

The N2pc component as an indicator of attentional selectivity

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Abstract

Event-related potentials (ERPs) were recorded during visual discrimination tasks in which stimulus arrays were presented that contained one lateral target and 3 (experiment 1) or one (experiments 2 and 3) non-targets. In experiments 1 and 2, targets differed from non-targets with respect to their form or their color. In experiment 3, word pairs were presented, with targets differing from non-targets with respect to their content. Subjects were required to respond to the identity of the target. In all experiments, an enhanced negativity was elicited at posterior electrodes contralateral to the location of the target. In the form discrimination tasks, this effect was present in the N1, N2, and P3 time intervals. In the color discrimination tasks, it was confined to the N2 time range. In the word discrimination task (experiment 3), this effect could only be observed over the left posterior hemisphere. It is argued that these lateralized negativities reflect the N2pc component that is assumed to indicate attentional filtering processes during visual search tasks. The present results extend this assumption by showing that this component is also elicited when targets are presented together with just one non-target item. It is argued that the N2pc may reflect the attentional selection of task-relevant stimuli.

Keywords: Event-related potentials; Visuo-spatial attention; Visual search; Pop-out; N2

1. Introduction

The role of visual attention in perceptual processing is usually studied in situations where single discrete stimuli are presented at different locations and subjects are instructed to selectively attend to a prespecified location where stimuli are most likely to occur. The detection of targets was found to be faster and more accurate when targets were presented at attended as compared to unattended locations (cf. Posner et al., 1980; Downing, 1988). However, attention may also play a role in a situation where a target has to be detected and identified within an array of multiple distracting items. In such visual search tasks, target detection is found to be fast and effortless when the target is characterized by a feature that is missing from the distracting items. In this situation, the target 'pops out' from the background formed by the distractors. In contrast, when the target is defined by a conjunction of features, detection performance is slower and seems to be due to a serial search of the display, since RT increased with the number of distractors (cf., Treisman and Gelade,

1980). Treisman and co-workers (Treisman and Gelade, 1980; Treisman and Souther, 1985) have argued that simple features may be detected in parallel without the intervention of attention, but that attention is needed for the detection of conjunction features. However, since a number of empirical findings did not fit with this proposal (cf. Wolfe et al., 1989), recent models of visual search assume that visual attention may be necessary both for the detection of simple features as well as for feature conjunctions (cf. Treisman and Sato, 1990).

If visual attention plays a role in the detection of targets in visual search tasks, this may also be reflected in systematic modulations of event-related brain potentials (ERPs). Recently, an ERP component has been described that seems to be specifically related to the detection of targets in this type of task. This component has been termed N2pc, as it can be observed in the N2 latency range at posterior electrodes contralateral to the position of the target. Luck and Hillyard (1994a) have shown that this component is elicited when a target is characterized by a single feature that is absent in all distractors and thus 'pops out' of the stimulus array. They estimated the locus of the generator processes responsible for the N2pc with

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the help of current source density analyses. The CSD focus of the N2pc was found to be above lateral striate or extrastriate cortex, that is, near to the CSD focus of the sensory-evoked P1 component. This makes it likely that the generator is located in the occipital lobe near to the primary visual cortex. According to Luck and Hillyard (1994a), the N2pc may reflect the selective activity of striate or extrastriate cortex that is under the control of feedback from higher areas.

The N2pc is not only elicited by pop-out items, but also by targets that have to be detected on the basis of conjunctive features (cf. Luck et al., 1993). This finding suggests that common processes may be operative in visual search both for simple and conjunctive feature detection. It is, however, unclear how the process that is reflected by the N2pc component is to be characterized in functional terms. In a study by Luck and Hillyard (1994b), the N2pc was elicited also by non-target stimuli that closely resembled the target, but not by dissimilar non-targets. No N2pc could be observed in the absence of distracting items or in a situation where all stimuli in an array were identical. From this the authors concluded that the N2pc component indicates the suppression of irrelevant or conflicting information during visual search. Alternatively, this component may also be regarded as reflecting the attentional selection of target stimuli. Such a selection could either be stimulus-driven, with the target attracting attention to its location, or due to top-down processes that result in a shift of attention to stimuli possessing relevant features.

The present experiments were conducted to further investigate the processes underlying the N2pc component. Two specific questions were raised. Firstly, is the N2pc restricted to visual search tasks, that is, to situations where targets are presented in an array consisting of numerous distracting items, or can this component also be observed when only very few distractors are presented simultaneously with the target? If the N2pc is specifically related to the suppression of conflicting stimuli, one would expect to find direct relationships between the number of distractors and the degree to which the N2pc component is elicited. If it primarily reflects the selection of task-relevant stimuli, however, it may be present in visual search tasks where the target is presented together with numerous distractors as well as in situations where only a single distracting stimulus is presented together with the target. In the present experiments, lateralized target stimuli were presented together with 3 distractors (experiment 1) or with just one distracting item (experiments 2 and 3) in order to find out whether a posterior negativity was elicited contralateral to the location of the target under these circumstances.

Secondly, if the N2pc is regarded as an index for the attentional selection of target stimuli, the question remains to be answered whether this selection is primarily due to stimulus-driven processes or guided by top-down influences. On the most basic level, it is possible that single

discontinuities in a visual array attract attention automatically and therefore elicit an N2pc. Evidence for this comes from the study by Luck and Hillyard (1994a), who observed an N2pc to pop-out items even when these items were non-targets, although this effect was considerably smaller as compared to the situation where the pop-out served as target. However, the fact that the N2pc is not exclusively elicited by pop-out stimuli, but also by conjunctive target features, makes the assumption that the N2pc solely reflects the results of a stimulus-driven attentional capture rather unlikely. Alternatively, attentional selection may be mediated by top-down processes directing attention to stimuli possessing relevant features. It is unclear, however, whether these processes are restricted to simple, physical target features like form, color or orientation, or whether more abstract discriminating features can also be used to elicit such a process. The present experiments investigated this issue by varying the complexity of the features upon which target detection was based. In experiments 1 and 2, targets and distractors differed with respect to one critical physical feature (either color or form). In experiment 3, words were used as stimuli and the discrimination between target and distractor required the semantic analysis of these words. If an N2pc is elicited in the latter condition, this would indicate that even abstract, semantic features of stimuli may be used to guide attention to task-relevant items.

2. Experiment 1

The aim of experiment 1 was to determine whether an N2pc can be obtained in a situation where a lateralized target stimulus is presented together with only 3 distracting items that are presented at a considerable distance from the target. In experiment 1a, target and distractors differed with respect to their form, while in experiment 1b, target and distractors were of different color.

2.1. Methods

2.1.1. Subjects

Ten paid volunteers (3 female), aged 22–35 years (mean age: 25.9 years) participated in the experiment. All subjects were right-handed and had normal or corrected-to-normal vision.

2.1.2. Stimuli, apparatus and procedure

Subjects were seated in a dimly lit, electrically shielded and sound attenuated cabin, with response buttons under their left and right hands. A computer screen was placed 110 cm in front of the subject's eyes and positioned so that the fixation point was in the center of the subject's horizontal straight-ahead line of sight. In each trial, an array of four stimuli was presented for 150 ms, with stimuli above and below and left and right of the fixation cross. The horizontal or vertical distance of each stimulus from

the fixation cross was 3.3°, and each stimulus subtended a visual angle of about 0.8°. In half of the experimental blocks, a letter stimulus (M or W) was presented together with 3 distractors (an arrangement of two long and two short vertical bars). In the other experimental half, one square in a relevant color (blue or green) was presented together with 3 distractors (yellow squares). In Fig. 1, examples of these different stimulus arrays are displayed. The interval between the offset of this stimulus array and the onset of the next array was 2 s.

The experiment consisted of 12 experimental blocks. Each block consisted of 64 trials and had a duration of approximately 2.5 min. In 6 experimental blocks (form discrimination task), letter stimuli served as target stimuli, while in the other 6 blocks (color discrimination task), targets were defined with respect to their color. The order in which these two experimental tasks were delivered was balanced across subjects. In the form discrimination task, left- or right-hand button presses were required to the target stimuli M and W. For half of the subjects, a left-hand response was required to the letter M and a right response to the letter W, while for the other half, these response assignments were reversed. In the color discrimination task, left- and right-hand button presses were required to blue and green squares. For half of the subjects, a left response was required to the green square and a right response to the blue square, while for the other half, these response assignments were reversed. In either case, target stimuli appeared with equal probability and in random order in one of the four possible locations (top, bottom, left, and right), resulting in a total of 8 trials per block for each combination of target type and target location. Subjects were instructed to respond as quickly and accurately as possible and to maintain central eye fixation during the trials. To make subjects familiar with these specific task requirements, several training blocks were run at the beginning of the experiment.

2.1.3. Recording and data analysis

EEG was recorded with Ag-AgCl electrodes from Fz, C₃, Cz, C₄, Pz (according to the 10–20 system), and from OL and OR (located halfway between O₁ and T₅, and O₂ and T₆, respectively). All electrodes were referenced to the right earlobe. Horizontal EOG was recorded bipolarly from electrodes at the outer canthi of both eyes, vertical EOG was recorded from electrodes above and beside the right eye. Electrode impedance was kept below 5 kΩ. The amplifier bandpass was 0.10–40 Hz. EEG and EOG were sampled with a digitization rate of 200 Hz, and stored on disk. Reaction times were recorded for each trial.

EEG and EOG were epoched off-line into periods of 700 ms, starting 100 ms prior to the onset of the letter stimulus, and ending 600 ms after letter onset. Trials with eyeblinks (VEOG amplitude exceeding $\pm 60 \mu\text{V}$), horizontal eye movements (HEOG amplitude exceeding $\pm 25 \mu\text{V}$), and response errors were excluded from analysis. In

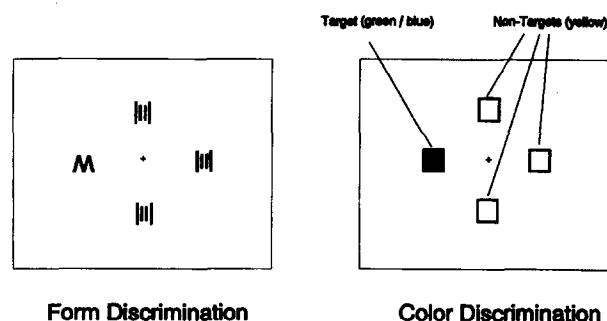


Fig. 1. Examples of stimulus arrays presented in the form discrimination task (left side) and in the color discrimination task (right side) of experiment 1. In the form discrimination task, the letters M and W served as targets, and 3 identical bar configurations as non-targets. In the color discrimination task, the target was a green or blue square that was presented together with 3 yellow non-target squares.

order to identify subjects with small but systematic eye deviations toward the target position that were not detected by the HEOG artifact rejection procedure, the computer-averaged horizontal EOGs in response to stimulus arrays containing targets on the left or on the right side were scored for systematic deviations of eye position toward the target position separately for each subject. A maximal residual EOG deviation exceeding $\pm 2 \mu\text{V}$ would have led to the disqualification of the subject. However, all EOG deviations were below this criterion. EEG was averaged separately for both experimental tasks (form and color discrimination) for all combinations of target location (top, bottom, left, or right) and target identity (M or W for form discrimination; blue or green for color discrimination), resulting in 8 average waveforms for each subject and electrode site. All measures were taken relative to the mean voltage of the 100 ms interval preceding the onset of the stimulus array.

Separate analyses were conducted for stimulus arrays containing a target at the left and right position and for arrays containing a target and the top or bottom position. Only the ERP modulations found at lateral occipital electrodes OL and OR will be reported. Mean ERP amplitudes were determined within the following post-stimulus time windows: 100–140 ms (P1), 140–200 ms (N1), and 220–300 ms (N2). Additionally, P3 amplitude was determined as the maximum positive voltage between 350 and 600 ms post-stimulus. The effects of experimental variables on these ERP amplitude measures were determined by conducting repeated measures analyses of variance for the factors: experimental task (form versus color discrimination), target contralaterality (target ipsi- versus contralaterally to the location of the electrode), electrode location (left versus right), and S-R compatibility (response required ipsi- versus contralateral to the position of the target). Additionally, separate ANOVAs were conducted for both task conditions, thus omitting the factor experimental task. To test whether target location yielded a systematic main effect, the ERPs elicited by arrays containing

left-side targets were compared to the ERPs elicited by right-target arrays with the help of paired *t* tests.

For the RT data, paired *t* tests were used to determine separately for both experimental tasks whether S-R compatibility had an effect on RTs to lateralized targets, and whether the RTs for top and bottom targets differed from the RTs to horizontally lateralized targets.

2.2. Results

2.2.1. Behavioral performance

In the form discrimination task, spatially compatible responses to left or right targets were significantly faster than incompatible responses (550 ms versus 563 ms; $t(9) = 2.31$; $P < 0.046$). The RTs to arrays containing targets in the top or bottom position were 572 ms and 582 ms, respectively. Additional *t* tests revealed that this difference was not significant, but that the RTs to these vertically lateralized targets were significantly slower than the RTs to horizontally lateralized targets. In the color discrimination task, spatially compatible responses to left or right targets were again significantly faster than incompatible responses (467 ms versus 489 ms; $t(9) = 4.10$; $P < 0.003$). When targets were presented in the top or bottom position, RT was 481 ms in either case. This was significantly slower than the RT to compatible targets, but did not differ significantly from the incompatible target RT.

2.2.2. ERP effects

For stimulus arrays containing targets at the left or right position, negative enhancements at occipital electrodes contralateral to the target location were clearly present in the N2 time range for both experimental tasks (cf. Fig. 2). This was reflected in a highly significant effect of contralaterality on N2 mean amplitude both for the form discrimination task ($F(1,9) = 29.53$; $P < 0.001$) and the color discrimination task ($F(1,9) = 20.40$; $P < 0.001$). In the overall ANOVA where both task conditions were included, a significant effect of contralaterality ($F(1,9) = 36.73$; $P < 0.001$) was accompanied by a significant interaction between contralaterality and experimental task ($F(1,9) = 7.42$; $P < 0.023$), reflecting the fact that the N2pc was larger in the form discrimination as compared to the color discrimination task. In the form discrimination task, contralaterality affected ERP amplitudes also in the N1 and P3 time range. An enhanced N1 was present at occipital electrodes contralateral to the location of the target (cf. Fig. 2). Although this effect was very small (about 0.35 μV), it was significant ($F(1,9) = 8.70$; $P < 0.016$). No such effect could be observed for the color discrimination task. Additionally, an enhanced P3 amplitude was present at ipsilateral as compared to contralateral electrodes in the form discrimination task, and was reflected in an effect of contralaterality on P3 amplitude ($F(1,9) = 7.52$; $P < 0.023$). Again,

this effect was absent in the color discrimination task.

For the stimulus arrays containing a target at the top or bottom position, a significant main effect of target location was found in the N2 time range ($F(1,9) = 9.41$; $P < 0.013$). Further analyses revealed an enhanced N2 elicited by stimulus arrays containing targets in the bottom position as compared to arrays containing targets at the top. However, no interactions between target location and electrode location were found at electrodes OL and OR for any time range, indicating that target location did not affect the ERPs at OL and at OR in a differential way.

2.3. Discussion

Experiment 1 demonstrated that an N2pc can be obtained in a situation where only very few (3) distractors are presented together with a target stimulus at a considerable horizontal and vertical distance. This shows that this electrophysiological indicator of visual-spatial attention is not restricted to visual search tasks where numerous distractors are presented together with the target, when attentional selection is likely to proceed through the selective inhibition of nearby conflicting distractors. However, in the present experiment, the target was defined by a distinctive feature that was missing from the 3 distractors, and is thus likely to 'pop out' from the background. It is therefore possible that the N2pc found in the present experiment reflects the detection of a lateralized pop-out target stimulus and thus may be comparable to the target pop-out effects reported by Luck and Hillyard (1994a) in a visual search task. In the next two experiments, the number of distracting stimuli will be reduced to just one, thereby excluding the possibility of target pop-out.

Another finding of the present experiment was that the N2pc component was significantly larger in the form discrimination task than in the color discrimination task. Furthermore, in the form discrimination task the effect of contralaterality was not confined to the N2 time range, but was also present in the N1 and P3 time intervals. This was not the case for the color discrimination task. In the former case, lateralized targets seemed to have elicited a longer lasting enhanced negativity at contralateral occipital electrodes that started in the N1 time range, became maximal in the N2 time window and may also have been responsible for a P3 amplitude reduction at contralateral relative to ipsilateral sites. In the color discrimination task,

¹ A surprising finding was that in the form discrimination task, P1 was significantly enhanced for stimulus arrays containing targets on the right side as compared to left-side targets ($t(9) = 4.78$; $P < 0.001$; cf. Fig. 2). This is hard to explain, since left and right targets were identical and equidistant from the central fixation cross. However, there was no interaction between this effect and other relevant experimental variables, and this effect could not be replicated in experiments 2 and 3.

this effect seemed to be restricted to the N2 time interval. What factors may be responsible for this difference? The fact that RT was about 90 ms faster for color as compared to form discrimination indicates that color discrimination was somewhat easier than the form discrimination task. This may be due either to the fact that target and distractors were harder to distinguish in the form discrimination condition, or to the fact that the discrimination between the two targets requiring different responses (M and W) was more difficult in this task. These two alternatives will be investigated further in the next experiment. In either case, the requirement for attentional selectivity may have been more pronounced in the form discrimination task, resulting in an enhanced N2pc and a longer-lasting contralateral negativity.

3. Experiment 2

In the first experiment, stimulus arrays consisting of a lateral target stimulus and 3 distractors yielded an N2pc component both for the form discrimination and the color discrimination task. In the next experiment, a target and a single distracting item were presented to the left or right of fixation. Again, targets and distractors differed either with respect to their form or their color. In this situation, there is no uniform background allowing a single target stimulus to pop out. Additionally, the possibility of interference of target processing due to competing distractors should be maximally reduced. If N2pc effects comparable to those found in experiment 1 are elicited under these conditions, this would suggest that the N2pc primarily reflects the selection of target stimuli and not the suppression of irrelevant distractors.

3.1. Methods

3.1.1. Subjects

Eleven paid volunteers participated in this experiment. One of them had to be excluded due to systematic HEOG deviations indicating a tendency to move the eyes to the target location. Thus, 10 subjects (4 female), aged 23–35 years (mean age 28.6 years) participated in the experiment. All subjects were right-handed and had normal or corrected-to-normal vision.

3.1.2. Stimuli, apparatus, and procedure

Stimuli and apparatus were identical to experiment 1, except that each stimulus array consisted of only two instead of 4 items. These items were presented to left and right of fixation at a horizontal distance of 3.3°. The stimulus arrays could either consist of a target and a distractor (distractor arrays) or of two identical target stimuli (target-only arrays). In the case of distractor arrays, the two targets (M and W for form discrimination, green and blue squares for color discrimination) could either appear at the left or right side, with the distracting item (the ver-

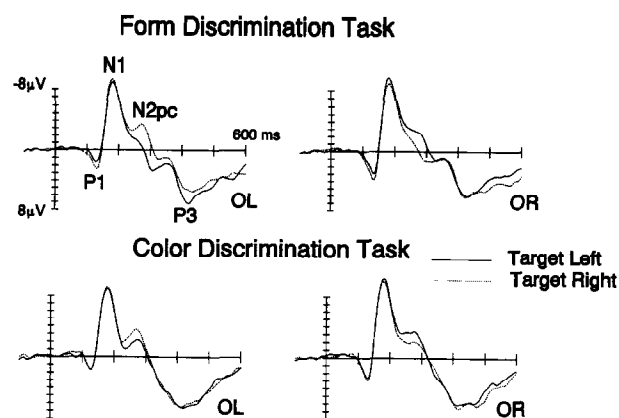


Fig. 2. Grand-averaged ERPs elicited in experiment 1 by stimulus arrays that contained a target on the left side (straight lines) or on the right side (dashed lines) at lateral occipital electrodes OL and OR. Top row, ERPs elicited in the form discrimination task. Bottom row, ERPs elicited in the color discrimination task. The N2pc component is visible as an enhanced negativity in the N2 time range elicited by stimulus arrays containing a target in the visual field contralateral to the electrode location.

tical bars or the yellow square) located at the contralateral position, resulting in four different distractor arrays.

Again, the experiment consisted of 12 experimental blocks, with 6 blocks where a form discrimination was required, and 6 blocks where targets were characterized by their color. A block consisted of 66 trials. The 6 different array types (4 distractor arrays and two target-only arrays) were presented in random order and with equal probability, that is, in 11 trials per block. Subjects were instructed to react in response to a target regardless of whether it was presented together with a distractor or in a target-only array. In all other respects, the procedure was identical to experiment 1.

3.1.3. Recording and data analysis

In addition to the electrodes used in experiment 1, EEG was also recorded from PL and PR (located halfway between Pz and the ear channels). In all other respects, the recording procedure was identical to experiment 1.

Epoching, artifact rejection, averaging and statistical analyses of ERP amplitude measurements obtained within the different time windows were the same as in experiment 1. Only the ERPs elicited by distractor arrays were further analyzed. In addition to OL and OR, analyses were also conducted for the ERP waveforms recorded at PL and PR.

For the RT analysis, data from both the distractor arrays and the target-only arrays were analyzed. Paired *t* tests were used to test whether the RT latencies for the different array types and task conditions were significantly different.

3.2. Results

3.2.1. Behavioral performance

In the form discrimination task, spatially compatible responses to left or right targets in distractor arrays were

significantly faster than incompatible responses (498 ms versus 516 ms; $t(9) = 2.75$, $P < 0.022$). The RTs to target-only arrays (475 ms) were significantly faster than for both compatible and incompatible distractor arrays. Analogous results were obtained for the color discrimination task: spatially compatible responses to lateralized targets in distractor arrays were faster than incompatible responses (458 ms versus 478 ms; $t(9) = 2.83$, $P < 0.020$), and responses to target-only trials were even faster (445 ms). An additional analysis was conducted to test whether the RT difference for target-only trials between the two task conditions (475 ms versus 445 ms) was significant. This turned out to be the case ($t(9) = 3.35$; $P < 0.009$).

3.2.2. ERP effects

Fig. 3 shows the ERP waveforms elicited by distractor arrays at lateral parietal and occipital electrodes ipsi- and contralateral to the side of the target stimulus. Again, an N2pc was elicited in both task conditions. This was reflected in highly significant effects of contralaterality in the N2 time range at occipital ($F(1,9) = 57.98$; $P < 0.001$) and parietal electrodes ($F(1,9) = 42.05$; $P < 0.001$). Moreover, interactions between contralaterality and task condition were obtained ($F(1,9) = 37.49$, $P < 0.001$, and $F(1,9) = 15.48$, $P < 0.003$ at occipital and parietal sites, respectively), indicating that the N2pc was again larger for the form discrimination task than for the color discrimination task. Further ANOVAs conducted separately for the two task conditions revealed significant effects of contralaterality both for the form discrimination task ($F(1,9) = 57.10$, $P < 0.001$, and $F(1,9) = 45.73$, $P < 0.001$ at occipital and parietal sites, respectively) as well as for the color discrimination task ($F(1,9) = 17.48$,

$P < 0.002$, and $F(1,9) = 11.02$, $P < 0.009$ at occipital and parietal sites, respectively).

Similar to experiment 1, a N1 enhancement at electrodes contralateral to the location of the target in the form discrimination task at occipital as well as at parietal sites, was reflected in significant effects of contralaterality ($F(1,9) = 27.71$, $P < 0.001$, and $F(1,9) = 8.08$, $P < 0.019$, respectively). In addition, an effect of contralaterality was also present in the P3 interval, with enhanced ipsilateral P3 amplitudes at occipital sites ($F(1,9) = 6.14$; $P < 0.035$). No such effects were present in the color discrimination task. P1 amplitude was not influenced by the experimental manipulations in either task condition.

3.3. Discussion

This experiment has shown that an N2pc component can be obtained in a situation where a lateral target stimulus is presented together with a single distracting stimulus, and these stimuli are presented in opposite visual hemifields with a lateral distance of about 7° . In this situation, no target pop-out is elicited, indicating that the N2pc is not confined to conditions where single stimuli differ from a homogeneous background with respect to a single critical feature. Moreover, the N2pc was present although the interference caused by distracting items was minimized in this situation as compared to usual visual search tasks. This may indicate that the N2pc is not directly related to the inhibition of surrounding distractors, but rather to the selection of task-relevant stimuli. As there was no target pop-out in the present experiment, the hypothesis may be rejected that the N2pc is primarily caused by a stimulus-driven capture of attention by a feature deviating from a uniform background. It is therefore more likely that this component reflects the allocation of attention to targets that is guided by a top-down mechanism sensitive to the presence of task-relevant features. This issue will be further explored in experiment 3.

The present experiment confirmed the existence of quantitatively different contralaterality effects for form and for color discrimination that had already been observed in experiment 1. The N2pc was again found to be significantly larger for the form discrimination task, and additional effects of contralaterality were present in the N1 and P3 time windows for the form, but not for the color discrimination task. Two explanations were put forward to account for these differences: either target and distractors are harder to distinguish in the form discrimination task, or discriminating between the two target stimuli is more difficult in the form (M versus W) than in the color discrimination task (green versus blue). Direct evidence in favor of the latter explanation comes from the RT data obtained in the target-only trials: responses to arrays containing two identical letter stimuli were 30 ms slower than responses to arrays containing two identically colored squares. Since no

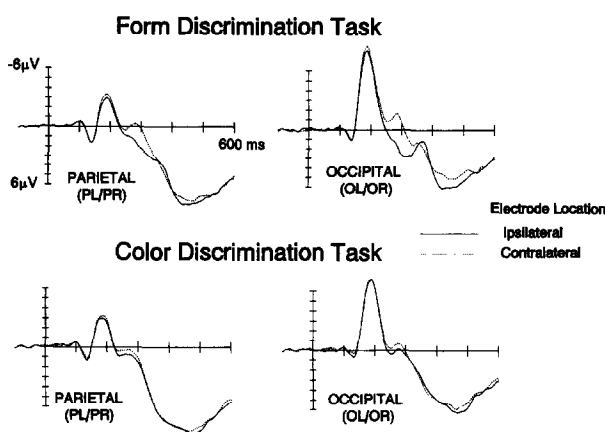


Fig. 3. Grand-averaged ERPs elicited in experiment 2 by arrays containing a left-side target or a right-side target at lateral parietal and occipital electrodes ipsilateral (straight lines) and contralateral (dashed lines) to the position of the target. Top row, ERPs elicited in the form discrimination task. Bottom row, ERPs elicited in the color discrimination task. The N2pc component can be seen as an enhanced negativity in the N2 time range elicited at electrodes contralateral to the position of the target.

interference due to distractors was present in these arrays, this difference should be attributed to more difficult between-target discrimination requirements in the form discrimination task. Moreover, the RT costs due to the presence of a distractor that can be estimated by comparing the RT for distractor arrays to the RT obtained for target-only arrays were similar for both tasks (32 ms versus 23 ms for form and color discrimination, respectively). These results indicate that the RT differences, and possibly also the differences in N2pc amplitude between the two task conditions, are primarily due to the more difficult discrimination between the two possible target stimuli in the form discrimination task.

4. Experiment 3

Experiment 2 showed that the N2pc is elicited under conditions where there is no target pop-out and only one distracting item is present in the opposite visual hemifield. It was concluded that this component may reflect the allocation of attention to the target stimulus that is guided by top-down mechanisms sensitive to task-relevant features. In the first two experiments, these were simple physical features (form or color). In a third experiment, it was investigated whether more abstract target-defining features may also result in the elicitation of an N2pc. Instead of letters or colored squares, word strings were used as targets and distractors. Target words differed from distractor words in terms of their semantic content. As in experiment 2, a target was presented together with a single distractor in opposite hemifields.

4.1. Methods

4.1.1. Subjects

Eleven paid volunteers participated in this experiment. One of them had to be excluded due to systematic HEOG deviations indicating a tendency to move the eyes to the target location. Thus, 10 subjects (4 female), aged 20–35 years (mean age 27.5 years) participated in the experiment. All subjects were right-handed and had normal or corrected-to-normal vision.

4.1.2. Stimuli, apparatus, and procedure

Four different uppercase word strings served as stimuli. The German words LINKS (left), RECHTS (right), WEISS (white), and BRAUN (brown) were used. Each stimulus array consisted of two words, one of them a location word (LINKS or RECHTS), and the other one a color word (WEISS or BRAUN). These two word strings subtended a visual angle of approximately $2.4 \times 0.8^\circ$, and were presented 2.7° to the left and right of the fixation cross (with the lateral distance measured relative to the center of the word string). In all other respects, the experimental circumstances were identical to the previous two experiments.

Again, the experiment consisted of 12 experimental blocks. Position words served as targets, and color words as distractors. In half of these blocks (target content condition), subjects were instructed to respond with the hand indicated by the content of the location word (that is, LINKS required a left-hand button press and RECHTS a right-hand button press). In the other half of the blocks (target location condition), a response spatially compatible to the location of the target word was required regardless of its content. That is, the words LINKS and RECHTS presented at the left side required a left-hand reaction; when one of them appeared at the right side, a right-hand button press was to be made. The order in which these two task conditions were delivered was balanced across subjects. A block consisted of 64 trials. Both target words could appear at the left and right side, and together with each of the two distractor words, resulting in a total of 8 different stimulus arrays. These different array types were presented in random order and with equal probability, resulting in 8 presentations of a single array per block. In all other respects, the procedure was identical to experiment 2.

4.1.3. Recording and data analysis

Recording was identical to experiment 2. Epoching, artifact rejection, averaging, and the computation of ERP amplitude measures obtained within the different time windows was the same as in the previous experiments. A repeated measures ANOVA was conducted on the ERP amplitude measures obtained at lateral parietal and occipital electrodes for the following factors: task condition (target content versus target location), contralaterality, electrode location, target identity (LINKS versus RECHTS), distractor identity (BRAUN versus WEISS) and S-R compatibility. Due to the different response assignments in the two task conditions, this latter factor was defined as spatial compatibility for the target content condition, and as semantic compatibility for the target location condition. In the former case, spatially compatible trials were those where the spatial location, the required response and the content of the target were identical (that is, LINKS presented on the left and requiring a left reaction, and RECHTS presented on the right and requiring a right reaction). In spatially incompatible trials, the location of the target differed from its content and the associated response. In the target location condition, all responses were spatially compatible to the target location. However, the content of the target word could either correspond to its location and the required response (semantically compatible trials), or could be different (semantically incompatible trials).

For the RT analysis, paired *t* tests were used to test whether the RT latencies were different for (spatially or semantically) compatible and incompatible trials, for left and right target words, and for targets accompanied by either of the two distractors.

4.2. Results

4.2.1. Behavioral performance

In the target content condition, spatially compatible reactions were significantly faster than incompatible reactions (519 ms versus 551 ms; $t(9) = 6.38$; $P < 0.001$). In the target location condition, the content of the target influenced response latencies, with faster RTs for semantically compatible trials than for semantically incompatible trials (511 ms versus 548 ms; $t(9) = 4.94$; $P < 0.001$). In addition, responses to the word LINKS were significantly faster in both task conditions (524 ms and 513 ms) than responses to the word RECHTS (546 ms for both task conditions). There was no significant difference in the overall RT between both task conditions.

4.2.2. ERP effects

As there was neither a main effect of task condition nor a significant interaction between this factor and the other experimental variables, Fig. 4 shows the ERP waveforms at lateral parietal and occipital electrodes collapsed over both task conditions. The ERPs obtained from left and right electrodes are displayed separately. Again, an enhanced N2 was elicited at electrodes contralateral to the target, resulting in a significant effect of contralaterality at both occipital and parietal electrodes ($F(1,9) = 13.35$, $P < 0.005$, and $F(1,9) = 29.43$, $P < 0.001$, respectively). In marked contrast to the previous experiment, however, an interaction between contralaterality and electrode location was present that was highly significant for occipital electrodes ($F(1,9) = 10.91$; $P < 0.001$) and approached significance at parietal sites ($F(1,9) = 4.02$; $P < 0.076$). As can be seen from Fig. 4, this interaction is due to the fact that an N2pc component was clearly present at left-hemisphere

electrodes, but seemed to be missing over the right hemisphere. These informal observations were substantiated by comparing the ERP amplitudes in the N2 interval elicited by left and right targets separately for left and right posterior electrodes. At OL and PL, a significant negative enhancement was present for contralateral targets ($t(1,9) = 4.71$, $P < 0.001$, and $t(1,9) = 3.69$, $P < 0.005$, for OL and PL, respectively). At OR and PR, however, no difference between ipsilateral and contralateral stimuli could be obtained at all.

Although an enhanced P3 for ipsilateral targets seems to be present in Fig. 4, this turned out not to be statistically significant. An additional effect of contralaterality was found in the N1 time range, where ipsilateral targets elicited a slightly enhanced negativities at occipital electrodes ($F(1,9) = 10.60$; $P < 0.010$).

4.3. Discussion

Two main results came out of experiment 3. First, and most importantly, an N2pc component was obtained even in a situation where target and distractor had to be distinguished on the basis of their semantic properties, as the target was a location word and the distractor was a color word. If the N2pc reflects the application of attention to relevant stimuli that is governed by top-down processes, this result shows that these processes may be sensitive not only to physical stimulus features, but also to rather abstract semantic properties. A second, and somewhat unexpected finding of the present experiment was that the N2pc was exclusively confined to the left hemisphere. No such hemispheric asymmetry has been found in the first two experiments or in other studies investigating the N2pc component. As meaningful words were used as stimuli in the present experiment, it may be argued that this effect reflects the activity of the left hemisphere that is known to be responsible for language processing. Alternatively, it is possible that this asymmetry reflects the fact that in our culture, linguistic material is usually processed from left to right. As can be seen from Fig. 4, a contralaterally enhanced N2 was elicited only when target words were presented on the right side. Here, the allocation of attention to the target may have been more necessary than in the case of targets in the left visual field, which are already in the default position for attentional selection. However, before additional empirical evidence has confirmed the observation that when subjects are confronted with lateralized target and non-target words, the N2pc is confined to the left hemisphere, or, alternatively, is elicited only by stimuli in the right visual field, these kinds of speculations seem premature. Moreover, it has to be noted that in all experiments reported here, a unilateral (right) earlobe reference was used. Although unlikely, the possibility cannot be excluded that this factor may have contributed to the lateral asymmetry of the N2pc found in this experiment.

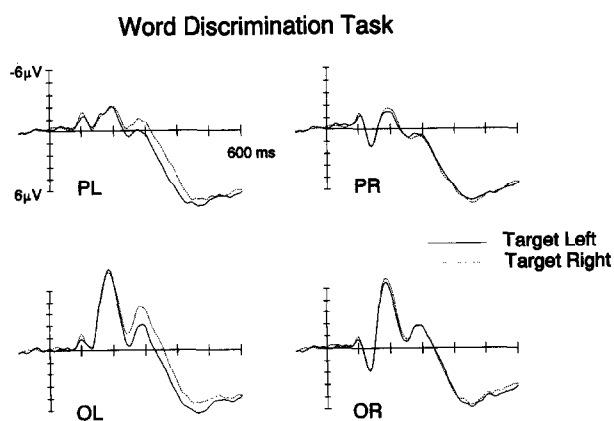


Fig. 4. Grand-averaged ERPs elicited in experiment 3 by stimulus arrays that contained a target word on the left side (straight lines) or on the right side (dashed lines) at lateral parietal electrodes (top row) and at lateral occipital electrodes (bottom row). At PL and OL, an enhanced negativity is present for target words presented in the right visual field. No such effect can be seen at PR and OR.

In contrast to the previous experiments, where target stimuli elicited an enhanced N1 at contralateral electrodes in form discrimination tasks, the N1 was found to be slightly larger at electrodes ipsilateral to the stimulus location in the present experiment. This may be due to subtle physical differences between target and non-target words that affected the amplitude of the sensory-evoked N1 component.

Before assuming that the N2pc component reflects the attentional selection of stimuli on the basis of semantic features, the possibility has to be taken into account that in the present experiment, target and non-target words may have been distinguished not by their semantic content, but primarily with the help of distinctive simple physical features. If this was the case, the detection of target location may have been possible on the basis of these features without an involvement of semantic processing. The finding that the RTs were generally faster to 'LINKS' than to 'RECHTS' indicates that despite all attempts to parallel all 4 stimuli with respect to their mutual discriminability, 'LINKS' was somewhat easier to distinguish from the context due to its physical characteristics than 'RECHTS'. However, the RT results obtained in the target location condition strongly suggest that the detection of target location was not accomplished solely on the basis of physical features. In this task condition, the content of the target word was irrelevant for response selection, as the response was dependent on the location of the target word. Nevertheless, there was a highly significant effect of semantic compatibility on RT, with responses to semantically compatible location words being about 30 ms faster than responses to incompatible words. This indicates that semantic processing of the target words was involved in the response selection process, and therefore most likely also in the process leading to the detection of target location.

5. Concluding remarks

The present experiments have provided converging evidence that the N2pc component is not as paradigm specific as previously thought. That is, the N2pc is not only elicited in genuine visual search tasks, but also in situations where the target is presented together with just one distracting stimulus, and these are located in opposite visual hemifields. The attentional selection process that is assumed to be reflected by the N2pc is thus not confined to situations where a target has to be located and identified among numerous adjacent distracting items, but is also elicited when the need to filter out irrelevant or conflicting information is minimized. This may indicate that the N2pc primarily reflects the selection of target stimuli that is independent of the number and distance of distracting items, and not a process by which irrelevant stimulation is attenuated or filtered out. However, in all of the present experiments, both targets and the distractor items differed

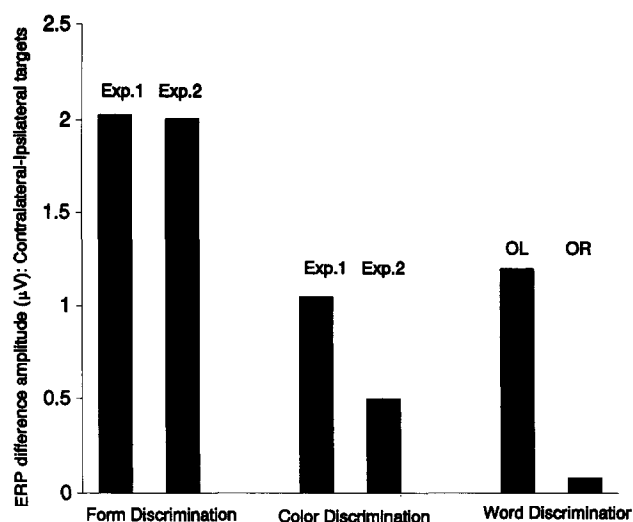


Fig. 5. Size of the N2pc effect at lateral occipital electrodes (OL, OR) for the different discrimination tasks in experiments 1–3. The N2pc effect was computed by subtracting the mean ERP amplitude in the N2 time range elicited by ipsilateral targets from the mean amplitude elicited by contralateral targets. For experiments 1 and 2, the resulting difference amplitude values were collapsed over OL and OR. For experiment 3 (word discrimination), these values are displayed separately for OL and OR (right side).

with respect to a common feature dimension (form, color, or semantic content). In order to further demonstrate that the N2pc is directly related to target selection, it has to be shown in future experiments that this component is also elicited when target and distractor stimuli belong to different feature dimensions (for example, when letters serve as targets and colored squares as distractors).

In addition, the present experiments have demonstrated that the N2pc is sensitive to differences in discrimination difficulty between tasks. This can be seen in Fig. 5, where the N2pc effects at lateral occipital electrodes obtained in these experiments are displayed separately for the different discrimination conditions. In the form discrimination tasks of experiments 1 and 2, the between-target discrimination was somewhat harder than in the color discrimination tasks. Correspondingly, the N2pc was significantly larger in the former conditions, and enhanced negativities at posterior electrodes contralateral to the target location were observed already in the N1 time range, and extended into the P3 time range. This may indicate differences in the attentional selection of target stimuli that are related to differences in the processing requirements of these two tasks.

Another finding that deserves more detailed empirical investigation was that the N2pc was confined to the left hemisphere in experiment 3 where targets and non-targets were words and differed with respect to their semantic category (cf. Fig. 5, right side). It is unclear whether this is due to a selective activation of the language-dominant left hemisphere, the specific need for attentional selection in a situation where an irrelevant word is presented on the

left and a relevant word on the right side, or to other factors that are specific for the detection and selection of task-relevant words among distracting word stimuli. In any case, additional empirical evidence is needed to confirm the finding that an N2pc is elicited exclusively over the left hemisphere in this type of task.

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