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Chapter 5. How directed attention affects the responses to novelty? An analysis of the novelty related ERPs in a context of variable allocation of attention.

Abstract

The brain responds strongly to novel stimuli, but there is little consensus about how this occurs. It has been suggested that novelty detection does not require attention, while other studies have shown that hat attention is essential in this process. In the present study we used a modified Von Restorff paradigm in which the attentional set was manipulated. Participants were asked to memorize words presented in a standard or novel fonts (in a within-subjects design), and to perform a recall task afterwards. EEG was recorded, and used to compute Evoked Response Potential components linked to novelty, commonly referred as the N2-P3 complex. We tested whether instructing participants to focus on novel font words would alter the amplitude of the N2-P3 complex, which would indicate a role for attention in novelty detection.

Our results confirm that the detection of novelty does not rely on attention, given that our manipulation did not change the amplitude of the early components N1 and P2. The expected N2 component was not elicited by our task, possibly because of the many repetitions of each color and font. Attention did affect later components in the P3 range, although this was not the case for a frontal component that may reflect the P3a.

Background

Novel stimuli are processed in different ways than familiar ones (Ranganath & Rainer, 2003). Intracranial recordings have shown that neurons in the medial temporal lobe respond more strongly when a stimulus is novel, than when this same stimulus has been presented several times (Halgren, Baudena, Clarke, Heit, Liegeois, et al., 1995; Halgren, Baudena, Clarke, Heit, Marinkovic, et al., 1995; Xiang & Brown, 1998). Outside of the cranium, stronger processing of novel stimuli is reflected in the N2 evoked-response potential (ERP) component, thought to reflect novelty detection (Daffner et al., 2000), and the P3a component, thought to reflect orienting towards these stimuli (Friedman et al., 2001).

As early as the 70’s it has been discussed how attention modulates such responses to novel stimuli (Johansson, 1970). Tiitinen and colleagues (1994) suggested that the process of novelty detection relies on two stages, and that the role of attention might be different in both. In the first stage, a deviant stimulus is detected automatically and a pre-attentively. This stage was indexed by the N2 and by Mismatch Negativity (MMN), and indeed the MMN occurs regardless of the direction of attention (Sussman, Winkler, & Wang, 2003). In a second stage the deviant stimulus attracts attention, which may or may not occur depending on attentional settings. This stage was index by the P3a or novelty P3 (Simons et al., 2001, indicate that Novelty P3 and P3a correspond to the same phenomenon, and are concepts interchangeable).Such a division was supported by a study by Tarbi and colleagues (2010) in which they presented participants with an oddball task while controlling the focus of attention. In the attend condition participants were required to respond to the novel stimuli by pressing a foot pedal. The same stimuli were presented in the ignore condition; however, now participants had to perform an n-back task on auditory stimuli presented in the interval in between visual stimuli (only a fixation cross was present). In the latter condition, participants could ignore the visual stimuli. The amplitude of the N2 amplitude was not modulated by the manipulation of attention, nor by the difficulty of the auditory task in the ignore condition. The subsequent P3a component, however, was modulated by these factors. The authors argued that attention is not required for the initial stages of novelty detection, but that it is required for the further processing of novelty indexed by the P3a. However, some studies involving the MMN component suggests that attention is actually also involved in the first stages of novelty detection. Yucel and colleagues (2005) showed that the complexity of a primary visual task modulates the amplitude of the MMN elicited by unattended novel and deviant sounds. Oades and Dittman-Balcar (1995) found that when tones were part of the task, the amplitude of the MMN component to novel and deviant sounds increases.

So far studies in attention and novelty detection have been restricted to a dual task approach, in which participants view or hear novel stimuli that they either attend to, or do not because they perform another task on stimuli presented in another modality. In all studies with this design, there is a confound in that not only the allocation of attention differs between conditions, but also the rate at which stimuli are presented (as extra stimuli are presented for the dual task, that are not present in the single task condition). This may be part of the reason for inconsistent results found so far.

Another way to manipulate attention is to make novels as a category either task-relevant or not. In that way, there is no division of attention over modalities. A suitable task for such a manipulation is the von Restorff task. In the 1930s, Hedwig von Restorff discovered that distinct, novel stimuli are better recalled than standard ones (Von Restorff, 1933). This effect has been replicated may times (for an overview see, Hunt & Lamb, 2001). More recent EEG studies replicated the behavioral effect, and found that the distinct stimuli in this paradigm elicit ERP components associated with novelty, such as the N2 and the P3a (Fabiani et al., 1990; Karis et al., 1984). These components, in particular the novelty-related P300 component, have sometimes been found to predict future recall specifically for novel stimuli (Wiswede et al., 2006). Sometimes this has been found to depend on the encoding strategy used (Fabiani, Karis, & Donchin, 1982), and in other studies the novelty components N2 and P3a elicited by the isolated items were predictive of future recall for all stimuli, and not just novels (Rangel-Gomez & Meeter, 2013).

The role of attention in the generation of the Von Restorff effect has already been investigated once. Johansson (1970) used character sequences to test his ‘Attention Hypothesis’, which stated that the Von Restorff effect is caused by the extra attention devoted to the novel items, relative to standard ones. He presented a series of letters with a single digit intermingled, and vice versa. Additionally, he manipulated the time of presentation of the visual stimuli and the presentation mode (successive versus simultaneous), thereby controlling the amount of attentional resources that could be allocated to the isolated, surprising digit or letter. His prediction was that the effect of isolates, meaning better remembering for this type of stimuli, would increase with longer presentation times and in simultaneous as compared to successive presentation. The data supported this, indicating that attention may influence the response of the brain to novel/isolated stimuli.

Our manipulation involved the usage of different instructions, in a within subjects design. It has been argued that the instructions and encoding strategy influence the interaction between the amplitude of the novelty ERPs and the encoding process. Fabiani and Donchin (1995) indicate that novels elicit higher amplitude on the P300 component than standards, and this effect depended on how they are encoded, in a physical (attention to the size) versus lexical (attention to the characters forming or not a word) decision task; with bigger effects for lexical than physical condition. The effect of instructions can be observed as early as the latency of the N1 component (Potts, Patel, & Azzam, 2004). If attention is a prerequisite for novelty detection and novelty processing, the novelty components N2 and P3a, and perhaps earlier components presumed to also be partially modulated by novelty, should be enhanced when attention is given to novels. Otherwise these components should be unaffected by our manipulation.

Methods

Participants.

Twenty-five volunteers from the student population of VU University Amsterdam were recruited for this study. Two participants were excluded due to technical problems at recording, and two others due to noise exceeding 20% of the trials. The final sample consisted of 21 participants (19 female, mean age 22, range 18-27). All gave informed consent and received either money (€ 10 per hour) or credits for participation. The study was approved by the ethics committee of VU University Amsterdam and performed in agreement with the Declaration of Helsinki.

EEG recordings.

Electroencephalograms were recorded with the aid of 64 active scalp electrodes using a BioSemi Active2 system (Biosemi, Amsterdam, The Netherlands). Electrodes were located according to the radial ABC system of BioSemi. Vertical and horizontal eye movements (VEOG and HEOG) were recorded. VEOG was obtained by the subtraction of the signal coming from electrodes placed below and above the right eye, HEOG was obtained by subtracting the signal from electrodes located on the outer canthus of each eye. Reference electrodes were located in the right and left mastoid bones. The sampling rate was set to 512 Hz.

EEG data analysis was conducted using the Matlab toolbox EEGlab (Delorme & Makeig, 2004) and custom-written scripts. EEG data were re-referenced to the average of the signal from the two mastoid bones electrodes, resampled to 500 Hz, and digitally filtered (0.05 - 30 hz). The data were epoched for the different conditions (novel and standard fonts, under attend to novel or attend to standard conditions). Epochs included 500 ms before and 1500 ms after the stimulus presentation. The baseline was defined as the 100 ms time window preceding the stimulus.

Independent Components Analysis (ICA) was applied on the epoched data, using binary infomax by Sigurd Enghoff, based on the Matlab version of Scott Makeig and collaborators (Makeig, Bell, Jung, & Sejnowski, 1996). Independent components accounting for blink artifacts were identified and removed from the data. Trials with muscle and movement artifacts were identified and removed from the data; the threshold for this rejection was defined as the signal with amplitude higher than 100 µV and lower than -100 µV. This procedure resulted in the rejection of approximately 5% of the trials. The decision about time windows of interest and electrode locations for the analysis was based on grand average waveforms for each condition.

Procedure and Stimuli.

The experiment consisted of 16 blocks. The blocks were equally divided over the two attentional conditions, attend-to-novels (ATN) and attend-to-standards (ATS). In both conditions, participants were asked to attend to all the words, but in the latter condition participants were informed that recall of only the standard font words would be tested, and in the former that recall of only the novel font words. Blocks belonging to the same condition were presented together. Which condition was presented first was pseudo-counterbalanced (since we had an uneven number of participants) per participant.

Each block included a study phase and a cued recall phase. During the study phase, participants were presented with a list of 40 concrete nouns, with length varying between 4 and 10 characters, selected from a pool constructed from the list provided by van Overschelde and colleagues (Van Overschelde et al., 2004) and complemented with an English dictionary. Words were subdivided over the 16 lists in such a way that list words belonged to different categories, and that there were no very obvious semantic associations between them.

Each trial started with the presentation of a fixation cross with a jittered duration ranging from 404 to 591 ms (mean, 489 ms; s.d., 58ms). Then a word was presented in the middle of as gray screen for 1000ms. Words were presented either in standard or in novel font. Standard font words had a font size of 19 dots, with black color and courier new as font type. Novel font words had a variable font size ranging from 12 to 30 dots (mean, 19; s.d., 5), a variable color (one of ten possible colors, with each color having a 60% probability of being repeated within a list) and variable font type (unique for each novel word within a list). These stimuli have previously been shown to elicit a von Restorff effect (Rangel-Gomez & Meeter, 2013). Participants were seated 80 cm from the screen (with size 21'), leading to the following visual angles: Standard words, 2.5 to 5 degrees, for novel words, 5.7 to 9.6 degrees (depending on the length of the words). The first six words of each list were always presented in standard font. Out of the remaining 34, a random 17 were presented in novel fonts and the remaining 17 in standard font. The order of the words and their assignment to condition, were randomized anew for each participant (two novel font words could thus follow one-another). See Figure 1.

After the study phase, participants were asked to recall 10 of the previously learned words. These were either a random selection from the 17 novel font words (in the attend-to-novel condition) or from the 23 standard font words (in the attend-to-standard condition). Participants were cued with the first two letters of each word and then had to complete that cue with a studied word (e.g., the "ne" had to be completed to "nectarine", if that was a studied word). The cues were all presented in the same format, which was the one used for the standard font words. The recall task for the last block included all the 40 words – thus, independent of condition both the novel and the standard words were tested.

EEG analysis.

The behavioral data was analyzed by simply comparing the performance on the eight blocks in the two attention conditions with each other. The electrophysiological data was analyzed by means of comparisons between novel and standard font words for both task conditions (attend-to-novel/ATN or attend-to-standard/ATS). For this part of the analysis we only used 34 trials per block, leaving out the first 6 trials of each block to assure that the standard font words were fully familiarized, and that the assignment to font was equally unpredictable for novel and standard font words.

We were also interested in the way the processing of one word affected processing of the subsequent one; therefore comparisons were also made between ERPs generated by novel font words preceded by a novel font word or a standard font word, and similarly for standard font words, for each task condition (ATN/ATS). The sequence of stimuli was added as a factor because it is known that changes in the inter stimulus interval (ISI) has effects on the amplitude of the novelty ERP components (Polich, 1987). It is therefore possible that these findings indicate that in a set of stimuli, sequentially presented, the preceding stimulus can affect the processing of the subsequent stimulus.

Principal component analysis (PCA) was applied to identify the time windows for the analysis, using the ERP PCA Toolbox (Dien, 2010a). The PCA was conducted in a two-step manner, applying first a temporal (Infomax) PCA, and then a spatial (Promax) PCA. As recommended by Dien (2010b), whom indicate that Promax generally produces cleaner separations, therefore should be applied first. Our analysis yielded 23 temporal factors, and five spatial factors. Only the combination of temporal and spatial factors that explained more than 1% of the variance of the signal were further analyzed. This criterion resulted in the selection of seven combinations of factors. The temporal factors had peaks in the following time points: 136 ms (TF(1)), 218 ms (TF(2)), 260 ms (TF(3)), and 450 ms (TF(4)). For the factors peaking at 218 ms and 450 ms, multiple spatial factors were chosen - three for the latter and two for the former.

Statistical analysis was performed on the factor scores converted into microvolt scaling. These scores are collapsed over location – electrode was therefore no factor in the analyses. Scores were subjected to a Repeated Measures (RM) ANOVA with three within-subjects factors: Attention (ATN/ATS), novelty (Novel/Standard-font-words), and sequence (Preceded-by-Novel/Preceded-by-Standard, depending on which stimulus was preceding the stimulus under study). Since performance in the memory task was low, there were too few correctly recalled trials to compare correct versus incorrect trials; therefore accuracy was not included as a factor in the EEG analysis. Greenhouse-Geisser correction was applied when the assumption of sphericity was violated (Greenhouse & Geisser, 1959).

Results

Behavioral results were analyzed separately for the first fifteen blocks, in which only attended words were tested (i.e., either novel or standard font words), and for the last block in which all words were tested. In the first 15 blocks cued recall was better for novel (mean, 27.3 %, s.d., 7.7 %) than for standard (mean, 21.4 %, s.d., 6.6 %) font words ($t_{20} = 2.94$, $p = 0.008$). However, for the very last block in which recall of all words was tested, there was no difference between novel (mean, 12.04 %, s.d., 7.8 %) and standard (mean, 12.22 %, s.d., 10.3 %) font words ($t_{20} = 0.06$, $p = 0.95$).

ERP waveforms for the novel and standard font words, depending on attentional conditions and the sequence of the presentation of the stimuli, can be seen in figure 1. The results of the RM ANOVAs, applied for each one of the seven combinations between temporal and spatial PCA components, are presented in Table 1.

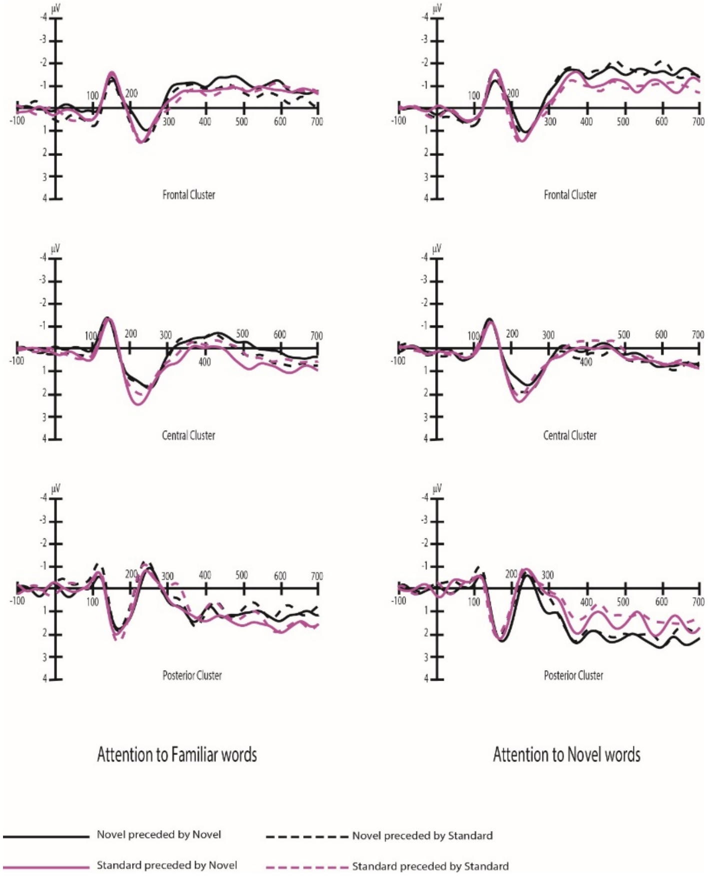

Figure 1. ERPs to the words during study. In the left panel, the attention-to-novels condition, and in the left panel the attention-to-standards. The continuous lines depict words preceded by novel font words, and the dotted lines the sequence preceded by standard font words. Magenta lines correspond to standard font words, and black lines to novel font words

Table 1

Results of the ANOVAs performed on the electrophysiological data. 'Attend' refers to whether participants were instructed to attend to standard font words (ATS) or to novel font words (ATN). 'Sequence' refers to whether the previous stimulus was a novel font word or standard font word. Rows that contain significant effects (p<0.05) are shaded. Temporal factors are noted by TF(xx) and Spatial factors are noted SF(xx), with the time point at which the component peaks.

PCA Comp/Effect	F	df	p
TF(1)SF(1) – 138 ms			
Novelty	4.49	1,20	0.047
Sequence	0.02	1,20	0.904
Attend	0.04	1,20	0.853
Novelty x Sequence	1.41	1,20	0.249
Novelty x Attend	1.14	1,20	0.298
Sequence x Attend	3.13	1,20	0.092
N x S x A	0.51	1,20	0.485
TF(2)SF(1) – 218 ms			
Novelty	10.51	1,20	0.005
Sequence	6.25	1,20	0.021
Attend	0.54	1,20	0.471
Novelty x Sequence	1.53	1,20	0.230
Novelty x Attend	0.45	1,20	0.510
Sequence x Attend	0.64	1,20	0.432
N x S x A	1.46	1,20	0.240
TF(2)SF(2) – 218 ms			
Novelty	82.06	1,20	< 0.001
Sequence	0.82	1,20	0.375
Attend	0.02	1,20	0.887
Novelty x Sequence	27.10	1,20	< 0.001
Novelty x Attend	0.54	1,20	0.473
Sequence x Attend	1.52	1,20	0.232
N x S x A	0.40	1,20	0.533
TF(3)SF(1) – 260 ms			
Novelty	1.68	1,20	0.210
Sequence	0.02	1,20	0.893
Attend	1.30	1,20	0.269
Novelty x Sequence	0.18	1,20	0.673
Novelty x Attend	0.07	1,20	0.788
Sequence x Attend	0.001	1,20	0.972
N x S x A	0.18	1,20	0.680
TF(4)SF(1) – 450 ms			
Novelty	10.71	1,20	0.004
Sequence	0.30	1,20	0.589
Attend	1.91	1,20	0.182
Novelty x Sequence	0.30	1,20	0.589
Novelty x Attend	1.44	1,20	0.244
Sequence x Attend	0.10	1,20	0.751
N x S x A	0.06	1,20	0.803

TF(4)SF(2) – 450 ms			
Novelty	8.06	1,20	0.010
Sequence	0.14	1,20	0.714
Attend	7.29	1,20	0.014
Novelty x Sequence	1.60	1,20	0.221
Novelty x Attend	10.46	1,20	0.004
Sequence x Attend	0.31	1,20	0.586
N x S x A	0.42	1,20	0.523
TF(4)SF(3) – 450 ms			
Novelty	0.11	1,20	0.742
Sequence	8.24	1,20	0.009
Attend	1.00	1,20	0.330
Novelty x Sequence	9.12	1,20	0.007
Novelty x Attend	18.77	1,20	< 0.001
Sequence x Attend	0.16	1,20	0.692
N x S x A	1.15	1,20	0.296

The first PCA component (peaking at 138 ms), with a timing and topography comparable with the N1 component (Vogel & Luck, 2000), showed a larger amplitude for standard font words than for novel font words. This was true regardless of attentional condition or the sequence of the stimuli. This resulted in a main effect of novelty; no other significant effects were obtained.

The second PCA component (peaking at 218 ms), with a timing and topography comparable with that of the P2 component (Crowley & Colrain, 2004), had two spatial components that explained more than 1% of the variance of the signal (see figure 3, for the topography of these components). The first spatial component, with a frontal distribution, showed a main effect of novelty and sequence. Standard font words elicited a higher amplitude than novel ones, and stimuli preceded by standard font words elicited a higher amplitude than those preceded by novel font words. There were no interactions among factors. The second spatial component, with central distribution, showed a main effect of novelty, with again higher amplitude for standard than for novel font words. Additionally, a significant interaction novelty x sequence was present. The preceding stimulus enhanced the response to the subsequent stimulus when it belonged to the opposite condition. Standard font words thus generated higher amplitude when they were preceded by novel font words, and Novel font words when they were preceded by standard font words.

The third PCA component (peaking at 260 ms) did not correspond to any of the commonly studied novelty ERP components, and did not show any statistically significant change in the signal.

The fourth PCA component (peaking at 450 ms), with a timing and topography corresponding to those of the P3b component (Polich, 2007), presented 3 out of 5 spatial components that explained more than 1% of the variance of the signal. The first spatial component, with positive central-posterior and negative frontal topography, showed a main effect of novelty, with higher amplitude for novel than for standard novel fonts. The second component, with a posterior topography, presented a main effect of novelty and attention, with larger amplitude for standard than for novel font words, and higher amplitude overall when attention was given to novel font words. Additionally, this spatial component presented a significant Attention x Novelty interaction. There was only a difference between standard and novel font words when attention was given to novel font words, with higher amplitude for novel font words. The third spatial component, with a central distribution, showed a main effect of sequence and a novelty x sequence interaction. Novel font words had higher amplitude when they were preceded by standard font words. A similar pattern was present for standard font words, higher amplitude when preceded by stimuli of the opposite condition. Additionally, an attention x novelty interaction was present. When attention was given to novel font words, stimuli of this type had higher amplitude. When attention was given to standard font words, amplitude was higher for these words.

Discussion

The present study aimed to investigate the effects of attention on the brain's responses to novelty. We hypothesized that if attention is required for novelty processing, our manipulation of the attentional set would modulate the amplitude of the N2 and P3a elicited by novel stimuli.

The data only partially supported the hypothesis of attention being required for the expression of novelty-ERP components. Unexpectedly, our novelty manipulation did not elicit an N2 component, nor was there a clear P3a. This component was modulated by attentional conditions. Interestingly, we also found novelty modulation of earlier components, namely the N1 and P2 components.

Indexes of earlier processing

Our study elicited novelty modulation of two ERP components that are usually related to discriminability of incoming stimuli, namely the N1 and P2. We did not find that attentional set affect the N1 component. In the visual modality this component has been related with the discrimination of stimuli presented at an attended location (Vogel & Luck, 2000). Since our manipulation did not change the location that participants had to attend, it is not surprising that it did not affect N1 size. However, the amplitude of the N1 component was modulated by physical features of the stimuli (either standard or novel fonts), which is coherent with the idea of this component reflects stimulus discrimination.

A second component associated with early processing of visual stimuli is the P2. This component has been found to be elicited by deviant non-target stimuli, often but not necessarily preceding the P3a component. It is thought to reflect a second stage of discrimination that informs the need of more or less processing resources (Crowley & Colrain, 2004). This idea is in line with our results. We found that this component is modulated by the physical features of the stimuli and by their deviation from the previous stimulus, but not by our manipulation of attention. This suggests that this component was generated relatively automatically.

A surprising finding was the absence of a novelty-N2 component. Previous studies from our group have found this component to be consistently elicited by a similar task (Rangel-Gomez et al., 2013; Rangel-Gomez & Meeter, 2013). However, our current task differed from that used in previous studies in ways that may explain the absence of an N2 component. Whereas in our previous studies novel font words were relatively rare and each font was used just once, here fully 50% of words in the latter part of the lists was presented in novel fonts. Moreover, since each font and color was used in each list, they were repeated 16 times over the course of the experiment. It may be that participants in our study habituated to the fonts and colors, and that this resulted in no N2 being apparent over the whole experiment.

The P3b component, topographically distinguishable sources

We found three independent spatial factors occurring in the range of the P3b component, which were modulated differently by our attentional manipulation. The only two spatial factors that showed an attentional modulation were posterior (main effect) and central (interaction novelty x attention), concordant with the characteristics of the P3b component (Polich, 2007). However, the third part, with a topography consistent with that of a P3a component was not modulated by the allocation of attention. If this was a P3a – even though it’s timing was more in line with that of a P3b- these results would be in opposition to what has been found before (Schomaker & Meeter, 2014b; Tarbi et al., 2010).

Conclusions

Our results show that the attentional set has different effects of different steps of the processing of novel stimuli. Early ERP components affected by novelty, most notably the P2, were not modulated by the attentional manipulation, which is consistent with the view that early neural responses to novelty are generated automatically and independent of attention (Sussman et al., 2003; Tarbi et al., 2010; Tiitinen et al., 1994). Later processing, in the P3 range, was affected by the attentional set. Surprisingly, was not the case for a frontal spatial factor in the P3 range, which was not affected by our attentional manipulation. If that factor corresponds to the P3a, our results would challenge the idea that P3a is task-dependent.