 1. A minimum of 33 and a maximum of 40 epochs contributed to the individual average ERPs for novels and targets in the Normal condition and targets in the Novels condition. For standards in the Normal condition, 200 epochs contributed while 240 epochs contributed for novels in the Novels condition. The same procedures as in Experiment 1 were used to perform a temporospatial PCA.

Statistical Analyses

PCA factors identified as anterior N2, novelty P3, and P3b were subjected to repeated measures ANOVAs 2*2 ANOVAs: [Condition (Normal, Scrambled)]*[Stimulus(Novel, Target)]. Standard stimulus trials were not analyzed as they were presented only in the Normal condition. For completeness, results from these conditions are reported in the figures. A significant interaction effect was followed up by *t*-tests investigating the effects of condition per stimulus. Again to rule out a task difficulty account the P3b for targets and novels was compared per condition using paired-samples *t*-tests. The same corrections were applied as for Experiment 1.

Results

Grand-average ERPs for the Normal and Novels condition can be found in Figure 2. Using a temporospatial PCA, factors were found that were interpreted as reflecting an anterior N2, a frontally oriented novelty P3, and a more posteriorly oriented P3b. Figure 5 shows the PCA waveforms and topoplots for the anterior N2, novelty P3 for novels and P3b for targets factors and the corresponding grand-average ERPs. Both the anterior N2 and novelty P3 were larger for novels than for standards. Targets elicited a larger P3b than novels.

Insert Figure 5 around here

Principal Component Analysis

Six factors were retained in the temporal PCA, accounting for 94.89 % of the variance. In the second step, the spatial PCA, five factors were retained explaining 89.51 % of the variance.

Sixteen out of 30 temporospatial factors met the threshold. One temporal factor peaked at 246 ms and a spatial factor showed a frontal negative peak. This temporospatial factor accounted for 3.34 % of the variance and was presumed to reflect the anterior N2. Another temporospatial factor showed a positive peak at 350 ms at a frontal site. It explained 4.74 % of the data, and was interpreted as the novelty P3. As in Experiment 1, this factor showed contributions of two negative components. These negative deflections may reflect contributions of the anterior N2 and RON, which may correlate with the novelty P3 to such extent that they are taken into one factor by the PCA. Finally, a more posteriorly oriented temporospatial factor peaked at 426 ms, and was interpreted as the P3b, accounting for 9.61 % of the variance

Anterior N2 Component

There was no effect of Condition on the anterior N2 PCA factor ($F < 1$), nor did Stimulus and Condition interact ($F < 1$). Novels elicited a larger anterior N2 than the targets, $F(1,13) = 15.22$, $p = .002$, $\eta^2 = .54$.

Novelty P3

The novelty P3 was larger for novels than for targets, $F(1,13) = 7.29$, $p = .018$, $\eta^2 = .36$. There was a trend for a larger novelty P3 in the Normal compared to the Novels condition, $F(1,13) = 4.37$, $p = .057$, $\eta^2 = .25$. We further investigated this trend effect: The novelty P3 was larger in the Normal compared to the Novels condition for novel stimuli, $t(13) = 3.43$, $p = .004$. No effect of Condition was found for targets ($p = .530$). There was no interaction between Condition and Stimulus, $F(1,13) = 2.14$, $p = .167$, $\eta^2 = .14$.

P3b Component

The P3b was larger in the Normal than in the Novels condition, $F(1,13) = 18.15$, $p = .001$, $\eta^2 = .58$, and for targets than for novels, $F(1,13) = 18.15$, $p = .001$, $\eta^2 = .58$. Stimulus and Condition did not interact, $F(1,13) = 1.01$, $p = .334$, $\eta^2 = .07$.

Behavioral Data

No significant differences between conditions were found for response times, $F(1,13) = 4.13$, $p = .063$, $\eta^2 = .24$, though there was a trend towards somewhat faster responding in the Novels condition. Accuracy was the same in the Normal and Novels conditions, $F(1,13) = 0.09$, $p = 0.926$, $\eta^2 < .01$. There were more false alarms in the Normal (mean = 0.47%) compared to the Novels condition (mean = 0.11%), $F(1,13) = 9.24$, $p = .009$, $\eta^2 = .42$.

Discussion

In Experiment 2 we aimed to further investigate the effects of deviance on the electrophysiological responses to novelty. Behaviorally, participants performed at ceiling in both

conditions, with accuracy above 99.75%, suggesting that if there were any differences in task difficulty, these would be minor. In both experiments novels elicited a larger anterior N2 than targets, while targets elicited a larger P3b. In Experiment 1 the novels elicited a larger novelty P3 than standards, and in Experiment 2 than targets. No differences between the two conditions were found in novelty detection as indexed by the anterior N2. This again suggests that detection of novelty is unaffected by context, and reflects stimulus characteristics (e.g., stimulus novelty or complexity) rather than deviance. Again, the two conditions did differ in the further evaluation of novelty as indexed by the novelty P3. More specifically, when novel stimuli did not deviate from their stimulus context, they elicited a much smaller novelty P3 than when novel stimuli were deviant. Also the P3b was larger in the Normal compared to the Novels condition, suggesting a reduction in the updating of working memory in the complex context of the Novels condition. Whether this also reflects differences in task difficulty is discussed below.

General Discussion

In two experiments, we investigated whether deviance and the complexity of the stimulus context play a role in the processing of stimulus novelty. Three ERP components were our main measures of interest: the anterior N2, thought to reflect detection of novelty, the novelty P3 reflecting attention subsequently devoted to novelty, and the P3b, reflecting the processing of task-relevant information and the updating of working memory.

Anterior N2 depends on stimulus characteristics, and the novelty P3 on deviance and contextual complexity

The novel-evoked anterior N2 did not differ between the Normal conditions, and conditions in which stimuli with a high degree of visual complexity were frequent (the Scrambled condition of Experiment 1 and the Novels condition of Experiment 2, which we will refer to below as the complex context conditions). This suggests that the anterior N2 is evoked independently of deviations from the context or the frequency of the stimulus category that elicits it, reinforcing the idea that the anterior N2 reflects a relatively automatic, stimulus-driven process (Chong et al., 2008; Tarbi et al., 2011)(Schomaker & Meeter, 2014). This process might reflect the reflexive detection of information that differs from anything in long-term memory, that is stimulus novelty (Daffner, Mesulam, Scinto, Calvo, et al., 2000; Daffner, Scinto, et al., 2000). Barkaszi, et al. (2013) found no differences in anterior N2 for complex deviants presented once, and complex deviants presented 50 times in the study. However, when the same image was used as standard and presented 500 times, the N2, though still visually larger than that for simple stimuli, was much reduced. This result suggests that the size of the anterior N2 is mainly a factor of stimulus complexity, with habituation occurring only after many repetitions of a stimulus. Our findings of a larger anterior N2 for the complex scrambled compared to the simple normal standards are in line with this suggestion.

In contrast, the novelty P3 was highly sensitive to deviance from the context *and* the complexity of the stimulus context. When novels did not deviate from their immediate stimulus context (as in the Novels condition) or when the stimulus context was complex (as in the Scrambled condition), processing of and attention to novel stimuli was reduced. This is consistent with previous findings (Barkaszi et al., 2013; Cycowicz & Friedman, 2007; Daffner, Mesulam, Scinto, Calvo, et al., 2000; Daffner, Scinto, et al., 2000), but it is the first time that such deviations from context are shown to be crucial for the processing of stimulus novelty in a direct experimental contrast.

Figure 6 summarizes these findings: the anterior N2 is linked to complexity, and both stimulus and contextual novelty. The novelty P3, on the other hand, is elicited when a stimulus is both deviant relative to the context, and the stimulus context is simple. As discussed in the

Introduction, the novelty P3 can also be elicited by simple nonnovel rare nontargets (e.g., infrequent squares presented among frequent circles (Comerchero & Polich, 1998), which suggests that when only simple stimuli are presented (and when task difficulty is high – though this factor is not considered in Figure 6), deviance alone is sufficient to elicit a novelty P3.

Insert Figure 6 around here

Results from the "mixed" condition of Daffner et al. (Daffner, Mesulam, Scinto, Calvo, et al., 2000; Daffner, Scinto, et al., 2000) do not fit into the ideas presented in Figure 6 very well. In this condition the rare nontargets were contextually novel but simple; the stimulus context (which consisted of complex standard and target stimuli), on the other hand, was complex. The simple, contextually novel, rare nontargets nevertheless elicited a novelty P3. There may be two ways to reconcile these findings with the view espoused in Figure 6. One is to suggest that deviance and contextual novelty together are sufficient to elicit the novelty P3. This would fit well with a view that gives a central role to expectations in the generation of the novelty P3 (see below). One other way to reconcile these findings was suggested by Barkaszi, et al. (2013). They suggested that since participants controlled the time of presentation by a self-paced response in the Daffner, et al. (2000a; 2000b) studies, the task-irrelevance and unexpectedness of the simple rare nontargets may have been decreased in those studies.

Task Difficulty

Not only novel stimuli are known to elicit a central P3 component (the novelty P3), also non-novel deviants can elicit such a component under certain circumstances. Processing of non-novel deviants is known to be sensitive to task difficulty. Katayama and Polich (1998) showed that when target/nontarget discrimination in an auditory three stimulus oddball paradigm was difficult the novelty P3 to non-novel deviants was larger than when discrimination was easy. The opposite was true for the target P3b. These findings have been replicated many times, suggesting that the novelty P3 can be elicited by non-novel deviant stimuli when attention is focused on the task, such as when the perceptual distinctiveness of the target and nontarget is difficult (Comerchero & Polich, 1998, 1999; Hagen, Gatherwright, Lopez, & Polich, 2006; Polich & Comerchero, 2003). A strong attentional focus could facilitate processing of all stimuli, leading to a larger central novelty P3 to nontargets (Demiralp, Ademoglu, Comerchero, & Polich, 2001; Polich & Comerchero, 2003). These effects are stronger for salient than for nonsalient nontargets (Comerchero & Polich, 1999). In the present study, target/nontarget discrimination was possibly more difficult in the Normal condition than in the complex context conditions: In the Normal condition, both the target and standard were triangles, and thus more similar to one another than the target triangle and scrambled standards or novels in the complex context conditions. Although behavioral outcomes were not suggestive of a difference in task difficulty between conditions, there was a trend for a larger target P3b in the Scrambled compared to the Normal condition in Experiment 1, suggesting that the task was indeed somewhat easier in the Scrambled condition. This possibly contributed to the reduction of the novelty P3 in this condition. However, in Experiment 2 the results for the P3b were reversed: The P3b was larger in the Normal compared to the Novels condition, suggesting that if anything, the task in the Normal condition was easier. Since the novelty P3 was larger in the Normal compared to the complex conditions both when this condition generated larger and when it generated smaller target P3bs, it is unlikely that task difficulty can explain the effect of condition on the novelty P3.

How does stimulus context affect the novelty P3?

In both experiments, our context manipulation affected the likelihood that complex stimuli would appear. It is known that a high target probability reduces the P3 amplitude to targets (Duncan-Johnson & Donchin, 1977; Polich, 1990a, 1990b; Polich & Bondurant, 1997; K. C. Squires, Donchin, Herning, & McCarthy, 1977; K. C. Squires, Wickens, Squires, & Donchin, 1976). The present study shows that the probability of task-irrelevant complex or novel stimuli can affect novelty processing as indexed by the novelty P3. This affected the novelty P3 for all stimuli. In a complex stimulus context the novelty P3 was reduced for novel stimuli, but also for standard and target stimuli. Our findings suggest that stimulus context sets a parameter that affects general novelty processing as reflected by the novelty P3. We propose that this parameter is derived from the observer's expectations about the stimuli that will be observed . Stimulus probability will change such expectations: Observers will pick up on the frequency with which certain categories of stimuli occur, altering expectations accordingly. This, we suggest, in turn affects novelty processing.

We are not the first to suggest that expectations affect the novelty P3. Cycowicz and Friedman (2007) found that the novelty P3 was reduced with repeated presentation for contextually novel stimuli that are familiar but novel in the experimental context (no such reduction was found for stimuli that possessed stimulus novelty). The reduction was only found when participants did not have a task concerning the contextually novel stimuli (the incidental condition; Cycowicz & Friedman, 2007). In conditions in which participants were explicitly told to memorize the novel events (the *intentional* condition) no reduction in novelty P3 amplitude was found with repeated presentation. The authors argued that the task of encoding novel stimuli into memory leads participants to expect the contextually novel stimuli, and that this reduced the orienting response to such an extent that the novelty P3 could not be further attenuated. They concluded that the novelty P3 is not only a function of the stimulus novelty, but also of the expectations of the participant (Cycowicz & Friedman, 2007). In our experiments, complex standard stimuli or frequent novels in our complex context conditions would have set participants to expect complex, novel stimuli. This could then reduce the attentional resources allocated to all stimuli, thus also to novels, resulting in a smaller novelty P3 in these conditions. Conversely, the novelty P3 could be the result of violated expectations: it could be elicited only when participants expect a simple stimulus, but see a complex one (as in the Normal condition). In addition, seeing an expected novel stimulus would require a smaller adjustment of expectancy, which is in line with our smaller P3b for novels in the Novels compared to the Normal condition, where the presentation of a novel could reflect the updating of expectations (Donchin & Coles, 1988).

The suggestion that deviance from either implicit or explicit expectations is a prerequisite for the generation of the novelty P3 is consistent with the evidence presented so far, but no study has as of yet independently manipulated expectations and looked at the effect on the novelty P3. It thus remains to be established that context affects the novelty P3 through the setting of expectations.

Conclusion

In sum, our findings suggest that the detection of novelty, indexed by the anterior N2, is a function of stimulus properties, and not overly influenced by context. In contrast, the orienting response as indexed by the novelty P3 is highly sensitive to stimulus context. In our experiments, complex novel stimuli only elicited a clear novelty P3 when they were both deviant and the stimulus context was simple. Our results indicate that both deviance from the context and low stimulus context complexity are required to elicit the novelty P3, and that stimulus novelty is no such requirement. In contrast, the anterior N2 to novels was not affected by deviance, suggesting it reflects a relatively automatic stimulus-driven process independent of stimulus context.

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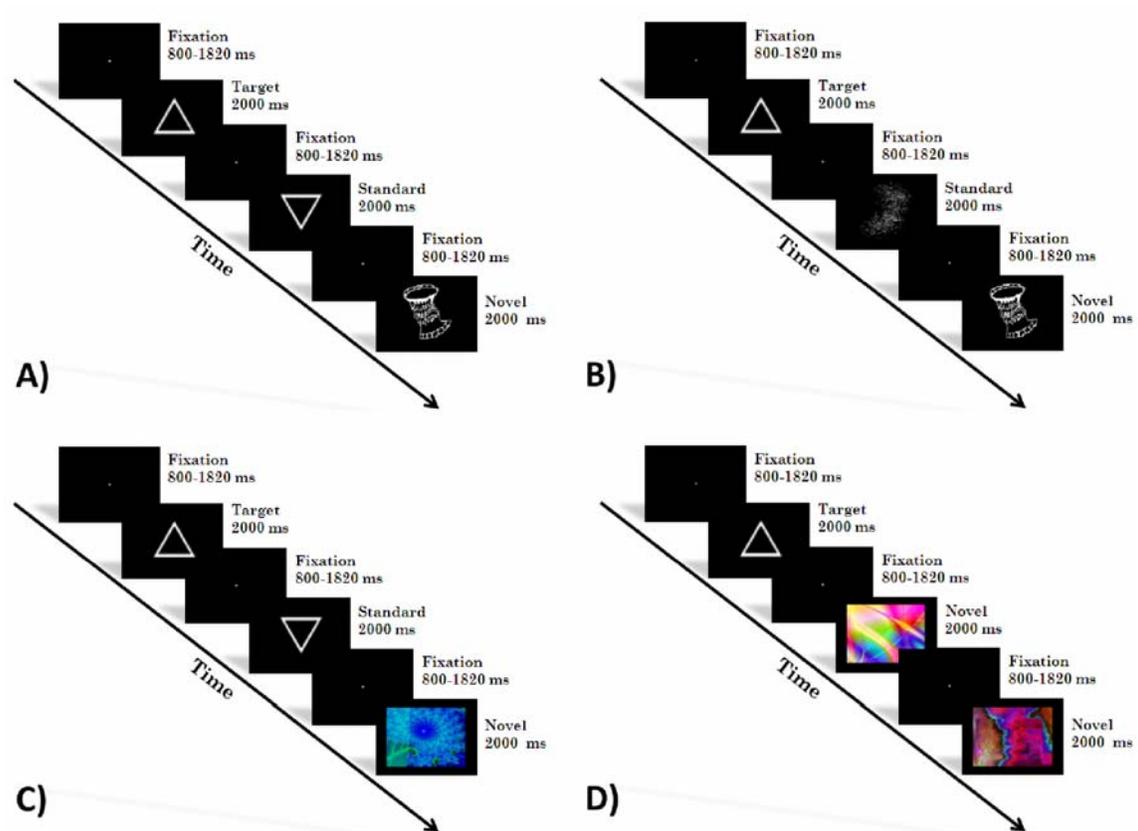
Figure 1. Example stimulus sequence of A) the Normal condition in Experiment 1; B) the Scrambled condition in Experiment 1; C) the Normal condition, with fractals as novels, in Experiment 2; D) the Novels condition in Experiment 2. Note, for demonstrational purposes the pictures are depicted larger relative to screen size than they were in the actual experiment. For actual stimulus sizes see the section Stimuli.
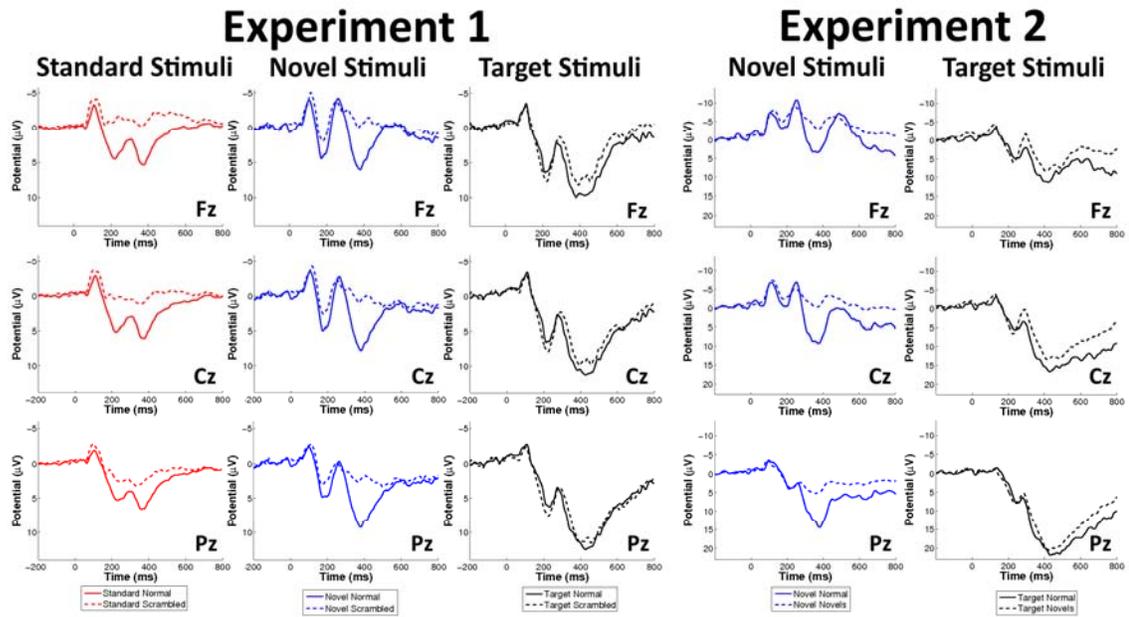
Figure 2. Grand average ERPs for the Normal and Scrambled condition or the Novels condition for A) Standard stimuli in Experiment 1; B) Novel stimuli in Experiment 1; C) Target stimuli in Experiment 1; D) Novel Stimuli in Experiment 2; E) Target stimuli in Experiment 2. Electrode locations are Fz, Cz and Pz.

Experiment 1

Experiment 2



Anterior N2   **Novelty P3**   **P3b**
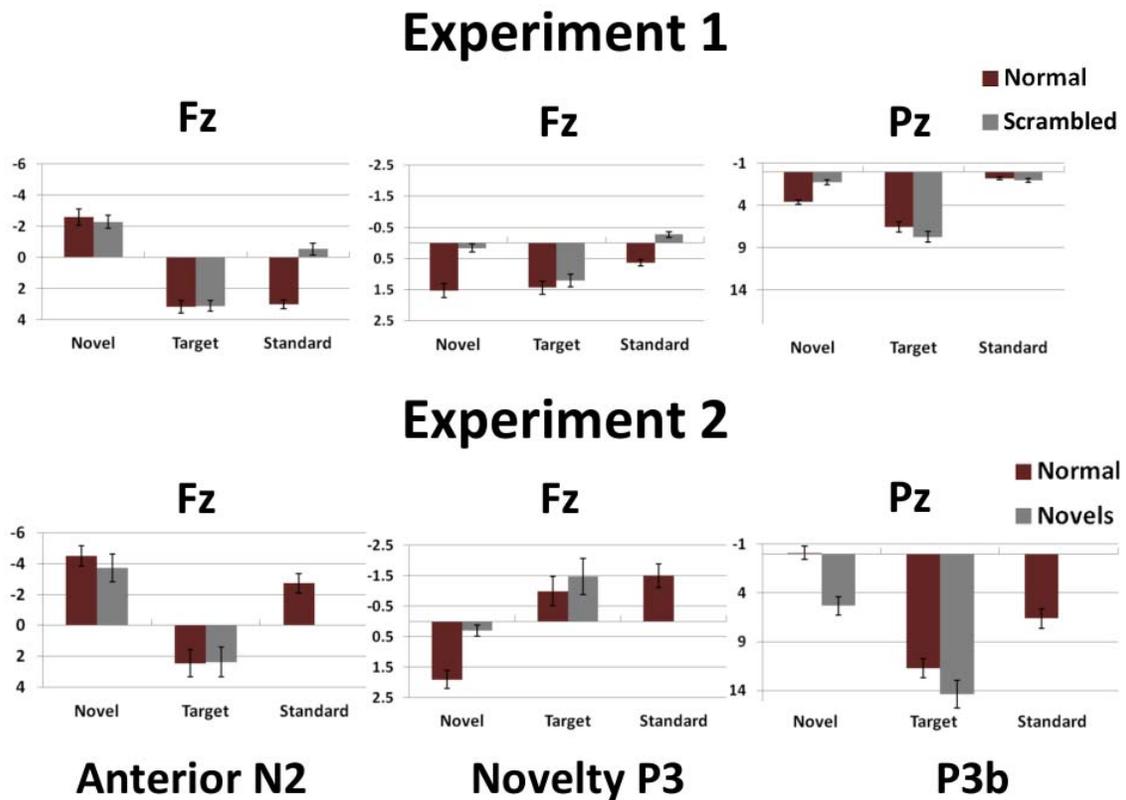
Figure 3. PCA factors (rescaled to microvolts) as subjected to the statistical analyses for the N2, novelty P3, and P3b components for all conditions. Note, electrode sites are arbitrary in temporospatial analyses, but for demonstrative purposes data for the typical peak electrode sites is depicted. Error bars reflect standard errors of the mean (SE).
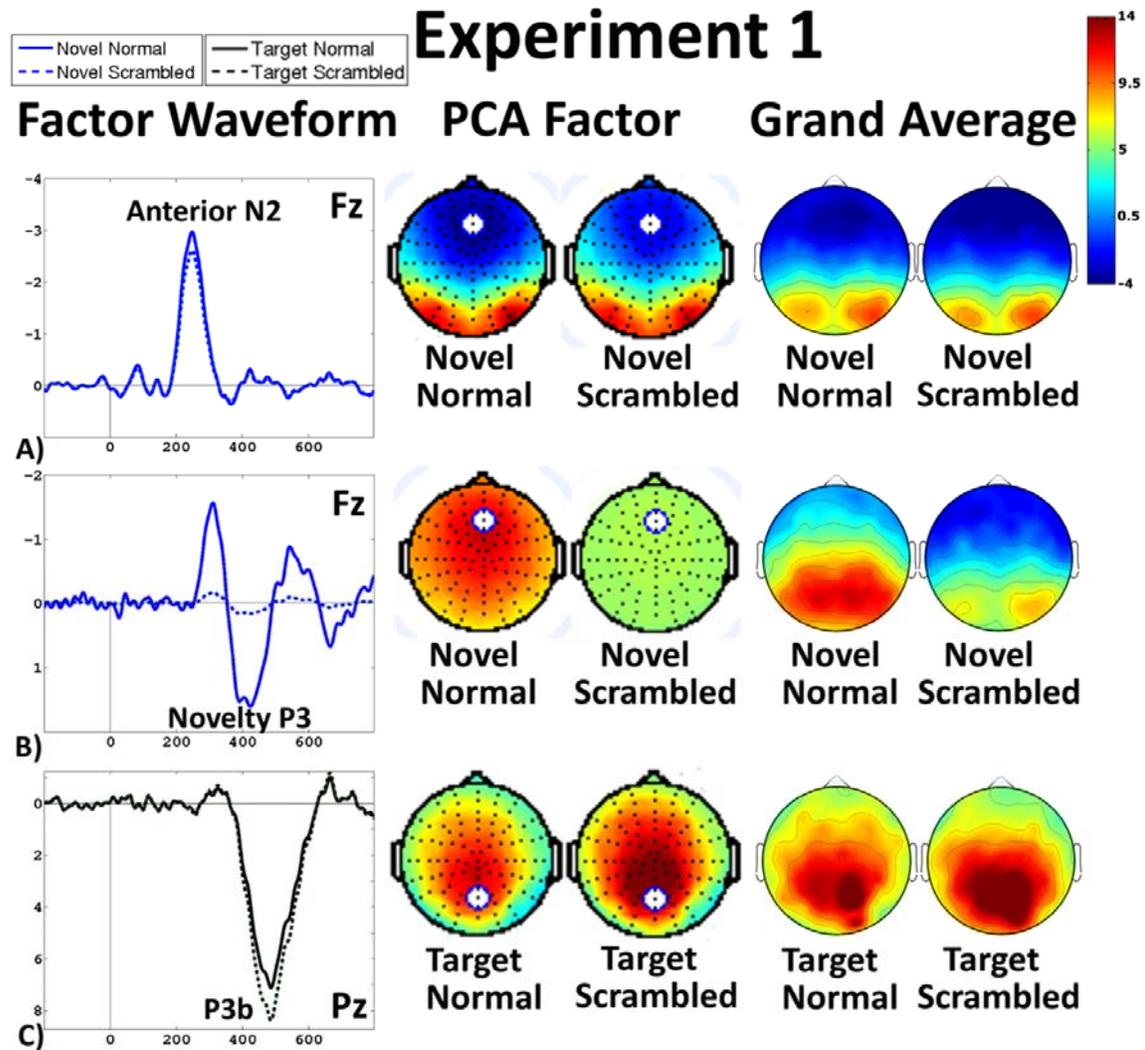
Figure 4. Temporospatial PCA factor waveforms, factor topoplots, and grand-average ERP topoplots for Experiment 1: A) Anterior N2; B) Novelty P3; C) P3b. Temporospatial PCA factor loadings were rescaled to microvolts and are depicted as waveforms (left panel), and as topoplots (middle panel) for the factor peak timepoint. For comparison grand-average ERP topoplots of the native data are shown (right panel). PCA factor topoplots are plotted on the same scale as the factor waveforms.
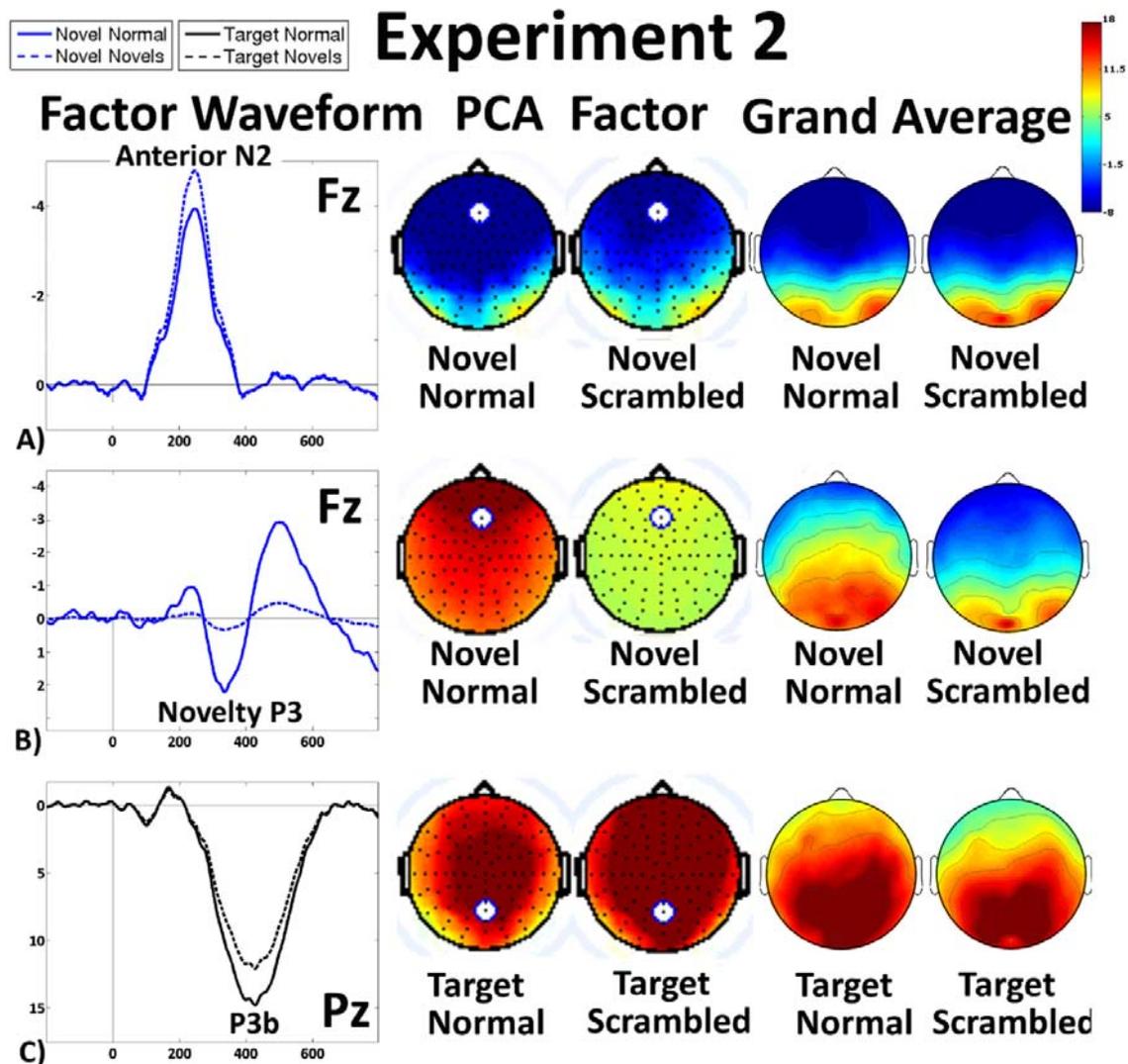
Figure 5. Temporospatial PCA factor waveforms, factor topoplots, and grand-average ERP topoplots for Experiment 2: A) Anterior N2; B) Novelty P3; C) P3b. Temporospatial PCA factors loadings were rescaled to microvolts and are depicted as waveforms (left panel), and as topoplots (middle panel) for the factor peak timepoint. For comparison grand-average ERP topoplots of the native data are shown (right panel). PCA factor topoplots are plotted on the same scale as the factor waveforms.
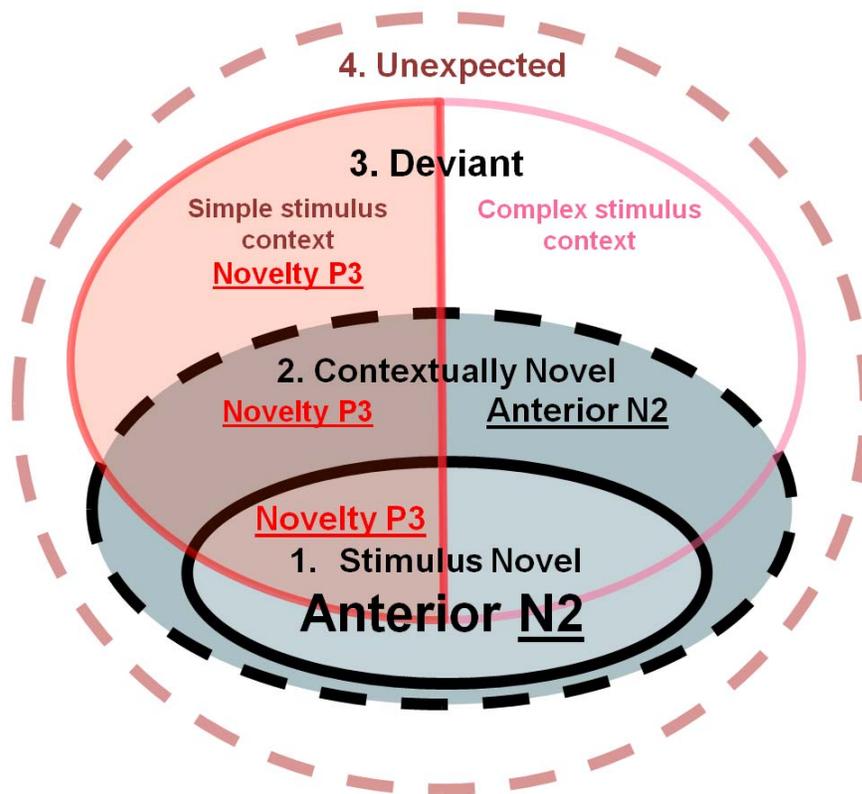
Figure 6. Venn diagram depicting the relation between different kinds of novelty, deviance from context, and expectation. Stimulus novelty is a subcategory of contextual novelty. Although novel stimuli often deviate from the context, this is not necessarily the case (see Experiment 2), nor are deviants necessarily novel. 'N2' and 'Novelty P3' indicate that this component is elicited by stimuli that fall within that particular part of the Venn diagram (see main text for justification). The anterior N2 is known to be elicited by novel stimuli, whereas the novelty P3 is elicited by deviant stimuli presented in a context consisting of mostly simple stimuli (indicated by "Simple stimulus context").