High- and low-level factors in visual attention

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This is a cumulative doctoral thesis that includes four articles published in peer-reviewed journals. The journal articles are not included in this electronic version of the dissertation due to copyright reasons. Instead, only the abstracts are embedded into this synopsis, but the corresponding URL of each article is provided. All articles are open access and can be simply achieved by clicking on the URL.

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Abstract

The visual sense has outstanding importance for humans' interaction with the environment and visual attention is the key mechanism that bundles our limited cognitive resources in order to enhance the perceptual processing of the most relevant environmental features at a certain point in time. Eye-Tracking technology enables us to accurately observe peoples' eye movement behavior i.e. overt attention. In the last decade, overt attention on real-world scenes gained increasing popularity in vision research. The higher ecological validity of such scenes in combination with a free-viewing task allows us to investigate human viewing behavior under natural conditions. In this context, the majority of previous studies focused on the impact of basal image properties, such as color and luminance differences, to quantify the extent to which our fixation behavior is guided by these so-called low-level image properties. However, in most experimental studies complex images are observed only one time, whereas we are continually confronted with repeated visual impressions in everyday life. Therefore, I introduce a repeated-presentation-design that allows scrutinizing the impact of low-level image properties and the power of scene types over time. Besides these low-level factors, I also address inter-individual differences in motivation as well as emotional components as so-called high-level factors in overt attention. Previous research on visual attention has widely neglected these factors, especially in the context of real-world images. On the basis of novel study designs and by means of various analysis techniques, I show how several low- and high-level factors influence overt attention on complex scenes, how they interact, and how eye movement parameters are interrelated.
In addition to that, I provide a comprehensive review of the previous literature on emotions' and personality traits' impacts on visual attention. On the basis of the inconsistent understanding of core concepts in the literature, I describe how behaviorally oriented studies investigate these high-level factors in visual attention, how the interplay between emotion and attention is conceptualized from a neuroscientific perspective, and I derive several conceptual and practical recommendations for future research. Finally, I outline some new ideas and venues for future research in the general discussion of the present work, for example how eye-tracking might overcome some fundamental problems of classical testing in psychological diagnostics, or how the view of embodied cognition can help us to get a better understanding of high- and low-level factors in visual attention.

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1. Introduction

The present doctoral thesis includes five experimental studies and an additional in-depth literature review. All work was merged to four distinct articles which were recently published in peer-reviewed journals. However, before the individual articles are presented, I will introduce into the field in order to provide a basis that allows understanding my central work by experts but especially by novices in the field of visual attention. In the following I will outline the reason why visual attention is important for humans, some basic concepts, the technique I used, different experimental approaches, and finally the core topic of my thesis.

1.1. Why is visual attention important?

Target-oriented and adaptive behavior in the environment is grounded on sensory inputs which we acquire by means of several sensory systems. In order to appropriately interact with the environment including other people we extract information from several sensory cues, inter alia, visual cues (Allison, Puce, & McCarthy, 2000), temperature cues (Williams & Bargh, 2008), haptic cues (Kaspar & Krull, in press), and vestibular cues (Kille, Forest, & Wood, 2013). Although it is argued that humans as other organisms can respond appropriately to some “perceptual information without the need to cognitively enrich the perceptual input” (Wilson & Golonka, 2013, p. 9), most of this sensory information is used to build a more abstract mental representation of the outside world. Objects are specified by several attributes (e.g. visual, auditory, gustatory, olfactory, and tactile) which are cognitively integrated to a coherent, spatiotemporally continuous, and bounded physical entity (Lewkowicz, 2010). Thereby, each sensory modality contributes relevant information, and recent research revealed that sensory inputs from different modalities interact at very early stages within the sensory-perceptual information processing timeframe (Butler, Foxe, Fiebelkorn, Mercier, Molholm, 2012). However, the visual sense has an outstanding position for human perception. Although we recognize the importance of other sensory modalities – e.g. the auditory sense – at the latest when their (neuro)biological substrate is damaged (Izumikawa, Minoda, Kawamoto, Abrashkin, Swiderski, Dolan, et al., 2005) or their normal functioning is temporarily hampered by experimental manipulations (Kaspar & Rübeling, 2011), the loss of the visual sense hampers our interaction with the environment more than anything else. Given the central role of our visual sense the question arises where to look at in order to gather the relevant sensory information. This is the point where attention comes into play.

Attention is limited and we have to carefully select the features in the environment at which we direct our attention to as attention mediates a more in-depth processing of these features (Chun, Colomb, & Turk-Browne, 2011). In this sense, attention is a bundling of our limited cognitive resources in order to adequately process environmental features which are relevant at a certain point in time (Kaspar & König, 2012). With respect to visual attention, we distinguish between overt and covert shifts of attention. The former are observable as they are constituted by saccadic eye movements (i.e. a jump of the eye from one location to another one), and all experimental studies in this thesis address this kind of visual attention. In contrast, covert shifts of attention occur without eye movements. However, both types are not independent, rather "the relationship of visuospatial attention and eye movements is controversial" (Corbetta, Akbudak, Conturo, Snyder, Ollinger, Drury, et al., 1998, p. 761). For example, we can attend to several locations in the environment without making saccades (Posner, 1980) whereas Hoffman and Subramaniam (1995) found evidence suggesting that we cannot make saccades to a specific location when attending another location. Besides this interrelation between covert and overt shifts of visual attention, Müller, Malinowski, Gruber, and Hillyard (2003) showed that we can also sustain the attention to several spatially distinct regions of the visual field. Hence, the focus of attention does not necessarily fit the current fixated location. Yet, overt shifts of attention are of particular interest for researchers and the validity of these data is assumed to be high. For example, eye movements and fixated locations were found to match well with retrospective verbalization of subjects' attention focus during a problem-solving task (Guan, Lee, Cuddihy, & Ramey, 2006). In another study, Tremblay, Saint-Aubin, and Jalbert (2006) found that the performance in a serial memory task was linked to fixation behavior.

To conclude, visual attention is the most important sensory modality for humans and attention is the key mechanism that bundles our limited cognitive resources in order to enhance the perceptual processing of the most relevant environmental features at a certain point in time. Hence, sometimes the attentional focus is described in terms of a spotlight that moves about the visual scene (Posner, 1980), but other metaphor-like models were also created in order to highlight specific features of attention (e.g. Treisman & Gelade, 1980). In general, we distinguish between covert and overt shifts of attention as described, whereby the latter will be addressed by the experimental studies in this thesis. Finally, I would like to emphasize that, although the idea of attention might appear simple at the first sight, a precise and generally accepted definition of attention is still lacking. I deepen this point in the present review article (Kaspar & König, 2012).

1.2. What is Eye-Tracking?

The rapid technical progress in the last decades enables us to easily track the course of eye movements. The so-called eye-tracking method allows observing human viewing behavior with relatively low costs for study participants. At the beginnings of eye movement research, methods were invasive and involved direct contact with the eye's cornea (Duchowski, 2003), but also first non-invasive, photography-based eye-tracking techniques were developed at the beginning of 19th century (Doge & Cline, 1901). The first head-mounted eye-tracker was invented by Hartridge and Thomson (1948). The camera they used took up to sixty frames per second and the system already controlled for head movements. Importantly, such techniques using the reflection of the eye's cornea (or other eye structures serving as reference points) in order to track eye movements differ significantly from the simple measurement of eye movements that was developed on the basis of electro-oculographic techniques i.e. differences in electric potential evoked by eye movements can be detected by electrodes which are mounted on the skin around the eyes. Today, this technique is still used in the context of electroencephalography (EEG) in order to control for EEG artefacts which derived from eye movements instead of changes in the brain's neuronal activity. However, when speaking of eye-tracking today, we usually mean techniques using video-based tracking of eye movements that was applied first by Fitts, Jones, and Milton (1950) who studied eye movements of pilots while interacting with a cockpit interface. The technique has advanced considerably and currently we track eye movements with very high temporal (up to 1000Hz) and spatial resolution (noise-limited at < 0.01 degree visual angle). Most often, we track changes in pupil position or use the reflection of the cornea to additionally enhance the spatial resolution. Thereby, we can choose between head-mounted and remote systems, each has its own advantages and disadvantages with respect to mobility, well-being of study participants during eye-tracking, and more. Both tracking systems require a calibration procedure before it can provide valid data because the system has to "know" how specific eye positions correspond with attended regions of the stimulus that is observed. More precise, during the calibration phase, the eye tracker learns which pixel coordinates of a monitor screen correspond to which eye position. In addition to the calibration, we must define some parameters and thresholds so that the eye tracker can distinct between fixations and movements i.e. saccades. Although the number of parameters (mainly fixation positions and saccades) we record in eye-tracking studies may appear low at the first sight, the situation changes dramatically in the analysis phase. Then, we can derive a bulk of further eye movement parameters post-hoc as shown in the experimental studies included in this thesis. They allow us to comprehensibly scrutinize human viewing behavior, whereby the parameters of interest highly depend on the experimental paradigm, the kind of stimuli, and the addressed research question.

1.3. What is “overt attention under natural conditions”?

Application areas of eye-tracking are diverse in the field of attention research. The longest tradition in eye movement research addresses reading behavior (c.f. Wade & Tatler, 2009) and it revealed, for example, that we do not read smoothly across a text. Instead we make a pause on some words, but skip others, and we also return to already scanned word elements. Besides linguistic-oriented research, stimuli varying in complexity – from simple dots (e.g. Engel, 1977) to complex real-world scenes (e.g. Land & Lee, 1994; Henderson, 2003) – are used to investigate aspects of human visual attention. While some researchers use artificial stimulus configurations, such as dot patterns, in order to scrutinize specific features of eye movements such as illusory motion perception of stationary objects (e.g. Souman, Hooge, & Wertheim, 2005), other researchers focused on more ecologically valid conditions of viewing behavior by investigating visual attention on web pages (e.g. Buscher, Cutrell, & Morris, 2009; Burmester & Mast, 2010; Kaspar, Ollermann, & Hamborg, 2011; Hamborg, Bruns, Ollermann, & Kaspar, 2012), or on natural scenes (e.g. Parkhurst & Niebur, 2004; Smilek, Birmingham, Cameron, Bischof, & Kingstone, 2006; Torralba, Oliva, Castelhano, & Henderson, 2006; Einhäuser & König, 2010). The latter research tradition is very young and gained increasing popularity within the last decade and it is often labeled as “overt attention under natural conditions” or as “overt attention on real-world scenes”. Although fully mobile recording of eye movements is also possible and enables us to investigate viewing behavior while subjects walk outside the laboratory (e.g. Jovancevic, Sullivan, & Hayhoe, 2006; Einhäuser, Schumann, Bardins, Bartl, Böning, Schneider, et al., 2007), we also speak of natural conditions when subjects sit in front of a computer screen and freely observe natural real-world or similar complex scenes. The experimental studies in this thesis used such a laboratory setting. It is important to note that one experimental setting does not overtrump another one in general. Instead, the choice of setting depends on the conditions and mechanisms of overt attention we are interested in. It is the usual trade-off between internal validity on the one hand, and external validity (i.e. ecological validity, Pawlik, 1976) on the other hand. The more complex the stimulus material becomes in terms of more real-world-like, the less control we have over specific stimulus properties, and hence internal validity might decrease. We compensate this fact by using large stimulus sets so that the individual stimulus compositions are averaged out, and by categorizing stimuli types in order to reduce the between-stimulus variance in subsets of images. Importantly, it is exactly this variation of image properties across images of the same category what is required in order to investigate overt attention under natural conditions. I will pick up this aspect in the general discussion section at the end of this thesis to deepen it against the background of the results I will present in Articles 2.1, 2.2, and 2.3.

In contrast to the internal validity, the external validity increases dramatically due to the realistic stimuli. The most ecologically valid setting can be created when using mobile eye tracker. However, attention research changes completely when doing this step as we have to particularly consider the interplay between sensory and motor systems (c.f. König, Wilming, Kaspar, Nagel, & Onat, in press), and constant experimental manipulations for each subject are difficult to realize. Consequently, for the experimental studies in this thesis I selected a well-controlled laboratory setting while the stimuli were exclusively complex scenes. This trade-off allowed investigating the impact of low- and high-level factors on overt attention in an optimal way.

1.4. What are low- and high-level factors in visual attention?

When talking about low- and high-level factors in visual attention we address the question "What guides visual attention?" As outlined above, attention is the mechanism that bundles our limited cognitive resources in order to adequately process those environmental features being important at a given time. However, who or what decides where to look at? There are many features at the same time which we can attend to, but we cannot simultaneously pay attention to all these features. High- and low factors characterize the potential operation direction of the attention system:

Classical neuroscientific studies of human visual perception conceptualized the brain and visual system as a very passive processor that primarily reacts to sensory inputs from the outside world but that does not actively create meanings (Engel, Fries, & Singer, 2001). According to this view, visual and other sensory information are sequentially extracted and successively recombined so that, at the end, we get a coherent, spatiotemporally continuous, and bounded representation of physical objects (Lewkowicz, 2010). For example, Biederman (1987) formulated a theory in which individual object features, such as edges (but also color and textures), are firstly extracted from the environment and, across various intermediate steps, are matched to an object representation relatively late in the process. In this context, also the classical studies of Hubel and Wiesel (1959, 1968) are of high significance: They investigated the activity of single neurons in cats (1959) and monkeys (1968) and provided strong evidence that specific neurons are sensitive to specific stimuli properties (e.g. color or orientation). Thereby, the specialization of neurons increases at later processing stages. For example, Desimone, Albright, Gross, and Bruce (1984) revealed neurons which are sensitive to faces. Against the background of this hierarchically organized neuronal architecture the prevailing view arises that visual attention is stimulus-driven. An illustrative example for stimulus-driven attention is the "pop-out" of specific environmental features, for example a compulsory look at an abrupt occurring stimulus (Yantis & Jonides, 1984) or to unique environmental features (Treisman & Gelade, 1980). Accordingly, we call this "bottom-up" processing or "low-level" impacts on attention. Sometimes it is not necessary, sometimes impossible, to precisely determine the level in the neuronal hierarchy where a specific stimulus feature has its primary effect, and hence we commonly label effects of simple object features as "low-level" without specifying how much low-level they actually are.

In the context of visual attention on real-world scenes the idea of low-level image properties became very popular in the last decade. On the basis of neurobiological findings Koch and Ullman (1985) developed the so-called "saliency map" (for a review of modified models see Itti & Koch, 2001). The idea is straightforward: visual scenes are compositions of several features which I call "low-level image properties" (Kaspar & König, 2011b), such as luminance, orientation, color, and saturation. These features are analyzed separately with respect to local differences on the image at different spatial scales. At the end, feature maps equally sized as the original image are computed for each feature and are subsequently merged to one saliency map. The saliency map indicates those regions of an image which are more likely to be attended than other regions. The predictions made by a saliency map fit (relatively) well with the actual fixation behavior of humans (Peters, Iyer, Itti, & Koch, 2005). In addition to this approach several researchers have begun to investigate the impact of individual low-level image properties on human viewing behavior. In Article 2.2 of this thesis I give a detailed overview of this research in order to prime new research questions and empirical findings.

In contrast to low-level impacts on attention, high-level factors are much more heterogeneous. It is difficult to give them a joint label. What is the commonality of these factors? It is, simply spoken, the fact that they are so high-level that it would be inappropriate to call them low-level because they include cognitive processes which are not directly linked to the visual system and are often localized in higher brain structures. Hence, we also speak of "top-down" processing when referring to high-level factors' impact on attention. The core idea is that attention is not only modulated by features of the outside world which unintentionally (and perhaps involuntarily) attract attention. Instead, high-level impact on attention includes expectations and task influences, but also previous experience (i.e. in terms of expertise or memory), as well as current emotional and motivational states of the observer. However, surprisingly little research has addressed high-level impacts on attention so far, and in the context of real-world scenes this topic has been largely neglected. In this thesis I show how individual motivation and motivational disposition (Article 2.1) as well as emotional factors (Article 2.3) influence viewing behavior under natural conditions. At the same time, Article 2.2, but also Articles 2.1 and 2.3, demonstrate the strong impact of low-level image properties. Indeed, both mechanisms commonly act simultaneously and a major challenge is to clarify which process is dominant under which conditions and how they interact.

1.5. Synopsis of the journal articles and their relation to each other

In this section I will shortly introduce the articles of this thesis and outline how they relate to each other.

1.5.1. Article 2.1: Overt attention and context factors: The impact of repeated presentations, image type, and individual motivation

In this article I focused on some high-level factors which I thought would affect overt attention under natural conditions.

On the one hand, I was interested in how previous experience i.e. memory affects viewing behavior on complex visual scenes. Underwood, Foulsham, and Humphrey (2009) conducted a study in which subjects observed identical complex scenes two times but with a temporal delay of one week. They found that fixations matched well between the two measurements but the actual scan pattern did not correspond with those predicted by saliency maps. Apart from this study – and a second one by Foulsham and Underwood (2008) – insights in attentional changes over repeated observations of identical static scenes were missing, especially in the case of more than two repetitions. I was interested in how global viewing parameters (i.e. saccade length, fixation duration, number of fixations, and spatial explorativeness), defining viewing activity, as well as the width of the attention focus are sensitive to memory traces of the past. Moreover, I included the inter-subject variance of fixation distribution maps that allows a better understanding of how reliable fixation distributions are. I additionally collected qualitative data in terms of subjects' verbal reports in order to scrutinize whether viewing behavior fits with subjects' individual impression about changes in their viewing behavior. Although such qualitative data are used very rarely in neuroscientific research, Smilek et al. (2006) impressively showed that attention research can benefit from verbal reports in the same way as other empirical disciplines (c.f. Kaspar, Hamborg, Sackmann, & Hesselmann, 2010; Kaspar, Kasten, & Gnambs, in press).

On the other hand, I speculated that in such a context of repeated image observation subjects' motivation would affect the changes in viewing behavior. Because motivation is an interplay between current situational conditions and personal dispositions (Heckhasuen & Heckhausen, 2006), I considered the perceived interestingness of the stimulus material as well as subjects' ability to stay within interesting activities without shifting prematurely to alternative activities – operationalized by means of the action control scale (ACS) developed by Kuhl (1994). In fact, no study had investigated the impact of personality traits on overt attention under natural conditions until then.

In addition to these high-level factors (i.e. memory and personality) I also considered the impact of the image category on viewing behavior. From previous studies in our laboratory (e.g. Acik, Onat, Schumann, Einhäuser, & König, 2009) we know that images of different categories have different influences on viewing behavior due to differences in visual composition (e.g. urban scenes depict sharp edged whereas nature scenes without man-made objects are devoid of such edges). In this sense the impact of image categories on viewing behavior is a signature for low-level effects on attention. Consequently, this study addressed both high- and low-level factors as well as their potential interactions.

1.5.2. Article 2.2: Viewing behavior and the impact of low-level image properties across repeated presentations of complex scenes

This article focuses on the impact of low-level image properties on fixation behavior. Article 2.1 showed that motivation and memory as high-level factors substantially influence overt attention. Additionally, subjects reported that they deliberately decided to scan previously neglected image regions at later presentations. The increasing inter-subject variability in fixation distributions across repeated image observations also indicated that subjects deliberately selected their individual regions of interest and that the low-level impact on viewing behavior decreased. Although these data provided clear evidence for time- and personality-dependent changes in viewing behavior, the question arose whether subjects were actually able to uncouple their fixation behavior from low-level image properties, such as color, saturation, edges, and luminance at different spatial scales.

Consequently, I completely reanalyzed the data of Article 2.1 and collected an additional data set to further scrutinize this research question. I firstly analyzed the eye-tracking data regarding the congruency of fixation distributions across repeated image observations while considering the image category and a simulation of randomly sampled fixations in order to assess effect sizes. This analysis allowed to estimate how strong the fixated regions differ between presentation runs of identical scenes. In this sense, I initially tried to validate subjects' verbal reports on objective eye-tracking data. With respect to the main research question, I analyzed the correlation between low-level image properties and fixation likelihood in order to quantify how much viewing behavior is guided by basal image properties and whether this association actually diminished as stated in subjects' verbal reports.

In addition to that, I included several further analyses to validate results of Article 2.1, but also to reveal further insights in processes of overt attention on real-world scenes. In this context a very in-depth analysis of the interplay between saccade lengths, one the one hand, as well as the correlation between low-level image properties and fixation likelihood, on the other hand, revealed novel evidence for the target accuracy of the human oculumotor system. Finally, I provided evidence that even on the level of low-level image properties between-subject differences are influential.

1.5.3. Article 2.3: Emotions' impact on viewing behavior under natural conditions

Against the background that motivation revealed as an important high-level factor in Article 2.1, I broadened the scope and focused on emotional aspects in Article 2.3. This step is obvious as motivation and emotion are frequently mentioned in the same breath (e.g. Parkinson & Colman, 1995; Lang, Bradley, & Cuthbert, 1998; Pessoa, 2009; Lang, 2010) because they are both fundamentally related to action whereby some theorists assume that "emotion fundamentally stems from varying activation in centrally organized appetitive and defensive motivational systems" (Bradley, 2000, p. 602). However, the concept of emotion is very ambiguous as outlined in Article 2.4.

Emotional impacts on visual perception and attention have been studied in several experimental paradigms, but a potential influence of emotion on viewing behavior under natural conditions had been widely neglected until my work. In Article 2.3, this empirical gap was bridged: In two experiments subjects observed complex scenes of different valence, on the one hand, and neutral target images embedded into a train of emotion-laden scenes, on the other hand. The main research questions were whether emotion-laden scenes differing in valence would be scanned in different ways (as proposed by brain imaging studies, e.g. Sabatinelli, Bradley, Lang, Costa, & Versace, 2007), and whether the viewing behavior on emotion-laden images simply transfers to neutral target images. I used the identical experimental setup and eye movement parameters as in Article 2.1 so that results and effect sizes are comparable. In Study 1, the intensity of the emotional priming was very strong and the study design was optimized to find an effect of emotion, if existent. In Study 2, the intensity of the emotional priming was reduced, but the types of targets were increased. I modified the original study design in order to investigate new research questions which were stimulated by the findings of Study 1. The article concludes with a comparison of the data of Study 2 and some data of Article 2.1 which served as a baseline condition here. Overall, to my best knowledge, this article was the first attempt to examine emotion as a high-level factor on overt attention under natural conditions and its findings should be of value for future research in this area.

1.5.4. Article 2.4: Emotions and personality traits as high-level factors in visual attention: a review

During my work on Article 2.1 and Article 2.3 I realized that personality traits (and other between-subject variables), as well as emotions are underrepresented elements in attention research. Although some work has been done with respect to these high-level factors, there is neither a clear research tradition nor an established systematization of concepts or experimental paradigms. Given these shortcomings of the current literature I tried to systematize the very heterogeneous literature on the impact of emotions and personality traits on visual attention. Firstly, I outlined some definitions and models of attention and emotion. In the next step, I reviewed a bulk of selected experimental studies to show the diversity of paradigms and research questions addressing the interplay between emotions and attention. Afterwards, I presented the current literature that examines the neuronal level of this interplay. Finally I derived several recommendations and theoretical consideration which I think will be fruitful for future research in this area. The last section of the review illustrates that the number of studies investigating personality traits' relation to attention is even significantly smaller than studies addressing the emotional component. In this context I provide some general methodological considerations regarding between-subject designs in attention research. Overall, this review provides an overview about the current literature (including behavioral and neuroanatomic studies) on two widely neglected high-level factors in visual attention. Thus, it also deepens the theoretical background and discussion of the experimental studies presented in Articles 2.1 and 2.3, e.g. the proposed distinction between internally and externally located emotional impacts on attention that was only shortly mentioned in Article 2.3 due to space limitation.

2. Journal articles

The journal articles are not included in this electronic version of the dissertation due to copyright reasons. Instead, the abstracts are presented in the following as well as the corresponding URL. All articles are open access and can be simply achieved by clicking on the URL.

2.1 Kaspar, K. & König, P. (2011a). Overt attention and context factors: The impact of repeated presentations, image type, and individual motivation. *PLoS ONE, 6,* e21719.

2.2 Kaspar, K. & König, P. (2011b). Viewing behavior and the impact of low-level image properties across repeated presentations of complex scenes. *Journal of Vision*, 11(13):26, 1-29.

2.3 Kaspar, K., Hloucal, T. M., Kriz, J., Canzler, S., Gameiro, R. R., Krapp, V., & König, P. (2013). Emotions' impact on viewing behavior under natural conditions. *PLoS ONE, 8,* e52737.

2.4 Kaspar & König (2012). Emotions and personality traits as high-level factors in visual attention: a review. *Frontiers in Human Neuroscience*, *6*, article 321.

2.1. Article 2.1: Overt attention and context factors: The impact of repeated presentations, image type, and individual motivation

Abstract

The present study investigated the dynamic of the attention focus during observation of different categories of complex scenes and simultaneous consideration of individuals' memory and motivational state. We repeatedly presented four types of complex visual scenes in a pseudo-randomized order and recorded eye movements. Subjects were divided into groups according to their motivational disposition in terms of action orientation and individual rating of scene interest. Statistical analysis of eye-tracking data revealed that the attention focus successively became locally expressed by increasing fixation duration; decreasing saccade length, saccade frequency, and single subject's fixation distribution over images; and increasing inter-subject variance of fixation distributions. The validity of these results was supported by verbal reports. This general tendency was weaker for the group of subjects who rated the image set as interesting as compared to the other group. Additionally, effects were partly mediated by subjects' motivational disposition. Finally, we found a generally strong impact of image type on eye movement parameters. We conclude that motivational tendencies linked to personality as well as individual preferences significantly affected viewing behaviour. Hence, it is important and fruitful to consider interindividual differences on the level of motivation and personality traits within investigations of attention processes. We demonstrate that future studies on memory's impact on overt attention have to deal appropriately with several aspects that had been out of the research focus until now.

URL

http://www.plosone.org/article/info%3Adoi/10.1371/journal.pone.0021719

2.2. Article 2.2: Viewing behavior and the impact of low-level image properties across repeated presentations of complex scenes

Abstract

Studies on bottom-up mechanisms in human overt attention support the significance of basic image features for fixation behavior on visual scenes. In this context, a decisive question has been neglected so far: How stable is the impact of basic image features on overt attention across repeated image observation? To answer this question, two eye-tracking studies were conducted in which 79 subjects were repeatedly exposed to several types of visual scenes differing in gist and complexity. Upon repeated presentations, viewing behavior changed significantly. Subjects neither performed independent scanning eye movements nor scrutinized complementary image regions but tended to view largely overlapping image regions, but this overlap significantly decreased over time. Importantly, subjects did not uncouple their scanning pathways substantially from basic image features. In contrast, the effect of image type on feature–fixation correlations was much bigger than the effect of memory-mediated scene familiarity. Moreover, feature–fixation correlations were moderated by actual saccade length, and this phenomenon remained constant across repeated viewings. We also demonstrated that this saccade length effect was not an exclusive within-subject phenomenon. We conclude that the present results bridge a substantial gap in attention research and are important for future research and modeling processes of human overt attention. Additionally, we advise considering interindividual differences in viewing behavior.

URL

http://www.journalofvision.org/content/11/13/26.full

2.3. Article 2.3: Emotions' impact on viewing behavior under natural conditions

Abstract

Human overt attention under natural conditions is guided by stimulus features as well as by higher cognitive components, such as task and emotional context. In contrast to the considerable progress regarding the former, insight into the interaction of emotions and attention is limited. Here we investigate the influence of the current emotional context on viewing behavior under natural conditions. In two eye-tracking studies participants freely viewed complex scenes embedded in sequences of emotion-laden images. The latter primes constituted specific emotional contexts for neutral target images. Viewing behavior toward target images embedded into sets of primes was affected by the current emotional context, revealing the intensity of the emotional context as a significant moderator. The primes themselves were not scanned in different ways when presented within a block (Study 1), but when presented individually, negative primes were more actively scanned than positive primes (Study 2). These divergent results suggest an interaction between emotional priming and further context factors. Additionally, in most cases primes were scanned more actively than target images. Interestingly, the mere presence of emotion-laden stimuli in a set of images of different categories slowed down viewing activity overall, but the known effect of image category was not affected. Finally, viewing behavior remained largely constant on single images as well as across the targets' post-prime positions (Study 2). We conclude that the emotional context significantly influences the exploration of complex scenes and the emotional context has to be considered in predictions of eye-movement patterns.

URL

http://www.plosone.org/article/info%3Adoi%2F10.1371%2Fjournal.pone.0052737

2.4. Article 2.4: Emotions and personality traits as high-level factors in visual attention: a review

Abstract

The visual sense has outstanding significance for human perception and behavior, and visual attention plays a central role in the processing of the sensory input. Thereby, multiple low- and high-level factors contribute to the guidance of attention. The present review focuses on two neglected high-level factors: emotion and personality. The review starts with an overview of different models of attention, providing a conceptual framework and illustrating the nature of low- and high-level factors in visual attention. Then, the ambiguous concept of emotion is described, and recommendations are made for the experimental practice. In the following, we present several studies showing the influence of emotion on overt attention, whereby the distinction between internally and externally located emotional impacts are emphasized. We also provide evidence showing that emotional stimuli influence perceptual processing outside of the focus of attention, whereby results in this field are mixed. Then, we present some detached studies showing the reversed causal effect: attention can also affect emotional responses. The final section on emotion–attention interactions addresses the interplay on the neuronal level, which has been neglected for a long time in neuroscience. In this context, several conceptual recommendations for future research are made. Finally, based on findings showing inter-individual differences in human sensitivity to emotional items, we introduce the wide range of time-independent personality traits that also influence attention, and in this context we try to raise awareness of the consideration of inter-individual differences in the field of neuroscience.

URL

http://www.frontiersin.org/human_neuroscience/10.3389/fnhum.2012.00321/abstract

3. General discussion

In my thesis I investigated overt attention under natural conditions and its dependency on low- and high-level factors. The high-level factors included the interestingness of the task, individual differences in motivational disposition, memory, and emotional impacts. All these factors have been substantially neglected in attention research so far, especially in the field of real-world scenes. In a final review I gave an overview about central definitions, theoretical approaches, and experimental paradigms. I emphasized several theoretical issues and derived recommendations which should be of relevance for future research.

The experimental studies provided strong evidence that human attention is partly determined by high-level impacts. This finding supports the paradigm shift in cognitive neuroscience that was recognized by Engel et al. (2001) about one decade ago. The visual system is not mainly stimulus-driven as proposed by classical theories (e.g. Biederman, 1987). However, the present results also revealed a strong impact of low-level image properties on eye movement parameters. I showed that low-level image properties, such as color, luminance, edges, and saturation, have a constant impact on fixation behavior, but the correlation between these image properties and fixation likelihood is modest in general, as also emphasized by other researchers (e.g. Tatler, Baddeley, & Gilchrist, 2005; Nyström & Holmqvist, 2008). Interestingly, the feature-fixation correlations depended on the length of the preceding saccade, but as shown by means of a novel analysis this effect is not a signature of target accuracy of the human oculomotor system. Finally, the image category revealed as a very strong factor. Images of different categories evoked very different viewing behaviors, but the image type also moderated the effect of some high-level factors on overt attention.

Because much has already been said and discussed in the individual articles, I will finally focus on those aspects which have not been addressed in detail so far:

First of all, I want to deepen the universal impact of the image category on diverse eye movement parameters in all studies. Images of different categories evoked differences in fixation duration, saccade length, and visual explorativeness in terms of entropy, but also in the inter-subject variance of fixation distributions (Article 2.1). Moreover, the image category moderated the time-dependent congruency of fixation distribution maps across repeated observations of identical stimuli, as well as the correlations between low-level image properties and fixation likelihood (Article 2.2). Moreover, the relationship between these feature-fixation correlations and the length of the preceding saccade depended on the image type, as shown in Article 2.2. Article 2.3 demonstrated that the image type also influenced the effect of emotion on overt attention, on the one hand, but that the main effect of the image type on eye movements was surprisingly robust and independent of the emotional treatment, on the other hand.

Consequently, future research has to intensify its effort to systematically investigate the effect of the image category on attention, but it also should develop more detailed criteria which allow clearly differentiating between categories. In the present studies the categorization of images was (relatively) easy as I only used images which were clearly separable. For example, nature images did not include any man-made objects, fractal images were computer-generated structures, and pink-noise images included second-order but random higher-order statistics. In this sense, the effect size regarding image differences was apparently large, but when images become more similar, discrimination becomes more complicated. In Study 2 of Article 2.2, urban images of different complexity were used and an inter-rater agreement was required to validate the pre-selection of image types. Overall, "image classification is a critical task for both humans and computers", and "one challenge lies in the large scale of semantic space" (Deng, Berg, Li, & Fei-Fei, 2010, p. 71). In my opinion, the differences in semantics are the most important point because differences in stimulis' semantic content induce quite different activity patterns on the neuronal level even though the stimuli do not differ regarding physical parameters as we have previously shown (Kaspar, Hassler, Martens, Trujillo-Barreto, & Gruber, 2010). Given the semantic-dependent neuronal activity pattern, it is obvious that images differing in semantic content induce different eye movements as shown in the present experimental studies.

In the context of images, a second aspect seems noteworthy: Currently no standardized and validated image set exists that provides complex images which are suitable for vision research on the one hand, but which independently vary in image valence and arousal, on the other one. In Article 2.3, the International Affective Picture Set (IAPS; Lang, Bradley, & Cuthbert, 2008) was used, but it does not include enough suitable complex scenes which cover the whole spectrum of valence and arousal. Future research on emotional aspects in attention would significantly benefit from a substantial set of appropriate real-world images in high resolution.

Overall, the selection of complex visual scenes is a not a trivial issue as also demonstrated, for example, in the method section of Study 1 in Article 2.3. Although complex scenes make it impossible to control all stimulus properties, we have to select the stimulus material as careful as it is done in other experimental paradigms. Furthermore, it is important to note that the variation of image properties across images of the same category is actually what is required in order to investigate overt attention under natural conditions.

I also want to suggest a radically new view on the relationship between inter-individual differences in motivational dispositions and personality traits at this point. The shown impact of individual disposition and motivation on viewing behavior opens new venues for research in the area of psychological diagnostics: Perhaps it is possible to reliably and validly distinct subjects according to their differences in eye movements on identical “test” images. This could overcome some general problems of classical diagnostics, especially subjects’ tendency to answer in a social desirable way or to (dis-)simulate in order to fit the requirements of a specific job-position. In fact, in a recent study Rauthmann, Seubert, Sachse, & Furtner (2012) demonstrated that differences in several personality traits predicted specific eye movement behaviors. Such findings should motivate researchers to systematically fathom possibilities how to substitute classical psychological tests by short eye movement tests. In this context, the main challenge is to create an appropriate stimulus material that maximizes viewing differences between subjects. Such a research has to refer to well-developed psychological theories about personality constructs and available operationalizations. This idea is similar to those of projective testing in psychoanalysis, but the apparent advantage of an eye-tracking-based approach would be the objectivity in data analysis and interpretation.

In addition to that, the repeated presentation of complex visual scenes is a useful new experimental paradigm. It allows a well-controlled and systematic investigation of how memory-mediated increasing familiarity of the environment changes the allocation of attention to specific features. As shown, the most significant change occured from the first to the second observation of real-world scenes, but further exposure to such scenes had additional effects. Repeated stimulus presentations are also interesting for other complex stimuli, e.g. web pages. For example, there is an ongoing controversy whether repeated exposure to similarly structured web pages induces a schema building process that mediates time-dependent changes in overt attention (e.g. Chalmers, 2003; Kaspar et al., 2011). This paradigm is also useful in the context of natural movies as shown in a study by Dorr, Martinetz, Gegenfurtner, and Barth (2010) who repeatedly presented natural movies and Hollywood trailers to their participants. Similar to the present findings, repeated observation of the same stimuli evoked significant differences in overt attention. Moreover, in general a

repeated-presentation-design is more ecologically valid than the majority of single-presentation-designs as we are “continually confronted with repeated visual impressions” in everyday life (Kaspar & König, 2011a, p. 14).
In this context, it is also important to note that the task itself is a strong high-level factor that triggers top-down guided attention. In the present studies, each subject was introduced to “observe the images as you want” (c.f. Einhäuser & Rutishäuser, & Koch, 2008). This instruction induces a free-viewing mode. In such a mode subjects’ viewing behavior is maximally self-determined (c.f. Article 2.1) but also very sensitive to image properties, i.e. low-level image properties can unfold their effect while subjects’ current inner state (e.g. motivational or emotional) can also affect overt attention in a top-down manner. In this context, Tatler et al. (2005) pointed out that “given any top down effects, different strategies can result in different viewing patterns. During free viewing, the number of strategies is effectively uncontrolled, with different observers employing different strategies and effectively performing different tasks.” (p. 645). While they used a specific task in their study in order to minimize this variability, in the present studies a specific task would have restricted the impact of high-level factors on attention in favour of low-level impacts (c.f. Tatler et al., 2005). From this point of view, the impact of low-level image properties revealed in Article 2.2 indicates the lower limit of the effect size. It is important to note that if the task is changed to an information search task, for example, completely different high-level factors will be influential, such as specific expectations about the locations of interest on a complex scene (Bernard, 2001). Furthermore, the impact of low-level properties can be enhanced (Tatler et al., 2005) or immediately reverse when task-demands change (Einhäuser et al., 2008). Consequently, in the next step it would be interesting to see whether the found effects of repeated image exposure and their interplay with low- and high-level factors are capped or pushed by a specific task.

Finally, I want to emphasize a very interesting view that has been neglected so far in this thesis and in the related literature: In Article 2.4 I proposed a distinction between internally and externally located impacts of emotion that is central for designing studies which examine the impact of emotional components on visual attention. More generally, this idea emphasizes the necessity to consider the origin of a high-level influence. With respect to emotions, this distinction sometimes becomes difficult. For example, when observing high valence stimuli (i.e. externally located emotional cues) at some point in time, the stimulus valence induces a corresponding emotional state in the observer (i.e. the emotional impact becomes internally located). This mechanism is also relevant for other high-level cues. High-level impacts on attention do not necessarily arise from abstract knowledge structures. The view of embodied cognition suggests an interesting idea: Several previous studies showed that incidental bodily sensations evoked by physical cues (e.g. in the haptic modality; for a recent review see Meier, Schnall, Schwarz, & Bargh, 2012) can affect higher cognitive processing. Binder and Desai (2011) argued from a neuroscientific perspective that not only sensory and motor inputs but also affective inputs serve as embodied cues which fleshes out already activated higher cognitive concepts. This view is similar to my concept of externally and internally located emotional cues as it is the same mechanism that is assumed. More generally, the embodiment perspective implies that there are various cues in the environment that activate, or at least manipulate high-level concepts. Given this perspective, there is much to do for attention research in order to identify low-level and high-level impacts on overt attention as well as their interrelations.

4. Disclaimer

All experiments reported in this thesis conform to national and institutional guidelines as well as the Declaration of Helsinki. I guarantee that I wrote this thesis independently and that I have not made use of resources other than those indicated. I guarantee that I significantly contributed to all materials used in this thesis.
Most parts of this thesis were published in various scientific journals (as listed above) and presented at the following conferences or corresponding proceedings:

1. Kaspar, K., & König, P. (2013). Zeitabhängige und zeitinvariante Aspekte des Blickverhaltens auf komplexen Szenen. *TEAP*, 24.-27.3. 2013, Vienna.
2. König, P., & Kaspar, K. (2013). Viewing behavior under natural conditions: The impact of emotions. *TEAP*, 24.-27.3. 2013, Vienna.
3. Kaspar, K., & König, P. (2011). Keine Entkopplung des Blickverhaltens von primären Bildeigenschaften bei wiederholter Betrachtung visueller Stimuli. *Psychologie und Gehirn*, 23.-25.6. 2011, Heidelberg.
4. Kaspar, K., Gameiro, R. R., & König, P. (2011). The Impact of Emotional Priming on Attentional Processing in the Visual Hierarchy. *OCCAM - Osnabrück Computational Cognition Alliance Meeting on "Natural Computation in Hierarchies"*, 22.-24.6. 2011, Osnabrück.
5. Kaspar, K., Canzler, S., & König, P. (2011). The Influence of Emotion as a High-Level Feature on Human Overt Attention. *OCCAM - Osnabrück Computational Cognition Alliance Meeting on "Natural Computation in Hierarchies"*, 22.-24.6. 2011, Osnabrück.
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