Gestalt perception modulates early visual processing

C. S. Herrmann[CA] and V. Bosch

Max Planck Institute of Cognitive Neuroscience, Postfach 500 355, 04303 Leipzig, Germany

[CA]Corresponding Author

Received 14 December 2000; accepted 16 January 2001

We examined whether early visual processing reflects perceptual properties of a stimulus in addition to physical features. We recorded event-related potentials (ERPs) of 13 subjects in a visual classification task. We used four different stimuli which were all composed of four identical elements. One of the stimuli constituted an illusory Kanizsa square, another was composed of the same number of collinear line segments but the elements did not form a Gestalt. In addition, a target and a control stimulus were used which were arranged differently. These stimuli allow us to differentiate the processing of colinear line elements (stimulus features) and illusory figures (perceptual properties). The visual N170 in response to the illusory figure was significantly larger as compared to the other collinear stimulus. This is taken to indicate that the visual N170 reflects cognitive processes of Gestalt perception in addition to attentional processes and physical stimulus properties. *NeuroReport* 12:901–904 © 2001 Lippincott Williams & Wilkins.

Key words: EEG; ERP; Gestalt perception; Illusory contours; Kanizsa figures; N170; VEP

INTRODUCTION

Early event-related potentials (ERPs) are strongly influenced by physical stimulus properties: e.g. the visual N170 is enhanced for stimuli which are composed of four rather than three inducer disks [1]. Therefore, the amplitude of the N170, for one part, reflects bottom-up processes which are mainly driven by physical stimulus properties. Moreover, it has been shown that attending to the hemifield in which a stimulus is presented can enhance the amplitude of the N170 [2]. Hence, the amplitude of the N170 also reflects processes of attention that operate at an early stage. It is still unclear, however, whether other cognitive processes, such as the identification of a Gestalt, also modulate the N170 amplitude.

Visual illusions are ideally suited to investigate this question. A Kanizsa square (Fig. 1a) does not differ from a non-Kanizsa square (Fig. 1b) in physical stimulus properties but an additional white square is perceived [3]. Therefore, Kanizsa figures have been used extensively to study the perceptual properties of the visual system in behavioural [4,5] and electrophysiological experiments [6–8].

The visual N170 has been shown to be larger in response to Kanizsa figures than to non-Kanizsa figures [1]. This indicates that perceptual processing beyond the analysis of physical stimulus properties may be reflected by the N170 amplitude. A potential confounder in investigating illusory figures is the presence of so-called inducer lines, i.e. collinear line segments which are virtually connected by perceptual processes according to Gestalt laws. It has been demonstrated that the presence of such inducer lines leads to neuronal discharges at locations where no real line is actually present [9,10]. In order for the brain to perceive an illusory figure, collinear inducer lines are necessary but not sufficient. The collinear lines also have to enclose a potential object.


(a) (b)

Fig. 1. Two stimuli used in a previous experiment showing enhanced N170 responses to the Kanizsa square (**a**) compared with the non-Kanizsa square (**b**).

In the above-mentioned experiment, which yielded larger N170 amplitudes to Kanizsa figures, the non-Kanizsa control figure did not contain any collinear inducer lines. Therefore, the enhanced N170 may have resulted from the collinear inducer lines rather than the illusory figure, since the collinearity and the illusory Gestalt were manipulated at the same time. To the best of our knowledge, no study has so far manipulated the illusory Gestalt properties without changing the number of collinear lines at the same time. We set out to differentiate the influence of these two features and designed a new set of stimuli to achieve this. We used one stimulus with neither collinear lines nor an illusory figure, one with collinear lines but without an illusory figure and one containing both.

MATERIALS AND METHODS

We used symmetrical black inducer disks to compose our stimuli (Fig. 2). Usually such inducer disks have one missing 90° segment with the length of the inducing edges equal to the radius. Instead, we used two such segments whose inducer lengths were 2/3 of the radius. These stimuli can be arranged to form a Kanizsa square (Fig. 2d), not to form a Kanizsa square but to have an equal number of collinear line segments (Fig. 2c), or to have no co-linear line segments at all (Fig. 2b).

Inducer disks subtended a visual angle of 2°18′ and were presented at an eccentricity of 2°24′. Thus, the whole stimuli are projected into the field of central vision, i.e. the first 5° that are covered by the macula [11]. The ratio of the inducing length to the total length of the illusory figures was 4/7. Figures were displayed on a computer monitor placed 1 m in front of the subjects. Stimuli were black on white background and presented for 500 ms with an inter-stimulus interval of 1 s. The experiment was run in four blocks with 100 stimuli per block.

In order to keep the subject's vigilance at a high level throughout the experiment, we performed a forced-choice target detection task, i.e. a response was required for every stimulus. Therefore, we designed an additional target stimulus composed of the same inducer disks at a different rotation angle (Fig. 2a). Subjects were instructed to press a button with their right hand in response to the target stimuli and another button with their left hand for the three non-target stimuli. We equiprobably presented the four stimuli shown below in a pseudo-randomized order resulting in a target probability of 0.25.

Fourteen right-handed student subjects participated in the experiment. All subjects gave written informed consent. They had normal or corrected to normal vision and showed no signs of neurological or psychiatric disorders. One subject had to be excluded from the analysis since he did not attend to the whole stimulus, but performed the task by solely looking at the lower right hand inducer disk. The remaining 13 subjects (7 female) were between 19 and 28 years old (mean age 23.3 years).

The EEG was recorded with TMS (Twente Medical Systems, Enschede, The Netherlands) amplifiers using 22 tin electrodes mounted in an elastic cap. Electrodes were placed according to the international 10-20 system. The ground electrode was C2 and all electrodes were referenced to the left mastoid (M1). Electrode impedance was kept below 5 kΩ. Horizontal and vertical EOG were registered with four additional electrodes. Data were sampled at 250 Hz and analog-filtered with a 0.05 Hz high-pass and a 70 Hz low-pass filter. ERPs were low-pass filtered at 25 Hz for display.

Averaging epochs lasted from 100 ms before to 800 ms after stimulus onset. All epochs were visually inspected for artefacts and rejected if eye movement artefacts or electrode drifts were visible. Baselines were computed in the −100 ms to 0 ms interval in each single trial and subtracted prior to computing the ERP averages.

Trials in which a response error was made were rejected from the data, as were trials in which the response time (RT) exceeded the mean by more than 2.5 standard deviations. RTs, error rates, and ERP data were investigated for effects of the condition by means of repeated measures ANOVAs. The factor condition comprised the following levels: Kanizsa, collinear, control, target.

ERP components were defined as mean amplitudes in the time intervals 80–110 ms (P100), 150–180 ms (N170) and 400–600 ms (P300). For the P100 and N170 time windows, ANOVAs were computed only for the three non-target conditions to avoid the potential confounding with target processing. The factors of the ANOVAs for ERP components were condition and electrode (O1, Oz, O2 in the P100 and N170 time window; P3, Pz and P4 in the P300 time window).

All effects with two or more degrees of freedom in the numerator were corrected for violations of sphericity and the Greenhouse-Geisser epsilon was used to adjust the p-values. *Post-hoc* contrasts were computed using repeated measures ANOVAs with a single factor comprising two levels which is equivalent to a paired t-test.

RESULTS

An ANOVA for the RTs revealed a significant main effect of condition ($F_{3,36} = 66.88$, $p < 0.0001$) indicating slower reaction times for the infrequent target (459 ms) than for the frequent non-targets (Kanizsa figure 402 ms, collinear non-Kanizsa figure 396 ms, and non-collinear stimulus 399 ms). *Post-hoc* comparisons of the three non-targets found no significant differences ($F_{2,24} = 1.43$, $p > 0.1$).

An ANOVA of the error rates also yielded a significant main effect of condition ($F_{3,36} = 33.80$, $p < 0.0001$) indicating higher error rates to targets (21%) than to non-targets (Kanizsa figure 1.2%, co-linear non-Kanizsa figure 0.5%, and non-collinear stimulus 0.8%). *Post-hoc* comparisons of the three non-targets found no significant differences ($F_{2,24} = 1.42$, $p > 0.1$).

Figure 3 shows the ERPs in response to all four stimuli. All stimuli resulted in a P100 and N170 component. Peak latencies of visual P100 and N170 were ~100 ms and 160 ms, respectively (Fig. 4). The target stimulus evoked an additional P300 component peaking around 450 ms. In the first (P100) time window no significant effects of condition could be detected at occipital electrodes ($F_{2,24} < 1$). Thus,

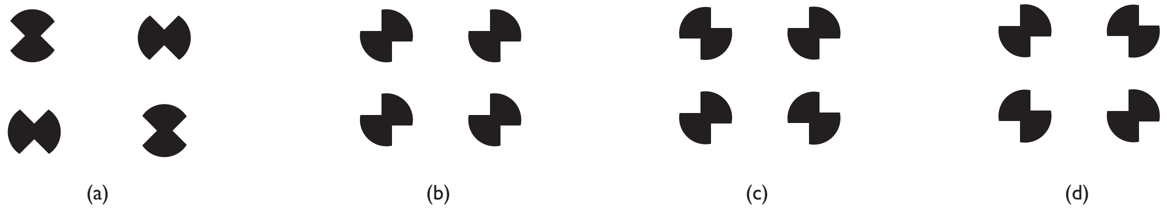

Fig. 2. The four stimuli used in our paradigm: The target (**a**), a control (**b**), the collinear non-illusory figure (**c**) and the illusory figure (**d**).

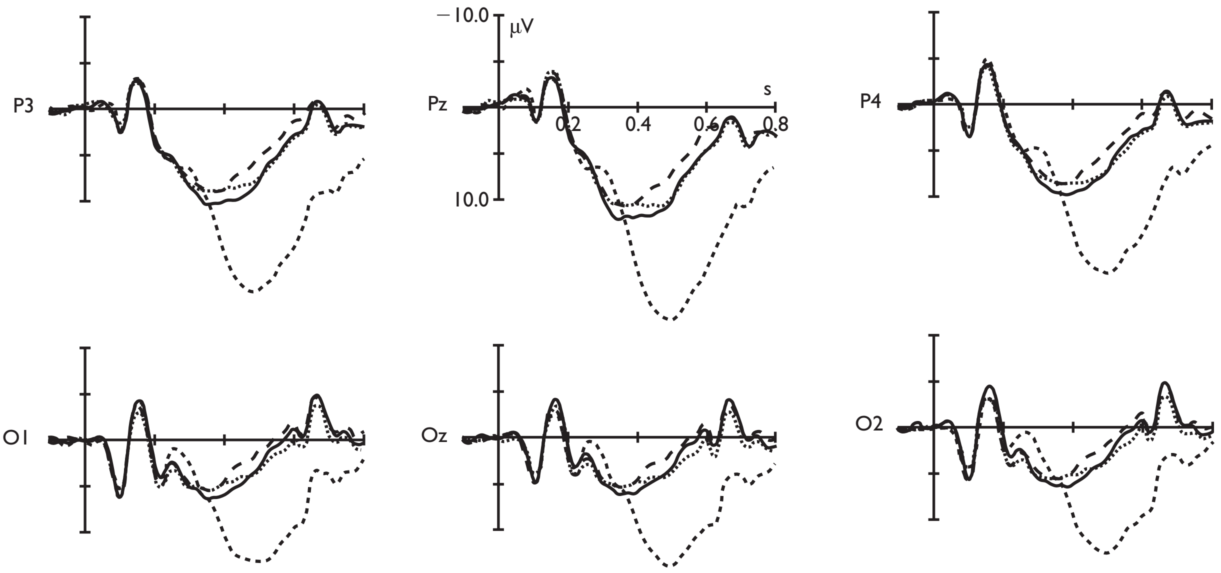

Fig. 3. ERPs at posterior electrodes in response to the Kanizsa square (—), the collinear non-illusory figure (····), the control (– – –) and the target (- - - -).

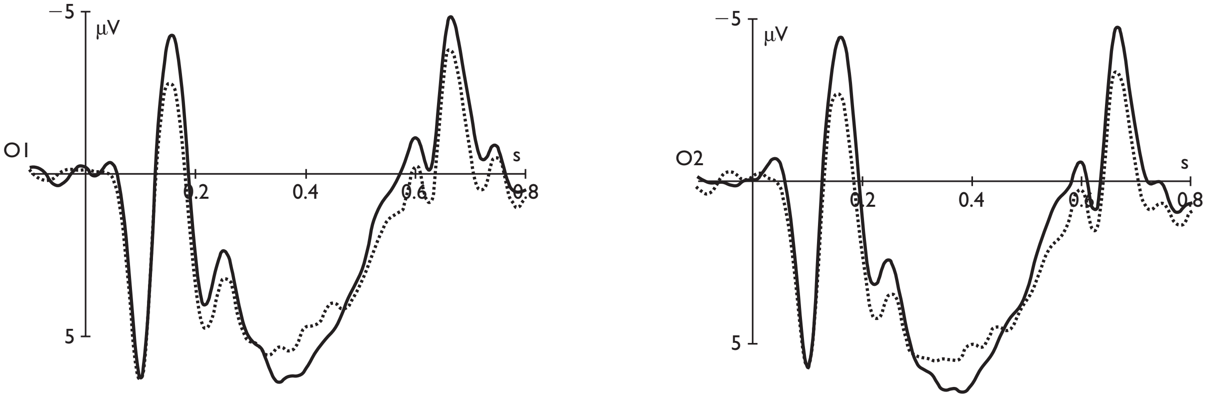

Fig. 4. ERPs at electrodes O1 and O2 in response to the Kanizsa square (—) and the collinear non-illusory figure (····) reveal a larger N170 for the illusory Kanizsa figure.

the P100 component was unaffected by the experimental manipulation. In contrast to this, the N170 varied as a function of condition as revealed by a significant main effect of condition ($F_{2,24} = 4.96$, $p < 0.05$) in the second time window (Kanizsa: $-3.75\,\mu V$, co-linear: $-2.10\,\mu V$, control: $-2.63\,\mu V$). Interestingly, the target evoked an intermediate N170 amplitude of $-3.14\,\mu V$.

In order to avoid a correction for multiple comparisons, only two independent *post hoc* contrasts were computed, more specifically, Kanizsa *vs* (collinear + control)/2 and co-linear *vs* control. The first contrast revealed that the N170 is significantly more negative in the Kanizsa condition than in the remaining two conditions ($F_{1,12} = 7.28$, $p < 0.05$). Furthermore, the second contrast revealed that the N170 was not significantly affected by collinearity ($F_{1,12} = 1.1$, $p > 0.1$).

An ANOVA for the P300 time window yielded a significant main effect of condition ($F_{3,36} = 43.56$, $p < 0.0001$) indicating larger amplitudes for the infrequent target than for the frequent non-targets. A *post-hoc* ANOVA yielded no significant main effect of condition for the three non-targets ($F_{2,24} = 2.8$, $p > 0.1$).

DISCUSSION

Our results demonstrate that the presence of illusory contours that constitute a Gestalt leads to larger N170 amplitudes than does a comparable stimulus with the same amount of collinear inducer lines but without Gestalt properties. Moreover, the stimulus with collinear line segments did not evoke larger N170 amplitudes than the control stimulus without collinear lines. This indicates that Gestalt properties rather than collinearity influence N170 amplitude.

Former interpretations of ERPs have proposed early components (N170 and earlier) to reflect exogenous stimulus characteristics while later components (P200 and later) reflect endogenous cognitive processes [12]. In addition, it has been demonstrated that top-down mechanisms of spatial selective attention can modulate the amplitudes of N170 and P100 [2,13]. Thus, processes of selective attention might be a possible explanation for the observed N170 differences between the Kanizsa figure and the collinear non-illusory figure. Similar to spatial selective attention, object selective attention towards Kanizsa squares could have led to an enhanced N170. If this were true, however, an enhanced P300 would have been expected for the Kanizsa figure as compared to the collinear non-illusory figure, since the P300 is sensitive for attended stimuli. Even though we did observe a significant P300 increase for the target as compared to the three standards, however, there were no significant differences in P300 amplitude between the standards. Furthermore, selective attention is known to influence RTs and error rates [14]. However, we did not observe any differences in RTs or error rates between the three standard conditions. Thus, we assume the two conditions of interest for our Gestalt argument, which are both standards, to catch a similar amount of attention. Nevertheless, the Kanizsa square evoked a larger N170 amplitude than the collinear non-illusory figure. Even the target which evoked a typical target P300 evoked a smaller N170 than the Kanizsa figure. Therefore we rule out that the observed N170 modulation reflects an effect of selective attention.

Thus, we argue that N170 amplitude reflects the perceptual processing of Gestalt properties in addition to the previously formulated exogenous and attentional modulations. These results are in line with findings that show hemodynamic responses to illusory figures in primary visual cortex V1 and V2 [15–17]. The mere presence of colinear lines does not seem to be sufficient for enhanced visual processing.

Other experiments also suggest that perceptual processes influence the N170 amplitude. In a binocular rivalry task, N1 amplitudes dramatically decreased when the percept remained stable in response to a stimulus change compared with when a conscious change of perception occurred [18]. Therefore, we propose that the endogenous processes underlying N170 generation are mainly those attributable to attention and conscious perception. Obviously, the presence of a Gestalt is an important parameter which modulates these processes.

REFERENCES

1. Herrmann CS, Mecklinger A and Pfeiffer E. *Clin Neurophysiol* **110**, 636–642 (1999).
2. Heinze HJ, Mangun GR, Burchert W *et al. Nature* **372**, 543–546 (1994).
3. Kanizsa G. *Sci Am* **234**, 48–52 (1976).
4. Kojo I, Linasuo M and Rovamo J. *Vision Res* **33**, 897–901 (1993).
5. Davis G and Driver J. *Nature* **371**, 791–793 (1994).
6. Brandeis D and Lehmann D. *Electroencephalogr Clin Neurophysiol* **73**, 507–519 (1989).
7. Tallon C, Bertrand O, Bouchet P *et al. Eur J Neurosci* **7**, 1285–1291 (1995).
8. Tallon-Baudry C, Bertrand O, Delpuech C *et al. J Neurosci* **16**, 4240–4249 (1996).
9. Peterhans E and von der Heydt R. *J Neurosci* **9**, 1749–1763 (1989).
10. Grosof DH, Shapley RM and Hawken MJ. *Nature* **365**, 550–552 (1993).
11. Zeki S. *A Vision of the Brain*. Oxford: Blackwell Scientific Publications; 1993.
12. Coles MGH and Rugg MD. In: Rugg MD and Coles MGH, eds. *Electrophysiology of Mind. Event-Related Brain Potentials and Cognition.* Oxford: Oxford Unversity Press; 1995, pp. 40–85.
13. Luck SJ, Heinze HJ, Mangun GR *et al. Electroencephalogr Clin Neurophysiol* **75**, 528–542 (1990).
14. Posner MI. *Q J Exp Psychol* **32**, 3–25 (1980).
15. Hirsch J, DeLaPaz RL, Relkin NR *et al. Proc Natl Acad Sci USA* **92**, 6469–6473 (1995).
16. Ffytche DH and Zeki S. *Neuroimage* **3**, 104–108 (1996).
17. Mendola JD, Dale AM, Fischl B *et al. J Neurosci* **19**, 8560–8572 (2000).
18. Kaernbach C, Schröger E, Jacobsen T *et al. Neuroreport* **10**, 713–716 (1999).

Acknowledgements: We express our thanks to Cornelia Schmidt for help during the acquisition of the EEG data and to Andrea Gast-Sandmann for help with the graphical display of the ERP data.