



Electrophysiological correlates of human texture segregation, an overview

MICHAEL BACH¹ & THOMAS MEIGEN²

¹Elektrophysiologisches Labor, Universitäts-Augenklinik Freiburg, Germany;

²Univ.-Augenklinik, Würzburg, Germany

Abstract. ‘Texture segregation’ results from parallel processing in the visual cortex. It occurs when the stimulus contains spatial gradients within a visual dimension. We here present an introductory overview of the field, concentrating on electrophysiological correlates in the human EEG (‘tsVEPs’) of the neuronal processes underlying texture segregation. We describe the isolation of the tsVEP from the background EEG, give examples of the correlation between saliency and tsVEP amplitude and compare texture segregation between visual dimensions.

Key words: electrophysiology, human, texture segregation, VEP

Abbreviations: tsVEP – VEP associated with texture segregation

Introduction

‘Texture segregation’ refers to an active research field that deals with the capability of our visual system to segment (segregate) areas of our visual field. Texture segregation is closely related to ‘grouping’ and ‘pop out’ (Figure 1) and is a fundamental mechanism to segregate a Gestalt from the background. The common feature of these perceptual phenomena is parallel processing of the visual field, without conscious or automatic sequential scanning (foveation). By definition, texture segregation occurs if detection of a certain feature is not compromised by an increasing number of detracting stimuli [1]. Our eventual goal is to understand how our visual system detects figures and objects from the ‘flat’ retinal image out of a distracting background. Texture segregation is an important intermediate step in figure-ground-segmentation (Figure 2).

Beck first noticed parallel processing of certain line elements [2]. Julesz first analyzed local statistical properties and later based his ‘texton theory’ on the presence of certain local features (line endings etc) [3]. We now believe that texture segregation is not determined by the presence or absence of local features, but rather by *spatial (or temporal) gradients* in the expression of a *visual dimension* [1, 4–6]. We consider as visual dimensions those properties of the visual world, for which our visual system has developed specific

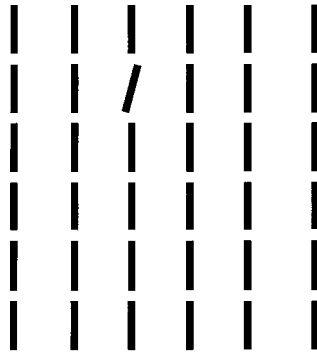


Figure 1. In this arrangement of vertical lines the oblique line is obvious at first glance, without sequential scanning of the image, a typical case of 'pop out'.

neuronal filters (receptive fields). The following list of visual dimensions is probably incomplete, it includes: luminance, orientation, spatial frequency, motion, stereo disparity and color (Figure 3).

Electrophysiological correlates of texture segregation

Texture segregation occurs spontaneously, without scanning of the visual field, as it is based on parallel processing. Such massive processing should leave its traces in the EEG, and consequently in the VEP. VEP findings provide a link between psychophysical results in humans and neuronal measurements in animal experiments and provide a fascinating possibility to analyze neural mechanisms of visual processing in the human visual system. In search of a VEP correlate of texture segregation, we wanted to introduce many orientation gradients in the stimulus and chose a 'global orientation checkerboard' as stimulus (Figure 4). The subject fixates the center of the screen, initially blank. Suddenly the pattern appears, evoking a VEP (Figure 5).

This VEP does not yet represent a specific correlate of texture segregation. Any visual change will trigger visual processing and consequently evoke a VEP. We will call the VEP evoked by the onset of the line elements themselves the 'low-level-VEP'. To extract a component associated with texture segregation (the 'tsVEP') we used the following rationale: The 'global orientation checkerboard' contains both vertical and horizontal line elements, so we also presented a pattern 'vertical only' and another 'horizontal only'. Since the 'global orientation checkerboard' contains half vertical and half horizontal line elements, we subtracted from the evoked VEP-mixture half of the response to the vertical and half of the response to the horizontal pattern.



Figure 2. 'Cirque Invisible' Victoria Chaplin & Jean-Baptiste Thierrée (photo: F. Simon, Hamburg 1994, with permission). Three Gestalten (clown, zebra and suitcase) segregate from each other and from the background by boundaries that are defined by gradients in luminance, orientation and spatial frequency (cf. Figure 3). For instance, between clown and zebra there is an orientation gradient (lines oblique on the coat, horizontal on the zebra), as well as a gradient in spatial frequency (stripes wide apart on the coat, close in the zebra).

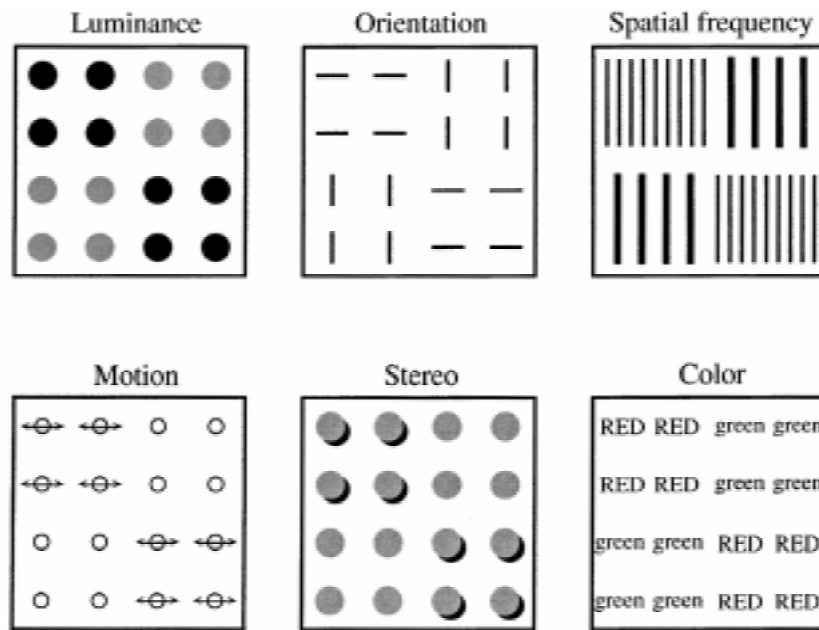


Figure 3. Texture segregation in different visual dimensions. The six squares segregate into 4 segments each, based on different visual dimensions. The vivid segregation by motion, stereo and color cannot be adequately presented here.

In other words: We assumed linearity and calculated the linear combination:

$$tsVEP = VEP_{checkerboard} - \frac{VEP_{vert.lines} + VEP_{horiz.lines}}{2} \quad (1)$$

Assuming linearity at this stage, the low-level VEP should thus be eliminated and a negative component just before 200 ms after stimulus onset appeared [7, 8]. The latency was in an ‘interesting’ range: clearly after the low-level-VEP, but before the time for cognitive potentials that occur typically at 300 ms. These results were confirmed and extended to segregation by motion, topographic- and cortical depth-analysis and recordings in monkeys by the Amsterdam group [9–11]. The assumption of linearity at this stage cannot easily be tested directly. Rather, to assess the viability of the tsVEP as a measure of segregation processing, we will now quantitatively compare the tsVEP and psychophysical measures.

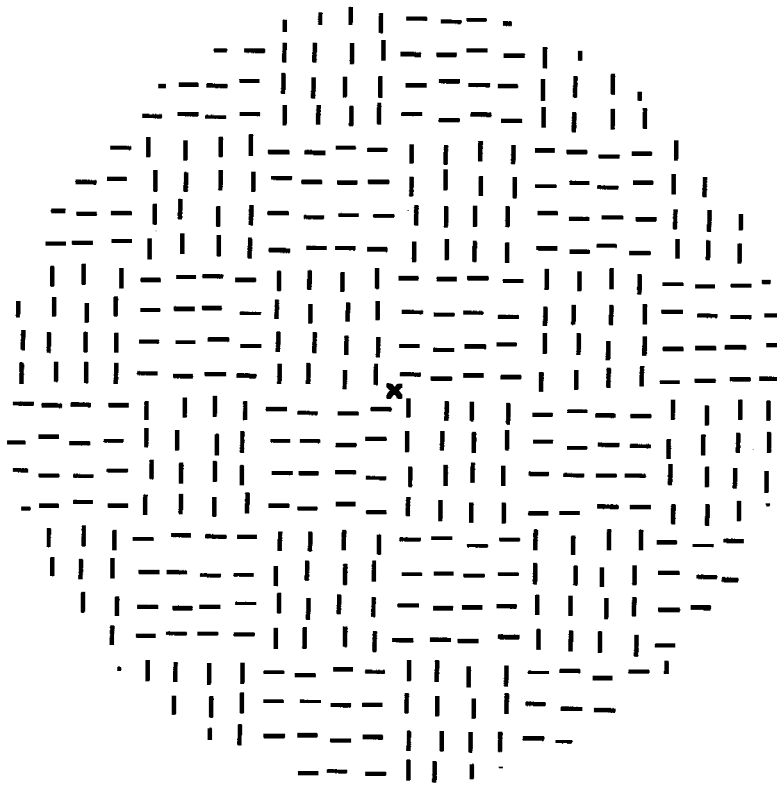


Figure 4. An 'orientation checkerboard' as seen by the subjects. The checks are defined by orientation gradients. The small displacements ('jitter') of the individual line elements against their regular lattice position are introduced to reduce luminance artifacts.

Correlation between psychophysical and electrophysiological findings in texture segregation – Four textons

Having isolated the tsVEP, we proceeded to study its relation to psychophysical saliency. Saliency of texture segregation depends on many stimulus parameters. We compared saliency, quantified in a ranking paradigm, and the tsVEP amplitude across four patterns that were inspired by Julesz' texton patterns.

All patterns were constructed from identical line elements, in Figure 6 the four patterns are depicted in a simplified way. When the line elements build up groups of 'U's that are rotated by 90° between groups (Figure 6 left, second pattern from bottom left), there appears a clear, if weak, percept of a global checkerboard (orientation based texture segregation, caused by the contrasting of 2 lines horizontal and 1 line vertical to 1 line horizontal and

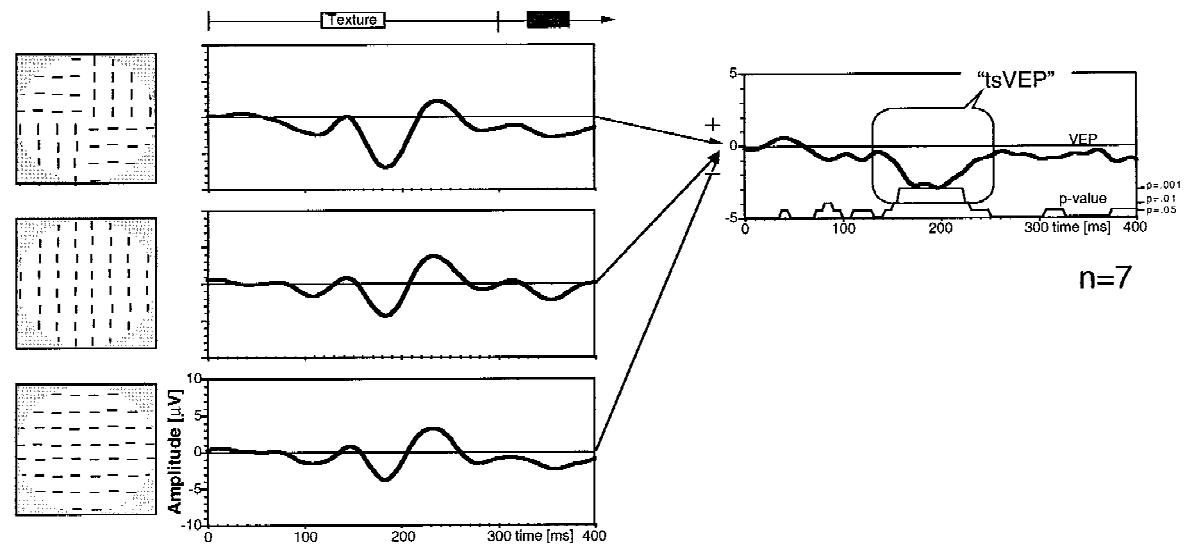


Figure 5. Isolation of a VEP component associated with texture segregation. At the very left are icons of the stimulus patterns (cf. Figure 4), the center shows the VEPs in response to onset of these patterns (grand mean of 7 subjects). On the right is a linear combination [Equation (1)] of these three responses, designed to cancel the local, or 'low-level VEPs'. This results in the 'tsVEP', a negativity around 200 ms. (Modified after [8]).

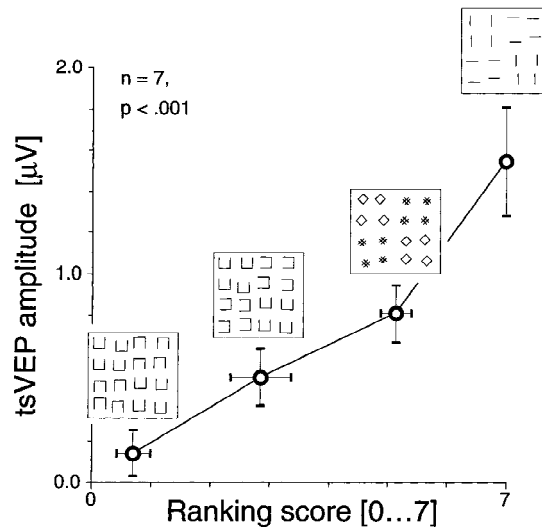


Figure 6. 'Four textons' experiment. Comparison of psychophysical saliency and tsVEP amplitude, grand mean of 7 subjects. The subjects estimated the 'strength of the global checkerboard' of four patterns. The actual patterns were arranged like Figure 4. Saliency as expressed by the ranking score and tsVEP amplitude are closely correlated. (Modified after [12]).

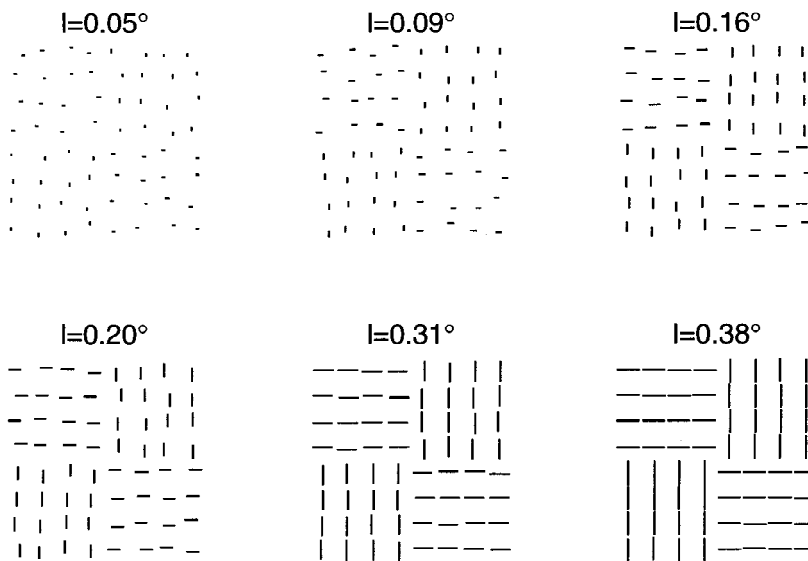


Figure 7. Line-length experiment, simplified stimulus patterns. The relative size of the line elements and the checks are as seen by the subjects, the full stimuli resembled those from Figure 4. Six different line lengths were presented, with length l from 0.05° to 0.38° with a constant raster width of 0.4° to manipulate the magnitude of orientation gradients.

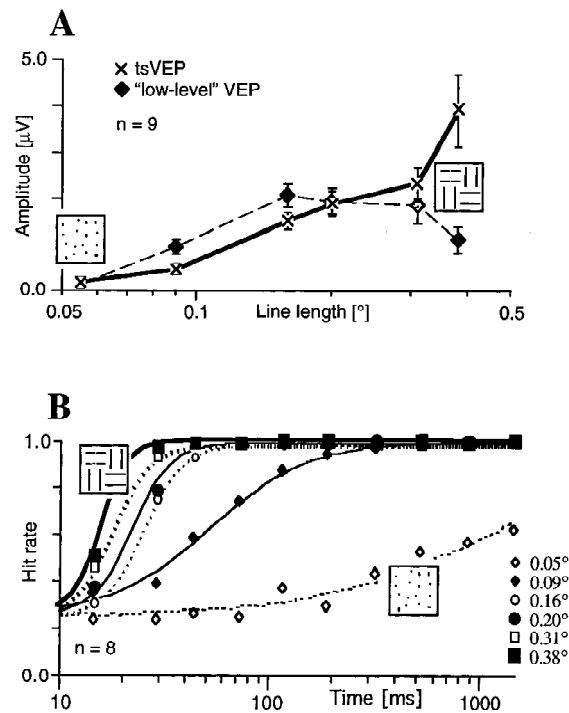


Figure 8. Line-length experiment, electrophysiological (A, top) and psychophysical (B, bottom) results. A. The diamonds represent the 'low-level VEP', peaking at an intermediate line length. The crosses represent the tsVEP, rising monotonically with line length. B. The probability of correctly identifying the location of a test patch in a 4AFC vs. stimulus presentation time. The smooth curves represent a logistic function fit. All psychometric functions represent an acceptable fit and show that saliency increases monotonically with line length.

2 lines vertical). If the 'U's are rotated by 180° , the global checkerboard can hardly be seen (Figure 6 bottom left). In this experiment we measured the tsVEP in a steady-state paradigm [12], and the appropriate Fourier-amplitude was vector-averaged across subjects. The results show a close correlation of saliency with tsVEP amplitude. This finding supports the hypothesis that the tsVEP actually is associated with neuronal processes underlying image segregation.

Line length – Saliency and tsVEP amplitude

To assess more quantitatively the relationship between tsVEP amplitude and psychophysical saliency in one visual dimension, we studied the influence of line length and used a test-mask paradigm for psychophysical measurements.

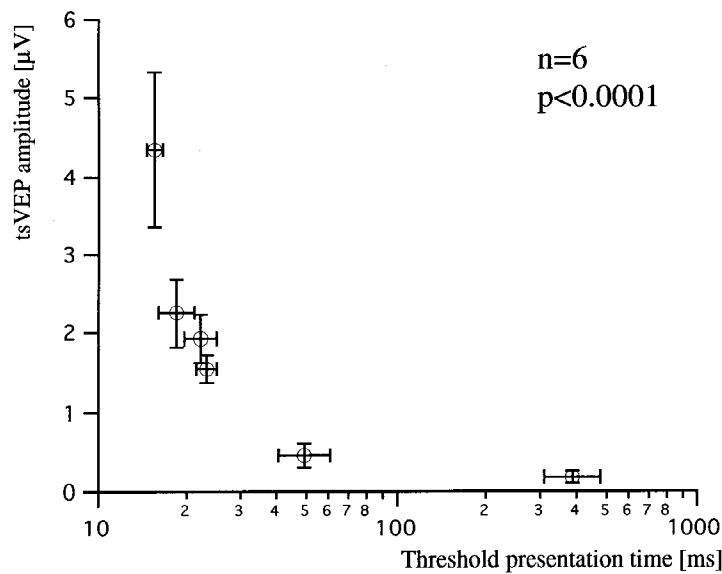


Figure 9. Line-length experiment, comparison of electrophysiological and psychophysical measures from Figure 8. A close correlation between tsVEP amplitude and threshold presentation time obtains across the line lengths tested.

Increasing line length can be thought of as increasing orientation gradient (Figure 7).

The tsVEPs were extracted in the frequency domain as in [12]. Two types of responses as grand mean from 9 subjects are plotted in Figure 8A: The crosses represent the tsVEP amplitudes resulting from a linear combination similar as in Figure 5, the diamonds represent a linear combination that cancels higher order components, leaving the ‘low-level VEP’ (cf. Figure 11, right). With increasing line length, the low-level VEP displays an intermediate maximum, whereas the tsVEP continues to rise monotonically until the line elements nearly touch each other. This different behavior suggests that two different mechanisms are tapped.

To measure the saliency, we employed a four alternative forced choice task: Instead of a global checkerboard, only a single check was presented. This check was embedded in a background of oriented lines, with a position right, top, left or bottom of the fixation point. The distance between the center of the check and the fixation spot was 2.4° . This test pattern appeared for a certain time and was followed by a mask of alternatingly oriented line elements. In a constant stimulus design the presentation time was varied between 14.6 ms (the frame interval) and 1460 ms in 10 steps. The stimuli were presented in an interleaved block design, each presentation time was

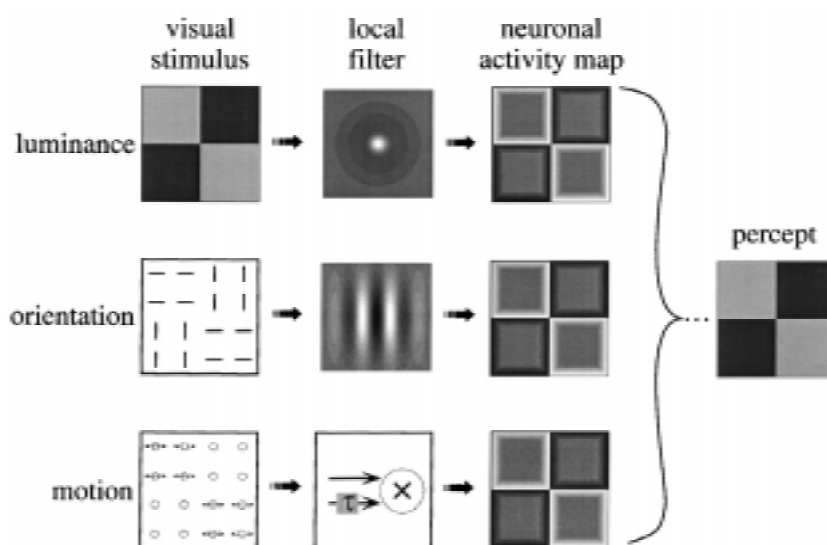


Figure 10. Model scheme of texture segregation. The image (left), which is segregated into four fields by one of three exemplary visual dimensions, is processed by local filters (second column, not to scale, the local filters correspond to known neuron types) into one common 'neuronal activity map' (third column). On this common activity map, which may simply be the sum of the outputs from the filter map in every visual dimensions, the gradient detectors operate. Finally, after more unknown steps, the percept 'checkerboard' arises.

tested 8 times per block, each line length was presented in two blocks. After the experiment, logistic functions were fitted using a maximum-likelihood procedure [13]. Figure 8B demonstrates that all psychometric functions represent an acceptable fit. Both inverse slope and time of steepest slope decrease monotonically with increasing line length.

The electrophysiological and psychophysical measures are compared in Figure 9 for those subjects for whom both measures were available. Obviously, a very close correlation ($P < 0.0001$, Pearson signed rank) between tsVEP amplitude and threshold presentation time obtains across the line lengths tested.

The independence of the texture segregation from the visual dimension

It is known that the texture segregation can appear at different visual dimensions. As it appears inefficient if detectors for gradients and neuronal recognition mechanisms would exist in every visual dimension, we propose the following model to explain the independence of texture segregation from

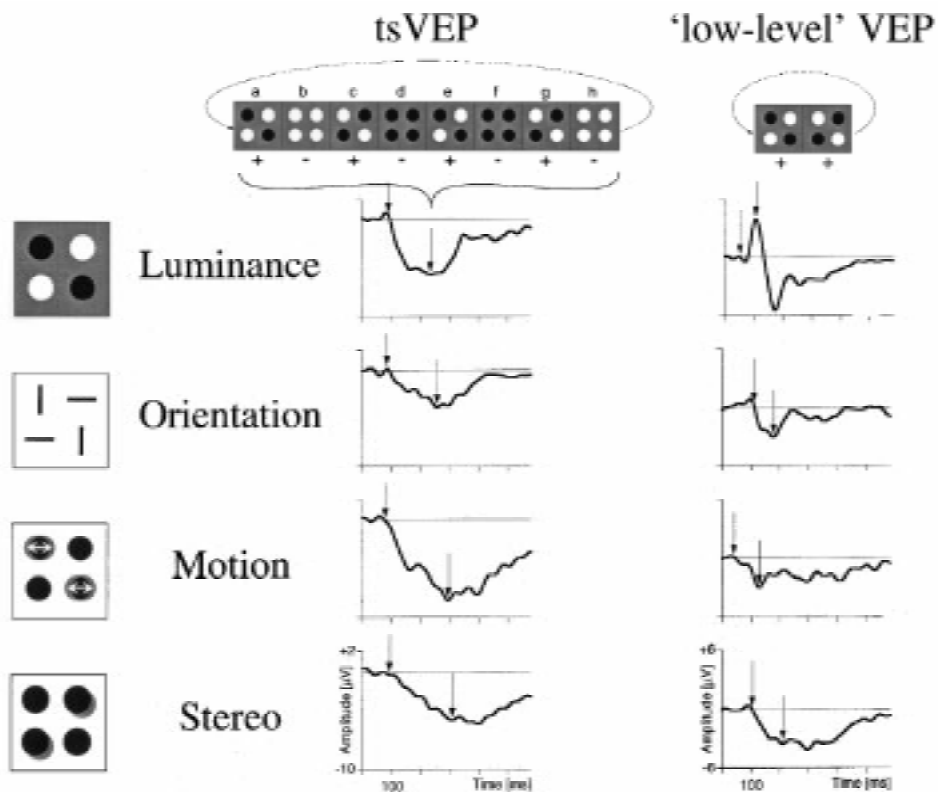


Figure 11. Visual evoked potentials associated with texture segregation (tsVEP, left) contrasted with low-level VEPs (right). On the very left the four visual dimensions are depicted symbolically. The next column depicts the respective tsVEP traces, which were extracted from the raw responses using the linear combination indicated by '+' or '-' in the stimulus pattern sequence at the top. On the right are the 'low-level VEPs' evoked by a 'reversal' of the respective visual dimension. The first arrow in each trace indicates implicit time, the second arrow denotes the major peak. Between the four visual dimensions, the tsVEPs have similarities (each shows a negativity at 230–310 ms) and dissimilarities. The similarities of the tsVEPs are striking when compared to those between the low-level VEPs. This suggests that the tsVEPs reflect a mechanism that has generalized to some degree across visual dimensions. (Modified after [14]).

the visual dimension (Figure 10). This model makes a number of predictions that can be experimentally tested. In the language of the VEPs, the filter outputs relate to the low-level-VEP, and the segregation mechanisms operating within the intensity map would generate the tsVEP.

To test this model, we compared the tsVEP with the low-level-VEP in four visual dimensions (brightness, orientation, movement and stereo). The results can be summarized as follows (Figure 11) [14]: The low-level-VEP

varies very strong among the visual dimensions. Compared to this, the tsVEP appears relatively similar among the visual dimensions (for example it is always negative). This result is consistent with the hypothesis sketched in Figure 10. The details of neuronal function still need to be elucidated. For example it is possible that the steps in Figure 10 are integrated within some neurons' receptive field properties: orientation gradients in monkeys [15, 16] orientation gradients cats [17, 18], motion gradients in monkeys [16, 19], and motion gradients in cats [20].

Conclusion

Texture segregation is an impressive capability of our visual system. Functional correlates of texture segregation in humans provide a link between perception and single cell data in animals. The following aspects of the tsVEP were covered here:

- identification of the tsVEP assumes linearity
- the tsVEP is a negative component around 200 ms
- tsVEPs have been found in all visual dimensions tested: orientation, motion, luminance, and stereo
- psychophysical saliency and tsVEP amplitude are highly correlated
- tsVEPs are similar across dimensions (tested for luminance, orientation, motion and stereo).

Acknowledgment

We gratefully acknowledge support by the Deutsche Forschungsgemeinschaft.

References

1. Treisman A. Preattentive processing in vision. *Comput Vis Graph Image Proc* 1985; 31: 156–77.
2. Beck J. Similarity grouping and peripheral discriminability under uncertainty. *Am J Psychol* 1972; 85: 1–19.
3. Julesz B, Bergen JR. Textons, the fundamental elements in preattentive vision and perception of textures. *Bell Sys Tech J* 1983; 62: 1619–45.
4. Treisman A, Sato S. Conjunction search revisited. *J Exp Psychology Human Perception and Performance* 1990; 16: 459–78.
5. Nothdurft HC. Texton segregation by associated differences in global and local luminance distribution. *Proc Royal Soc London B* 1990; 239: 295–320.

6. Bach M, Meigen T. Electrophysiological correlates of texture segregation – Effect of orientation gradient. *Invest Ophthalmol Vis Sci (ARVO Suppl.)* 1992; 33: #1349.
7. Bach M, Meigen T. Electrophysiological correlates of texture-segmentation in human observers. *ARVO Abstracts. Invest Ophthalmol Vis Sci* 1990; 31 (suppl): 104.
8. Bach M, Meigen T. Electrophysiological correlates of texture segregation in the human visual evoked potential. *Vision Res* 1992; 32: 417–24.
9. Lamme VAF, van Dijk BW, Spekreijse H. Texture segregation is processed by primary visual cortex in man and monkey. Evidence from VEP experiments. *Vision Res* 1992; 32: 797–807.
10. Lamme VA, van Dijk BW, Spekreijse H. Contour from motion processing occurs in primary visual cortex. *Nature* 1993; 363: 541–3.
11. Lamme VA, van Dijk BW, Spekreijse H. Organization of texture segregation processing in primate visual cortex. *Vis Neurosci* 1993; 10: 781–90.
12. Meigen T, Bach M. Perceptual ranking vs VEP for different local features in texture segregation. *Invest Ophthalmol Vis Sci* 1993; 34: 3264–70.
13. Meigen T, Lagrèze W, Bach M. Asymmetries in preattentive line detection. *Vision Res* 1994; 34: 3103–9.
14. Bach M, Meigen T. Similar electrophysiological correlates of texture segregation induced by luminance, orientation, motion and stereo. *Vision Res* 1997; 37: 409–14.
15. Knierim JJ, van Essen DC. Neuronal responses to static texture patterns in area V1 of the alert macaque monkey. *J Neurophysiol* 1992; 67: 961–80.
16. Lamme VA. The neurophysiology of figure-ground segregation in primary visual cortex. *J Neurosci* 1995; 15: 1605–15.
17. Blakemore C, Tobin BA. Lateral inhibition between orientation detectors in the cat's visual cortex. *Exp Brain Res* 1972; 15: 439–40.
18. Kastner S, Nothdurft HC, Pigarev I. Neuronal responses to orientation and motion contrast in feline striate cortex. *Soc Neurosci Abst* 1995.
19. Allinan J, Miezin F, McGuinness EL. Effects of background motion on the response of neurones in the first and second cortical visual areas. In: Edelman GM, Gall WE and Cowan MW, eds. *Signal and Sense: Local and Global Order in Perceptual Maps*. New York: Wiley-Liss, 1991: 131–41.
20. Kastner S, Nothdurft H-C, Pigarv IN. Neuronal correlates of pop-out in cat striate cortex. *Vision Res* 1997; 37: 371–6.

Address for correspondence: M. Bach, Univ.-Augenlinik, Killianstr. 5, D-79106 Freiburg, Germany

Phone ++49 (761) 270-4060; Fax: ++49 (761) 270-4052; E-mail:bach@uni-freiburg.de