Two Visual Systems and their Eye Movements: Evidence from Static and Dynamic Scene Perception

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Abstract

The existence of two distinct visual pathways in the primate brain is a persistent theme for evolutionary, neurophysiological, motor control and neuropsychological research. As one of the most widely cited results in cognitive neuroscience, this distinction has survived decades of critical analysis under different guises (e.g. ambient vs. focal or visuomotor vs. cognitive). However, the interplay between these two processing streams in the solution of everyday tasks remains to be an unresolved issue. In particular, how do they guide eye movements, their most immediate output? Results from our recent study on hazard perception in a simulated driving environment demonstrated that specific combinations of eye movement parameters are indicative to an involvement of either of the two systems. In a further experiment, we tried to validate these parameters by testing assumptions about memory representations related to these two modes. After a short presentation of various real world scenes, subjects had to recognize cut-outs from them, which were selected according to their fixation parameters. Random cut-outs from not seen pictures (catch trials) were also presented. The results confirmed our hypothesis: cut-outs corresponding to presumably focal mode of processing were better recognized than cut-outs similarly fixated in the course of ambient exploration.

Keywords: Active Vision; Dorsal and Ventral Streams; Ambient and Focal Attention; Scene Perception; Recognition; Eye Movements.

Introduction

In contemporary studies of visual cognition, one can discover several clusters of research that are only loosely connected to each other (for similar arguments, see Simons & Rensink, 2005). An intensive albeit still controversial discussion is, for instance, how and even whether visual information is retained across saccades while viewing a scene (Bridgeman, Van der Heijden, and Velichkovsky, 1994).

Irwin's *object file theory of transsaccadic memory* emphasises the crucial role of visual attention in what local visual information from a scene is or is not represented (Irwin, 1992). Attending an object in a visual scene allows binding its features into a unified object description (Treisman, 1988). This object description is linked to a spatial position in a master map of locations, forming a temporary representation in visual short-term memory (VSTM). According to Irwin (1992) three to four discrete objects can be hold at a time in VSTM. Finally, object files are the primary content of transsaccadic memory providing local continuity from one fixation to the next. More recently, *coherence theory* (Rensink, 2000a, 2000b) proposed a similar explanation of the fact that despite the 'snapshot-like' character of visual information acquisition the world around us is experienced as being stable, coherent and richly detailed. Just as in object file theory visual attention is the premise to bind sensory features into a coherent object representation, which can be hold in VSTM preventing them from disruptions like saccades. Prior to focused attention, proto-objects with only limited temporary and spatial coherence are formed in parallel across the visual field but being volatile and replaced on appearance of a new stimulus at their position. On withdrawal of attention a coherent object resolves into its constituent proto-objects again leaving no or only little after-effect of attention (Rensink, 2000a).

Both these *visual transience hypotheses* (Hollingworth & Henderson, 2002) rely on the idea, that a complete metric representation of a visual scene is neither possible nor necessary. O'Regan and Noe (2001) go even further saying (actually paraphrasing Brooks, 1991, p. 139) “the world serves as its own memory”. One drawback of these approaches to scene perception is, however, that they consider eye movements as mechanical events of no further interest. The classification is simply based on measuring whether the subject is holding their eyes stable at a designated position (fixation) or is doing a jerky eye movement (saccade). Presentation or extinction of visual stimuli (e.g. a scene or an object) is in the majority of cases executed in relation to the start or end of a saccade. The underlying processing, which may be reflected in the variation of fixation durations, is neglected.

There is another line of research analyzing the duration of visual fixations in terms of task complexity, levels of processing or skills, especially for reading tasks (Velichkovsky, 1999). In a recent study by Unema, Pannasch, Joos, and Velichkovsky (2005) subjects viewed computer generated images of rooms containing different interior, in order to be able to answer questions about the distribution of objects within the room or about the presence/absence of *particular objects*. The authors found a clear shift of the ratio of fixation durations and saccadic amplitudes across the tasks and also over the viewing time. At the beginning of image inspection fixations with shorter durations and saccades with longer amplitudes were measured. With increasing inspection time they reported a shift to shorter saccades (stabilized after ca. 2s) and longer fixations (stabilized after ca. 3 to 4s). Similar results were reported by Irwin and Zelinsky (2002), who discovered a continuous increase of fixation duration over a period of 15 fixations, but no explanations were offered for the findings. In fact, already Kahneman (1973, p. 59) discussed the phenomenon as a kind of paradox: if fixation duration is a measure of intensity of visual information processing, then why at the beginning of perception of a new picture when there is more information to be processed visual fixations are shorter and not longer?

In still another line of research, visual processing has been described in terms of two-stage models (Hoffman, 1999; Norman, 2002; Velichkovsky, 1982). Though earlier statements can be found (Bernstein, 1947), the distinction of two routes of visual processing in the brain came to prominence with a special issue of *Psychologische Forschung* in 1967 (Held, Ingle, Schneider, & Trevarthen, 1967). In this publication and in the following years, a number of dichotomies have been suggested, such as evaluating-orienting (Ingle, 1967), what-where (Schneider, 1967), focal-ambient (Trevarthen, 1968), examining-noticing (Weiskrantz, 1972), figural-spatial (Breitmeyer & Ganz, 1976) and foveal-ambient (Stone, Dreher, & Leventhal, 1979). Ungerleider and Mishkin (1982) later argued that in primates vision is dominated by distinct cortical mechanisms, ventral and dorsal pathways. This work laid the foundations for the currently dominant model of dual visual processing (Milner & Goodale, 1995), which has been developed partly through studies of neurological patients with selective lesions of brain (Milner et al, 1991; 2003). This later model emphasizes the sensorimotor and cognitive character of dorsal versus ventral processing.

Surprisingly, the idea of two visual systems has never been related to the major output of visual processing that is eye movements. Is it possible that both visual pathways can selectively influence oculomotor mechanisms and that the balance of these influences can change flexibly? Assuming there are indeed different processes accompanied by distinct eye movement behavior it would be interesting to find a method for their reliable distinction, for instance, by a combined consideration of parameters of both, fixations and saccades. Neurophysiology tells us that dorsal stream areas can mediate large saccades throughout much of the visual field on the basis of simple visual properties such as contrast and location. In contrast to this, ventral stream areas receive inputs chiefly from central regions of the retina (Falchier & Kennedy, 2002), but construct a richer, memory-based representation of the stimulus, including its semantic properties (Creem & Proffitt, 1999; Milner & Goodale, 1995).

In a recent study of a simulated driving activity in hazardous conditions, we received evidence that these three lines of research – scene perception, eye movements and visual pathways analysis – are much closer tighten together than it seemed (Velichkovsky et al., 2002). Twelve healthy and well-trained subjects had to drive in a dynamic virtual environment fulfilling all the common rules and in particular preventing accidents. The hazardous events were sudden changes of traffic lights from green to red, pedestrians' appearance on the road and the behavior of other drivers. The experiment, which lasted for five consecutive weeks, has allowed collecting a large database on parameters of eye movements in this dynamic situation and on their correlation with correct or erroneous reactions to dangerous events.

First of all, we found that there is a systematic combination of the visual fixation duration with amplitude of the following saccades. There have been two distinctive segments on the scale of fixation durations. The first segment, with fixations from 90 to about 260 ms, was related to larger saccades of more than 5 deg that is beyond the parafoveal region of retina. In other words, these saccades aimed at targets seen as blobs not as individualized objects – a strong case for the ambient mode of processing. Fixations longer than 260–280 ms rather seemed to be related to focal processing: they initiated saccades mainly within the parafoveal region where objects are relatively easily seen and continuously attended. The next major result of the study was a strong relationship between parameters of two to three visual fixations that immediately preceded a hazardous event and subject performance: if such an event hit them in their ambient processing mode there was a significantly higher chance for an error than otherwise.

Experiment

In the present study, our goal was to validate the findings from the previous experiments in a more traditional, static scene setting. We tried to prove theoretical assumptions about different memory representations linked with each mode of processing. The focal mode has to be memory-based because its underlying ventral pathway utilizes stored representations to identify objects. In contrast, there can be no extensive storage of visual information in ambient mode as its underlying dorsal pathway uses, at most, only a very short-term storage necessary for the execution of immediate motor behavior (see also Post, Welch & Bridgeman, 2003). With these assumptions in mind we predicted, that if the systems can be separated according to eye movement data, the recognition of scene's snapshots must differ for 'ambient' and 'focal' visual fixations.

Method

Subjects Nineteen participants were recruited from psychology courses at Dresden University of Technology. Five subjects were removed from the study for their high false alarm rates in the recognition task (above 80%), and two were removed due to technical problems with the eye movement recording. The data reported below were therefore based on the remaining 12 participants (6 males, 6 females). They either received course credit or € 8 for participating in the experiment.

Stimuli The materials for this experiment consisted of 48 photo realistic scenes of building interiors. Pictures were paired (2 x 24) according to their semantic content, color composition and brightness contrast. One picture of each pair served as the study picture whereas the other was used to generate random cut-outs in the recognition task (catch trials). The pictures subtended 25.6 deg horizontally and 19.8 deg vertically. The cut-outs for the recognition task were 2 x 2 deg in size. Cut-outs were either presented in the center of the screen (*screen-centered* condition) or according to their initial fixation positions (*fixation-centered*) in the study picture. As a second factor the cut-outs were presented either in the order of the fixation sequence in the study phase (*original-order* condition), in the reversed order (*reverse-order*) or in random order (*random-order*). Thus the underlying design was 2 x 3 resulting in 6 conditions.

Apparatus Eye movements were recorded at 250 Hz by using the SR Research Ltd. EyeLink eye tracking system with on-line detection of saccades and fixations. Fixation onset was detected and transmitted to the presentation system with a delay of approximately 12 ms. Pictures were displayed using a GeForce2 MX card and a CRT display (19-inch Iiyama Vision Master 451) at 1152 by 864 pixels at a refresh rate of 100 Hz.

Procedure Subjects began the experiment by reading the instruction given on the stimulus screen. The same instruction was presented orally from the computer. After restating the instruction subjects performed a nine-point calibration routine. Calibration was repeated if any fixation point was in error by more than one deg or if the average error for all points was above 0.5 deg. Subjects were given initially two study trials in order to get acquainted with the task. Calibration was repeated every second picture and each picture presentation was preceded by a drift correction. The experiment consisted of two blocks of study trials with 12 pictures each. A short break was given between the blocks.

After 20 fixations (study phase) the picture was removed and subjects were shown 30 cut-outs – intermixed 20 of the original picture as well as 10 random cut-outs from the corresponding catch-trial pair. Subjects had to decide whether the given cut-out belongs to the previously seen picture or not. They also had to indicate the certainty of their answer on a five-point scale by choosing “0”, “25”, “50”, “75” or “100”. Subjects were unaware that the cut-outs were selected according to their fixation positions in time or in space (see below). Following completion of the experiment, the participants were given a questionnaire asking for strategies of the task solution.

A given subject was tested with 24 pictures, 4 in each condition (screen-centered/original order, screen-centered /reversed order, screen-centered/random order, fixation-centered/original order, fixation-centered/reversed order, fixation-centered/random order). Assignment of pictures to conditions was counterbalanced so that each picture appeared equally often in each condition across subjects. The experiment lasted approximately 1 h 15 min.

Results

In the analysis of eye movement data, only fixations of duration within the range from 20 ms to 600 ms were further taken into account. Fixations with distances of closer than 1.5 deg within an image were recognized as refixations and were also discarded from a further analysis. In sum, this trimming process excluded 36.5% of all fixations.

As a consequence of the experimental setup subjects' recognition responses could be classified as “hit”, “miss”, “false alarm” or “correct rejection” in terms of signal detection theory. Therefore we converted subjects' performance data into measures of *d'* to compare influences of presentation order (original, reversed, random), presentation position (screen-centered, fixation-centered) and eye movement behavior (fixation duration, saccadic amplitude, combination of fixation duration and saccadic amplitude) on recognition performance.

In processing data, we firstly entered the *d'* values into a two-way repeated measures ANOVA to analyze the influences of temporal order and spatial position. No significant effects were found, neither for presentation order, F (2,22) = 0.425, p = .659, nor for presentation position, F (1,11) = 0.152, p = .704. The interaction of both factors however was significant, F (2,22) = 3.649, p < .05, revealing a recency effect that was apparent in reversed-order testing for screen-centered conditions and a spatial compatibility effect of the cut-out's position within the picture but only for random-order presentation. This interaction will not be discussed here further due to the nonsignificant main effects.

Figure 1 shows the Median for subsequent saccade amplitudes for all fixations up to 600 ms. A drop in the amplitudes of saccades can be seen at around 180 ms. Therefore fixations longer than 180 ms are labelled henceforth as *long* fixations, whereas fixations shorter than 180 ms are categorized as *short* fixations. Due to the fact that only objects within a region of circa 5 deg around the center of the fovea can be processed by (para)foveal vision, a second cut-off was made at this point (Figure 1, horizontal dotted line).

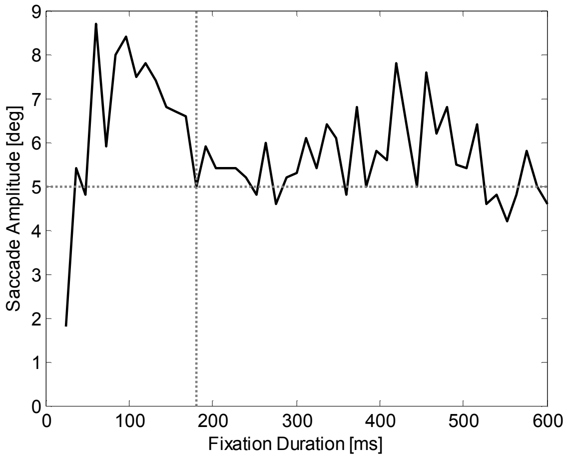

Figure 1: Saccadic amplitude as a function of fixation duration.

The one-way repeated measures ANOVAs revealed significant differences for *d'*, F (1,11) = 23.967, p < .001,

$\eta 2 = .685$, for the categorization based on fixation duration and $F\ (1,11) = 5.416$, $p < .05$, $\eta^2 = .330$ for the categorization based on saccade amplitudes. Values for *d'* are smaller for shorter fixations ($M = 0.78$) and larger saccades ($M = 0.84$), whereas longer fixations ($M = 0.94$) and shorter saccades ($M = 0.97$) are accompanied by better discrimination results. The combination of both parameters again revealed significant differences for *d'*, $F\,(3,33) = 9.199$, $p < .001$, $\eta^2 = .455$. As can be seen in Figure 2, the combination of short fixations with subsequent long saccades differs significantly from both long fixation conditions, $p < .005$, whereas for short fixations followed by short saccades the significance level is marginally exceeded, $p = .093$.

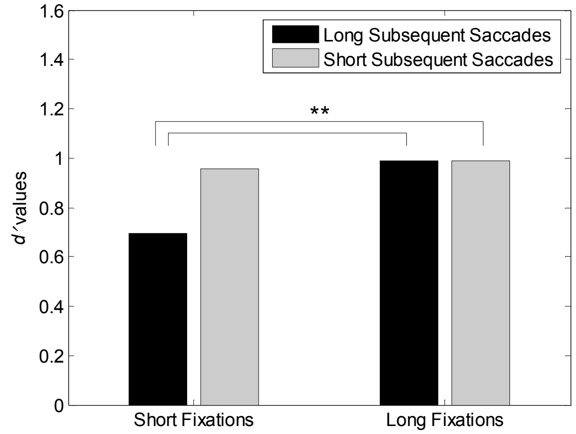

Figure 2: Mean *d'*-values for the four fixation duration and saccade amplitude combinations.

Of particular interest are therefore data on how subjects estimated the certainty of their responses in the recognition task. We aggregated these subjective estimations using the Median over the four eye movement categories described above resulting in a pattern similar to that of *d'* (see Figure 3). The application of the Friedman test again revealed significant overall differences for the certainty judgements, $p < .005$. Paired comparisons using the Wilcoxon rank signed test demonstrated statistically significant differences for the combination of short fixations and subsequent long saccades from the other three conditions, $p < .05$.

In a further analysis, we checked up a possible dependency of fixation durations and saccadic amplitudes on the viewing time. Replicating previous reports (Irwin and Zelinsky, 2002; Unema et al., 2005), this dependency has been indeed confirmed but only for the first 2 to 3 fixations (saccades) – probably due to a piecemeal character of our testing procedure. A post-hoc comparison of average temporal positions of fixation and saccades in the four categories furthermore revealed that they belonged to the middle part of the sequence of 20 fixations/ saccades at the study phase.

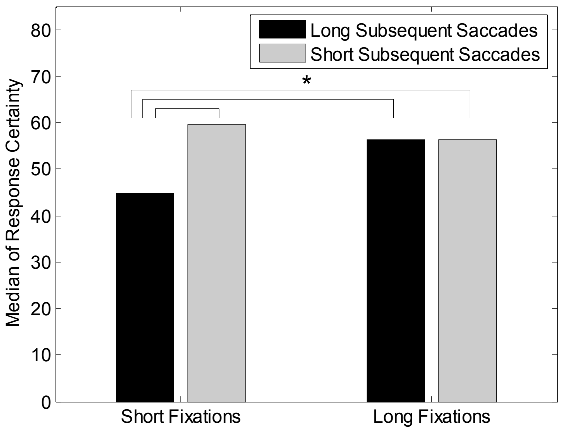

Figure 3: Median of Response Certainty relative to the fixation duration and saccade amplitude combinations.

Discussion

The results of the study testify that the particular version of recognition task using very narrow cut-outs of initial scenes could be afforded by subjects though only with efforts and with a relatively high proportion of false alarms. It may be of interest that 5 subjects that demonstrated excessive false alarm rates and have to be discarded on this reason from further consideration all had on average a remarkably large proportion of short fixations, ca. 40 % more than the rest of the group.

The essential result is of course the clear dependence of recognition performance on the duration of fixations at study phase and, to a slightly lesser extent, on their saccadic context. Here the question is whether these results can be explained by a gradual accumulation of information over time of fixation what also could, on the first sight, explain our results in a dynamic setting (Velichovsky et al., 2002) or a more complex explanation is needed, one that takes into account possible qualitative differences between modes of processing between and perhaps also within separate fixations.

There are at least two facts that, in our opinion, make this second hypothesis more parsimonious. First of all, data on short and long fixations in context of short-range saccades demonstrate not only a relatively good recognition but also a subjects' significantly higher confidence in the correctness of answers. This pattern of eye movements gives evidence for focal processing mode so is the recognition performance that presupposes an involvement of the ventral visual pathway. An alternative explanation that short saccades may permit a preview for information in immediate neighborhood can be rejected because we excluded all fixations related to saccades with amplitudes of less than 1.5 deg. The second fact is the changing pattern of saccades and fixations over the time of scene viewing that has been observed in this study and in a number of earlier works (e.g. Kahneman, 1973; Unema et al., 2005). The fact is compatible with the idea that the dorsal system – with its function of exploring the spatial layout – dominates initially the processing of a scene. On this basis and with a time lag, a more focal, object-directed processing emerges based on the involvement of ventral visual stream. The hypothesis that visual information gradually accumulates over time of fixation would rather lead to wrong predictions (see above).

By comparing these results with data from our driving simulation study (Velichkovsky et al., 2002), we can see similarities as well as differences. Firstly, fixations were on average longer in the dynamic environment. Secondly, while demonstrating the same global shape, the function related fixation durations and saccade amplitudes in dynamic conditions was also extended towards longer times so that the critical drop that differentiated the 'short' and the 'long' of fixation durations has been observed at about 300 ms. Both these facts can be naturally explained by a smooth pursuit component of the most of fixations. Furthermore, in a dynamic setting there is no asymmetry of eye movement over time of viewing as the activity is continuous. The phases of ambient processing (shorter fixations and long-range saccades) are also more apparent. Again, a parsimonious explanation is that motion in the field biases the balance of both underlying systems towards motion-sensitive dorsal mechanisms. We cannot propose any account of this fact from the hypothesis of a pure accumulation of information during the time of fixation.

All evidence for a relationship between eye movements and the brain mechanisms presented here is indirectly demanding further studies with measurement of brain activity. We believe that these studies will finally show that different topics of the contemporary literature in visual cognition are not insulated domains but approaches converging on the same functional and structural mechanisms.

A word of caution is that the ambient-focal model certainly is a theoretical simplification as there are controlling instances 'above' the object-oriented focal stage. In particular, conceptually-driven (semantic), and self-referential (metacognitive) processes characterize these mechanisms that residue in the frontal structures of the brain (Posner, 2004; Velichkovsky, 2002). Furthermore, training and expertise can lead to the automatization of skills, so that with time their components can be processed at lower levels. Nevertheless the model is a useful first approximation to consider eye movements from the multilevel perspective. One can expect that higher levels of encoding may be correlated with longer fixations. Indeed, levels of encoding in visual memory tasks could be isolated by the analysis of fixations (Velichkovsky, 1999).

Conclusions

Our data from studies of scene perception in static and dynamic settings demonstrate a systematic relationship between parameters of individual visual fixations and recognition performance. This relationship can be parsimoniously explained by a balanced control on the part of dorsal and ventral visual pathways that have different access to memory representations. If supported by further studies, this conclusion may lead to a possibility of an on-line behavioral monitoring of relative dominance in underlying neurophysiological mechanisms.

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References

Bernstein, N. A. (1947). O postrojenii dvizhenij [On the construction of movements]. Moscow: Medgiz.

Breitmeyer, B., & Ganz, L. (1976). Implications of sustained and transient channels for theories of visual pattern masking, saccadic suppression and information processing. *Psychological Review, 83*, 1-36.

Bridgeman, B., Van der Heijden, A. H. C., & Velichkovsky, B. M. (1994). A theory of visual stability across saccadic eye movements. *Behavioral and Brain Sciences, 17*(2), 247-292.

Brooks, R. (1991). Intelligence without representation. *Artificial Intelligence, 47*, 139-159.

Creem, S. H., & Proffitt, D. R. (1999). Separate memories for visual guidance and explicit awareness. In B. H. Challis & B. M. Velichkovsky (Eds.), *Stratification in cognition and consciousness* (pp. 73-96). Amsterdam: John Benjamins Publishing Company.

Falchier, A., & Kennedy, H. (2002). Connectivity of areas V1 and V2 in the monkey is profoundly influenced by eccentricity. *FENS Abst., 1*, A051.058.

Held, R., Ingle, D., Schneider, G., & Trevarthen, C. (1967). Locating and identifying: Two modes of visual processing. A symposium. *Psychologische Forschung, 31*, 42-43.

Hoffman, J. E. (1999). Stages of processing in visual search and attention. In B. H. Challis & B. M. Velichkovsky (Eds.), *Stratification in cognition and consciousness* (pp. 43-71). Amsterdam: John Benjamins Publishing Company.

Hollingworth, A., & Henderson, J. M. (2002). Accurate Visual memory for previously attended objects in natural scenes. *Journal of Experimental Psychology: Human Perception and Performance, 28*(1), 113–136.

Ingle, D. (1967). Two visual mechanisms underlying the behavior of fish. *Psychologische Forschung, 31*, 44-51.

Irwin, D. E. (1992). Memory for position and identity across eye movements. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18*(2), 307-317.

Irwin, D. E., & Zelinsky, G. J. (2002). Eye movements and scene perception: memory for things observed. *Perception & Psychophysics, 64*(6), 882-895.

Kahneman, D. (1973). *Attention and effort*. Englewood Cliffs: New Jersey: Prentice-Hall.

Milner, A. D., Dijkerman, H. C., McIntosh, R. D., Rossetti, Y., & Pisella, L. (2003). Delayed reaching and grasping in patients with optic ataxia. *Progress in Brain Research, 142*, 225-242.

Milner, A. D., & Goodale, M.-A. (1995). *The visual brain in action*. Oxford, UK: Oxford University Press.

Milner, A. D., Perrett, D. I., Johnston, R. S., Benson, P. J., Jordan, T. R., & Heeley, D. W. (1991). Perception and action in 'visual form agnosia'. *Brain, 114 (Pt 1B)*, 405-428.

Norman, J. (2002). Two visual systems and two theories of perception. *Behavioral and Brain Sciences, 25*(1), 73-144.

O'Regan, J. K., & Noe, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioural and Brain Sciences, 24*(5), 939-973.

Posner, M.I. (2004). Progress in attention research. In M.I. Posner (Ed.), Cognitive neuroscience of attention. New York: The Guilford Press.

Post, R.B., Welch, R.B., & Bridgeman, B. (2003). Perception and action: Two modes of processing visual information. In J. Andre, D.A. Owens & L.O. Harvey (Eds.), *Visual perception: The influence of H.W. Leibowitz* (pp. 143-154). Washington, DC: APA.

Rensink, R. A. (2000a). The dynamic representation of scenes. *Visual Cognition, 7*, 17-42.

Rensink, R. A. (2000b). Seeing, sensing, and scrutinizing. *Vision Research, 40*(10-12), 1469-1487.

Schneider, G. E. (1967). Contrasting visuomotor functions of tectum and cortex in the golden hamster. *Psychologische Forschung, 31*(1), 52-62.

Simons, D. J., & Rensink, R. A. (2005). Change blindness: past, present, and future. *Trends in Cognitive Sciences, 9*(1), 16-20.

Stone, J., Dreher, B., & Leventhal, A. (1979). Hierarchical and parallel mechanisms in the organization of visual cortex. *Brain Research Review, 1*, 345-394.

Treisman, A. (1988). Features and objects: The fourteenth Bartlett memorial lecture. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 40*, 201-237.

Trevarthen, C.-B. (1968). Two mechanisms of vision in primates. *Psychologische Forschung, 31*, 299-337.

Unema, P. J. A., Pannasch, S., Joos, M., & Velichkovsky, B. M. (2005). Time course of information processing during scene perception. *Visual Cognition 12*(3). 473-494.

Ungerleider, L., & Mishkin, M. (1982). Two cortical visual systems. In D. J. Ingle, M. A. Goodale & R. J. W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 549-586). Cambridge, MA: MIT Press.

Velichkovsky, B. M. (1982). Visual cognition and its spatial-temporal context. In F. Klix, J. Hoffmann & E. v. Meer (Eds.), *Cognitive research in psychology* (pp. 63-79). Amsterdam: North Holland.

Velichkovsky, B. M. (1999). From levels of processing to stratification of cognition. In B. H. Challis & B. M. Velichkovsky (Eds.), *Stratification in cognition and consciousness* (pp. 203-235). Amsterdam: John Benjamins Publishing Company.

Velichkovsky, B. M. (2002). Heterarchy of cognition: The depths and the highs of a framework for memory research. *Memory, 10*(5/6), 405-419.

Velichkovsky, B. M., Rothert, A., Kopf, M., Dornhoefer, S. M., & Joos, M. (2002). Towards an express diagnostics for level of processing and hazard perception. *Transportation Research, Part F, 5*(2), 145-156.

Weiskrantz, L. (1972). Behavioral analysis of the monkey's visual system. *Proceedings of the Royal Society of London (Biology), 182*, 427-455.