Attentional capture by emotional stimuli

Evidence from saccade trajectories

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Abstract

This thesis aims to investigate to what extent the human attentional system adapts to environmental changes of superior relevance. In particular, it aims to study to what extent emotional stimuli capture human visual attention. Because emotional stimuli signal a potential threat or opportunity, they are of superior importance to the organism and should therefore be processed as fast as possible even when they are completely irrelevant for the observer's current goal.

Unfortunately, the paradigms typically used so far to address this question are associated with a number of important methodological issues, which limit the interpretation of the findings in terms of a fast and involuntary attentional processing. For this reason, this thesis employs a different paradigm and a different measure which allow to more validly interpret the effects in terms of attentional capture. The paradigm used in this thesis makes use of the inherent characteristics of the eye movements, in particular, their trajectories as they have been shown to be highly sensitive to covert attentional shifts towards task-irrelevant stimuli (Doyle & Walker, 2001). More specifically, eye movement trajectories have been shown to curve away from a task-irrelevant stimulus, which has been attributed to inhibitory mechanisms operating on the neurons that code the eye movement towards the task-irrelevant stimulus.

Although few previous studies provided evidence for the existence of involuntary higher-order influences on eye movement trajectories, the evidence is still very scarce. Moreover, it suggests that these influences take place only late in time. Therefore, this thesis aims to provide further evidence that eye movement trajectories are influenced by the emotional content of task-irrelevant stimuli as well as to provide evidence that this influence can take place early in time. To this end, a series of five experiments was conducted, in which an eye movement target appeared at the vertical meridian above or below fixation, while a task-irrelevant distractor face depicting an angry, happy, or neutral

expression appeared in one of the four quadrants of the screen. The hypothesis is that due to their particular relevance, emotional facial distractors will appear more salient and therefore will produce more oculomotor activation than neutral faces. As a result, emotional distractors will compete with the target more strongly than neutral distractors (i.e., emotional distractors will more strongly inhibit the target and thus will more strongly prevent it from reaching the threshold). Thus, more inhibition will be required with emotional than with neutral distractors for the target to reach the threshold, leading to stronger trajectory curvature away with emotional than with neutral distractors. In addition, given previous studies showing stronger attentional bias towards negative than towards positive stimuli (i.e., negativity bias hypothesis), a stronger curvature away with angry than with happy distractors is hypothesized.

Experiment 1 successfully replicated the basic effect of eye movement trajectories curving away from neutral distractor stimuli. Experiment 2 investigated eye movement trajectories with schematic facial expressions of emotion. However, no effect of emotion was found in Experiment 2 possibly due to the limited complexity and variability of the schematic faces, which might have produced a habituation effect. Experiment 3, therefore, used pictures of natural emotional expressions as they are more variable and ecologically more valid than the schematic facial expressions and thus decrease the probability of habituation effect. As hypothesized, the emotional expression of the facial distractors modulated saccade trajectories, with angry faces producing stronger curvature away than happy faces. Importantly, this effect was not observed with inverted faces, ruling out the possibility that perceptual features drove the effect of emotion with upright faces. Experiment 4 aimed to provide an even more direct evidence for early involuntary attentional capture by emotional distractors. To this end, conditions were created that have been shown to favor very fast saccades and thus prevent inhibition from taking place (as indicated by curvature towards). The conditions in Experiment 4 were not sufficient to prevent inhibition from taking place. Although the numerical pattern of the results in Experiment 4 was in line with the results in Experiment 3, the effect of emotion was not significant in Experiment 4 possibly due to the increased number of trials with fast saccades and the reduced curvature away effect. However, the effect of emotion was significant across both Experiment 3 and 4, and it did not differ between them, suggesting that the non-significant effect in Experiment 4 might have been due to statistical power limitations. Experiment 5 conceptually replicated the results from Experiment 3 using a more complex task of saccade target selection and more complex target stimuli.

Taken together, the present findings provide support for the hypothesis that the emotional content of a completely task-irrelevant stimulus captures human visual attention in an involuntary manner and very early in time. It seems therefore that the human cognitive system is equipped with highly sophisticated mechanisms that enable the organism to act in a very fast and adaptive manner.

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Preface

Contrary to our subjective impression, we can see only a very small part of our visual field in great detail. In fact, it has been estimated that our brain would weigh several tons if we could process our entire visual field with the same precision we process this small part (Findlay & Gilchrist, 2003). Even more importantly, the acuity with which we can visually process the objects from our visual field drops off very rapidly in the periphery. Therefore, in order to have a fine-detailed picture of the world surrounding us, we need to constantly (typically 2-3 times per second) orient our gaze to new objects and locations from our visual field (Gilchrist, 2011). This type of eye movements is termed saccades and defined as very fast movements of the eyes that are followed by a fixation period of time, during which the eyes are relatively stationary and visual information can be gathered (see Gilchrist, 2011, for a recent review on saccadic eye movements).[1]

In everyday life, where our eyes are going to land next is very often driven by our current task or goal. For example, if we are in the supermarket looking for a honey pot to buy, our eyes are very likely to go to the honey pot on the shelf in front of us while ignoring the other types of products surrounding it. But what would happen if the moment we decide to look at the honey pot, the supermarket customer next to us directs an angry look at us? This angry person clearly constitutes a threat to us and is therefore of particular importance to our well-being and probably even for our survival if we think of other contexts. It would be therefore in our interest to register and process that danger as fast as possible so that we can act in a fast and adaptive manner, for example by running away, starting fighting, or simply asking the person if everything is alright. As previously mentioned, however, in order to be processed

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[1] This thesis focuses exclusively on the saccadic eye movements, which are to be distinguished from other types of eye movements such as the pursuit eye movements (see Barnes, 2011, for a recent review) and the microsaccadic eye movements (see Martinez-Conde & Macknik, 2011, for a recent review).

effectively, a peripheral stimulus needs to be fixated by our eyes. Otherwise, only very limited amount of information can be extracted about the stimulus, which might be insufficient for us to get the clear picture we need in order to act adequately. Thus, a conflict or a competition arises in our visual system between our initial target (the honey pot) and the unexpected distracting information (the angry person), which is of superior relevance. In such a “conflict” situation, there seem to be two possible outcomes. The first possible outcome is that the honey pot “wins” the competition, suggesting that the angry person did not attract our attention. Whereas it clearly enables us to effectively accomplish our tasks and pursue our goals, such “straightforward” behavior might turn out maladaptive in the long run as it cannot protect us from potential dangers. The second possible outcome is thus that the angry person “wins” the competition such that instead of looking towards the honey pot we look towards the angry person. Such outcome clearly indicates that the angry person attracted our attention. Importantly, such “as-a-precaution” behavior protects us from potential threats as it enables us to inspect the stimulus of interest in greater detail. However, such behavior might also turn out maladaptive in the long run as it would make us unable to effectively pursue our goals or accomplish our tasks. Instead, we would be constantly distracted by information that initially seemed to be a threat, but eventually turned out to be a false alarm.

Importantly, a look towards the honey pot would not necessarily mean that the angry person did not attract our attention. In particular, if the reaction time with which we direct our gaze towards the honey pot is slowed down by the presence of the angry person (as compared to the presence of a person with neutral facial expression), one might infer that the angry person indeed attracted our attention to a certain extent, but not to the extent that we give up our initial goal. Thus, as it allows us to pursue our current goal while remaining vigilant for potential dangers, such behavior seems to be much more adaptive than the previous two.

Although it is reasonable to assume that emotional relevance affects attention, cognitive psychology had neglected the emotional relevance of stimuli for long time. The interest in the interaction between emotional stimuli and attention emerged only about two decades ago, when researchers started extensively using paradigms from the cognitive psychology field in combination with emotionally connotated stimuli (for a review, see Yiend, 2010). As a result, the research on the interaction between emotional relevance and attention has been mainly dominated by two behavioral measures: reaction times and errors. However, whereas the everyday life example described above related the two measures to eye movements (i.e., the time taken to look towards the task-relevant stimulus vs. whether the eye movement is correctly directed towards the task-relevant stimulus), the research on attentional processing has mainly used reaction times and errors of *manual* reactions (e.g., the time to press a key button vs. whether the correct key button is pressed). From a sceptical point of view, whether one derives the two measures from eye movements or from manual reactions should not make a big difference. After all, in both modalities the same aspects of performance are measured (i.e., speed vs. accuracy). Moreover, as a part of the cognitive revolution in psychology, the research on visual attention focused mainly on covert attention, thus neglecting the motor aspects of attention orienting (i.e., the eye movements; see Findlay & Gilchrist, 2003). Last but not least, for long time the recording of eye movements used to be very difficult and highly intrusive for participants, which prevented researchers from measuring eye movements.

However, as previously illustrated, eye movements are our natural way of visual selection. Thus, understanding the processes underlying eye movements would provide us with more valid knowledge about visual attention. In fact, by focusing solely on reaction times and errors (i.e., the *outcome* of the cognitive process), one runs the risk of ignoring the *temporal* and *spatial dynamics* of the cognitive processes as well as many other eye movement characteristics, the study of which might further our understanding about the dynamic properties of the cognitive processes (Spivey, 2007). To come back to the dilemma situation described above, in which the visual system must “decide” whether to direct the eyes to the honey pot or the angry person: Whereas a delayed look to the honey pot indeed allows to effectively accomplish our current task (i.e., to look at the honey pot) while processing potentially threatening information from the periphery, this kind of behavior still does not seem adaptive enough as it compromises the temporal efficiency with which the current task is accomplished. Interestingly, eye movement *trajectories* have been shown to be particularly sensitive to the presence of task-irrelevant stimuli, indicating attentional processing of that stimuli. Eye movement trajectories have been observed to involuntarily curve away from a task-irrelevant stimulus (e.g., Doyle & Walker, 2001). Moreover, many distractor effects on trajectories have been repeatedly observed in the absence of latency differences, suggesting that eye movements trajectories are a highly sensitive measure of attentional processing (see Van der Stigchel, 2010, for a recent review). Given this line of evidence, it is therefore reasonable to assume that in the conflict situation described above our eyes will neither go towards the angry person, nor will they go towards the honey pot with delayed reaction time. Instead, on their way to the honey pot our eyes might simply curve away from the angry person without compromising the reaction time. Similarly to the outcome described above, this outcome would suggest that the angry person attracted our attention without compromising the effectivity of our task performance. In the long run, however, such “flexible” behavior might prove the most adaptive one as it does not compromise the temporal efficiency of task performance.

Importantly, the evidence that eye movement trajectories are influenced by task-irrelevant higher-order information such as emotional relevance is still very sparse (see Chapter 3, for a review). The aim of this thesis is therefore to provide further evidence that emotional stimuli do indeed influence eye movement trajectories. Demonstrating that eye movement trajectories are influenced by the emotional connotation of task-irrelevant information would provide strong evidence that even at a very basic level of attentional processing our cognitive system does not operate in a hard-wired encapsulated way, but is highly adaptive to environmental changes of superordinate relevance to the organism. Crucially, demonstrating an effect of emotional distractor stimuli on eye movement trajectories in the absence of an effect on eye movement latencies would provide strong evidence that the low-level adaptation of our cognitive system to those environmental changes does not take place at the expense of the observer’s current goal, but that it operates in a temporally highly efficient way.

From a paradigm-oriented view, investigating the effects of emotional distractor stimuli on eye movement trajectories allows to overcome some important methodological issues associated with the paradigms that have been typically used to investigate the involuntary attentional allocation towards emotional stimuli. As will be seen in Chapter 1, the evidence from those paradigms indeed suggests attentional bias towards emotional stimuli. However, it will also become clear that strictly speaking these paradigms do not allow an interpretation in terms of a *fast* and *involuntary* attentional processing, thus pointing to the necessity of gaining convergent evidence from other paradigms and other measures.

In Chapter 2, the saccade trajectory measure and the paradigm based on it are introduced. In addition, the population coding theory (e.g., Godijn & Theeuwes, 2002; McSorley, Haggard, & Walker, 2004; Tipper, Howard, & Houghton, 2000) and the race model (e.g., Godijn & Theeuwes, 2002; Trappenberg, Dorris, Munoz, & Klein, 2001) are described as they provide an explanation of the underlying mechanisms of saccade target selection, and can thus explain the distractor effects on saccade trajectories and saccade latencies. As will be seen in Chapter 2, saccade trajectories appear to be a promising continuous measure that taps into the spatially and temporally dynamic properties of attentional processing and allows to investigate involuntary attentional orienting towards emotional stimuli.

In Chapter 3, the empirical evidence for higher-order influences on eye movement trajectories is reviewed. It will become clear that the empirical evidence for higher-order influences on eye movement trajectories is still very scarce, pointing to the necessity of gaining further evidence for higher-order influences on saccade trajectories.

Chapter 4 outlines the aim and the scope of this thesis. The main differences with regard to stimulus material, experimental procedure, and trajectory measure compared to previous studies are addressed. The main hypothesis is then formulated, namely that the emotional content of a distractor stimulus affects the trajectory modulation effect.

Chapter 5 describes five experiments, in which this hypothesis was tested. Taken together, the results from these experiments support the hypothesis that eye movement trajectories are influenced by the emotional content of the distractor stimuli, even when these stimuli are completely irrelevant for the observer's current task. In contrast, no differences were observed in eye movement latencies.

Chapter 6 summarizes the experimental results and discusses them with regard to the existing literature. In addition, it points to the limitations of this thesis that need to be considered in future research. Finally, questions for future research are discussed such as possible modulation of the emotion effect on saccade trajectories by motivational and interindividual variables.

1 Attentional processing of emotional stimuli

1.1 Theoretical foundations

1.1.1 Attentional processing of emotional stimuli and the concept of selection

"*Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought. Focalization, concentration, of consciousness are of its essence. It implies withdrawal from some things in order to deal effectively with others, and is a condition which has a real opposite in the confused, dazed, scatter-brained state which in French is called distraction, and Zerstreutheit in German.*" (James, 1890)

As observed already by James (1890), the concept of *selection* plays a central role in attentional processing. Attention and selection, however, started receiving profound scientific interest much later, in the 1950s, with the start of the cognitive revolution. To investigate the mechanisms underlying visual selection, attention researchers typically design a simple task, which requires participants to visually process a stimulus presented on the display and subsequently give a discrete manual response based on this processing (e.g., a button press). The key assumption in this approach is that cognitive processing must be completed in order for the response to be given. Therefore, the speed of giving a response is assumed to reflect the speed of cognitive processing. Importantly, in order to validly attribute the effects found on performance to cognitive processing alone and not to response-related processes, attention psychologists have made particular efforts to isolate cognitive processes (i.e., *stimulus selection*) from response-related processes (i.e., *response selection*). Stimulus selection has been extensively studied in the last decades (Johnson & Proctor, 2004; Pashler, 1998; Styles, 2006). Among the questions that have received particular interest in the literature are when stimulus selection takes place (i.e., to what extent is a particular information processed before it gets selected for attentional processing; e.g., perceptual processing vs. semantic processing), how stimulus selection takes place (i.e., what are the exact mechanisms underlying stimulus selection; e.g., inhibition vs. activation), and why stimulus selection takes place (i.e., what is the function of stimulus selection; e.g., perception vs. awareness vs. action).

Which stimuli are selected for attentional processing is strongly driven by the observer's current goal. Therefore, a complete understanding of stimulus selection must include an understanding of the process of *goal selection* and the interactions between the two processes. Despite its central role in attentional processing, goal selection has received remarkably little interest in the literature on attention. This might be not surprising given that in the laboratory the goal is clearly defined by task instructions, making the investigation of goal selection processes difficult to implement. The process of goal selection started drawing more interest about two decades ago, when researchers started studying the effects of emotional stimuli on attention (see Yiend, 2010, for a review). As they have potential consequences for one's well-being (i.e., opportunities) and survival (i.e., dangers), emotional stimuli constitute a strong competitor to the observer's current goal and are therefore assumed to automatically capture observer's attention. Thus, the study of the effects of emotional stimuli on attention would provide important insights into how flexible the process of stimulus selection is.

1.1.2 Attentional biases towards negative stimuli and the concept of automaticity

Although it is reasonable to assume that attention is biased towards both positive (i.e., opportunities) as well as negative information (i.e., dangers), overlooking a danger is often more harmful than overlooking an opportunity. Therefore, from an evolutionary point of view, an attentional bias towards negative information seems to be more adaptive than an attentional bias towards positive information. The research on attention towards emotional stimuli has been therefore strongly dominated by the *negativity bias hypothesis*, according to which attention is particularly biased towards negative information (e.g., Hansen & Hansen, 1988; Pratto & John, 1991).

Two branches of research emerged in the literature on attentional biases towards negative information. Whereas some authors were interested in the attentional biases towards negative information across the general population, others were particularly interested in the attentional biases towards negative information in psychopathological populations (e.g., any effects of anxiety level on attentional biases towards threat-related information). Importantly, a recent extensive meta-analysis revealed that a threat-related bias in attentional processing is apparent across different types of anxious populations (i.e., individuals with different clinical disorders, high-anxious nonclinical individuals, anxious children and adults) but not in control populations (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007). It should be noted, however, that the control populations used in studies on attentional biases in psychopathology typically comprise individuals who fall below a lower threshold on the anxiety trait. Therefore, such individuals can be considered as abnormally insensitive to threat-related information and therefore not comparable to individuals from studies on attentional biases in the general population.

Importantly, the two branches of research have focused on rather different questions. The studies of attentional biases in the general population focused mainly on the question to what extent negative stimuli are processed differently from other stimuli. In contrast, the studies of attentional biases in psychopathological populations particularly aimed to characterise the attentional processing of negative information. Thus, whereas in the former case very early automatic processes come into consideration, the studies in the latter case encompass a wide range of attentional processes. This is important to note because the meta-analysis mentioned above took into account only studies that used the color-naming task, the dot-probe paradigm, and the emotional cueing paradigm as these are the three experimental paradigms that have been mainly used to study the threat-related attentional biases in anxiety. However, although all these paradigms reflect attentional performance, they do not tap into the same aspects of attentional processing and they do not measure attentional processing with the same temporal and spatial sensitivity. Paying a particular attention to the aspects of attentional processing that are measured in a given paradigm and to the sensitivity with which this paradigm measures attentional processing is, however, of uttermost importance if one seeks to find any early and (possibly) subtle effects of emotion on attention.

As has been argued above, emotional, and in particular, negative stimuli have potential consequences for one’s well-being and survival. Therefore, they are assumed to *automatically* capture attention even in individuals from the general population. The concept of automaticity, however, has not been consistently used in the literature on attention. Instead several features have been typically related to it (see Moors & DeHouwer, 2006, for a meticulously conducted theoretical and conceptual analysis of automaticity). Among the features that have been considered to characterize an automatic process are the fast speed with which the process takes place, the minimal resources that the process requires, the occurrence below the threshold of conscious awareness, the operation in parallel, the resistance to intentional control, and the inevitability. Because these features do not always co-occur, it is necessary to always specify which aspect of automaticity is under current investigation. The literature review in the next chapter will therefore relate each paradigm and the findings observed with it to the automaticity feature that the paradigm aims to investigate. In doing so, a particular attention is paid to the speed of the attentional processes measured and their resistance to intentional control as these two features are of particular importance in the context of attentional capture by emotional stimuli. More specifically, a particular attention is paid to how fast emotional stimuli capture attention and whether attentional capture occurs in an involuntary manner, that is, even when the emotional stimuli (i.e., their content and location) are completely irrelevant for the observer's current goal.

1. 2 Empirical evidence for attentional capture by emotional stimuli in the general population

In the following, evidence from two of the most often used paradigms to investigate attentional biases towards negative information in the general population is reviewed: the visual search paradigm and the cueing paradigm. The color-naming task is not taken into account as although it was extensively used in the context of anxiety research (see Williams, Mathews, & MacLeod, 1996, for a review), it was only rarely employed to study attentional biases in the general population (e.g., Pratto & John, 1991; Wentura, Rothermund, & Bak, 2000). Moreover, the emotional information in the color-naming task is presented centrally. In real-life settings, however, emotional information that is irrelevant for one's ongoing goal but is nevertheless of superior relevance for the observer often appears in the periphery. Therefore, the ecological validity of stimulus selection is strongly limited in the color-naming task. For this reason, the following literature review focuses exclusively on evidence from the visual search paradigm and the cueing paradigm.

1.2.1 Empirical evidence from the visual search paradigm

In addition to the cueing paradigm, the visual search paradigm is the most extensively used paradigm in the literature on attention to emotional information in the general population. In this paradigm, stimulus selection is investigated by inducing competition between multiple stimuli that are simultaneously present in the visual field at any given time. In a typical visual search experiment investigating the effects of emotional stimuli on attention, an array of stimuli (typically faces) is presented, one of which might depict a discrepant emotional expression (i.e., the target). Participants are asked to respond (e.g., to detect, locate, or identify) to the discrepant face or to its presence/absence as fast as possible by pressing a button (see Frischen, Eastwood, & Smilek, 2008, for a review).

Classical studies on visual search with neutral stimuli have shown that under certain conditions (e.g., when the target is defined by unique simple features, when the target is easily distinguished from the distractors, and when the distractors are similar to each other) target stimuli are responded to very fast, with the reaction times remaining relatively stable irrespective of the number of stimuli present in the display (i.e., the set size). The target in such cases is said to “pop out”. Such flat search slopes are interpreted as evidence for preattentive processing, that is, processing that occurs very early in time prior to attentional selection and in parallel (Treisman & Gelade, 1980). A flat search slope in the visual search paradigm is therefore considered as a measure of automaticity and attentional capture. The question that arises in the emotional variant of the visual search paradigm is, therefore, whether emotional stimuli also “pop out” (i.e., produce flat search slopes).

One of the first and most prominent studies on visual search with emotional stimuli is the study by Hansen and Hansen (1988). The authors in this study used pictures of natural, happy, and angry faces, and asked participants to decide whether a discrepant face was present or not. The authors found that the discrepant face was detected faster when it depicted an angry expression than when it depicted a happy expression, and this effect did not vary with the number of stimuli present (i.e., three vs. eight). Later, however, this study was heavily criticized because the effect was found to be due to a confound in the perceptual features of the stimuli, namely a small dark patch on the chin of the angry face (Purcell, Stewart, & Skov, 1996). Therefore, many researchers started using schematic faces as they allow a better control over the perceptual differences between stimuli. For example, using schematic faces, Öhman, Lundqvist, and Esteves (2001) found faster detection of threatening targets compared to friendly targets. However, although search was performed efficiently with both friendly and threatening targets, no difference was observed in the search slopes between the two types of targets, suggesting no emotion-specific pop out. In a related study also using schematic faces, Eastwood, Smilek, and Merikle (2001) asked participants to localize the target face, and found that reaction times were influenced by the set size to a lesser extent for negative compared to positive faces (i.e., reaction times increased with increasing set size to a lesser extent with negative target faces compared to positive target faces), suggesting stronger attentional guidance by negative faces. The detection times for the negative faces, however, still increased with increasing set size, thus suggesting no pop out by negative faces.

Importantly, the studies by Öhman et al. (2001) and Eastwood et al. (2001) described above used – in contrast to Hansen and Hansen (1988) – at least three set sizes, which is an important prerequisite for determining whether the search slope is flat or not (i.e., whether reaction times increase with increasing set size). In addition, the target in these studies was an emotional face, whereas the distractors were neutral faces, which is another prerequisite to interpret the data in terms of attentional guidance by the target. In contrast, search among emotional distractors is assumed to reflect distraction or delayed disengagement. In fact, there is evidence showing that angry crowds are searched more slowly than happy crowds (e.g., Fox et al., 2000), which suggests faster processing of happy faces and/or delayed disengagement by angry faces. For this reason, results from studies that used emotional targets among emotional distractors are rather difficult to interpret (e.g., Hansen & Hansen, 1988; Öhman et al., 2001, Experiment 3).[2]

It should be pointed out that in the vast majority of the studies on visual search for emotional stimuli, attentional processing has been measured by manual reaction times, and manual reactions in these studies are often as slow as 1000 ms. In fact, search matrices had often large sizes (e.g., 7° × 7.5°, 10.1° × 10.1°, 19° × 20.5°), which strongly increased the need for eye movements (see Öhman et al., 2001). Thus, manual reaction times seem to be not fine-grained and immediate enough to tap into the early attentional processes that are the subject of interest in the visual search paradigm. In contrast, eye movements seem to be the response that more validly reflect early attentional processing. For this reason, more recent studies investigated the effects of emotional information on search performance using eye movements as a measure of attention in addition to manual reaction times. The reasoning in these studies is that the amount of time and number of fixations until the first target fixation reflects preattentive processing, whereas the amount of time between the first target fixation and the manual response reflects postattentive processing. For example, using schematic faces Reynolds, Eastwood, Partanen, Frischen, and Smilek (2009) found that less time and fewer fixations were required to fixate the target for the first time when it was negative compared to when it was positive. This difference was found to increase with increasing set size. The authors found no influence of set size on the performance after target fixation, suggesting that the difference in search efficiency between positive and negative faces is due to guidance of attention by the targets (preattentive) rather than focal (postattentive) processing. In another eye-tracking study, Calvo, Nummenmaa, and Avero (2008) found that happy, surprised, and disgusted faces were manually detected more quickly and accurately,

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[2] It should be noted, however, that the search for angry face targets among happy face distractors has the advantage of contrasting stimuli that clearly signal threat (angry faces) with stimuli that clearly do not signal threat (happy faces), whereas neutral faces are often perceived as mildly hostile (Horstmann & Bauland, 2006; see Öhman et al., 2001).

were more likely to receive the first fixation, and were fixated faster and with fewer fixations, compared to fearful, angry, and sad target faces, thus suggesting no anger-superiority effect in preattentive processing.

Although the use of eye tracking in the studies on visual search for emotional stimuli considerably improves the measure validity, there is still one important issue that strongly limits the interpretation of the results in terms of involuntary attentional capture. The emotional expression of the faces is namely task-relevant in visual search studies. In other words, participants need to pay attention to the emotional expression of the stimuli in order to give a correct response. Thus, the interpretation of the results in terms of involuntary attentional processing is rather limited. One study investigated attentional allocation to emotional faces under conditions in which the emotional expression was task-irrelevant (Horstmann & Becker, 2008). Participants in this study were asked to search for a target feature (e.g., the shape of a nose or a conjunction of color) in a crowd of 1, 6, or 12 schematic faces, one of which depicted a unique expression. Importantly, the target feature appeared at the position of the discrepant face at chance level. The authors found faster detection times with targets that appeared at the position of the discrepant face compared to targets that appeared at the position of a non-discrepant face. The evidence for emotion-specific search benefit was however weak.

1.2.2 Empirical evidence from the cueing paradigm

In contrast to the visual search paradigm, the cueing paradigm investigates attentional processing in a quite different way (Posner, 1980; Posner & Petersen, 1990). In the cueing paradigm, one peripheral cue is presented for a brief period of time (e.g., 100 ms) followed by a target that appears either at the location of the cue stimulus (*cued* condition) or at the opposite location (*uncued* condition). Participants’ task is to decide whether the target is present (in this case, catch trials are included in which no target is presented after cue presentation), or to identify the target in terms of a feature that is orthogonally varied to the target location.[3] The rationale in the cueing paradigm is that attention gets engaged at the location of the cue. Thus, when the target appears at the cue location, target processing directly takes place, eventually resulting in fast reaction times. The speed of task performance on cued trials is thus assumed to reflect the speed of attentional *engagement* to the cued location. In contrast, when the target appears at the location opposite to the cue location, the attention must be disengaged from the cued location and then shifted towards the target location, resulting in slow reaction times. Therefore, the speed of task performance on uncued trials is assumed to reflect the speed of attentional *disengagement* from the cued location and the speed of attentional *shift* towards the target location.

The critical factor in the emotional variant of the cueing paradigm is that the emotional connotation of the cue is varied. Thus, the difference between cued emotional and cued neutral trials is assumed to reflect the difference in the attentional engagement between emotional and neutral cues (i.e., attentional capture). In contrast, the difference between uncued emotional and uncued neutral trials is assumed to reflect the difference in the attentional disengagement between emotional and neutral cues.

Thus, the cueing paradigm allows to investigate attentional processes in a temporally much more fine-grained scale than the visual search paradigm, as more specific inferences about the underlying attentional processes can be made with it. Moreover, in contrast to the emotional stimulus in the visual search paradigm, the emotional stimulus in the single cueing paradigm is task-irrelevant, allowing to make more valid inferences regarding involuntary attentional processing. The evidence from the cueing paradigm for the existence of an attentional capture by emotional information in the general population is, however, mixed. For example, using aversively conditioned neutral stimuli as cues, Koster, Crombez, Van Damme, Verschuere, and DeHouwer (2004)

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[3] Importantly, in the detection task and the identification task the response categories are unrelated to the target location, thus preventing participants from attending to only one location.

found facilitated engagement and impaired disengagement with threatening cues compared to neutral cues. In contrast, Fox, Russo, Bowles, and Dutton (2001) found no advantage for angry faces over positive or neutral faces in attracting attention to their location. Also, Koster, Verschuere, Burssens, Custers, and Crombez (2007) found no facilitated cueing by emotional faces, suggesting that emotional faces are not special in automatically engaging visual attention.

The absence of an emotion-specific engagement effect in the cueing paradigm might be attributed to the inherent characteristics of the cueing task. In particular, although the process of engagement is closely related to stimulus selection, strictly speaking, the cueing paradigm does not create conditions for stimulus selection. As only one cue stimulus is present at any given time, attention might be assumed to inevitably be oriented to it regardless of its emotional valence (i.e., this stimulus is inevitably selected; e.g., Yantis, 1996).

One way to study whether the absence of an emotion-specific engagement effect in the cueing paradigm is because the cue inevitably attracts attention regardless of emotion relevance is to present a second cue stimulus at the opposite location. In fact, this is exactly what is done in the dot-probe paradigm, which is a slightly modified variant of the single cueing paradigm and which has been typically used in the experimental psychopathology field (e.g., MacLeod, Mathews, & Tata, 1986; Mogg & Bradley, 1999).[4] For example, using the dot-probe paradigm Fox (2002) observed an attentional bias towards fearful facial expressions with participants with high levels of trait anxiety. However, no attentional bias towards fearful faces was found with control participants in this study.

It should be noted that the dot-probe paradigm is also associated with some important issues that limit the interpretation of the results in terms of early involuntary attentional processing. In particular, compared

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[4] The name of the dot-probe paradigm stems from the nature of the task, which requires participants to respond to a dot probe that appears at the location of one of the two cue stimuli.

with single cueing studies from the basic cognitive research, a rather long stimulus onset asynchrony of cues and probes has been used in dot-probe studies (i.e., 500 – 1250 ms). Therefore, the reaction time bias could be attributed to either enhanced vigilance or delayed disengagement of attention (e.g., Fox, Russo, Bowles, & Dutton, 2001; Koster, Crombez, Verschuere, & De Houwer, 2004). Furthermore, in studies on basic attentional processes (i.e., cueing by a sudden onset neutral cue), such long stimulus onset asynchronies have been demonstrated to produce longer reaction times for validly cued trials compared to uncued or neutral trials (i.e., inhibition of return; Posner & Cohen, 1984). Moreover, such long stimulus onset asynchronies are sufficient for the programming and execution of at least one eye movement, raising again the question about the measure validity of manual reaction times. Last but not least, although the emotional connotation of the cue in the single cueing and the dot-probe paradigm is indeed not relevant for participants' task, the location of the cue is still task-relevant (i.e., the locations that are used as cue locations also serve as target locations). Thus, any interpretation of results from single-cueing and dot-probe studies in terms of involuntary attentional capture has to be made with caution only.

1.3 Interim conclusion

Given this background, it becomes clear that further evidence is needed from other paradigms and other measures to more validly investigate whether the emotional relevance of a stimulus captures early attention in an involuntary fashion in the general population. The research on attention towards emotional stimuli has considerably advanced by having used basic paradigms from the literature on general attentional processes (i.e., visual search and cueing). However, the evidence for attentional capture by emotional information from the above described paradigms in the general population is mixed. Moreover, the interpretation of the results from these paradigms in terms of early involuntary attentional capture is still limited.

As has been shown, the limitations associated with the visual search paradigm and the cueing paradigm are to a great extent due to the strong reliance on manual reaction times, which are strongly limited in their validity as a measure of attentional processing. The strong reliance on manual reaction times is not surprising given that the choice of response has been often driven by the state of the art in behavior monitoring devices and data computing at the time of paradigm introduction. As for long time eye movement recording was very laborious and intrusive for participants, researchers had to rely mainly on data from manual reactions. Anyway, this did not keep them from approaching attentional processes in a surprisingly valid way. For example, the three-component model of attention put forward by Posner and Petersen (1990), in which attention has been assumed to consist of three components (i.e., engage, shift, and disengage), strongly reminds of the way in which the human eyes move. Moreover, with the fast advances in eye tracking technology there is now a growing body of studies on visual search using eye movement measures in addition to manual reaction times. The close look at the existing literature, however, points to the necessity of gaining further evidence from other paradigms and measures of attentional processing.

2 Saccade trajectories as a measure of attention

Although the literature on attention has been mainly interested in the attentional processes prior to a response with only little interest in the nature of the response, a close look at the literature suggests that the nature of the response might play a crucial role in understanding the attentional processes. In fact, although attention psychology has been particularly interested in the attentional processes prior to a response, the measures that have been typically used to study them (i.e., manual reaction times and manual errors) mainly focus on the outcome of the processes, neglecting their *temporal* and *spatial dynamics*. The problem with such discrete off-line measures is that they operate on a large time scale, which makes changes in cognitive states appear to occur instantaneously, when in fact they occur gradually (Spivey, 2007). Importantly, by using such measures one runs the risk of failing to find subtle effects of alternative cognitive representations which are so weak that they never reach the strength to slow down reaction times or produce an erroneous overt response.

A close look at the nature of responses reveals that similarly to cognitive processing response processing also unfolds over time. For example, a simple reach movement involves several components, including the starting point of the hand movement, the path that the hand takes towards the target, the speed and acceleration with which the hand is moved, and eventually the ending point of the hand movement. Even a response as simple as pressing a button unfolds over time and constitutes of several components, including the time from movement initiation to full key depression, the time from full key depression to full key release, the time spent on full key depression, and the force with which the button is pressed. Importantly, eye movements do not constitute an exception. Similarly to a hand reach movement, an eye movement constitutes of several components, including the starting point of the eye movement, the path that the eye takes towards the target, the velocity and acceleration of the movement, and its ending point. Most importantly, the exact path that the eye takes towards the target is rarely straight but is strongly influenced by the presence of other stimuli in the visual field.

2.1 Empirical evidence for saccade trajectory modulation by visual stimuli

Although the observation that saccade trajectories are rarely straight and often exhibit a certain amount of curvature is not new (Yarbus, 1967), the processes underlying this effect have only recently started receiving systematic scientific. In fact, most of the work on saccade trajectories has been done as recently as in the last ten years (for recent reviews on saccade trajectories, see Van der Stigchel, 2010; Van der Stigchel, Meeter, & Theeuwes, 2006). This work, however, offered a number of important insights into the way in which visual selective attention operates. In the following, empirical evidence for saccade trajectory modulation by visual stimuli that is relevant in the present context is reviewed.

Saccade trajectories deviate away from task-relevant cues

Sheliga, Riggio, and Rizzolatti (1994) were the first to show that eye movement trajectories are influenced by the presence of visual stimuli in the visual field. In their seminal study, participants were presented with a cue in one of four boxes located in the upper visual field (see Figure 1 for an illustration of the target display). The participants were asked to make a downward saccade towards a target box located in the lower visual field as soon as a cue appeared in one of the four upper boxes. Thus, participants needed to voluntarily direct attention to the cue in order to successfully accomplish the task. Crucially, Sheliga and colleagues found saccade trajectories to deviate away from the horizontal location of the cue. According to the authors, the cue onset triggered a strong exogenous covert attentional shift. As participants were instructed not to look at the cue, the eye movement towards the cue had to be suppressed, which made the trajectory deviate to the side opposite to the cue location.

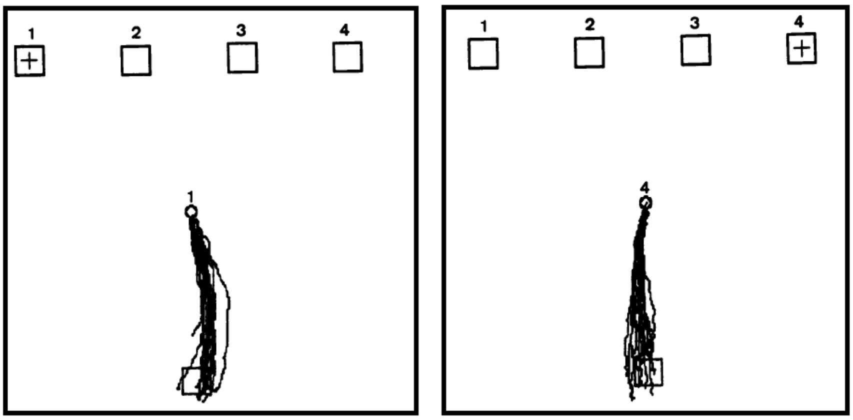

Figure 1. The influence of voluntary covert attention on saccade trajectories. Figure adapted from Rizzolatti, Riggio, and Sheliga (1994).

It should be pointed out that the finding observed by Sheliga et al. (1994) constitutes a milestone in the literature on visual selective attention. A central question in the literature on visual selective attention has been namely what the relationship is between covert attention (i.e., shifts in attention that take place without eye movements) and overt attention (i.e., eye movements), when overt attention is not prevented. According to the independence account, for example, the two processes are completely independent of each other, but co-occur because they are driven by similar visual input (Klein, 1980). Alternatively, the sequential attentional model proposed that the two processes are tightly coupled to each other, with saccadic eye movements being directed by the location of covert attention (Henderson, 1992). Importantly, the finding observed by Sheliga et al. speaks neither in favor for the independence account nor for the sequential attentional model. Instead it strongly supports the premotor theory of visual attention (Rizzolatti, Riggio, Dascola, & Umiltá, 1987; Rizzolatti, Riggio, & Sheliga, 1994; but see Belopolsky & Theeuwes, in press). According to this theory, a covert shift of attention to a given location in space is simply a by-product of the programming of a saccade eye movement towards that location.

Since the study by Sheliga et al. (1994) numerous other studies extensively investigated the nature of saccade trajectories and the mechanisms underlying the saccade trajectory modulation effect. For example, Sheliga, Riggio, and Rizzolatti (1995) demonstrated that this deviation effect extends to downwards as well as upwards saccades and that it occurs when attention is oriented exogenously (i.e., by peripheral cues) as well as endogenously (i.e., by central cues). Moreover, this deviation effect has been shown to hold for vertical as well as horizontal saccades (Sheliga, Riggio, Craighero, & Rizzolatti, 1995). Thus, these studies provide strong evidence that directing covert attention to a cue has a direct spatial effect on the oculomotor response. Most importantly, they reveal saccade trajectories as a promising measure of attentional processing that might yield deeper insights into the exact mechanisms involved in attentional processing.

Trajectory modulation strength reflects the amount of attention

In a more recent study, Van der Stigchel and Theeuwes (2007) provided evidence suggesting that the strength of saccade modulation reflected the amount of attention allocated to any particular location (see also Theeuwes & Van der Stigchel, 2009). In this study, participants were given a standard cueing task, in which they were cued by a central cue to covertly attend to a peripheral location without making eye movements. In line with the literature on the cueing paradigm, manual reaction times were faster to targets that appeared at the cued condition compared to targets at the uncued condition. Crucially, on a subset of the trials a specific letter (‘go signal’) that was presented at either the cued or uncued location indicated that participants had to make an eye movement towards a target location above or below the fixation cross. The authors found that in these eye-movement trials saccade trajectories deviated away from the location of both the go signals that appeared at the cued location and the go signals that appeared at the uncued location. However, this deviation effect was less strong in the trials in which the go signal appeared at the uncued location. As manual reaction times were faster with targets at cued compared to targets at uncued trials (i.e., more attention was allocated to the cued compared to the uncued location), these data suggest that the strength of trajectory deviation reflects the amount of attention. More specifically, these data suggest that the more oculomotor activation is generated at a certain location in space, the stronger the inhibition that must be applied in order for the cue to be effectively inhibited (see below for a more detailed explanation of the trajectory modulation effect in terms of inhibition).

Saccade trajectories deviate away from task-irrelevant distractors

It should be noted that the cues in the studies described above were task-relevant. In other words, observers in those studies needed to voluntarily attend to the cues for the cues to modulate the saccade trajectories. However, saccade trajectories have been also observed to deviate away from task-irrelevant distractors. In a seminal study, Doyle and Walker (2001) asked participants to execute upwards and downwards saccades, while a task-irrelevant distractor appeared laterally from fixation. In line with the findings from the studies described above, the authors found saccade trajectories to deviate away from the distractor location. Based on this finding, one can conclude that observers do not need to voluntarily attend to a stimulus for it to modify the saccade trajectories. Moreover, the deviation away from task-irrelevant distractors was found to occur with endogenous saccades (i.e., saccades triggered by a central cue) as well as exogenous saccades (i.e., saccades triggered by a peripheral target onset), indicating that the curvature effect is not due to voluntary control.

2.2 Theories of saccade target selection

To account for the trajectory modulation found with task-relevant cues and task-irrelevant distractors several inhibition accounts of saccade target selection have been proposed (e.g., Godijn & Theeuwes, 2002; McSorley et al., 2004; Tipper et al., 2000). According to these accounts, the modulation of saccade trajectories is the result of competitive interactions between the representations of potential saccade targets within a common motor map (see Figure 2 for an illustration of the population coding theory put forward by Tipper et al., 2000). In particular, the direction of an eye movement is assumed to be coded by a population of neurons. The simultaneous presentation of target and distractor activates two neuron populations – one coding the movement towards the target and one coding the movement towards the distractor. As participants are instructed to look to the target and not to the distractor, a competition arises between the two neuron populations. This competition is assumed to be resolved by inhibiting the population that codes the movement to the distractor. Since the population code is distributed in nature and therefore the two neuron populations can overlap (i.e., some neurons are activated by the presence of both target and distractor), inhibiting the population coding the movement towards the distractor will inhibit a subset of the population coding the movement towards the target. As a result, the saccade trajectory curves away from the inhibited distractor side.

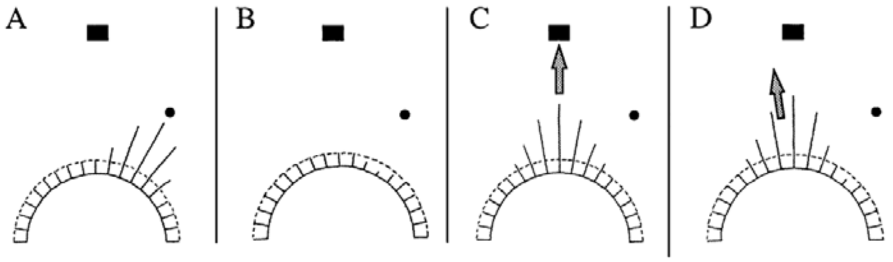

Figure 2. Schematic illustration of the population coding theory. A. The population of neurons that codes the eye movement towards the distractor gets activated by the distractor onset. B. The population of neurons that codes the eye movement towards the distractor gets inhibited below baseline. C. The population of neurons that codes the eye movement towards the target gets activated by the target onset. D. The combined activity of the populations coding the movement towards the target and the distractor. Figure from Tipper, Howard, and Houghton (2000).

Some of the models proposed to account for the trajectory deviation effect have also made specific statements as to the neural correlates of the saccade trajectory control (e.g., McSorley et al. 2004). In particular, the frontal eye fields and the superior colliculus have been postulated as the two brain regions mainly involved in the saccade trajectory control and target selection process. The intermediate layers of the superior colliculus are assumed to constitute the salience map on which the representations of the potential targets compete with each other. These layers have been shown to contain a map of oculomotor space such that activation/stimulation of neurons at a given location in the map generates a saccade with the amplitude and direction depending on the location of the activation/stimulation (see White & Munoz, 2011, for a recent review on the superior colliculus). According to the model put forward by McSorley et al. (see Figure 3 for an illustration), the superior colliculus receives bottom-up visual signals (A) as well as top-down task-related signals from the frontal eye fields (i.e., excitatory signals about target location, B, and inhibitory signals about distractor location, C). Thus, the superior colliculus might be regarded as a platform, on which bottom-up and top-down signals are integrated. The result of this integration process, which includes saccade amplitude and direction information, is then sent to the brainstem premotor circuitry (E). The curvature back towards the actual target location is attributed to the cerebellum, which compares in a feedback loop the independent target position signal from the frontal eye fields (D) with the current eye position signal from the superior colliculus (G), and modulates the trajectory based on this comparison (F).

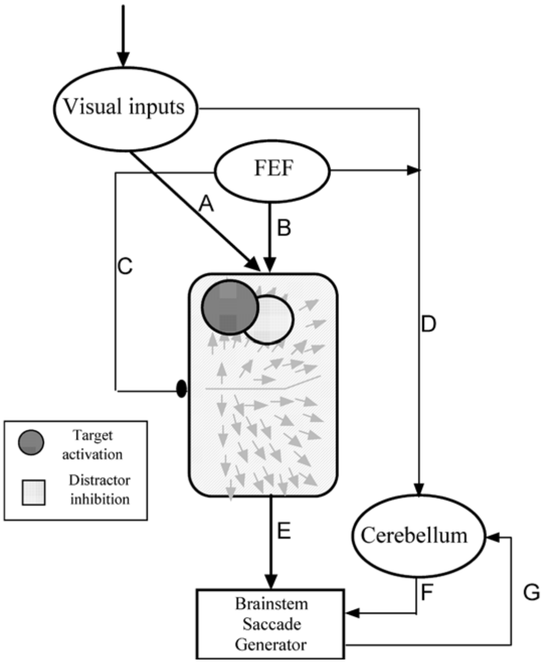

Figure 3. Schematic illustration of the model put forward by McSorley, Haggard, and Walker (2004).

It is important to note that when using saccade trajectories as a measure of eye movement competition, one also needs to take saccade latencies into account because the competition that arises between two potential saccade targets has also an effect on the saccade latencies (see Sumner, 2011, for a recent review on determinants of saccade latencies). In particular, saccade latencies have been consistently found to be delayed when an irrelevant stimulus appears in addition to the saccade target as compared to the condition when no distractor is presented (i.e., remote distractor effect; e.g., Walker, Deubel, Schneider, & Findlay, 1997). This effect can be explained by so-called *race models* (e.g., Godijn & Theeuwes, 2002; Trappenberg et al., 2001). According to these models, the saccade programs of both stimuli (i.e., target and distractor) get into competition with each other as their onset automatically produces a saccade-related signal (see Figure 4 for a schematic illustration of the race model). These signals are assumed to start at a certain baseline level and rise with a certain rate. In order for a saccade to be made to the target, the signal that is associated with the target must reach a certain threshold. Importantly, the target and distractor signals are assumed to mutually inhibit each other, thus slowing down each other's rate of rise. To prevent that the distractor inhibits the target to the point of winning the race, a second inhibition mechanism is postulated (i.e., a top-down inhibition mechanism), which biases the race in favor of the saccade target.

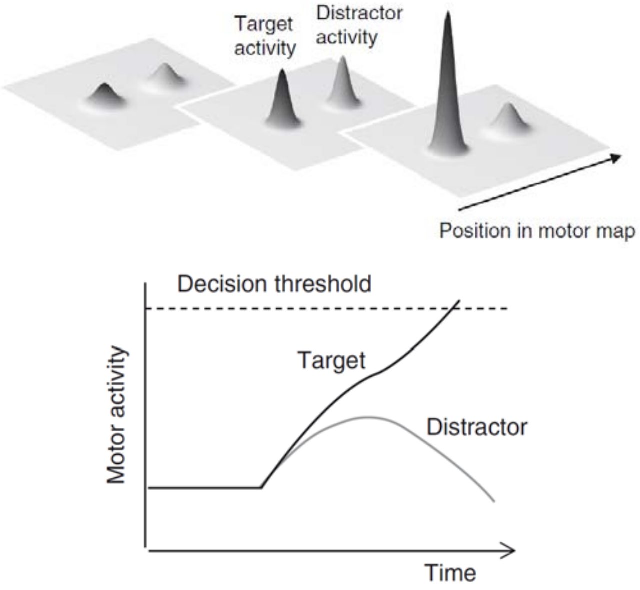

Figure 4. Schematic illustration of the time course of saccade competition. Figure from Sumner (2011).

In line with the race model of distractor effects on saccade latencies, the magnitude of saccade trajectory modulation has been shown to vary as a function of the saccade latency (McSorley, Haggard, & Walker, 2006). This study used the fixation gap paradigm, in which the fixation cross is removed from the display at variable stimulus onset asynchronies relative to the target onset. This manipulation is known to elicit a broad range of saccade latencies (Ross & Ross, 1980; Saslow, 1967). In particular, fixation cross removal shortly before target onset has been shown to favor fast saccade latencies (i.e., < 200 ms), whereas fixation cross removal after target onset has been shown to favor slow saccade latencies (i.e., > 200 ms). As hypothesized, McSorley et al. found saccades with shorter latencies to deviate towards the distractor, whereas saccades with longer latencies deviated away from the distractor. This finding provides strong evidence that the oculomotor inhibition process takes a certain amount of time to start operating and develops over time. As a result, early in time the target selection process is less strongly influenced by inhibition, whereas late in time the selection process is more strongly driven by inhibition. In terms of population coding, this finding suggests that early in time the neurons coding the eye movement towards the distractor are high in activation, whereas their activation decreases late in time. It should be noted, however, that although certain conditions can indeed produce a curvature towards effect, this effect is not that robust as the curvature away effect (for a recent review, see Van der Stigchel, 2010).[5]

The strong relationship between saccade latencies and saccade trajectories found in the study described above points to the importance of interpreting saccade trajectory results always in the context of saccade latencies. More importantly, although they have been shown to tap into the same processes (i.e., inhibition vs. activation), both measures do not make themselves completely redundant but rather complement each other. As saccade trajectory effects have been repeatedly observed in the absence of any saccade latency effects, saccade trajectories seem to be a more sensitive measure of oculomotor competition than saccade latencies. Moreover, in contrast to saccade latencies, a plenty of measures can be derived from saccade trajectories (see Van der Stigchel et al., 2006, for an overview of saccade trajectory measures). These measures can be categorized based on (1) whether their computation is based on all sample points of the trajectory or only one sample point, and (2) whether their computation is based on a reference line to a predefined target (i.e., deviation) or whether their computation is based on a reference line to the saccade endpoint (i.e., curvature; see Figure 5).

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[5] This can be attributed to the nature of saccade latencies, in particular, to the fact that even under conditions that favor very fast saccades many saccades are still triggered with considerable delay (see Sumner, 2011). Although the underlying mechanism of this observation is still unknown, it appears that an oculomotor system which is by default in an inhibited state offers advantages of particular evolutionary importance (see Sumner, 2011).

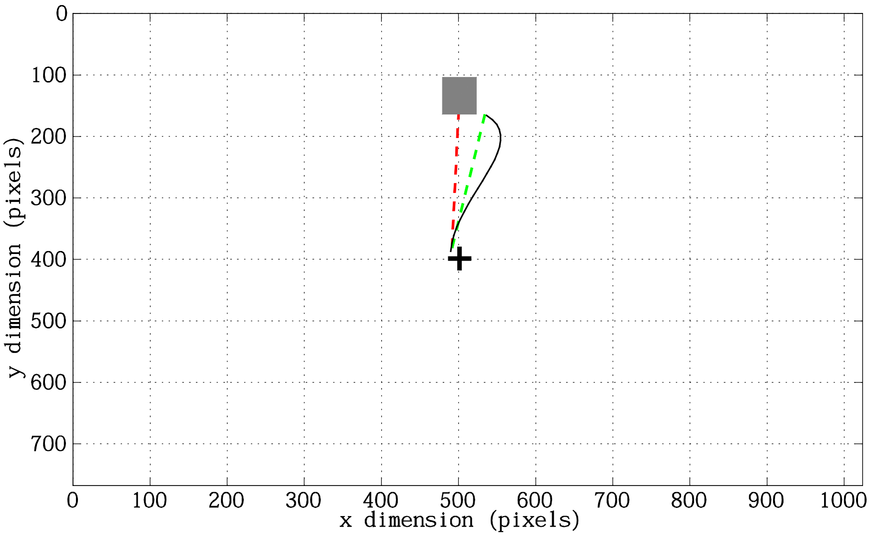

Figure 5. Saccade trajectory measures are characterized based on (1) whether their computation is based on all sample points of the trajectory or only one sample point, and (2) whether their computation is based on a reference line to a predefined target (i.e., saccade deviation; red dashed line) or on a reference line to the saccade endpoint (i.e., saccade curvature; green dashed line).

Although many trajectory measures have been shown to correlate with each other (Ludwig & Gilchrist, 2002), a recent study showed that different measures of trajectories measure oculomotor processing at different points in time (McSorley, Cruickshank, & Inman, 2009). In this study, participants were presented with a saccade target and distractor, which appeared at various distances from the target. Results showed that when the distractor was close to the target, trajectory and landing position deviated towards the distractor location at all saccade latencies. In contrast, greater target-to-distractor separations produced different effects for both measures. In particular, landing position was accurate at all saccade latencies. In contrast, saccade trajectory deviations were found to depend on saccade latency, such that saccades with short latencies deviated towards the distractor, while saccades with longer latencies deviated away from the distractor. This pattern of results suggests that trajectory and landing position measure the same underlying competition processes at different points in time, with trajectory deviations reflecting activity at saccade initiation and endpoint deviations reflecting activity at saccade end. Moreover, these findings point to caution in the choice of measure and the interpretation of the results.

2.3 Interim conclusion

To conclude, saccade trajectories appear to be a promising continuous measure of attentional processing that in contrast to the discrete off-line measures used in the literature so far rather taps into the temporally and spatially dynamic properties of attentional processing. In contrast to the manual responses, eye movements seem to operate at a time scale that is small enough to reflect the dynamic properties of attentional processing. As they are faster to trigger than manual reactions, eye movements can be considered as a nearly immediate measure of attentional processing. More importantly, their trajectories show subtle systematic modulations that are sensitive enough to reveal very early effects of competing distractors even when those effects are so subtle that they remain undetected by temporal measures. Thus, eye movement trajectories seem to be a promising measure of attention not only as compared to manual responses but also as compared to other eye movement measures that have been used in the literature on attention to emotion so far (e.g., latencies, probability of first fixation, and number of fixations prior to target fixation).

From a paradigm-oriented view, investigating the effects of task-irrelevant stimuli on saccade trajectories allows to overcome the issues associated with the visual search paradigm and the cueing paradigm. In contrast to the cueing paradigm, the trajectory-based paradigm allows to investigate stimulus selection in its strictest sense as the task-irrelevant stimulus is simultaneously present in the visual field with the task-relevant stimulus. In contrast to the visual search paradigm, the distractors in the saccade trajectory paradigm can be made completely irrelevant for the observer’s task. It is namely possible to make not only the distractor content task-irrelevant (i.e., the emotional connotation), but also its location. Thus, by always presenting the distractors at locations other than those used as target locations, and informing participants about this, one can more validly measure the effects of distractors on involuntary attentional processes. Therefore, the saccade trajectory paradigm seems to be perfectly suited to investigate fast and involuntary effects of task-irrelevant emotional stimuli on attention. Moreover, the theories on saccade target selection described above do not rule out the existence of any effects of emotional content on saccade target selection. Thus, given their particular importance for the observer’s well-being and survival, it is reasonable to assume that emotional stimuli will appear more salient than neutral stimuli, thus inducing stronger trajectory modulation than neutral stimuli.

3 Empirical evidence for higher-order influences on saccade trajectories

Surprisingly, although the saccade trajectory paradigm is perfectly suited to explore fast and involuntary effects of higher-order distractor information on attention, only few studies have investigated this question so far. The first study on top-down influences on saccade trajectories was Ludwig and Gilchrist (2003). In this study, the saccade target was defined by color instead of onset. In the beginning of each trial, participants were presented with two placeholders, which subsequently changed their color into red and green. Half of the participants were required to saccade to the red target, whereas the other half were required to saccade to the green target. Importantly, the abrupt onset distractor was either in the target color (similar condition) or in a different color (dissimilar condition). In line with previous studies, saccade trajectories were found to curve away from all distractor types. However, target similarity was found to modulate the curvature away effect, with saccades curving more strongly away from similar compared to dissimilar distractors. Importantly, this effect was found only when the distractor appeared before the target or when saccade onset was delayed, indicating that early in time the selection process is mainly driven by bottom-up signals, whereas late in time top-down signals get integrated in the selection process.

The influence on saccade trajectories of a rather different type of higher-order information was investigated in Weaver, Lauwereyns, and Theeuwes (2011). In this study, the effect of semantic information on saccade trajectory deviations was investigated using taboo and neutral cue words. Participants were presented with three placeholders in one of the two vertical hemifields (see Figure 6 for an illustration of the trial sequence). The cue word, which was unpredictive of the saccade target location, appeared in one of the lateral locations. After a variable stimulus onset asynchrony, a central arrow indicated to which of the three locations a saccade was to be made. Only vertical saccades were analyzed. At the shorter stimulus onset asynchronies (i.e., 0 and 300 ms), no difference between the two cue types was found, with both cue types producing a significant deviation away effect. In contrast, at the long stimulus onset asynchrony (i.e., 700 ms) taboo words produced significantly stronger deviation away than neutral words. The authors attributed the absence of a cue type effect with short stimulus onset asynchrony to the strong potential of abrupt onset to capture attention independently of semantic content. However, with longer stimulus onset asynchrony more time was available for processing of the cue content, which might explain the decrease of activity with neutral cues over time and the maintenance of activity with taboo words even at a later point in time. These results can be thus regarded as evidence for delayed disengagement of attention from taboo words.

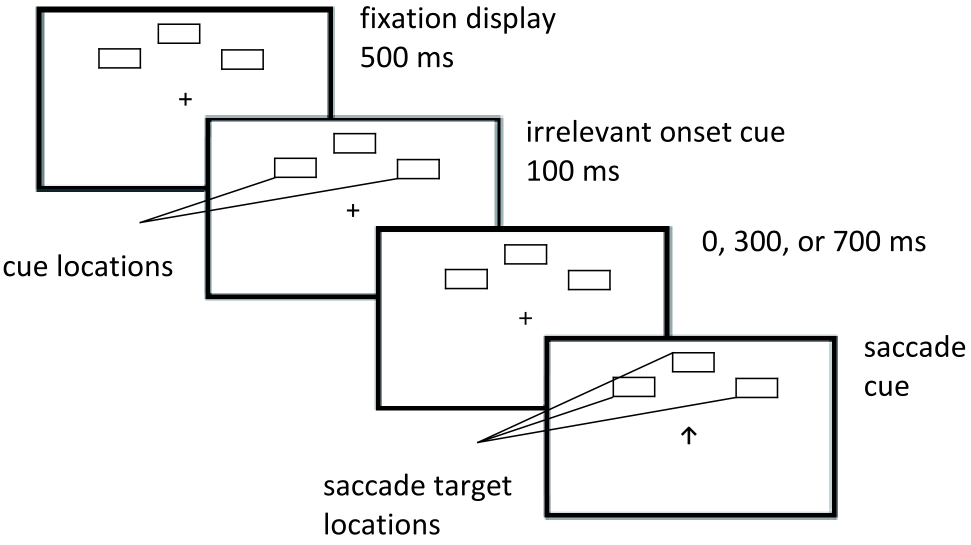

Figure 6. An illustration of the trial sequence in Weaver, Lauwereyns, and Theeuwes (2011).

Finally, Nummenmaa, Hyönä, and Calvo (2009) investigated higher-order influences on eye movement trajectories using pairs of pictures that depicted complex neutral and emotional scenes (Experiment 3). The picture pairs appeared laterally from fixation either simultaneously with the saccade target or 150 ms before it. The participants were required to make vertical saccades towards a target onset which appeared above or below the fixation point. The authors found that the saccade *endpoint* deviated away from the emotional stimulus, both with simultaneous presentation of target and distractors and when the distractors preceded the target with a stimulus onset asynchrony of 150 ms. Saccade *curvatures*, however, were found to deviate away from the emotional stimulus with the 150 ms stimulus onset asynchrony only. No difference between pleasant and unpleasant distractors was found. The authors attributed these findings to the somewhat time-consuming process of emotional connotation encoding. Importantly, as saccade curvatures have been shown to reflect activity at saccade start, whereas saccade endpoint deviations have been shown to reflect activity at saccade endpoint (McSorley et al., 2009), these findings suggest that higher-order information influences saccade processing only late in time and are therefore in line with Weaver et al. (2011) and Ludwig and Gilchrist (2003).

As stated in the previous chapter, it is reasonable to assume that emotional stimuli will appear more salient than neutral stimuli, thus inducing stronger initial activation than neutral stimuli. Given that the target signal and the distractor signal inhibit each other mutually, the stronger the distractor signal is, the stronger the inhibition is that it applies to the target signal. Therefore stronger top-down inhibition should be applied to emotional distractors than to neutral distractors for the target to successfully reach the threshold. In fact, in line with this argument previous studies showed that the strength of saccade modulation reflected the amount of attention allocation to any particular location (Theeuwes & Van der Stigchel, 2009; Van der Stigchel & Theeuwes, 2007). Therefore, the stronger curvature/deviation away found with emotional stimuli in Nummenmaa et al. (2009) can be interpreted as stronger attentional capture by the emotional stimuli as compared to the neutral stimuli. However, it is also plausible to argue that a strong initial activation signal is more difficult to get inhibited, eventually resulting in less curvature away.

To sum up, the evidence so far suggests that saccade trajectories can indeed be affected by higher-order information. However, the literature so far suggests that this influence takes place only at a later point in time (i.e., at saccade end and/or after longer stimulus onset asynchrony). Most importantly, the evidence is still very sparse, pointing to the importance of gaining further insight.

4 Aim and scope of the doctoral thesis

The first and foremost aim of this thesis is to investigate to what extent the human attentional system adapts to environmental changes of superior relevance. In particular, it aims to investigate to what extent emotional stimuli capture human visual attention. As they signal potential dangers or opportunities, emotional stimuli are of superior importance to the organism. It is therefore reasonable to argue that emotional stimuli are processed as fast as possible even when they are completely irrelevant for the observer's ongoing goal. As the paradigms typically used so far are associated with a number of important methodological issues, this thesis aims to approach the question using a different paradigm and a different measure, which allow to investigate the question in a more valid way. In particular, the saccade trajectory based paradigm was used. Although there is already evidence suggesting that higher-order information affects saccade trajectories in an involuntary fashion, this evidence is still very scarce. Moreover, it suggests that saccade trajectories are influenced by higher-order information only at a later point in time (i.e., after longer stimulus onset asynchronies and/or at saccade end). Therefore, this thesis aims to provide convergent evidence that saccade trajectories are influenced by emotional stimuli in an involuntary manner as well as extending the previous literature on higher-order influences on saccade trajectories by demonstrating that task-irrelevant emotional stimuli can affect saccade trajectories also early in time. To this end, several issues have been taken into consideration.

4.1 Stimulus material

To study the effects of emotional information on early saccade processing this thesis used facial stimulus material. Compared to word stimuli, facial stimuli are much more naturalistic. In natural settings, single words are rarely the source of threat or opportunity (biological preparedness; see Seligman, 1970). Moreover, for the threat or opportunity to be recognized from word stimuli, the word stimuli must be first semantically processed. Compared to emotional scenes, faces are less complex. Thus, the use of facial material favors fast processing to a greater extent than the use of scenes. In fact, for humans, human faces are probably the most emotionally significant visual stimuli. A human face carries different kinds of information that are crucial for social interactions and survival (e.g., emotional expression, gender, age, identity, race, attractiveness, and direction of eye gaze). It is thus reasonable to assume that faces are processed more efficiently compared to other types of stimuli. There is now a vast amount of literature on face detection, categorization, identity recognition, and expression perception showing that faces are processed in a very fast and involuntary manner (see Palermo & Rhodes, 2007, for a review). For example, using magnetoencephalography recordings, Liu, Harris, and Kanwisher (2002) found a face-selective response already at 100 ms after stimulus onset, which was correlated with the successful categorization of the stimuli as faces. Also emotional faces have been shown to elicit very fast responses in the brain. For example, enhanced amygdala responses to emotional compared to neutral faces have been shown to occur within 180 ms after stimulus onset (Streit et al., 2003). In another study, Whalen et al. (1998) found stronger amygdala activation with fearful compared to happy faces, even though the faces were presented for 33 ms and masked by a backward mask consisting of neutral face, and participants reported having seen only neutral faces.

Given this background, it is a priori more probable to find an *early* effect of emotion with facial stimuli compared to other types of stimuli. Moreover, one might even expect a more differentiated effect of emotion, with difference in attentional processing between positive (e.g., happy) faces and negative (e.g., angry) faces. In addition, the use of faces makes the experiments comparable to most visual search and cueing studies on the effects of emotional stimuli on attention.

The use of faces, however, has been associated with one important issue. Although it indeed allows a better control of perceptual features compared to the use of other emotional stimuli, the facial material remains still prone to perceptual artefacts (e.g., Hansen & Hansen, 1988; Purcell et al. 1996; see Chapter 1). For this reason, many authors preferred to use schematic faces instead of natural faces. However, given the limited ecological validity of this approach and the fast technological progress in graphics editing programs, a trend has been observed in recent years towards the use of natural faces. In this thesis, schematic faces were used only in Experiment 2. The rationale is that schematic facial expressions are less complex and less variable than natural faces, thus making emotional expression easier to recognize and finding an effect of emotion more likely. As this approach is strongly limited in the ecological validity and prone to habituation effects, pictures of natural facial expressions were used in the subsequent experiments. To rule out the possibility that the effects of emotion on attention are due to differences in low-level perceptual features of the pictures rather than the emotional content, a condition was included in which the orientation of the faces was manipulated (Experiment 3 and 4). Inversion has been shown to distort the holistic processing of faces, while maintaining the low-level perceptual features intact (i.e., face-inversion effect; e.g., Fox & Damjanovic, 2006; Leder & Bruce, 2000; Tanaka & Farah, 1993). Thus, if the effect of emotion on saccade trajectories is due to holistic processing of the emotional content rather than processing of the perceptual features, then it should not be observed with inverted faces.[6]

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[6] It should be noted that some studies showed that the effect of emotional faces on attentional processing is driven by the perceptual features of the facial expressions (e.g., curved mouth; e.g., Horstmann & Bauland, 2006). This finding, however, is not necessarily to be interpreted as evidence against the claim that the attentional processing is influenced by the emotional content of the stimuli. For example, according to the sensory-bias hypothesis put forward by Horstmann and Bauland, the facial expressions of emotion evolved the way they did to exploit the extant capabilities of the visual system. Thus, as stated by Horstmann and Bauland, a confounding of perceptual features and emotional content should be considered not only as unavoidable but also as unproblematic.

4.2 Experimental procedure and dependent variables

The task in the current experiments involved participants making a vertical saccade towards a target that appeared above or below the fixation cross. A distractor face depicting an angry, happy, or neutral expression was *simultaneously* presented with the target onset in the upper left, upper right, lower left, or lower right part of the screen. Importantly, the distractor location and distractor content were completely irrelevant for the task. In contrast to Weaver et al. (2011), the saccade target never appeared at the locations that served as distractor locations. Moreover, the target and distractor locations were varied orthogonally (i.e., target and distractor could appear in the same or in the opposite visual hemifields). Thus, distractor location could not be used as a cue about the hemifield in which the target appeared. It should be noted that these strategies for making the distractor location completely task-irrelevant decreased the probability of finding an effect of emotion. As participants knew in advance that the distractor content and location were totally irrelevant for their task, they could in advance ignore the whole visual field except the vertical meridian where the target could appear. Finding an effect of emotion under such “conservative” conditions would, thus, allow to more validly attribute the effects to involuntary attentional processing.

In contrast to Nummenmaa et al. (2009), this thesis used single distractors instead of paired distractors. It should be noted that the single-distractor approach is prone to a ceiling effect due to the strong potential of abrupt onsets to capture attention independently of emotional content (e.g., Doyle & Walker, 2001). Nevertheless, it increased at the same time the probability of finding an early effect on saccade processing because less information was present in the visual display and therefore fast processing was favored.[7]

To investigate early effects of emotion on saccade processing a measure of trajectory curvature was used as it has been shown to reflect the oculomotor activity at saccade onset (McSorley et al., 2009). In particular, the quadratic curvature was calculated (Ludwig & Gilchrist, 2002; see Chapter 5 for detailed description of the computation procedure). This measure is defined as the quadratic coefficient of the second-order polynomial that is fitted to the normalized saccade. In contrast to the curvature measure used by Nummenmaa et al. (2009), which was based on one sample point only, the quadratic measure includes all sample points on the saccade trajectory, and thus minimizes the influence of sample noise. In addition, given the close relationship between saccade trajectories and saccade latencies (see Chapter 2), saccade latencies are also reported in addition to the curvature measure.

4.3 Hypothesis

The main hypothesis in this thesis is that saccade trajectories are influenced by the emotional expression depicted by the task-irrelevant facial distractor. More precisely, due to their particular relevance to the observer's well-being and survival, emotional facial distractors will appear more salient and therefore produce more oculomotor activation than neutral faces. As a result, emotional distractors will compete with the target more strongly than neutral distractors (i.e., emotional distractors will more strongly inhibit the target and thus will more strongly prevent it from reaching the threshold). Thus, based on the previous literature on saccade trajectories (Nummenmaa et al., 2009; Theeuwes & Van der Stigchel, 2009; Van der Stigchel & Theeuwes,

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[7] Moreover, it should be noted that there is a certain amount of ambiguity in the two-distractor approach used by Nummenmaa et al. (2009) because a curvature away from a given distractor might be alternatively interpreted as a curvature towards the competing distractor.

2007), it is hypothesized that more inhibition will be required with emotional than with neutral distractors for the target to reach the threshold, leading to stronger curvature away with emotional than with neutral distractors.

To test the negativity bias hypothesis, according to which attention is particularly biased towards negative information, two emotional expressions were included: happy vs. angry. Although both emotional expressions are of particular relevance to the observer's well-being and survival, failing to detect a danger typically has more negative consequences than failing to detect an opportunity. Therefore, given that stronger curvature away reflects stronger attentional capture, a stronger curvature away is hypothesized to occur with angry compared to happy faces.

Overview of the experiments

To investigate the effects of emotional facial distractors on saccade trajectory modulation a series of five experiments was conducted.[8] Experiment 1 aimed to replicate the basic effect of curvature away by using a simple geometrical figure as a distractor. Experiment 2 aimed to investigate the effect of emotion on saccade trajectories using schematic facial expressions. As they are less complex and less variable than natural faces, schematic faces should facilitate the emotional processing and make an early involuntary effect of emotion more likely.

Experiment 3 aimed to investigate the effect of emotion on saccade trajectories using pictures of natural emotional faces as they are more variable and ecologically more valid than the schematic faces and thus

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[8] Experiment 1 reported in this thesis was previously published as a part of the journal article "Cultural influences on oculomotor inhibition of remote distractors: Evidence from saccade trajectories" (Petrova, Wentura, & Fu, 2013). Experiment 3 and 5 were previously published as a part of the journal article "Upper-lower visual field asymmetries in oculomotor inhibition of emotional distractors" (Petrova & Wentura, 2012).

decrease the probability of a habituation effect. To disentangle emotional from perceptual processes inverted faces were used in addition to upright faces. It is hypothesized that if the effect of emotion on saccade trajectories is due to the holistic processing of the emotional content rather than the processing of the perceptual features, it should be observed with upright faces but not with inverted faces.

As has been previously noted, although stronger curvature away is typically interpreted as stronger attentional capture, an alternative interpretation that the literature on saccade trajectories does not rule out is that a strong initial activation is more difficult to get inhibited, thus producing a weaker curvature away. Therefore, Experiment 4 aimed to provide a more direct evidence that the emotional content of facial distractors modulates saccade trajectories early in time by measuring the saccade trajectory curvature before the inhibition process started operating. Based on the results of Experiment 3 and the negativity bias hypothesis, it is hypothesized that angry facial distractors will be more strongly activated than happy facial distractors. However, because this time the inhibition process is expected not to occur, a stronger curvature *towards* rather than a stronger curvature away is hypothesized with angry than with happy distractors. To test this hypothesis, a small change in the experimental procedure was made to speed up saccades and thus prevent inhibition from taking place.

Experiment 5 aimed to conceptually replicate the results from Experiment 3, which demonstrated stronger curvature away from angry compared to happy facial distractors, but only when the target appeared in the lower visual field. To this end, a more complex task of target selection was employed. The task required participants to select between two action-affording objects by saccading towards one of them. Thus, the modulation by target location could be more validly related to the special role of the lower visual field in near space representation and action control (Previc, 1990).

5 Saccade trajectories with emotional distractors

5.1 Oculomotor inhibition of neutral distractors (Experiment 1)

The aim of Experiment 1 was to establish the basic curvature effect by showing that saccades curve away from task-irrelevant distractors compared to the condition in which no distractor is presented.

5.1.1 Method

Participants. Twenty-six non-psychology students of Saarland University participated in the experiment (13 female). Their median age was 23.5 years (ranging from 18 to 30 years). All participants reported having normal or corrected-to-normal vision. Participants were paid 6 € for their participation.

Apparatus & Material. Eye movements were recorded with a video-based column eye tracker (iView X Hi-Speed, SensoMotoric Instruments) with a temporal resolution of 500 Hz and a spatial resolution of 0.01°. A chin rest was used to minimize head movements and to maintain the viewing distance at 64 cm. A forehead rest was used to allow participants to keep their head parallel to the display. This ensured that the stimuli subtended the same visual angle independent of the visual hemifield in which they appeared. Data were recorded from the dominant eye. The stimuli were presented on a black background. The fixation cross was a white cross subtending a visual angle of 1.79° × 1.79°. The target was a gray diamond subtending a visual angle of 2.24° × 2.24°. The target appeared 10.27° above or below fixation. The distractor was a gray ellipse subtending a visual angle of 1.52° × 2.42°, which appeared in the upper-left, upper-right, lower-left, and lower-right part of the screen (at a vertical distance of 3.58° between the fixation cross and the innermost edge of the ellipse, and a horizontal distance of 5.81° between the fixation cross and the innermost edge of the ellipse). The stimuli were presented on a 21-in flat color monitor with a refresh rate of 75 Hz and a resolution of 1024 × 768 pixels.

Design. The design comprised three within-subject factors, namely target location (upper vs. lower), vertical distractor location (upper vs. lower), and horizontal distractor location (left vs. right). In addition, two no-distractor conditions (target upper vs. target lower) were included, which served as a baseline. Each participant completed a total of 400 trials (40 trials per distractor condition and 40 trials per no-distractor condition).

Procedure. Participants were tested in individual experimental sessions. Participants first provided informed consent. Individual eye-tracker adjustments were performed followed by a 13-point calibration. Subsequently, the instructions were given on the display. There were 10 practice trials and 6 buffer trials. Participants could take an unlimited number of breaks. The experimental session lasted approximately 45 minutes.

Each trial began with a central fixation cross which remained on the screen until the experimenter pressed the space bar. The experimenter carried the trial on if participants fixated the fixation cross. If participants' gaze did not land on the fixation cross due to impairment in tracking accuracy (e.g., due to a change in body or head posture), a recalibration was performed. Subsequently, the target rhombus and distractor ellipse appeared simultaneously and remained on the screen for 1500 ms. The target display was followed by an inter-stimulus interval of 500 ms, after which the next trial started. Participants were instructed to look at the target as quickly and accurately as possible and to maintain their gaze on the target as long as it remained on the display. Participants were told that in most trials a distractor ellipse would appear at one of the intercardinal points of the display, simultaneously with the target.

Participants were told that this ellipse was totally irrelevant for their task and therefore was to be ignored.

Data analysis. The SMI software BeGaze identified saccade start and end points using a 40°/s velocity criterion. Saccade latency, direction, and amplitude were derived from the eye movement records for the first saccade in each trial. Saccades were excluded from further analysis if (1) the gaze deviated more than 1.93° from the display centre at the time of target onset, (2) the latency was less than 80 ms, (3) the saccade was not directed to the correct target location, or (4) the amplitude was less than 6° or greater than 16°.

After saccades had been identified, the curvature measure was computed using MATLAB. The quadratic coefficient of the second-order polynomial that is fitted to the normalized saccade was used as a measure of curvature (Ludwig & Gilchrist, 2002). To this end, each saccade trajectory was first plotted in a two dimensional space (see Appendix A, Figure 15a). In a second step, the trajectory was rotated such that the straight line between the start and the end point lied on the abscissa, and the values on the ordinate indicated the perpendicular deviations from the straight line (see Appendix A, Figure 15b). In a third step, the trajectory was normalized by rescaling the horizontal axis such that each saccade started at `x = -1` and ended at `x = 1` (see Appendix A, Figure 15c). Finally, a quadratic polynomial was fitted to the normalized trajectory (see Appendix A, Figure 15d). The normalization leaves the shape of the saccade and the function unaffected, but makes the coefficients of the second-order polynomial interpretable. In particular, the quadratic coefficient can be used as a direct estimate of the amount of curvature (see Appendix A, Figure 15e). The logic behind this procedure can be understood by determining what the predicted deviation is at the start and endpoint of the saccade (see Appendix A, Figure 15e for an illustration). Due to the normalization, each saccade now starts at `x = -1` and ends at `x = 1`. Therefore, the predicted deviation at saccade start equals `a – b + c`, which is what results when one substitutes `x` by `-1` in the quadratic equation $ax^2 + bx + c$; the predicted deviation at saccade end equals $a + b + c$, which is what results when one substitutes x by $+1$ in the quadratic equation $ax^2 + bx + c$. The average of those two values is $a + c$, which is the point on the ordinate that lies exactly in the middle between the predicted deviation at saccade start (i.e., $a - b + c$) and the predicted deviation at saccade end (i.e., $a + b + c$). What a is indicative of, becomes evident when one takes c into account. C corresponds to the point on the ordinate where the polynomial intersects the ordinate. C equals the predicted deviation in the middle of the saccade (i.e., at $x = 0$), which is what results when one substitutes x by 0 in the quadratic equation $ax^2 + bx + c$.

Since saccade trajectories are highly idiosyncratic and never completely straight, curvature scores were calculated by subtracting the quadratic curvature observed in the no-distractor conditions from the quadratic curvature observed in the distractor conditions. The baseline curvature for each participant was calculated and subtracted for each target location separately. Thus, the effect of distractor on trajectory reported here reflects the difference in curvature between the distractor and the corresponding no-distractor conditions. Trajectories curving towards the distractor were assigned positive values, whereas trajectories curving away from the distractor were assigned negative values. The trajectory curvatures are reported in degrees of visual angle.

5.1.2 Results

The exclusion criteria (see above) led to a mean loss of 18.5 % of the trials.

Saccade curvature

Importantly, the mean curvature score was significantly smaller than zero, $t(25) = 5.67$, $p < .001$ ($M = -0.07$, $SD = 0.06$), indicating that saccades curved away from the distractors (see Appendix C for mean curvature scores in each condition from the complete design). Preliminary analyses showed that the horizontal distractor location did not significantly modulate any effect, all *F*s < 3.45. Therefore, to reduce the complexity of the analyses the distractor conditions were collapsed across the horizontal distractor location. Curvature scores were submitted to a 2 (target location: upper vs. lower) × 2 (distractor location: upper vs. lower) within-subject MANOVA. The main effect of target location was significant, $F(1,25) = 26.45$, $p < .001$, $\eta_p^2 = .51$, indicating that downwards saccades curved more strongly away from the distractors than upwards saccades ($M = -0.13$, $SD = 0.11$ vs. $M = -0.01$, $SD = 0.05$). The main effect of distractor location was significant, $F(1,25) = 4.65$, $p < .05$, $\eta_p^2 = .16$, indicating stronger curvature away with upper distractors than lower distractors ($M = -0.08$, $SD = 0.07$ vs. $M = -0.06$, $SD = 0.07$). The interaction of target location and distractor location was significant, $F(1,25) = 24.17$, $p < .001$, $\eta_p^2 = .49$, indicating stronger curvature away when target and distractor appeared in the opposite hemifields than when they appeared in the same hemifield ($M = -0.11$, $SD = 0.08$ vs. $M = -0.03$, $SD = 0.07$).

Saccade latency

Saccade latencies were significantly faster in the baseline conditions than in the distractor conditions, $t(25) = 9.77$, $p < .001$, $d = 1.91$ ($M = 242$ ms, $SD = 58$ ms vs. $M = 259$ ms, $SD = 59$ ms). Saccade latencies from the distractor conditions were submitted to a 2 (target location: upper vs. lower) × 2 (distractor location: upper vs. lower) within-subject MANOVA (see Appendix D for mean saccade latencies in each condition from the complete design). The main effect of target location was significant, $F(1,25) = 42.25$, $p < .001$, $\eta_p^2 = .63$, indicating faster latencies with upwards compared to downwards saccades ($M = 244$ ms, $SD = 63$ ms vs. $M = 275$ ms, $SD = 58$ ms). The main effect of distractor location was not significant, $F(1,25) < 1$. The interaction of target location and distractor location was significant, $F(1,25) = 45.05$, $p < .001$, $\eta_p^2 = .64$, indicating faster latencies when the target and the distractor appeared in the same hemifield than when they appeared in the opposite hemifields ($M = 251$ ms, $SD = 56$ ms vs. $M = 267$ ms, $SD = 63$ ms).

5.1.3 Discussion

Experiment 1 aimed to establish the basic curvature away effect. To this end, participants were asked to look at a target onset as quickly and accurately as possible. A single neutral distractor (i.e., ellipse) was presented simultaneously with the target onset in one of the four quadrants of the screen. As hypothesized and in line with the literature on saccade trajectories, curvature scores were significantly smaller than zero, indicating that saccades curved significantly away from the distractor. According to population coding theories, saccade curvatures reflect the strength of the oculomotor programs present on a common motor map at the moment the eye movement is initiated (e.g., McSorley et al., 2004; Tipper et al., 2000). In particular, the distractor-related activation is assumed to be inhibited resulting in saccade curvature away from the distractor location.

The curvature score was found to be moderated by the target location, which can be attributed to the latencies being faster with upwards saccades than with downwards saccades. As inhibition unfolds over time (McSorley et al., 2006), less time is available with upwards saccades for the distractor population to get inhibited, resulting in less curvature away. Moreover, stronger curvature away was observed when target and distractor appeared in the opposite hemifields (i.e., far from each other) compared to when they appeared in the same hemifield (i.e., close to each other). This finding is in line with previous research showing that trajectory deviation away decreased with decreasing distance between distractor and target (McSorley et al., 2009). It has been attributed to mutual excitation with visual signals that are close to each other and mutual inhibition with visual signals that are further away from each other (Dorris, Olivier, & Munoz, 2007; McSorley et al. 2009).

Experiment 1 also replicated the remote distractor effect typically found with saccade latencies (e.g., Walker et al., 1997). In particular, saccade latencies were found to be faster in the baseline conditions than in the distractor conditions. In addition, saccade latencies were faster when the distractor appeared in the same hemifield as the target than when it appeared in the opposite hemifield. These remote distractor effects have been shown to be very robust. They have been attributed to inhibitory processes operating on the population that codes the saccade towards the distractor (for a review, see Sumner, 2011). In particular, when a distractor is presented in addition to the target, a competition arises between the two signals associated with them. The delayed reaction time in the distractor conditions compared to the baseline conditions is attributed to the inhibition that the distractor applies to the target, which slows down the target's rate of rise and prevents it from winning the race. When the distractor is presented close to the target (i.e., in the same hemifield), its activity excites the activity of the target, such that the threshold for the initiation of the saccade is reached more quickly, producing short saccade latencies. In contrast, when the distractor is presented farther away from the target (i.e., in the opposite hemifield), its activity inhibits the activity of the target. Therefore, the distractor activity must be inhibited. As a result, the threshold for the initiation of the saccade is reached more slowly, producing long saccade latencies.

Latencies in the present experiment were also found to be faster with upwards saccades compared to downwards saccades. Although its underlying mechanisms are still unclear, this asymmetry has been repeatedly reported in previous studies (e.g., Honda & Findlay, 1992; Ludwig & Gilchrist, 2003; Previc, 1996). According to Danckert and Goodale (2003), this asymmetry in saccade latencies might have ecological origins. In particular, it might compensate the poor visual performance typically observed in the upper visual field with various tasks (for a review on upper-lower visual field asymmetries, see Danckert and Goodale, 2003).

To sum up, Experiment 1 successfully replicated a number of distractor effects typically found in the literature on saccade trajectories and saccade latencies. Given this basis, Experiment 2 aimed to follow up using schematic emotional faces as distractors.

5.2 Oculomotor inhibition of schematic facial distractors (Experiment 2)

Experiment 2 aimed to investigate potential effects of emotion on saccade curvatures using schematic facial distractors depicting angry, happy, and neutral expressions. Schematic facial expressions were used in Experiment 2 because perceptual features can be better and more easily controlled in schematic faces as compared to natural faces. This is of particular importance if one wants to attribute any effects of facial expression on attentional performance to the emotional content of the facial expression and not to its perceptual features (see Chapter 1). Moreover, schematic facial expressions are less complex and less variable than natural faces, making the emotional expression easier to recognize and an effect of emotion more likely.

It was hypothesized that due to their superior relevance emotional distractors will appear more salient and therefore will induce more activation. As a result, emotional distractors will induce more potent competition (i.e., emotional distractors will more strongly inhibit the target and prevent it from winning the race). Therefore, more inhibition will be applied with emotional distractors compared to neutral distractors for the target to win the race, leading to stronger curvature away. In addition, given that faces are processed in a very fast and involuntary manner, a more differentiated effect of emotion on the trajectory modulation was expected, with the angry faces producing more potent competition and therefore stronger curvature away than the happy faces.

5.2.1 Method

Participants. Twenty-one non-psychology students of Saarland University participated in the experiment (16 female). Their median age was 24 years (ranging from 21 to 26 years). All participants reported having normal or corrected-to-normal vision. Participants were paid 5 € for their participation.

Apparatus & Material. Eye movements were recorded with the same apparatus as in Experiment 1. Data were recorded from the right eye. The stimuli were presented on a black background. The fixation cross was a white cross subtending a visual angle of 1.52° × 1.52°. The target was a gray diamond subtending a visual angle of 1.79° × 1.79°. The target appeared 8.93° above or below fixation. Distractors were schematic faces depicting a neutral, angry, and happy expression (see Figure 7). The distractors subtended a visual angle of 4.03° × 4.92° and appeared in the upper-left, upper-right, lower-left, and lower-right part of the screen (at a vertical distance of 2.24° between the fixation cross and the innermost edge of the face picture, and a horizontal distance of 4.47° between the fixation cross and the innermost edge of the face picture). The stimuli were presented on a 17-in CRT monitor with a refresh rate of 75 Hz and a resolution of 1024 × 768 pixels.

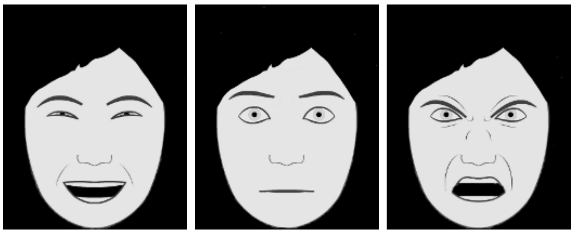


Figure 7. The distractor stimuli used in Experiment 2. The stimuli were taken from the Grimace Project (Vienna University of Technology; http://grimace-project.net/).

Design. The design comprised four within-subject factors, namely distractor emotion (angry vs. happy vs. neutral), target location (upper vs. lower), vertical distractor location (upper vs. lower), and horizontal distractor location (left vs. right). In addition, two no-distractor conditions (target upper vs. target lower) were included, which served as a baseline. Each participant completed a total of 300 trials (10 trials per distractor condition and 30 trials per no-distractor condition).

Procedure. Participants were tested in individual experimental sessions. Participants first provided informed consent. Individual eye-tracker adjustments were performed followed by a 13-point-calibration.

Subsequently, the instructions were given on the display. There were 6 practice trials and 2 buffer trials. There was a break after the first half of the experiment, after which the eye tracker was recalibrated. The experimental session lasted approximately 30 minutes.

Each trial began with a central fixation cross presented for 800, 900, 1000, 1100, or 1200 ms (randomly determined with equal probability), which participants were asked to look at (see Figure 8 for an illustration of the trial sequence). Subsequently, the target rhombus and the distractor face appeared simultaneously and remained on the screen for 1500 ms. The target display was followed by an inter-stimulus interval of 500 ms, after which the next trial started. Participants were instructed to look at the target as quickly and accurately as possible and to maintain their gaze on the target as long as it remained on the display. Participants were told that in most trials simultaneously with the target a face would appear at one of the intercardinal points of the display. Participants were told that these faces were totally irrelevant for their task and therefore were to be ignored.

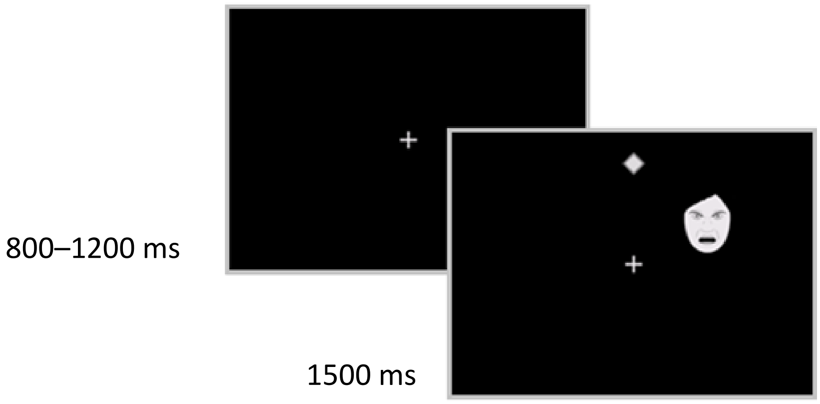


Figure 8. An illustration of the trial sequence in Experiment 2. The saccade target (grey rhombus) appeared above or below the fixation cross. In most trials, simultaneously with the target a distractor face depicting an angry, happy, or neutral expression appeared in one of the four quadrants of the display.

Data analysis. Data were prepared in the same way as in Experiment 1.

5.2.2 Results

The exclusion criteria (see above) led to a mean loss of 19.9% of the trials.

Saccade curvature

Preliminary analyses showed that the horizontal distractor location did not significantly modulate any emotion effect, all *F*s < 1.53. Therefore, to reduce the complexity of the analyses the distractor conditions were collapsed across the horizontal distractor location (see Appendix C for mean curvature scores in each condition from the complete design). Importantly, saccades curved again away from the distractors (see Table 1 for mean curvature scores). Curvature scores were submitted to a 3 (distractor emotion: angry vs. happy vs. neutral) × 2 (target location: upper vs. lower) × 2 (distractor location: upper vs. lower) within-subject MANOVA. Since the multivariate approach for repeated measures was used, the tripartite factor of emotion is – as part of the procedure – transformed into a vector of two orthogonal contrast variables (e.g., Dien & Santuzzi, 2005). The contrasts were a priori chosen in a way that they represent the specific hypotheses outlined above. That is, the first contrast is the contrast between angry and happy faces, representing the hypothesis of larger curvature for angry compared to happy faces. For the second contrast, scores are averaged across angry and happy faces and contrasted with the neutral faces. This contrast represents the hypothesis that emotional stimuli in general produce larger curvature compared to neutral stimuli. Although emotional distractors produced numerically stronger curvature away than neutral distractors (see Table 1), the main effect of distractor emotion was not significant, $F(2,19) < 1$. The main effect of target location was significant, $F(1,20) = 29.47$, $p < .001$, $\eta_p^2 = .60$, indicating that downwards saccades curved more strongly away from the distractors than upwards saccades. There was a significant interaction of target location and distractor location, $F(1,20) = 5.41$, $p < .05$, $\eta_p^2 = .21$, indicating stronger curvature away when target and distractor appeared in the opposite hemifields than when they appeared in the same hemifield. There were no other significant main effects or interactions, all *F*s < 1.77.

Table 1.

Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in Experiment 2 (in degrees, with standard deviations); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

Emotion	LVF target		UVF target	
	LVF distractor	UVF distractor	LVF distractor	UVF distractor
Angry	-0.16* (0.15)	-0.22* (0.16)	-0.11* (0.10)	-0.09 (0.16)
Happy	-0.16* (0.14)	-0.25* (0.16)	-0.10* (0.08)	-0.05 (0.15)
Neutral	-0.14 (0.22)	-0.20* (0.12)	-0.09* (0.09)	-0.07 (0.17)

* $p < .05$ (overall level, i.e., Bonferroni alpha-corrected) Curvature score significantly different from zero.

Saccade latency

Saccade latencies were significantly faster in the baseline conditions than in the distractor conditions (i.e., remote distractor effect; Walker et al. 1997), $t(20) = 8.09$, $p < .001$, $d = 1.77$ ($M = 208$ ms, $SD = 39$ ms vs. $M = 231$ ms, $SD = 37$ ms). Saccade latencies from the distractor conditions were submitted to a 3 (distractor emotion: angry vs. happy vs. neutral) × 2 (target location: upper vs. lower) × 2 (distractor location: upper vs. lower) within-subject MANOVA (see Appendix D for mean saccade latencies in each condition from the complete design). There was no main effect of distractor emotion, $F(2,19) = 1.11$, $p = .35$, $\eta_p^2 = .11$. Again, there was a significant main effect of target location, $F(1,20) = 42.31$, $p < .001$, $\eta_p^2 = .68$, showing that upwards saccades had faster latencies than downwards saccades ($M = 217$ ms, $SD = 33$ ms vs. $M =$

245 ms, *SD* = 43 ms). There was a significant interaction of target location and distractor location, $F(1,20) = 32.09$, $p < .001$, $\eta_p^2 = .62$, indicating that saccade latencies were faster when the target and the distractor appeared in the same hemifield than when they appeared in the opposite hemifields (i.e., remote distractor effect; *M* = 224 ms, *SD* = 37 ms vs. *M* = 237 ms, *SD* = 38 ms). There were no other significant main effects or interactions, all *F*s < 1.17.

5.2.3 Discussion

Experiment 2 aimed to investigate possible effects of emotion on trajectory curvatures. To this end, participants were asked to look at a target onset as quickly and accurately as possible. A single schematic facial distractor depicting an angry, happy, or neutral expression appeared simultaneously with the target onset in one of the four quadrants of the screen. Again, the distractor effects typically found in the literature on saccade trajectories and saccade latencies were successfully replicated. Saccade trajectories curved significantly away from the distractor and saccade latencies were slowed down by the presence of the distractor. However, no effect of distractor emotion was found although numerically the emotional distractors produced stronger curvature away than the neutral distractor. This might seem surprising given that schematic facial expressions are less complex and less variable than natural faces, thus making the emotional expression easier to recognize and an effect of emotion more likely. However, it might be the case that the limited variability of the facial stimuli (i.e., one stimulus per emotion) resulted in habituation. Moreover, although schematic faces are easier to control for low-level perceptual features, their ecological validity is strongly limited. For this reason, a follow-up experiment was conducted in which pictures of natural emotional expressions were used and the stimulus variability within the individual emotions was increased.

5.3 Oculomotor inhibition of natural facial distractors (Experiment 3)

The aim of Experiment 3 was to investigate the effect of emotional facial expressions on saccade trajectories by making several improvements as compared to Experiment 2. To increase the ecological validity of the stimuli pictures of natural emotional faces were used. As previously stated, however, pictures of natural emotional faces are more difficult to control for perceptual features. For this reason, a condition was included which aimed to rule out the possibility that perceptual features drive the effect of emotion. In particular, the inversion procedure was employed, in which the face stimuli are presented upside-down. The reasoning behind the inversion procedure is that inversion impairs the holistic processing of faces, including emotion processing, whereas the perceptual processing of the single components remains intact (e.g., Fox & Damjanovic, 2006; Leder & Bruce, 2000; Tanaka & Farah, 1993). Thus, if the effect of angry versus happy faces on saccade curvature is due to processing of the emotional content rather than processing of the low-level perceptual features of the images, then it should be observed with upright faces but not with inverted faces. Thus, if face orientation (i.e., upright vs. inverted) moderates the effect of emotion, one can plausibly infer that the emotional connotation is the underlying influence.

Moreover, a gaze-contingent feedback on task compliance was included. In particular, the target color changed to green as soon as participant’s gaze reached it. This change was made to the procedure to enhance participants’ engagement in the task and therefore to improve the eye movement data quality. In addition, to counteract any possible habituation effects, the number of different stimuli per distractor emotion was increased (i.e., ten different stimuli per distractor emotion instead of one). Finally, to increase the reliability of the curvature measure the number of distractor trials was doubled.

5.3.1 Method

Participants. Twenty-three non-psychology students of Saarland University participated in the experiment (14 female). Their median age was 25 years (ranging from 20 to 29 years). All reported having normal or corrected-to-normal vision. Participants were paid 7,50 € for their participation. They gave their informed consent prior to the experiment session.

Apparatus & Material. Eye movements were recorded with the same apparatus as in Experiment 1. Data were recorded from the dominant eye. The stimuli were presented on a black background. The fixation cross was a white cross subtending a visual angle of 1.79° × 1.79°. The target was a gray diamond subtending a visual angle of 2.24° × 2.24°. The target appeared 10.27° above or below fixation. Distractors were the neutral, angry, and happy face photographs of 10 individuals (5 female) from the Karolinska Directed Emotional Faces Set (Lundqvist, Flykt, & Öhman, 1998). Non-facial features were cropped by applying an oval shape that retained the eyebrows, the eyes, the nose, and the mouth in each image. The distractors subtended a visual angle of 3.58° × 4.92° and appeared in the upper-left, upper-right, lower-left, and lower-right part of the screen (at a vertical distance of 2.24° between the fixation cross and the innermost edge of the face photograph, and a horizontal distance of 5.37° between the fixation cross and the innermost edge of the face photograph). The mean luminance of the face photographs was assessed using Adobe Photoshop CS4. The distractor photographs did not differ in mean luminance, $F(2,27) = 2.15$, $p = .14$. The stimuli were presented on the same monitor as in Experiment 1.

Design. The design comprised one between-subject factor, namely distractor orientation (upright vs. inverted), and four within-subject factors, namely distractor emotion (angry vs. happy vs. neutral), target location (upper vs. lower), vertical distractor location (upper vs. lower), and horizontal distractor location (left vs. right). Distractor orientation was varied between subjects in order to avoid carry-over effects (i.e., that the processing of the upright faces subsequently affects the processing of the inverted faces). In addition, two no-distractor conditions (target upper vs. target lower) were included, which served as a baseline. Each participant completed a total of 540 trials (20 trials per distractor condition and 30 trials per no-distractor condition).

Procedure. Participants were tested in individual experimental sessions. The procedure was the same as in Experiment 1 with the exception that the target color changed to green as soon as the participants fixated it (see Figure 9 for an illustration of the trial sequence). This change was made to the procedure to provide participants with feedback on task compliance and to enhance their engagement in the task, thus improving the eye movement data quality. The experimental session lasted approximately 45 minutes.

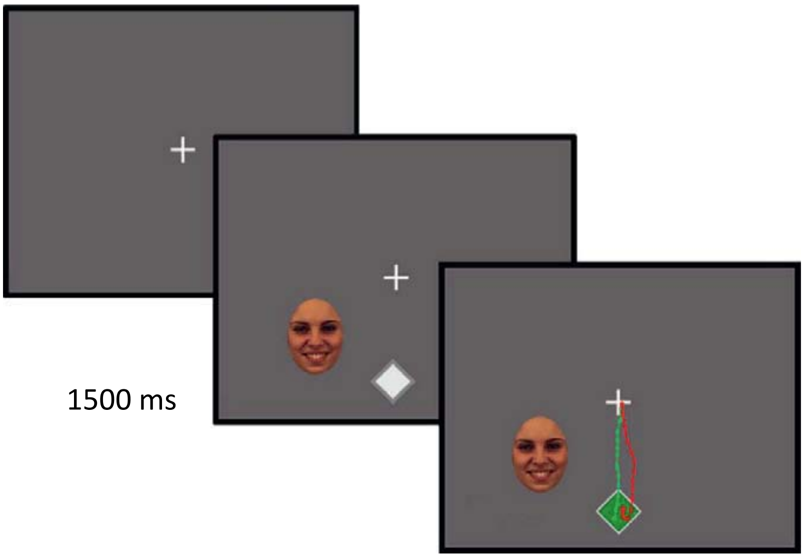


Figure 9. An illustration of the trial sequence in Experiment 3. The target (grey rhombus) appeared above or below the fixation cross; the distractor face appeared in the upper-left, upper-right, lower-left, or lower-right quadrant of the display. The target's color changed to green as soon as the participant fixated the target. Depicted are also two sample saccade trajectories from the distractor condition (red line) and the corresponding no-distractor baseline condition (green line).

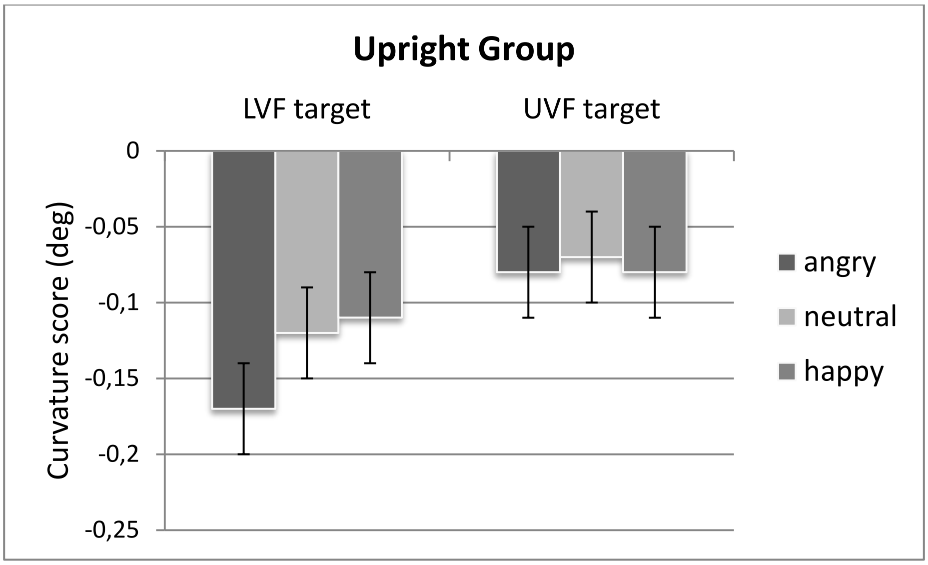
Data analysis. Data were prepared in the same way as in Experiment 1.

5.3.2 Results

The exclusion criteria (see above) led to a mean loss of 13.3 % of the trials.

Saccade curvature

Preliminary analyses showed that the horizontal distractor location did not significantly modulate any emotion effect, all *F*s < 2.53. Therefore, to reduce the complexity of the analyses distractor conditions were collapsed across the horizontal distractor location (see Appendix C for mean curvature scores in each condition from the complete design). Saccade trajectories curved again away from the distractors (see Figure 10 for mean curvature scores). Curvature scores were submitted to a mixed 2 (distractor orientation: upright vs. inverted) × 3 (distractor emotion: angry vs. happy vs. neutral) × 2 (distractor location: upper vs. lower) × 2 (target location: upper vs. lower) MANOVA. The main effect of target location was significant, $F(1,21) = 6.49$, $p < .05$, $\eta_p^2 = .24$, indicating that downwards saccades curved away from the distractor more strongly than upwards saccades ($M = -0.14$, $SD = 0.12$ vs. $M = -0.08$, $SD = 0.11$). The interaction of distractor emotion and distractor location was marginally significant, $F(2,20) = 3.44$, $p = .05$, $\eta_p^2 = .26$ ($F(1,21) < 1$, for angry vs. happy; $F(1,21) = 4.23$, $p = .05$, $\eta_p^2 = .17$, for neutral vs. emotional). In the upper visual field, mean curvature scores were numerically (but not significantly) greater for neutral compared to emotional distractors ($M = -0.11, -0.10, -0.12$, for angry, happy, and neutral, respectively; $F(2,21) = 2.19$, $p = .14$, $\eta_p^2 = .17$; $F(1,22) = 1.87$, $p = .19$, $\eta_p^2 = .08$, for emotional vs. neutral); in the lower visual field, it was the other way round ($M = -0.12, -0.11, -0.09$, for angry, happy, and neutral, respectively; $F(2,21) = 1.44$, $p = .26$, $\eta_p^2 = .12$; $F(1,22) = 2.87$, $p = .10$, $\eta_p^2 = .12$, for emotional vs. neutral). Note that this interaction was *not* qualified by distractor orientation (i.e., upright vs. inverted), $F(2,20) < 1$. Thus, it had presumably nothing to do with emotional processing.



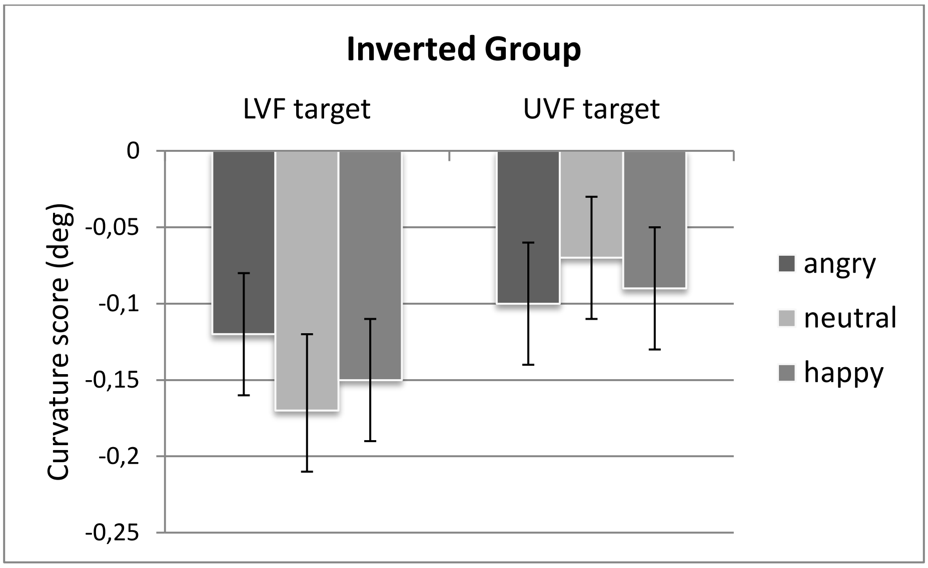


Figure 10. Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in Experiment 3 (in degrees; error bars represent the standard error of the mean); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

Most importantly, the interaction of distractor orientation, distractor emotion, and target location was significant, *F*(2,20) = 5.58, *p* = .01, η_p^2 = .36, suggesting that face inversion (i.e., whether a face directly signals an emotion or not) modulated the two-way interaction of emotional face type and target location (see Figure 10). This interaction was due to a significant contrast between the angry and the happy distractors, $F(1,21) = 10.58$, $p < .01$, $\eta_p^2 = .34$, but not due to the contrast between the emotional distractors (i.e., angry and happy stimuli collapsed) and the neutral distractors, $F(1,21) = 2.44$, $p = .13$, $\eta_p^2 = .10$. There were no other significant effects or interactions (all *F*s < 2.59). To further examine the interaction of distractor orientation, distractor emotion, and target location separate analyses for each distractor orientation group were conducted.

Analysis of upright faces: the effect of emotion. For the upright distractor orientation group, a significant interaction of distractor emotion and target location emerged, $F(2,10) = 4.41$, $p < .05$, $\eta_p^2 = .47$. Again, this result was due to a significant difference between the happy and the angry distractors, $F(1,11) = 9.63$, $p = .01$, $\eta_p^2 = .47$ ($F(1,11) < 1$, for emotional vs. neutral). The curvature scores were analyzed for each target location separately. For the upper target location, the main effect of distractor emotion was not significant, $F(2,10) < 1$. For the lower target location, however, the main effect of distractor emotion was significant, $F(2,10) = 4.39$, $p < .05$, $\eta_p^2 = .47$. It was again almost exclusively due to the significant difference between the angry and the happy distractors, $F(1,11) = 9.66$, $p = .01$, $\eta_p^2 = .47$ ($F(1,11) < 1$, for emotional vs. neutral).

Analysis of inverted faces: controlling for perceptual features. As can be seen from Figure 10, the numerical pattern of curvature scores was different for inverted faces compared to upright faces. The interaction of distractor emotion and target location missed the conventional level of significance, $F(2,9) = 3.15$, $p = .09$, $\eta_p^2 = .41$. Even more importantly, the contrast angry vs. happy (i.e., the essential difference for upright faces) was clearly non-significant for inverted faces, $F(1,10) = 2.74$, $p = .13$, $\eta_p^2 = .22$ ($F(1,10) = 5.53$, $p < .05$, $\eta_p^2 = .36$, for emotional vs. neutral). Although the interaction missed the conventional level of significance, the curvature scores were analyzed for each target location separately corresponding to the upright group analysis. Importantly, the main effect of emotion was not significant with either target location, $F(2,9) < 1$, for the upper target location, $F(2,9) = 2.59$, $p = .13$, $\eta_p^2 = .37$, for the lower target location ($F(1,10) = 3.97$, $p =$

.07, $\eta_p^2 = .28$, for angry vs. happy; $F(1,10) = 2.59$, $p = .14$, $\eta_p^2 = .21$, for emotional vs. neutral).

Saccade latency

Saccade latencies were significantly faster in the baseline conditions than in the distractor conditions (i.e., remote distractor effect; Walker et al., 1997), $t(22) = 3.88$, $p = .001$, $d = 0.81$ ($M = 234$ ms, $SD = 35$ ms vs. $M = 244$ ms, $SD = 33$ ms). Since the magnitude of saccade trajectory modulation depends on saccade latency (McSorley et al., 2006), saccade latencies from the distractor conditions were submitted to a mixed 2 (distractor orientation: upright vs. inverted) × 3 (distractor emotion: angry vs. happy vs. neutral) × 2 (distractor location: upper vs. lower) × 2 (target location: upper vs. lower) MANOVA (see Appendix D for mean saccade latencies in each condition from the complete design). The main effect of target location was significant, $F(1,21) = 89.41$, $p < .001$, $\eta_p^2 = .81$, indicating that upwards saccades were faster than downwards saccades ($M = 230$ ms, $SD = 32$ ms vs. $M = 258$ ms, $SD = 36$ ms). The interaction of target location and vertical distractor location was significant, $F(1,21) = 80.86$, $p < .001$, $\eta_p^2 = .79$, indicating that saccades were faster when target and distractor appeared in the same visual hemifield than when they appeared in the opposite hemifields (i.e., remote distractor effect; $M = 238$ ms, $SD = 34$ ms vs. $M = 249$ ms, $SD = 34$ ms). Importantly, the interaction of distractor orientation, distractor emotion, and target location was not significant, $F(2,20) = 1.08$, $p = .36$, $\eta_p^2 = .10$. No other significant main effects or interactions emerged, all Fs < 2.08.

To investigate whether the effect of angry versus happy faces found in the upright group with downwards saccades was because the latencies were slower in the lower visual field compared to the upper visual field, a multiple regression approach for repeated measures was used (Lorch & Myers, 1990). The procedure can be best understood by assuming that curvature scores are regressed on distractor emotion (angry vs. happy), target location, and saccade latency, as well as on the interaction terms distractor emotion × target location and distractor emotion × saccade latency for each participant of the upright sample separately (using trials as cases). Means of regression coefficients across the sample are then tested on whether they significantly deviate from zero. If the test for distractor emotion × target location is significant, whereas it is not significant for distractor emotion × saccade latency, one can legitimately claim that location and not latency is the decisive factor. Actually, an equivalent procedure to the one just described (suggested by Lorch & Myers, 1990) that delivers the same result in a single analysis of the participants × trials data set was used (see also Van den Noortgate & Onghena, 2006). Using this procedure, the interaction of target location and distractor emotion (angry vs. happy) was found to be significant, $F(1,11) = 5.36$, $p < .05$, whereas the interaction of latency and distractor emotion was not significant, $F(1,11) < 1$.

5.3.3 Discussion

Experiment 3 aimed to investigate the effects of emotional facial expressions on saccade trajectories by introducing several improvements as compared to Experiment 2. In particular, pictures of natural emotional faces were used, and the number of different stimuli per distractor emotion was increased. Moreover, a gaze-contingent feedback on task compliance was provided to the participants, and the number of distractor trials was increased. Again, the distractor effects typically found in the literature on saccade trajectories and saccade latencies were successfully replicated. More importantly, saccade trajectories were significantly modulated by the emotion depicted by the distractor faces. This effect was observed with upright faces but not with inverted faces. Therefore, it is unlikely to be due to differences in the perceptual features of the face types. This can be compared with the marginally significant interaction of emotional distractors and distractor location, which was *not* further moderated by orientation. There was a trend of stronger curvature away with the emotional distractors in the lower visual field as compared to the neutral distractors in the lower visual field. It might be that the components that constitute emotional faces in contrast to neutral ones (e.g., curved mouth compared to straight mouth) are more salient (see Horstmann & Bauland, 2006), and that the observers' perceptual sensitivity is better in the lower visual field for these features. However, such an effect is presumably not caused by the emotionality of the faces.

There might be several reasons why an effect of emotion was observed in Experiment 3 but not in Experiment 2. One possible reason is the use of natural emotional faces. In contrast to the schematic facial expressions used in Experiment 2, the natural emotional faces used in Experiment 3 were much more ecologically valid. Another plausible reason is the gaze-contingent feedback with which participants were presented. As it provided participants with feedback on task compliance, the amount of data noise might have consequently decreased. In fact, the proportion of trials that had to be excluded was considerably smaller in Experiment 3 (13.3%) than in Experiment 1 (18.5%) and Experiment 2 (19.9%). Also the larger number of distractor trials might have additionally reduced the amount of data noise. Finally, the discrepancy in the results between Experiment 2 and 3 might be attributed to the difference in stimulus variability between the two experiments (i.e., one vs. ten different stimuli per distractor emotion), which might have prevented any habituation effects to take place in Experiment 3.

According to the population coding theory, saccade trajectory modulations reflect the strength of the other oculomotor programs at the moment the eye movement is initiated (e.g., McSorley et al., 2004; Tipper et al., 2000). As more initial activation requires a greater amount of inhibition for successful suppression (e.g., Theeuwes & Van der Stigchel, 2009; Van der Stigchel & Theeuwes, 2007), the present results suggest that angry distractors evoked more initial activation than happy distractors and therefore required more inhibition. As previously stated, however, although stronger curvature away is typically interpreted in the literature as stronger attentional capture, it might also be the case that a strong initial activation signal is more difficult to be inhibited, resulting in a weaker curvature away. Therefore, a follow-up experiment was conducted which aimed to replicate the results from Experiment 3 by introducing a small change in the procedure which is known to create conditions that favor the measurement of the very initial activation (Experiment 4).

Importantly, the effect of emotion was restricted to saccades directed to lower targets. The lower visual field has been assumed to represent near space and be specialized for action (Previc, 1990). Thus, a downward saccade might have induced representations of near space, therefore increasing the vigilance for stimuli of superior relevance such as angry faces. To investigate whether the interaction found with target location was driven by this, another follow-up experiment was conducted in which conceptually more meaningful targets were used (Experiment 5).

5.4 Oculomotor activation of natural facial distractors (Experiment 4)

As previously stated, the measure of curvature away is associated with some ambiguity regarding its interpretation in terms of the strength of the very initial oculomotor activation. In particular, although weak curvature away (i.e., weak inhibition) has been generally interpreted as weak initial oculomotor activation and small amount of attention (e.g., Theeuwes & Van der Stigchel, 2009; Van der Stigchel & Theeuwes, 2007), a weak curvature away might alternatively be interpreted as strong initial activation, which was difficult to get inhibited. Experiment 4, therefore, aimed to replicate the findings from Experiment 3 using the more direct measure of initial oculomotor activation, namely the measure of curvature towards. Inhibition has been shown to be a slow process that requires a certain amount of time to start operating (i.e., > 180 ms; McSorley et al., 2006). Thus, accelerating saccade latencies should prevent the inhibition process from getting active and therefore produce curvature towards. A stronger curvature towards the angry distractors compared to the happy distractors would therefore provide a replication of the finding from Experiment 3 using a more direct measure of oculomotor activation.

To accelerate the saccade latencies the fixation cross was removed from the target display and a blank screen was presented for 200 ms prior to the target display. These conditions have been shown to accelerate the saccade latencies (i.e., gap effect; Ross & Ross, 1980; Saslow, 1967). This acceleration has been attributed to the inhibition operating on the signal associated with the target-directed saccade. In particular, when a fixation cross is presented, the signal associated with the fixation cross remains active, thus inhibiting the signal associated with the saccade towards the target, slowing down its rate of rise. In contrast, when the fixation cross is removed prior to the target onset, the signal associated with the fixation cross gets deactivated. As a result, no additional inhibition is applied to the target signal, leading to faster threshold reaching.

It should be noted, however, that although saccade latencies were successfully accelerated and curvature direction varied as a function of saccade latency in Experiment 4, on the level of mean curvature scores the curvature towards effect could be successfully induced only in the inverted upper target conditions (see below for more details and discussion). The focus of Experiment 4 remained therefore on a replication of the finding from Experiment 3 with the curvature away measure.

5.4.1 Method

Participants. Twenty-one non-psychology students of Saarland University participated in the experiment (13 female). Their median age was 24 years (ranging from 20 to 36 years). All reported having normal or corrected-to-normal vision. Participants were paid 6,50 € for their participation. They gave their informed consent prior to the experiment session.

Apparatus & Material. Eye movements were recorded with the same apparatus as in Experiment 1. Data were recorded from the dominant eye. The stimuli were the same as in Experiment 3. They were presented on the same monitor as in Experiment 3.

Design. The design was the same as in Experiment 3. Each participant completed a total of 540 trials (20 trials per distractor condition and 30 trials per no-distractor condition).

Procedure. Participants were tested in individual experimental sessions. The procedure was the same as in Experiment 3 with the exception that a blank screen appeared after the initial fixation cross for 200 ms and no fixation cross was presented on the target display (see Figure 11 for an illustration of the trial sequence). The experimental session lasted approximately 45 minutes.

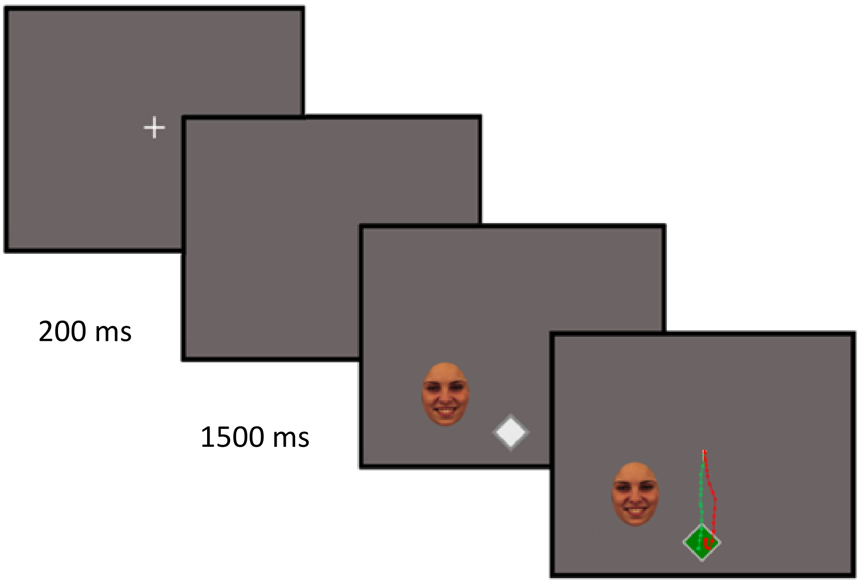


Figure 11. An illustration of the trial sequence in Experiment 4.

Data analysis. Data were prepared in the same way as in Experiment 1 with the exception that saccades were excluded from further analysis if the latency was faster than 50 ms[9] (McSorley et al., 2009) and if the amplitude was less than 4° (McSorley et al., 2009; Van der Stigchel & Theeuwes, 2007). These changes were made to ensure that more trials enter into the statistical analyses.

5.4.2 Results

The exclusion criteria (see above) led to a mean loss of 26.1% of the trials.

Saccade curvature

Curvature scores were submitted to a mixed 2 (distractor orientation: upright vs. inverted) × 3 (distractor emotion: angry vs. happy vs. neutral) × 2 (distractor location: upper vs. lower) × 2 (target location: upper vs. lower) MANOVA (see Appendix C for mean curvature scores in each condition from the complete design). As can be seen in Table 2, although the presentation of a gap generally reduced the curvature away as compared to the previous experiments, it was not sufficient to induce curvature towards on the level of mean scores (M = -0.04, SD = 0.13). The main effect of target location was significant, $F(1,19) = 8.84$, $p < .01$, $\eta_p^2 = .32$. Whereas downwards saccades significantly curved away from the distractor, $t(20) = 2.44$, $p < .05$ (M = -0.10, SD = 0.20), upwards saccades curved numerically towards the distractor, although the curvature score did not significantly deviate from zero, $t(20) = 1.07$, $p = .30$ (M = 0.03, SD = 0.14). The main effect of distractor orientation was significant, $F(1,19) = 4.80$, $p < .05$, $\eta_p^2 = .20$, indicating stronger curvature away with upright faces compared to inverted faces (M = -0.09, SD = 0.11 vs. M = 0.03, SD = 0.13). The interaction of target location and distractor location was significant, $F(1,19) = 19.11$, $p < .001$, $\eta_p^2 = .50$, indicating stronger curvature away when target and distractor appeared in the opposite hemifields than when they appeared in the same

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[9] The latency criterion was set more liberal because the presentation of a gap is known to induce very fast saccades whose latencies might be as fast as 50 ms (i.e., express saccades; Fischer & Boch, 1983).

hemifield (*M* = -0.10, *SD* = 0.10 vs. *M* = 0.03, *SD* = 0.19). Although in line with Experiment 3 angry faces produced numerically stronger curvature away than happy faces when the target appeared in the lower visual field in the upright condition, the interaction of distractor orientation and distractor emotion was not significant, *F*(2,18) < 1, neither was the interaction of distractor orientation, distractor emotion, and target location significant, *F*(2,18) < 1. There were no other significant main effects or interactions, all *F*s < 2.34.

Table 2.

Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in Experiment 4 (in degrees, with standard deviations); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

Distractor emotion	Upright		Inverted	
	LVF target	UVF target	LVF target	UVF target
Angry	-0.17 (0.20)	-0.01 (0.13)	-0.06 (0.24)	0.09 (0.13)
Happy	-0.14 (0.17)	-0.04 (0.10)	-0.05 (0.21)	0.12 (0.21)
Neutral	-0.15 (0.17)	-0.04 (0.11)	-0.04 (0.22)	0.10 (0.12)

Saccade latency

A closer look at the saccade latencies shows that the gap condition successfully accelerated the saccade latencies (*M* = 169 ms, *SD* = 14 ms). Saccade latencies were again significantly faster in the baseline conditions than in the distractor conditions (i.e., remote distractor effect; Walker et al., 1997), *t*(20) = 13.81, *p* < .001, *d* = 3.01 (*M* = 158 ms, *SD* = 14 ms vs. *M* = 180 ms, *SD* = 15 ms). Saccade latencies from the distractor conditions were submitted to a mixed 2 (distractor orientation: upright vs. inverted) × 3 (distractor emotion: angry vs. happy vs. neutral) × 2 (distractor location: upper vs. lower) × 2 (target location: upper vs.

lower) MANOVA (see Appendix D for mean saccade latencies in each condition from the complete design). Again, the main effect of target location was significant, $F(1,19) = 21.42$, $p < .001$, $\eta_p^2 = .53$, indicating that upwards saccades were faster than downwards saccades (M = 170 ms, SD = 20 ms vs. M = 190 ms, SD = 15 ms). The interaction of target location and distractor location was significant, $F(1,19) = 78.29$, $p < .001$, $\eta_p^2 = .81$, indicating faster latencies when target and distractor appeared in the same visual field compared to when they appeared in the opposite visual fields (i.e., remote distractor effect; M = 175 ms, SD = 14 ms vs. M = 185 ms, SD = 16 ms). The interaction of distractor emotion and distractor location was significant, $F(2,18) = 3.72$, $p < .05$, $\eta_p^2 = .29$. Since this interaction was *not* qualified by distractor orientation (i.e., upright vs. inverted), $F(2,18) < 1$, and therefore had presumably nothing to do with the emotional connotation of the faces, no further analyses were performed. There were no other significant main effects or interactions, all Fs < 1.53.

A closer look at the saccade latency distribution (see Figure 12) shows an early mode between 50 ms and 100 ms, which is typically found under gap conditions. These very fast saccades have been termed express saccades (e.g., Fischer & Boch, 1983) and are especially common in experiments in which the conditions favor rapid saccades such as in the gap paradigm. To examine whether curvature scores in the current experiment varied as a function of latency (McSorley et al., 2006), the multiple regression approach for repeated measures was employed (Lorch & Myers, 1990; see Experiment 3 for details). In particular, curvature scores were regressed on saccade latency. As expected, latency significantly predicted curvature scores, $F(1,20) = 18.61$, $p < .001$, indicating positive curvature scores (i.e., curvature towards) with fast latencies and negative curvature scores (i.e., curvature away) with slow latencies.

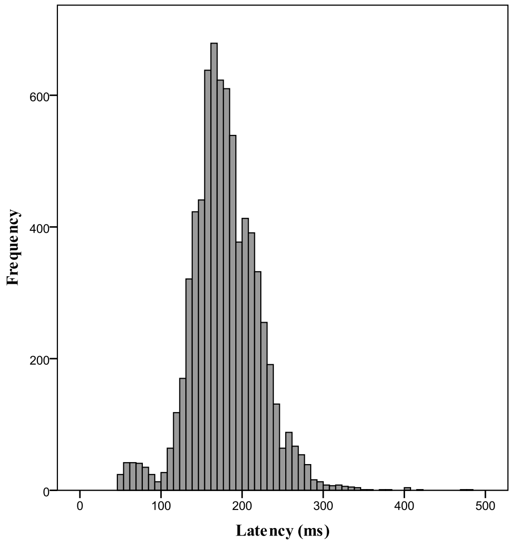


Figure 12. Saccade latency distribution in Experiment 4.

5.4.3 Discussion

The aim of Experiment 4 was to replicate the findings from Experiment 3 using the more direct measure of initial oculomotor activation, namely the curvature towards. To this end, the gap paradigm was employed because it has been shown to favor very fast saccade latencies (e.g., Saslow, 1967), and saccades with fast latencies have been shown to prevent inhibition from taking place, thus exhibiting curvature towards (McSorley et al., 2006). In the present experiment, saccade acceleration was successfully induced and curvature scores varied as a function of saccade latency. However, although the saccade acceleration considerable decreased the curvature away effect, it was not sufficient to induce curvature towards on the level of mean curvature scores.

One possible reason why on the level of mean curvature scores a curvature away was observed in most conditions is the relatively large proportion of saccades slower than 180 ms – which is the turning point where curvature turns towards the distractor (McSorley et al., 2006). Moreover, the target location in the study by McSolrey et al. was unpredictable to a greater extent than the target location in the present experiment (i.e., four vs. two possible target locations). This might play a crucial role as prior knowledge of target location has been also shown to influence the curvature direction (Walker, McSorley, & Haggard, 2006). In particular, when target location was unpredictable, fast saccades curved towards the distractor and slow saccades curved away from the distractor. In contrast, when target location was predictable (i.e., previously cued by a central cue), fast as well as slow saccades curved away from the distractor. In the present experiment, although target location was not predictable in terms of previously cued by a central cue, the number of possible target locations was considerably smaller than the number of possible target locations in Walker et al. (i.e., two vs. eight). In addition, distractors in the present experiment never appeared at the locations that also served as target locations. In contrast, in the study by Walker et al. distractors appeared in one of the flanking positions of the target, which served also as target locations. Thus, as participants knew in advance that the target was going to appear in one of *only* two possible locations and that the distractors were *never* going to appear in these locations, inhibition in the present experiment might have started building up already prior to distractor onset. Thus, distractor inhibition might have been possible even when saccades were triggered very quickly. This might also explain why curvature away was stronger in the upright group than in the inverted group. In particular, as upright faces were more meaningful than inverted faces and therefore attracted attention more strongly, more inhibition might have been applied prior to trial onset in the upright group compared to the inverted group.

Even though a curvature away was observed in most conditions in the present experiment, the effect of emotion was not significant. Although numerically the same pattern of results was observed as in Experiment 3, with angry faces producing stronger curvature away than happy faces when the target appeared in the lower visual field, the effect was not significant. It might be the case that the effect of emotion was not significant due to limitations in statistical power. In fact, although the sample size in the present experiment is comparable to the sample size in Experiment 3, one might still argue that it is not large enough. Moreover, the reliability of the curvature away measure was limited in the present experiment due to the increased number of trials with fast saccade latencies and reduced amount of curvature away.

5.5 Comparison of Experiment 3 and 4

One possibility to approach the question whether the non-significant effect of emotion in Experiment 4 is due to limitations in statistical power is to conduct an overall analysis in which the data sets from Experiment 3 and 4 are submitted into a mixed MANOVA with experiment (Experiment 3 vs. Experiment 4), distractor emotion (angry vs. happy vs. neutral), and target location (upper vs. lower) as factors. The rationale behind this approach is that if the effect of emotion (or the interaction of distractor emotion and target location) turns out non-significant across both experiments, one can validly conclude that Experiment 4 failed to replicate the findings from Experiment 3, putting into question the findings from Experiment 3. Similarly, if the interaction of distractor emotion and experiment turns out significant, with the effect being significantly larger in Experiment 3 than in Experiment 4, one can again legitimately report a replication failure in Experiment 4, again putting into question the findings of Experiment 3. Alternatively, if the effect of emotion turns out significant across both experiments without being qualified by an interaction with experiment, one can – with somewhat caution – attribute the null result in Experiment 4 to limitations in statistical power. In fact, the analysis described above revealed no significant interaction of experiment, distractor emotion, and target location, $F(2,20) < 1$. However, the interaction of distractor emotion and target location was significant, $F(2,20) = 3.74$, $p < .05$, $\eta_p^2 = .27$. It was due to a significant contrast between the angry and the happy distractors, $F(1,21) = 7.61$, $p = .01$, $\eta_p^2 = .27$ ($F(1,21) < 1$, for the contrast emotional vs. neutral). To see whether the effect of distractor emotion was again restricted to the lower target conditions, separate analyses were conducted for each target location. For the upper target location, the main effect of distractor emotion was not significant, $F(2,21) < 1$. In contrast, for the lower target location, angry distractors produced significantly stronger curvature away than happy distractors, $F(1,22) = 6.60$, $p < .05$, $\eta_p^2 = .23$ ($F(1,22) < 1$, for the contrast emotional vs. neutral; $F(2,21) = 3.18$, $p = .06$, $\eta_p^2 = .23$, for the overall analysis). Thus, the difference in curvature between the angry and the happy distractors with lower targets did not differ between both experiments, and it was significant even when both experiments were collapsed.

To investigate whether the effect of angry versus happy faces found in the upright group with downwards saccades across both experiments was because the latencies were slower in the lower visual field compared to the upper visual field, a multiple regression for repeated measures was conducted (Lorch & Myers, 1990). In particular, curvature scores were regressed on distractor emotion (angry vs. happy), target location, and saccade latency, as well as on the interaction terms distractor emotion × target location and distractor emotion × saccade latency for each participant of the upright sample separately (see Experiment 3 for details). Again, the interaction of target location and distractor emotion (angry vs. happy) emerged significant, $F(1,22) = 5.61$, $p < .05$, whereas the interaction of latency and distractor emotion was not significant, $F(1,22) < 1$.

Based on this overall analysis, one might with somewhat caution conclude that the non-significant effect of emotion in Experiment 4 can be attributed to limitations in statistical power. In fact, the effect of emotion in the analysis above was again qualified by an interaction with target location. In particular, the angry faces produced stronger curvature away than the happy faces only when the target appeared at the lower vertical meridian. As mentioned in the discussion of Experiment 3, this asymmetry might be due to the association of the lower visual field with near space and action control (Previc, 1990). To investigate this possibility, a follow-up experiment was conducted which aimed to conceptually replicate the interaction of distractor emotion and target location using a more complex task and more complex target stimuli.

5.6 Oculomotor inhibition of natural facial distractors under action mode condition (Experiment 5)

According to Previc (1990), the upper and the lower visual field serve different ecological functions. In particular, the lower visual field has been assumed to be mainly involved in performing actions in peripersonal space, and therefore, be functionally specialized for near vision and action control. As a result, visual information has been argued to be processed more efficiently in the lower visual field than in the upper visual field, and action control has been assumed to be better in the lower visual field than in the upper visual field. In contrast, the upper visual field has been assumed to be mainly involved in visual search and scene scanning in extrapersonal space, and therefore, be functionally specialized for far vision and visual search.

Whereas the evidence for the upper visual field specialization is rather scarce (Fecteau, Enns, & Kingstone, 2000; Niebauer & Christman, 1998; Previc & Blume, 1993; Previc & Naegele, 2001; Shelton, Bowers, & Heilman, 1990), a great body of literature has shown lower visual field advantage in a number of tasks, suggesting action control specialization and near space representation (see Danckert & Goodale, 2003, for a review). For example, Rapcsak, Cimino, and Heilman (1988) reported a neglect patient with bilateral lesions including the posterior parietal cortex, who placed the perceived midpoint of vertical lines above the true midpoint and who showed extinction to stimuli in the lower visual field (i.e., neglect of the lower visual field). The same patient has been also reported to bisect lines extending away from the body beyond the true midpoint (i.e., neglect of near space; Mennemeier, Wertman, & Heilman, 1992). In addition, studies with healthy patients showed lower visual field advantage with directing visually guided actions (e.g., Danckert & Goodale, 2001), visual attention towards graspable objects (Handy, Grafton, Shroff, Ketay, & Gazzaniga, 2003), and segmentation of an image into figures and background (Rubin, Nakayama, & Shapley, 1996). Moreover, better visual performance at the lower vertical meridian than at the upper vertical meridian has been observed in motion processing (e.g., Amenedo, Pazo-Alvarez, & Cadaveira, 2007), contrast sensitivity, and spatial resolution (e.g., Abrams, Nizam, & Carrasco, 2012; Cameron, Tai, & Carrasco, 2002; Carrasco, Talgar, & Cameron, 2001; Talgar & Carrasco, 2002).

Given this background, one might therefore attribute the modulation of the emotion effect by target location found in Experiment 3 to the specialization of the lower visual field for action control and near space representation. In particular, a saccade towards a lower target might have invoked representations of near space and therefore induced increased vigilance for stimuli of particular action relevance to protect the peripersonal action space from interference. Experiment 5 aimed to conceptually replicate the visual field asymmetry found in Experiment 3 using a new kind of task that allows to relate the visual field asymmetry effect to recent research on the perception-action link. The task was modified from a study by Forti and Humphreys (2008), in which pictures of eight different (graspable) objects were presented in a circular arrangement. Participants in this study were instructed to look for and to fixate the target object that was previously defined by a cue. Several eye movement parameters were analyzed as a function of visual field. As expected, the authors found increased probability of first fixation on prototypical-view targets (i.e., a view that resonates with action schemata represented in the dorsal stream) in the lower visual field. The authors attributed this result to the strong representation of the lower visual field in the dorsal visual stream, which is known to be functionally specialized for object-directed actions.

In Experiment 5, participants were presented with pictures of two graspable objects (in prototypical view) above and below the fixation cross. One of the objects was predefined by a preceding cue as the target. Thus, in contrast to the previous experiments, where saccades were exogenously triggered by a single sudden-onset meaningless target, the task in Experiment 5 had a stronger action character as intentional selection of a semantically defined object was required. Again, a task-irrelevant distractor face appeared in one of the four quadrants of the screen simultaneously with the target stimulus. Thus, if again the effect of distractor emotion (i.e., stronger curvature away for angry vs. happy faces) is restricted to targets at the lower vertical meridian, one can more plausibly interpret the visual field asymmetry in terms of perception-action coupling.

As an aside, the cue type was varied (i.e., noun vs. verb, e.g., scissors vs. cut paper) since Forti and Humphreys (2008) found an interaction of cue type and target location for some of their dependent variables (e.g., the duration of the first fixation was shorter on targets in the lower visual field only in the verb cue condition). Thus, verb cues might enhance the action character of the task. Therefore, a further moderation of the distractor emotion × target location interaction by cue type might be expected (i.e., that the distractor emotion × target location interaction is enhanced in the verb cue condition). However, Forti and Humphreys did not find a cue type × target location interaction for the probability of first fixation, which compared to the other eye movement measures used by the authors rather reflects attentional capture and is thus more comparable to the saccade trajectories. Thus, a second-order interaction of distractor emotion, target location, and cue type could not be strongly hypothesized.

5.6.1 Method

Participants. Twenty-two non-psychology students of Saarland University participated in the experiment (11 female). Their median age was 22.5 years (ranging from 19 to 28 years). All reported having normal or corrected-to-normal vision. Participants were paid 8 € for their participation. They gave their informed consent prior to the experiment session.

Apparatus & Material. The apparatus was the same as in Experiment 1. Data were recorded from the dominant eye. The stimuli were presented on a white background. The fixation cross was a black cross subtending a visual angle of 1.79° × 1.79°. The stimuli were black-and-white photographs of real objects that were highly likely to activate a grasp response (e.g., scissors; see Appendix for a complete list of the stimuli). The photographs of the objects subtended a visual angle of approx. 6° × 6°. They appeared at a vertical distance of approx. 7° between the fixation cross and their inner edge. Distractors were the same as in Experiment 3.

Design. The design comprised five within-subject factors, namely distractor emotion (angry vs. happy vs. neutral), target location (upper vs. lower), vertical distractor location (upper vs. lower), horizontal distractor location (left vs. right), and cue type (noun vs. verb). In addition, four no-distractor conditions (target location × cue type) were included, which served as a baseline. Each participant completed a total of 600 trials (10 trials per distractor condition and 30 trials per no-distractor condition).

Procedure. Participants were tested in individual experimental sessions. Participants first provided informed consent. Individual eye-tracker adjustments were performed followed by a 13-point-calibration. Subsequently, the instructions were given on the display. The two cue type conditions were presented in two separate blocks of 300 trials each. Block order was randomized across participants. There were four practice trials prior to each block. The object photographs used in the practice trials were different from those used in the experimental trials. After every 75 trials participants could take a break, after which the eye tracker was recalibrated. The experimental session lasted approximately 60 minutes.

Each trial started with the instruction regarding what to look at for 750 ms (see Figure 13 for an illustration of the trial sequence). Subsequently, a central fixation cross was presented until the experimenter pressed a key. If participants’ gaze did not land on the fixation cross due to impairment in tracking accuracy, a recalibration was performed and the instruction regarding what to look at reappeared.

Subsequently, the target display appeared for 1000 ms. The target display consisted of the distractor face, which appeared obliquely from the fixation cross, and two object photographs presented above and below the fixation cross, one of which was the saccade target. The target display was followed by an inter stimulus interval of 500 ms, after which the next trial started. Participants were instructed to look at the target object photograph without making erratic eye movements to the other object photograph and to maintain their gaze on the target as long as it remained on the display. To provide participants with feedback on task compliance, a green frame appeared around the target object photograph as soon as participants fixated it. Participants were told that in most trials, a face would appear at one of the intercardinal points of the display, simultaneously with the target. Participants were told that these faces were totally irrelevant for their task and therefore were to be ignored.

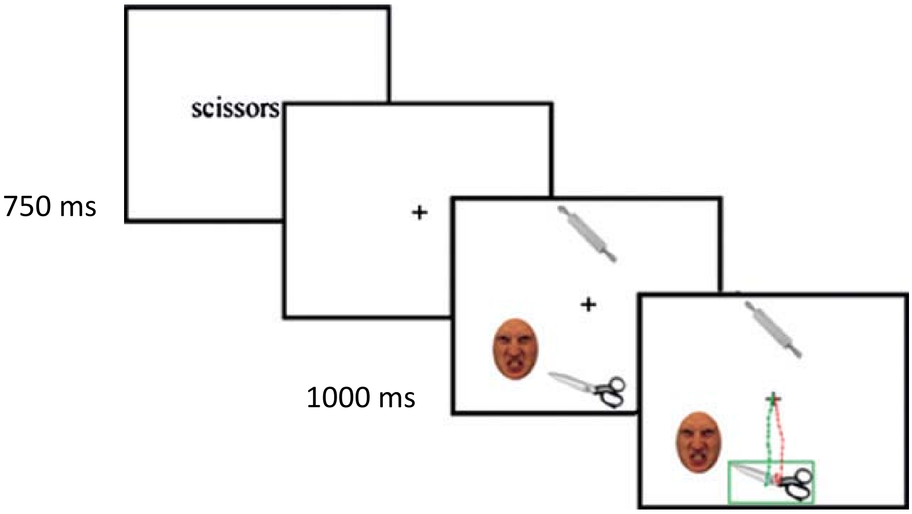


Figure 13. An illustration of the trial sequence in Experiment 5. The target (e.g., scissors) appeared above or below the fixation cross; the distractor face appeared in the upper-left, upper-right, lower-left, or lower-right quadrant of the display. A green frame appeared around the target object photograph as soon as participants fixated it.

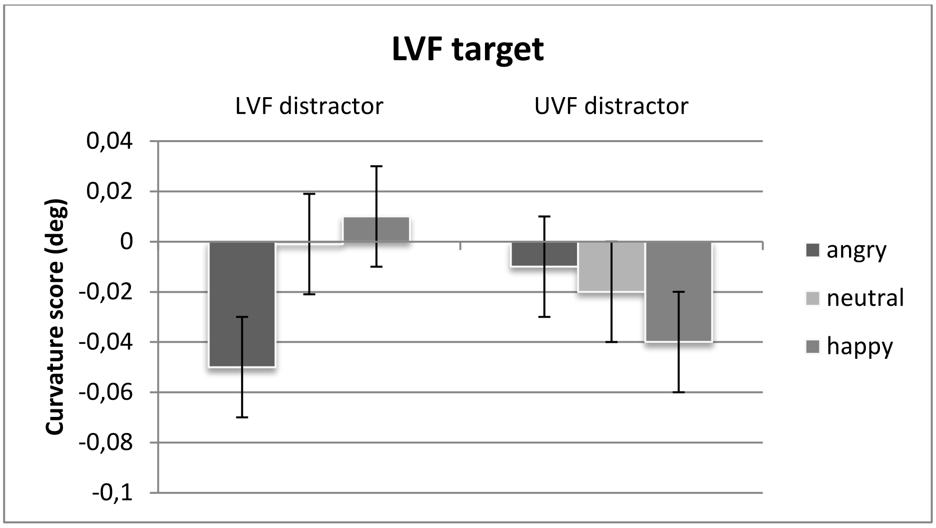
Data analysis. Data were prepared in the same way as in Experiment 1 with the exception that the only threshold value for the saccade amplitude was 4°. This change was made since the targets were bigger in size, which resulted in a larger variance of the saccade amplitude.

5.6.2 Results

The exclusion criteria (see above) led to a mean loss of 20.9% of the trials.

Saccade curvature

Preliminary analyses showed that the horizontal distractor location and the cue type did not significantly modulate any emotion effect, all *F*s < 2.76. Therefore, to reduce the complexity of the analyses the data were collapsed across the horizontal distractor location and the cue type (see Appendix C for mean curvature scores in each condition from the complete design). Figure 14 depicts the mean curvature scores of the remaining conditions. Curvature scores were submitted to a 3 (distractor emotion: angry vs. happy vs. neutral) × 2 (target location: upper vs. lower) × 2 (distractor location: upper vs. lower) within-subject MANOVA. The main effect of target location was significant, $F(1,21) = 4.76$, $p < .05$, $\eta_p^2 = .19$, indicating that the curvature away was stronger with downwards saccades than upwards (*M* = -0.02, *SD* = 0.03 vs. *M* = -0.003, *SD* = 0.03).



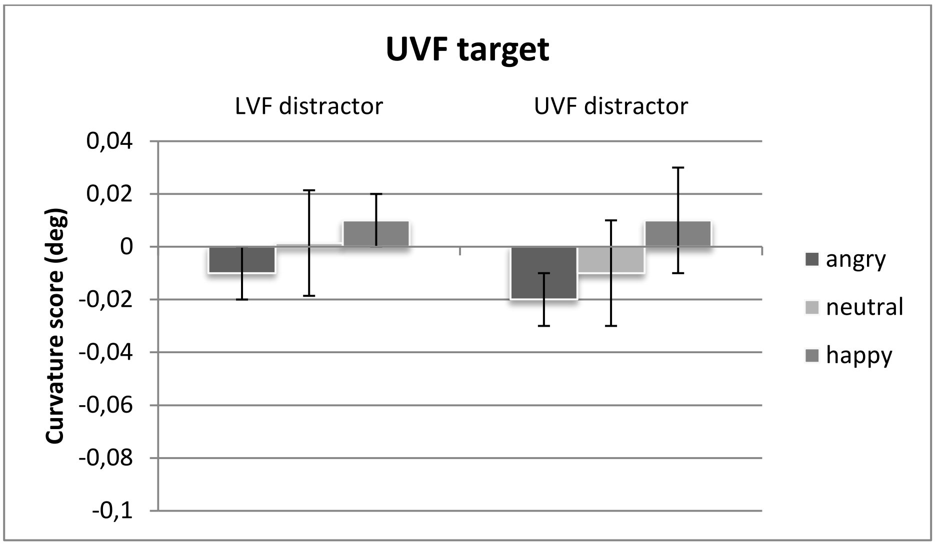


Figure 14. Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in Experiment 5 (in degrees; error bars represent the standard error of the mean); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

With regard to distractor emotion, it can be easily seen in Figure 14 that target location as well as distractor location did matter. This is reflected in a significant three-way interaction of distractor emotion, target location, and distractor location with regard to the contrast angry versus happy, $F(1,21) = 3.94$, $p = .03$ (one-tailed[10]), $\eta_p^2 = .16$ ($F(1,21) < 1$, for emotional vs. neutral; $F(2,20) = 3.01$, $p = .07$, $\eta_p^2 = .23$, for the overall

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[10] Note, given the specific prediction (i.e., curvature angry > curvature happy) and the equivalence of an F-test with one numerator df to a two-tailed t-test, a one-tailed test is allowed even for F-tests (see Maxwell & Delaney, 1990).

interaction). With upwards saccades, the interaction of distractor emotion and distractor location was not significant, $F(2,20) < 1$. With downwards saccades, the interaction of distractor emotion and distractor location was significant, $F(2,20) = 4.39$, $p < .05$, $\eta_p^2 = .31$. When the distractor appeared in the lower visual field (i.e., matched the target location), the contrast between the happy and the angry distractors was significant, $F(1,21) = 4.17$, $p = .05$, $\eta_p^2 = .17$ ($F(1,21) = 2.32$, $p = .14$, $\eta_p^2 = .10$, for emotional vs. neutral; $F(2,20) = 3.38$, $p = .055$, $\eta_p^2 = .25$, for the overall emotion effect). In contrast, when the distractor appeared in the upper visual field (i.e., mismatched the target location), no significant effect of distractor emotion emerged, $F(2,20) < 1$. There were no other significant main effects or interactions, all *F*s < 2.00.

Saccade latency

Saccade latencies in the baseline conditions did not differ significantly from saccade latencies in the distractor conditions, $t(21) = 0.83$, $p = .42$, $d = 0.18$ (*M*distractor = 323 ms, *SD*distractor = 68 ms vs. *M*baseline = 321 ms, *SD*baseline = 64 ms). The saccade latencies in the distractor conditions were submitted to a 3 (distractor emotion: angry vs. happy vs. neutral) × 2 (target location: upper vs. lower) × 2 (distractor location: upper vs. lower) within-subject MANOVA (see Appendix D for mean saccade latencies in each condition from the complete design). The main effect of target location was significant, $F(1,21) = 20.83$, $p < .001$, $\eta_p^2 = .50$, indicating that upwards saccades had faster latencies than downwards saccades (*M* = 312 ms, *SD* = 68 ms vs. *M* = 334 ms, *SD* = 70 ms). The interaction of target location and distractor location was significant, $F(1,21) = 10.74$, $p < .01$, $\eta_p^2 = .34$, indicating that saccades were faster when target and distractor appeared in the same visual hemifield (*M* = 320 ms, *SD* = 68 ms vs. *M* = 326 ms, *SD* = 68 ms). Importantly, the three-way interaction of distractor emotion, target location, and distractor location was not significant, $F(2,20) < 1$. There were no other significant main effects and interactions, all *F*s < 1.

As latencies in this experiment were again faster with upwards compared to downwards saccades, again the possibility was tested that the effect of distractor emotion found with downwards saccades was due to their slower latencies, using a multiple regression approach for repeated measures (Lorch & Myers, 1990; see Experiment 3 for details). Whereas – corresponding to the main analysis – the interaction of target location, distractor location, and distractor emotion was significant, $F(1,21) = 4.35$, $p < .05$, the interaction of latency, distractor location, and distractor emotion was not significant, $F(1,21) = 2.48$, $p = .13$.

5.6.3 Discussion

Experiment 5 aimed to conceptually replicate the findings of Experiment 3 by showing that the effect of emotion on saccade curvature was restricted to targets at the lower vertical meridian. To this end, participants were required to select between two action-affording objects by saccading towards one of them, which had been previously defined as the target. Again, angry faces produced stronger curvature away than happy ones and this effect was observed only when the target object appeared at the lower vertical meridian. In addition, the effect of emotion on saccade trajectories was qualified by the vertical distractor location, indicating that angry faces produced stronger curvature away than happy faces only when the distractor appeared in the lower visual field as well. The present experiment goes beyond a simple replication of Experiment 3 since it allows to relate the effect to recent research on the perception-action coupling. The task in the present experiment, which was a modified version of the object search task introduced by Forti and Humphreys (2008), had a stronger action character than the task in the previous experiments. Thus, the present findings can be more plausibly attributed to the lower visual field specialization for action.

It should be noted that cue type (i.e., noun vs. verb) had no effect in Experiment 5. A moderation of the distractor emotion × target location interaction by cue type in terms of a greater emotion effect with lower targets in the verb condition than in the noun condition would have indeed further supported the interpretation in terms of perception-action coupling. However, although it was rational to employ this manipulation, a strong hypothesis with regard to this factor was impeded from the start on as Forti and Humphreys (2008) found no effect for this manipulation on the probability of first fixation on the target, which compared to the other measures used by the authors rather reflects attentional capture and is thus more comparable to saccade trajectories.

In Experiment 3, only target location modulated the emotion effect, whereas in Experiment 5 both target and distractor location influenced the emotion effect. This difference can be attributed to two facts. First, the relative salience of the distractors was different. Although the absolute size of the distractors was the same in both experiments, their relative size was much bigger in Experiment 3 than in Experiment 5, making them perceptually more salient in Experiment 3 than in Experiment 5. Second and more important, the difference in results can be attributed to the fact that in Experiment 5 there were two sources of potential interference (i.e., the face distractor and the non-target object). Especially in the trials in which the target object appeared in the lower visual field and the distractor face appeared in the upper visual field, the non-target object was close to the distractor, which might have made potential distractor effects more noisy.

A final word has to be said on the fact that some distractors in Experiment 5 did not induce a curvature different from zero (i.e., no curvature; see Figure 14), which might seem surprising given the literature on saccade trajectories. This can be attributed to the great task difficulty of Experiment 5, where the target competed with another potential target in addition to the distractor. As a result, the relative salience of some distractors might have diminished leading to reduced activation. In addition, the great difficulty of the task might also explain the generally longer saccade latencies found in the present experiment compared to the previous experiments as well as the absence of a difference in latencies between the distractor conditions and the baseline conditions. In fact, this kind of rather complex cueing-and-selection procedure with conceptually meaningful targets was used for the first time in combination with saccade trajectories.

6 General discussion

This thesis aimed to investigate to what extent the human attentional system adapts to environmental changes of superior relevance. In particular, it aimed to study to what extent emotional stimuli capture human visual attention. As emotional stimuli signal a potential threat or opportunity and are therefore of particular relevance to the observer’s well-being or survival, it is plausible to assume that even when they are completely irrelevant for the observer’s current goal, emotional stimuli capture attention very early in time. The paradigms and the measures mainly used in the literature so far are associated with a number of important methodological issues. Therefore, this thesis aimed to investigate the effects of goal-irrelevant emotional stimuli on early attentional processing using a different paradigm and a different measure, which allow to measure involuntary early attentional processing in a more valid way, namely saccade trajectories. Prior studies suggesting that saccade trajectories are influenced by higher-order information in an involuntary manner are sparse, and the evidence so far suggests that higher-order information affects saccade trajectories only late in time (i.e., after longer stimulus onset asynchronies and/or at saccade end). Therefore, this thesis aimed to provide convergent evidence that saccade trajectories are modulated by emotional information in an involuntary manner, and to extend the previous literature by showing that saccade trajectories can be modulated by emotional information in an involuntary manner also early in time (e.g., at saccade start and with simultaneous presentation of target and distractor).

The main hypothesis of this thesis was that the emotional content of a task-irrelevant stimulus modulates the extent of the trajectory curvature effect. In particular, it was hypothesized that due to their particular action and biological relevance, emotional distractors would appear more salient than neutral distractors, and therefore would produce more oculomotor activation than neutral distractors. As a result, emotional distractors would compete with the target more strongly than neutral distractors, preventing it more strongly from reaching the threshold. Thus, stronger inhibition would be necessary with emotional distractors than with neutral distractors for them to be successfully inhibited, which should result in greater curvature away. In addition, an emotion-specific effect was expected, with angry faces producing a more potent competition and therefore triggering more inhibition than happy faces (i.e., negativity bias hypothesis). A series of five experiments was conducted to test this hypothesis.

6.1 Summary of experimental results

Experiment 1 aimed to replicate the basic curvature away effect with simple neutral distractors. To this end, a target rhombus was presented at the vertical meridian above or below fixation, while a distractor ellipse appeared in one of the four quadrants of the screen. In line with the literature on saccade trajectories, saccade trajectories in Experiment 1 curved significantly away from the distractor. In addition, Experiment 1 replicated the remote distractor effects typically found with saccade latencies. In particular, saccade latencies were slowed down by the distractor, and they were faster when the target and the distractor appeared in the same visual field compared to the condition in which they appeared in the opposite hemifields (Walker et al., 1997).

Experiment 2 aimed to investigate the effects of task-irrelevant emotional distractors on saccade curvatures using schematic facial expressions. Because schematic facial expressions are less complex and less variable than natural facial expressions, emotional processing was expected to be facilitated, and finding an effect of emotion was expected to be more likely. Similarly to Experiment 1, a saccade target onset (i.e., rhombus) was presented at the vertical meridian above or below fixation, while single schematic facial distractors depicting an angry, happy, or neutral expression appeared in one of the four quadrants of the screen. In line with the results of Experiment 1 and the literature on distractor effects on saccade processing, the curvature away effect with saccade trajectories and the remote distractor effect with saccade latencies were successfully replicated in Experiment 2. However, the effect of distractor emotion was not significant.

One possible reason why no effect of emotion was found in Experiment 2 is a habituation effect due to the reduced variability of the schematic faces. Moreover, although schematic faces offer the advantage of a better control over the perceptual features, their ecological validity is still strongly limited. Therefore, Experiment 3 was conducted, in which several improvements were made as compared to Experiment 2. In particular, to increase the ecological validity of the stimuli, pictures of natural emotional faces were used. To counteract habituation effects, a larger number of different stimuli per distractor emotion was used. Finally, to improve the data quality a gaze-contingent feedback was presented to the participants and the number of distractor trials was increased. To isolate perceptual processes from emotional processes, a condition was included in which the faces were presented in an inverted orientation. It was hypothesized that if the effect of emotion on saccade trajectories is due to the holistic processing of the emotional content rather than the processing of the perceptual features, then it should be observed with upright faces but not with inverted faces. Again, the distractor effects typically found on saccade curvature and saccade latencies were replicated. Most importantly, the distractor emotion significantly modulated the curvature away effect, such that the angry faces produced stronger curvature away than the happy faces. This difference was observed with upright faces but not with inverted faces, suggesting that it is due to the processing of the emotional connotation of the stimuli and not due to their different perceptual features.

Although the stronger curvature away has been typically interpreted as stronger attentional capture (Theeuwes & Van der Stigchel, 2009; Van der Stigchel & Theeuwes, 2007), it might be also the case that a strong initial activation is more difficult to get inhibited, resulting in weaker curvature away. Experiment 4 therefore aimed to provide a more direct evidence that the emotional content of facial distractors modulates saccade trajectories early in time by measuring the saccade trajectory curvature before the inhibition process starts operating. It was hypothesized that because the inhibition process was prevented from taking place, the stronger activation of angry distractors compared to happy distractors would result in stronger curvature *towards*. To test this hypothesis, a blank screen was included between the fixation cross and the target display. This manipulation is known to accelerate the saccade latencies and thus prevent the inhibition process from becoming active. Although the saccade latencies were successfully accelerated and the curvature direction varied as a function of the saccade latency, the blank screen presentation was not sufficient to induce curvature towards the distractors on the level of mean curvature scores. Moreover, although a curvature away was observed in most conditions and numerically the same pattern of results was observed as in Experiment 3, the emotion effect was not significant in Experiment 4. It might, however, be the case that the emotion effect did not reach significance in Experiment 4 due to limitations in statistical power. For example, although the samples in both experiments were of comparable size, they were still relatively small. Moreover, the reliability of the curvature away measure was somewhat impaired in Experiment 4 due to the increased number of trials with fast saccade latencies and the reduced amount of curvature away. In fact, an overall analysis of Experiment 3 and 4 revealed that the effect of emotion was significant after both experiments were collapsed. Furthermore, both experiments did not differ between each other in the effect of emotion on saccade curvature (i.e., stronger curvature away from angry faces compared to happy faces). Thus, one can – with somewhat caution – conclude that statistical power limitations account for the non-significant result in Experiment 4.

An interesting finding in Experiment 3 and the overall analysis of Experiment 3 and 4 was that the effect of distractor emotion occurred only when the targets appeared at the lower vertical meridian. The lower visual field has been argued to have a special role in near space representation and action control, which provides a plausible explanation for the visual field asymmetry found in the present experiments (Previc, 1990). To attribute this asymmetry more validly to perception-action coupling, Experiment 5 was conducted. The aim of Experiment 5 was to conceptually replicate the findings from Experiment 3 using a more complex task of target selection. Participants were required to select between two action-affording objects by saccading towards one of them. As hypothesized, angry faces produced stronger curvature away than happy ones, and this effect was observed only when the target object appeared at the lower vertical meridian.

Taken together, the findings of this thesis suggest that the emotional content of task-irrelevant distractor stimuli can indeed modulate saccade trajectories in an involuntary fashion. Moreover, they suggest that this influence can take place already early in time (i.e., with simultaneous presentation of target and distractor, and as indicated by the curvature measure). Thus, it seems that even at the level of very early basic attentional processing the human cognitive system does not operate in a hard-wired manner, but is highly adaptive to environmental changes of superior relevance.

6.2 Discussion of experimental results

6.2.1 Anger-superiority effect in the general population

The present findings are in line with the negativity bias hypothesis, according to which attention is biased towards negative stimuli (e.g., Hansen & Hansen, 1988; Pratto & John, 1991). They are consistent with previous studies on manual reaction times showing an “anger-superiority effect” in attentional processing (e.g., Fox & Damjanovic, 2006; Hansen & Hansen, 1988; Mogg & Bradley, 1999; Öhman et al., 2001). Importantly, the present findings extend the previous literature on attentional biases because they demonstrate an anger-superiority effect using a different paradigm and a different measure. The emotional stimulus in the paradigm employed in the present experiments was completely irrelevant for the participant’s task in terms of both location and content. Therefore, the present findings can be more validly interpreted in terms of involuntary attentional processing. Moreover, the measure of attentional processing in the present experiments was more direct than the measures used in the majority of the studies on attention towards emotional stimuli. Therefore, the present findings can be more validly attributed to early attentional processing.

It should be pointed out that the anger-superiority effect in the present experiments was found with a non-selected sample from the general population. This might seem surprising given the findings of a recent meta-analysis, which revealed a threat-related bias across different types of anxious populations (i.e., individuals with different clinical disorders, high-anxious nonclinical individuals, anxious children and adults), but no threat-related bias with control populations (Bar-Haim et al., 2007). However, this meta-analysis focused exclusively on the color-naming task, the dot-probe paradigm, and the emotional spatial cueing paradigm as these are the three experimental paradigms that have been most often used to study threat-related attentional biases in anxiety. As shown in Chapter 1, these paradigms and the measures used with them are associated with a number of methodological issues that might be responsible for the general failure to find a threat-related bias in the control populations in this meta-analysis. Moreover, the control populations used in studies on attentional biases in psychopathology typically comprise individuals who fall below a lower threshold on the anxiety trait. These populations can be therefore considered as abnormally insensitive to threat-related information.

6.2.2 Saccade trajectory modulation by emotional stimuli

The present findings are in line with the previous literature on higher-order influences on saccade trajectory as they all revealed that saccade metrics are influenced by higher-level distractor information in an involuntary manner (Ludwig & Gilchrist, 2003; Nummenmaa et al., 2009; Weaver et al., 2009). However, the present experiments extend the previous literature as they demonstrate that higher-order information can influence saccade processing also early in time. In the previous studies, the effect of higher-order information on saccade trajectories was found only after long stimulus onset asynchronies and/or at saccade end. In contrast, the present findings demonstrate an effect of higher-order information on saccade trajectories with saccade curvatures (i.e., at saccade start; McSorley et al., 2009) and with simultaneous presentation of target and distractor. This difference in findings between the present experiments and the previous studies might be attributed to the stimulus material, which in the present experiments comprised face stimuli, whereas in the other studies it comprised complex emotional scenes (Nummenmaa et al., 2009) or words (Weaver et al., 2011). Thus, as facial stimuli are processed in a highly fast and automatic manner, less time was necessary for them to affect trajectory processing.

It should be noted that no general effect of emotion was found in the present experiments (i.e., no stronger curvature with emotional compared to neutral distractors). This finding might seem surprising given the superior relevance of both positive and negative stimuli to the organism’s well-being and survival. Moreover, Nummenmaa et al. (2009) observed a general emotion effect but no difference between positive and negative stimuli. The absence of a general effect of emotion in the present experiments might be attributed to the differences between the neutral faces and the neutral scenes in the way they behave as a baseline condition. Compared to neutral scenes, neutral faces are rather ambiguous in nature. In fact, neutral faces can be easily interpreted as slightly hostile (e.g., Bar, Neta, & Linz, 2006; see Hansen & Hansen, 1988; Öhman et al., 2001). Moreover, neutral faces have been shown to appear positive or negative depending on contextual and individual variables (Cooney, Atlas, Joormann, Eugène, & Gotlib, 2006; Jellema, Pecchinenda, Palumbo, & Tan, 2011; Lee, Kang, Park, Kim, & An, 2008).

6.2.3 The role of subcortical structures in processing of emotional stimuli

The effect of emotional content on saccade trajectories found in the present experiments suggests that subcortical structures – particularly, the superior colliculus – are involved in the processing of emotional information. The pattern of activation in the superior colliculus at the moment an eye movement is initiated has been shown to determine the direction and the amplitude of the eye movement (for a review, see White & Munoz, 2011). The superior colliculus has been shown to be a key structure in the oculomotor system which rapidly integrates bottom-up and top-down signals. The present findings provide evidence that emotion-related input is also rapidly taken into account in this integration process. Due to their particular relevance, angry facial distractors appeared more salient and therefore produced more oculomotor activation in the oculomotor map of the superior colliculus than happy faces. As a result, angry distractors competed with the target more strongly than happy distractors (i.e., angry distractors inhibited the target more strongly and thus prevented it more strongly from reaching the threshold). Thus, more inhibition was required with angry than with happy distractors for the target to reach the threshold, which resulted in stronger curvature away with angry than with happy distractors (see Theeuwes & Van der Stigchel, 2009; Van der Stigchel & Theeuwes, 2007).

Thus, the present findings can shed some light on a current debate on the neuropsychological mechanisms underlying emotion processing (Pessoa & Adolphs, 2011; De Gelder, Van Honk, & Tamietto, 2011). According to the *two-pathway hypothesis* of emotional processing, the fast and non-conscious processing of coarse emotional information is mediated by a fast subcortical pathway, which reaches the amygdala from magnocellular visual input through the superior colliculus and the pulvinar nucleus of the thalamus (e.g., Vuilleumier, 2005). In contrast, a slow cortical pathway in the occipital and temporal cortex is assumed to be involved in the slow detailed perceptual analysis that is necessary to make fine perceptual discriminations. Recently, however, Pessoa and Adolphs put this account into question, proposing that the primary role of the amygdala and the pulvinar in visual processing is to coordinate the function of cortical networks during evaluation of the biological significance of affective visual stimuli, with the cortex playing a crucial role in emotion processing. Given the prominent role of the superior colliculus in saccade trajectory control, however, the present findings seem to support rather the two-pathway account.

6.2.4 Oculomotor activation vs. oculomotor inhibition

Although the effect of emotional information in this thesis was found with a saccade curvature measure (i.e., activation at saccade start; McSorley et al., 2009) and with simultaneous presentation of target and distractor, these findings should be still interpreted with somewhat caution in terms of early attentional effects. In particular, although the curvature away measure reflects attentional processing much earlier in time than manual reaction times and other eye movement measures, it still measures the very initial oculomotor activation in an indirect manner (i.e., by measuring the amount of inhibition subsequently applied). Although Experiment 4 aimed to provide a more direct evidence by measuring the very initial activation instead of the subsequent inhibition, the change that was made in the procedure was not sufficient to induce curvature towards on the level of mean curvature scores. As stated in the discussion of Experiment 4, this might be because the number of possible target locations was highly limited and the distractors never appeared at the target locations. As a result, inhibition might have been applied to the distractor location already prior to trial onset.

One possible way to overcome this issue is to make the target and distractor locations less probable such that no (or less) inhibition can be applied in advance to the distractor locations. This can be done, for example, by increasing the number of possible target locations and presenting the distractors at the flanker positions that can also serve as target locations (e.g., Walker et al., 2006). It should be noted, however, that this approach is susceptible to the global effect (e.g., Coren & Hoenig, 1972; Walker et al., 1997). The global effect constitutes the finding that the endpoint of an eye movement is not positioned on the centre of the eye movement target, but deviates in the direction of another stimulus that is closely presented to the target (for a review, see Van der Stigchel & Nijboer, 2011). Importantly, when the two stimuli differ in size between each other, the saccade endpoint has been shown to deviate towards the larger stimulus (Findlay, 1982). Moreover, fast saccades have been observed to produce a global effect even when task instructions explicitly emphasized performance accuracy (Ottes, Van Gisbergen, & Eggermont, 1985). Therefore, future research on the effects of emotional content on the very initial oculomotor activation should take these issues into consideration.

The absence of a general curvature towards effect in Experiment 4 might be also attributed to the saccades being often triggered with a considerable delay even under conditions that favor very fast reaction times. Although the exact mechanisms behind the large delay of many saccades are still unknown, it is now generally accepted that most saccades are initiated with a considerable delay because the default state of the oculomotor system is a state of inhibition (see, e.g., Sumner, 2011). From an evolutionary point of view, it can be speculated that a default state of inhibition provides the organism with an overall adaptive advantage that outweighs the seeming drawbacks (i.e., slow reaction times) that arise from having that advantage. According to Carpenter (1999), for example, a procrastination mechanism allows higher levels of the brain to weigh up information in a top-down manner, that is, to determine what their relevance is to the organism (e.g., a potential threat or opportunity). It has been argued that without this procrastination a top-down evaluation of the environment would be not possible. Instead, our eyes would be always guided in a bottom-up manner to the visually most salient stimuli in the visual field. The relatively large delay in saccade reaction times and their large variability have been also argued to offer the evolutionary advantage of being unpredictable and flexible (Carpenter, 1999). After all, the ability to not always act in the same way given the same circumstances is of particular importance in real-life dangerous settings that include threatening opponents and predators.

6.2.5 Saccade trajectory modulation by emotional stimuli and the concept of automaticity

As stated in Chapter 1, the notion of automaticity may refer to several different features, including the speed with which the process takes place, the resources that the process requires, the occurrence below the threshold of conscious awareness, the operation in parallel, the resistance to intentional control, and the inevitability (Moors & DeHouwer, 2006). Thus, while the present findings allow to relate the effect to very fast and involuntary attentional processing, they do not allow to draw any conclusions as to whether the emotional content of the distractors was consciously processed. In fact, although awareness has been the feature of automaticity most extensively studied within the field of attention to emotional information, this has been typically done with centrally presented stimuli (see Yiend, 2010). As previously noted, however, the ecological validity of stimulus selection in tasks in which the stimuli are presented centrally is strongly limited. Thus, future research investigating the effects of subliminal peripheral emotional distractors would provide further important insights into the extent to which emotional stimuli capture visual attention. Recently, for example, Van der Stigchel, Mulckhuyse, and Theeuwes (2009) showed that subliminal peripheral distractors (of neutral connotation) can indeed interfere with the execution of an eye movement. The subliminal presentation of the distractor in this study was realized by presenting participants with four distractor stimuli in each quadrant of the screen simultaneously with the target onset. Crucially, one of the distractors appeared 17 ms prior to the others. To ensure that the subliminal presentation of the distractor was successful, participants were asked to report its location in a subsequent session. Importantly, even though participants could not detect the distractor that preceded the other three distractors, eye movement trajectories deviated away from this distractor.

6.3 Questions for future research

6.3.1 Visual field asymmetries in attentional processing of emotional stimuli

An interesting finding in this thesis is that angry faces produced stronger curvature away than happy faces only when the target appeared at the lower vertical meridian (Experiment 3 and 5). One plausible explanation for this visual field asymmetry is that the lower visual field plays a special role in near space representation and action control (Previc, 1990). However, although the findings of Experiment 5 argue for this possibility, an interpretation of the visual field asymmetry in terms of perception-action coupling should be still made with somewhat caution. For example, the density of ganglion cells and cone cells has been shown to be greater in the superior hemiretina (which receives input from the lower visual field) than the inferior hemiretina (which receives input from the upper visual field; Curcio & Allen, 1990; Drasdo, Millican, Katholi, & Curcio, 2007; Perry & Cowey, 1985), providing an alternative explanation for the visual field asymmetry effect.

The processing advantage of stimuli in the lower visual field might be also attributed to differences in sensitivity between the upper and lower visual field. Targets in the present study were presented at the vertical meridian, where the upper versus lower asymmetry in sensitivity has been shown to be strongest. However, Abrams, Nizam, and Carrasco (2012) recently showed that the upper versus lower asymmetry in sensitivity is gone by 30° of polar angle from the vertical meridian. Whereas this suggests that the lower targets in the present study were better processed due to the better sensitivity at the lower vertical meridian, the distractor interference effect observed here is rather unlikely to be due to differences in sensitivity because the distractors in the present study were presented at approx. 67° angular distance from the vertical meridian. Anyway, the differences in experimental design and stimulus material between the present experiments and the study by Abrams et al. make it difficult to definitely exclude differences in sensitivity as a possible explanation for the visual field asymmetry found in the present experiments.

Therefore, further research is needed to examine the exact mechanisms underlying the visual field asymmetry observed in the present experiments. Although the present findings suggest that the asymmetry effect found in emotional processing might be due to the special role of the lower visual field in action control and near space representation, further evidence is required to support this claim. One possible direction for future research is to investigate the asymmetry effect in 3-D scenes as they allow to include distance information (i.e., near vs. far) in a relatively simple way. For example, recent studies using 3-D stimulus material demonstrated that seeing objects not only activates motor responses, but that the object evokes a compatible action only when it is presented in the accessible space, suggesting that the operational space is an important factor worth considering in future studies on visual field asymmetries (Costantini, Ambrosini, Scorolli, & Borghi, 2011; Ferri, Riggio, Gallese, & Costantini, 2011). Importantly, using 3-D scenes will make the experimental settings more similar to the real-life ones and thus will increase the ecological validity of the findings.

6.3.2 The influence of motivational variables

The present findings indicate a threat-related bias in attentional processing, and thus support the negativity bias hypothesis (e.g., Hansen & Hansen, 1988; Pratto & John, 1991). It should be noted, however, that although the negativity bias hypothesis is highly plausible, it should be qualified. In particular, only few dangers are really fatal for the organism, and overlooking opportunities will put the organism at a chronic disadvantage in the long run. Thus, it seems reasonable to assume that positive information is also processed in a highly efficient way (i.e., positivity bias hypothesis; e.g., Taylor & Brown, 1988). In line with this argument, recent studies demonstrated attentional biases for positive stimuli that are of particular importance to reproduction and nurture, such as potential mating partners and babies (e.g., Brosch, Sander, & Scherer, 2007; Maner, Gailliot, & DeWall, 2007).

It seems therefore that neither a general negativity bias hypothesis nor a general positivity bias hypothesis can provide an adequate account of affective processing. Rather, the asymmetry in the processing of valent information seems to be flexible and dependent on the individual's current motivation (for a review, see Rothermund, 2011). According to the counter-regulation hypothesis, a negativity bias is observed in a state of success or positive outcome focus, whereas a positivity bias is observed in a state of failure or negative outcome focus (see Rothermund, Voss, & Wentura, 2008). The rationale behind the counter-regulation hypothesis is that focusing exclusively on positive information in a state of success or positive outcome focus would lead to impulsive behavior and would prevent the organism from processing negative information that is necessary for achieving success. In contrast, focusing exclusively on negative information in a state of failure or negative outcome focus would lead to immobility or giving up. Therefore, to prevent motivational orientations from escalating and becoming chronic, a counter-regulation mechanism seems to be crucial to bias the processing towards information that is incongruent to the current affective-motivational state.

Recent evidence for the counter-regulation hypothesis came from studies on speeded evaluation. For example, Rothermund, Gast, and Wentura (2011) found categorization of positive stimuli to be faster after participants received negative feedback, whereas categorization of negative stimuli was faster after participants received positive feedback. In a related study, interference by positive distractors was found to be stronger during blocks with a negative outcome focus (i.e., participants could lose money), whereas interference by negative distractors was found to be stronger during blocks with a positive outcome focus (i.e., participants could win money), indicating a processing bias towards stimuli that were opposite in valence to the current motivational orientation (e.g., Rothermund et al., 2008). Thus, affective processing does not seem to be stable or driven by a general preference towards information of a specific valence. Instead, the studies described above suggest that affective processing is flexible, context-dependent, and mainly driven by the subjective relevance of the information to the individual.

Given this evidence, it becomes clear that the effect of emotion found on saccade trajectories in this thesis need to be further investigated by taking into account participants' current affective-motivation state. The counter-regulation mechanism has been assumed to operate in an automatic manner already during early processing. The evidence for that claim is however still very scarce. Thus, further research is needed to study how deeply the counter-regulation mechanism penetrates cognitive processing. The saccade trajectory paradigm used in this thesis seems to provide a suitable tool for testing this. Finding evidence for a counter-regulation mechanism at the level of saccade trajectory control would thus provide not only corroborating evidence for the existence of such sophisticated adaptation mechanism in attentional processing, but would also suggest that this mechanism operates already at the very basic level of attentional processing.

6.3.3 The influence of interindividual differences

Given the high sensitivity of saccade trajectories as an attentional measure, it is reasonable to expect a modulation of the emotion effect by interindividual differences in *stable* personality traits. As previously mentioned, a great body of research on the color-naming task, the single cueing paradigm, and the dot-probe paradigm suggests strong attentional biases towards threat-related information with anxious populations but not with non-anxious populations (Bar-Haim et al., 2007). Thus, given that saccade trajectories are sensitive enough to reveal an effect of emotion with the general population, one might expect to find a correlation between anxiety and the effect of threat-related information on saccade trajectory. In particular, if the attentional capture by threat-related stimuli is stronger with anxious compared to non-anxious individuals, then the magnitude of the emotion effect on saccade trajectory curvature should increase with increasing anxiety levels.

However, previous studies have argued that anxious individuals have particular deficits in the inhibition function (e.g., Eysenck & Derakshan, 2011; Eysenck, Derakshan, Santos, & Calvo, 2007). Thus, if increased level of anxiety is indeed associated with deficits in inhibition, then less curvature away with threat-related compared to other stimuli should be observed with anxious but not with non-anxious individuals. In fact, recent evidence from the domain of developmental psychology suggests that saccade trajectory curvatures can be indeed modulated by interindividual differences in the inhibition function. For example, Campbell, Al-Aidroos, Pratt, and Hasher (2009) found that older adults did not show a deviation away from the distractor, although the deviation towards decreased with increasing saccade latency. In contrast, younger adults showed the typical effect of deviation towards with fast saccade latencies and deviation away with slow saccade latencies (see also Campbell, Al-Aidroos, Fatt, Pratt, & Hasher, 2010). The authors attributed these results to the difference in the inhibition function between the two age groups, in particular, to the age-related decline in the frontal inhibitory mechanism, which is responsible for the trajectory deviation away from distractors.

Finding a modulation of the anger-superiority effect on saccade trajectories by interindividual differences in anxiety would provide important insights into the exact cognitive mechanisms underlying anxiety. Although there is now a general agreement that anxiety is associated with attentional biases towards threat-related information, there is still theoretical controversy as to the specific attentional mechanisms that underlie anxiety. For example, according to Williams, Watts, MacLeod, and Mathews (1997), anxious individuals tend to direct their attention towards threat-related information during early (automatic) stages of processing, whereas during later (strategic) stages of processing, they tend to direct their attention away from threat-related information. In contrast, Fox et al. (2001) argued that anxiety does not influence the initial attentional orienting but rather the subsequent maintenance of attention on the threat-related information (see also Fox, Russo, & Dutton, 2002; Yiend & Mathews, 2001). However, as the paradigms and the measures typically used to study early attentional processing towards emotional information do not – strictly speaking – validly measure early involuntary attentional processing, any conclusions with regard to interindividual differences in early involuntary attentional processing should be made with caution. The use of the saccade trajectory paradigm would therefore provide deeper insights into the mechanisms underlying anxiety and shed some light on the theoretical controversy in the literature. Given the crucial role that inhibition processes play in saccade trajectory control, finding interindividual differences in the effects of emotion on saccade trajectories would provide evidence that differences in the inhibition function underlie anxiety.

Another interesting issue that is worth further research is the influence of individuals' *transient* affective states. There is now a growing number of studies that support the claim that positive affective states expand the scope of attention, whereas negative affective states constrict it (for a review, see Clore & Huntsinger, 2007; Friedman & Förster, 2010). According to Derryberry and Tucker (1994), for example, narrowed attentional window is adaptive in threatening situations as it facilitates concentration on the danger at hand. In contrast, broadened attentional window has been assumed to be adaptive in non-threatening situations as it increases the likelihood of detecting opportunities. It seems therefore reasonable to assume that the magnitude of the distractor effects on saccade trajectories depends also on participants' current affective state. In particular, if positive affective states indeed broaden the attentional window size, then distractors under such circumstances should be more strongly activated and therefore should be more strongly inhibited, leading to stronger curvature away. In contrast, if negative affective states indeed narrow the attentional window size, then distractors under such circumstances should be less strongly activated and therefore should require weaker inhibition, leading to weaker curvature away. Finding such effects of affective state on saccade trajectories would provide further evidence that the human attentional processing operates in a highly adaptive manner already at a very low level.

6.4 Conclusion

The aim of this thesis was to examine the extent to which the human attentional system adapts to environmental changes of superior relevance to the organism. More specifically, it aimed to investigate whether the emotional content of a stimulus captures visual attention early in time even when this stimulus is completely irrelevant for the observer's ongoing goal. To examine this question, this thesis employed a rather new paradigm in the domain of attention to emotional information. This paradigm offers several methodological advantages over the paradigms used so far. In a series of five experiments, participants were asked to look towards a target that appeared at the vertical meridian. Simultaneously with the target onset, a distractor face depicting an angry, happy, or neutral expression appeared in one of the four quadrants of the screen. As hypothesized, the emotional expression depicted by the facial distractors modulated participants' attentional performance. In particular, the angry faces induced stronger saccade curvature away than the happy faces. This finding suggests that the visual system responds in a highly flexible way when it is faced with a dilemma situation in which a stimulus occurs that is irrelevant to the observer's current goal but of particular importance to his well-being or survival. The present findings suggest that in such a dilemma situation the visual system neither continues pursuing the current goal ignoring everything else nor does it completely sacrifice the current goal in order to reorient to the stimulus of potential interest. It seems that under such conditions, our visual system does both in an impressively fast and flexible manner: It continues performing the current task and registers at the same time the stimulus of superior relevance, without compromising the temporal efficiency of the task performance. Our cognitive system, therefore, seems to be equipped with highly sophisticated attentional mechanisms that enable us to very quickly adapt to environmental changes of superior relevance.

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8 Appendix

Appendix A: Illustration of the calculation of the quadratic curvature measure

Appendix B: Stimulus material in Experiment 3, 4, and 5

Appendix C: Mean curvature scores in Experiment 1, 2, 3, 4, and 5

Appendix D: Mean saccade latencies in Experiment 1, 2, 3, 4, and 5

Appendix A

Illustration of the calculation of the quadratic curvature measure

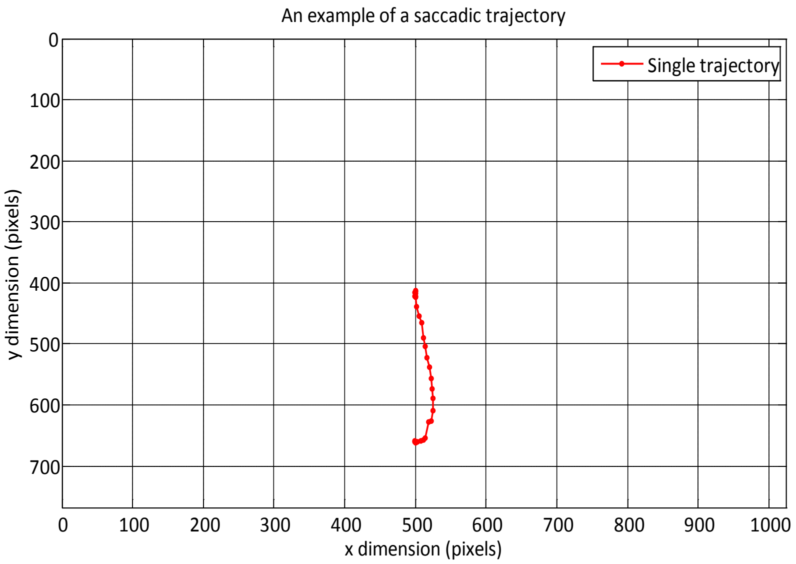

Figure 15a. A sample trajectory plotted in a two-dimensional space.

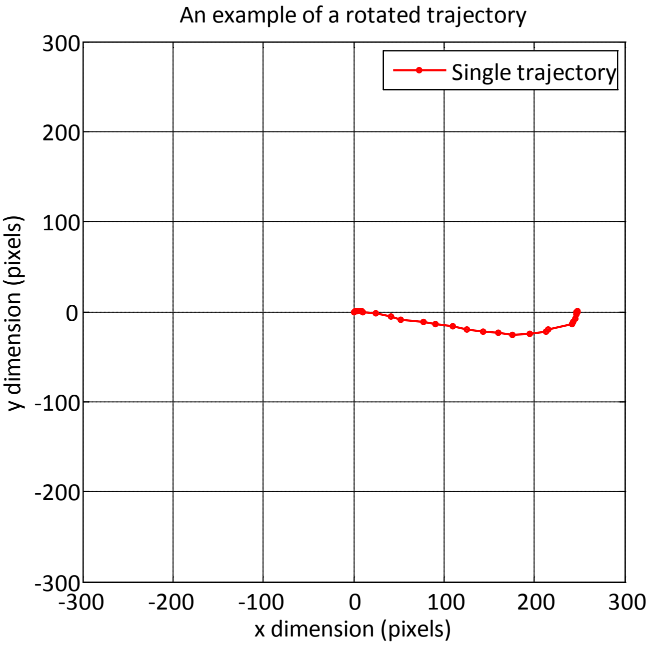

Figure 15b. A sample trajectory rotated such that the saccade endpoints lie on the abscissa.

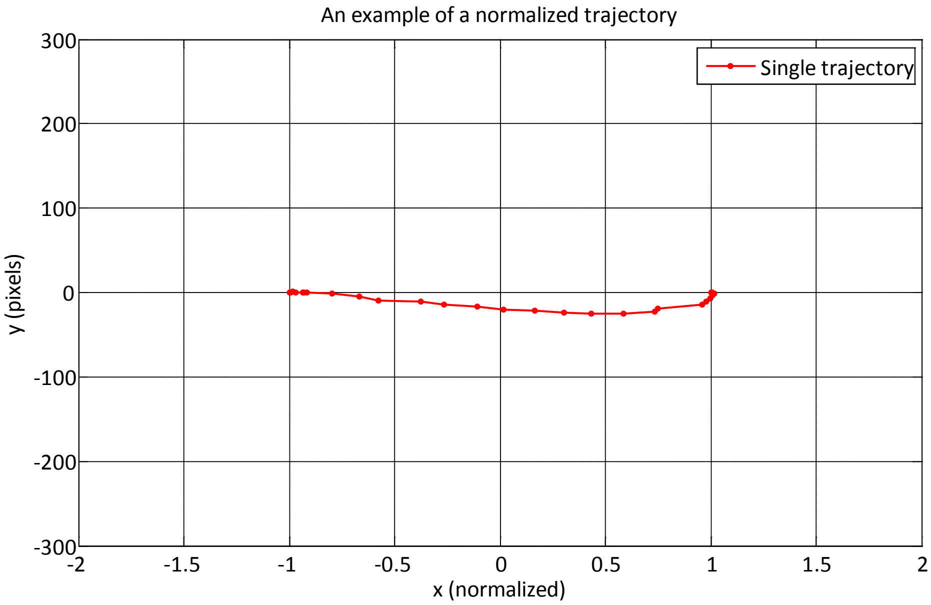

Figure 15c. A sample trajectory normalized such that the saccade starts at x = -1 and ends at x = 1.

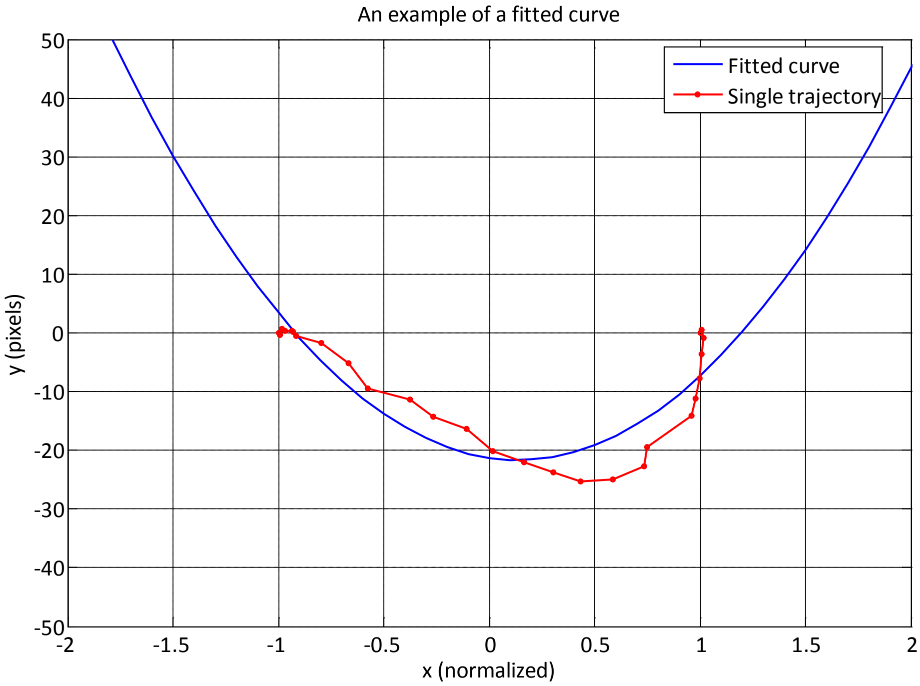

Figure 15d. A second-order polynomial fitted to the normalized rotated trajectory.

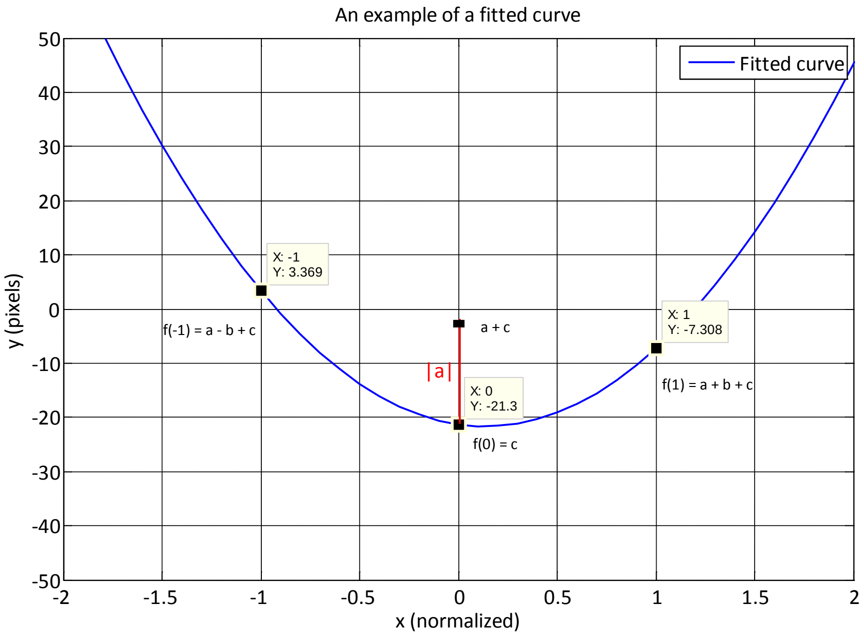

Figure 15e. An illustration of the quadratic coefficient of the second-order polynomial fitted to the normalized rotated saccade.

Appendix B

Distractor stimuli in Experiment 3, 4, and 5

KDEF numbers of the distractor pictures:

AF01, AF20, AF22, AF23, AF31, AM07, AM10, AM17, AM29, AM30

Target stimuli and filler stimuli in Experiment 5

Targets: Axt (axe) – Holz schlagen (chop wood), Besen (broom) – Boden kehren (sweep floor), Büroklammer (paper clip) – Seiten zusammenhalten (hold paper sheets), Fotokamera (camera) – Bilder aufnehmen (take pictures), Gabel (fork) – etwas essen (eat something), Gießkanne (watering pot) – Pflanzen bewässern (water plants), Gitarre (guitar) – Musik spielen (play music), Hammer (hammer) – Nägel einschlagen (hit nails), Hantel (dumbbell) – Muskeln trainieren (train muscles), Kamm (comb) – Haare frisieren (tidy hair), Kleiderbügel (hanger) – Kleidung aufhängen (hang clothes), Koffer (suitcase) – Reisebedarf transportieren (carry travel items), Korkenzieher (corkscrew) – Weinflasche öffnen (open wine bottle), Kugelschreiber (pen) – etwas aufschreiben (write something), Lineal (ruler) – Länge messen (measure length), Lupe (magnifier) – Dinge vergrößern (magnify things), Pfanne (pan) – etwas braten (fry something), Pinsel (paint brush) – Wände anstreichen (paint walls), Schere (scissors) – Papier schneiden (cut paper), Schlüssel (key) – Tür öffnen (open door), Schneebesen (egg whisk) – Eier schlagen (whisk eggs), Streichhölzer (matches) – Zigaretten anzünden (light cigarettes), Tasse (mug) – etwas trinken (drink something), Telefon (phone) – jemanden anrufen (call someone).

Fillers: Aktentasche (briefcase), Einkaufstasche (shopping bag), Etui (little case), Fernbedienung (remote control), Geldbeutel (purse), Kompass (compass), Korb (basket), Locher (perforator), Maus (mouse), Nagellack (nail polish), Ordner (folder), Pfeffermühle (pepper mill), Pinzette (tweezers), Radiergummi (rubber), Reibe (grater), Schmucktruhe (coffer), Schneidebrett (cutting board), Spitzer (sharpener), Stecker (plug), Taschenrechner (calculator), Teigrolle (rolling pin), Tennisschläger (tennis racket), Thermometer (thermometer), Zahnbürste (tooth brush).

Appendix C

Mean curvature scores in Experiment 1, 2, 3, 4, and 5

Table 3.

Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in Experiment 1 (in degrees, with standard deviations); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

Horizontal distractor location	LVF target		UVF target	
	LVF distractor	UVF distractor	LVF distractor	UVF distractor
left	-0.04 (0.18)	-0.13 (0.21)	-0.05 (0.11)	0.01 (0.09)
right	-0.12 (0.12)	-0.22 (0.15)	-0.03 (0.09)	0.03 (0.16)

Table 4.

Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in Experiment 2 (in degrees, with standard deviations); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

Distractor emotion	LVF target				UVF target			
	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	-0.18 (0.29)	-0.14 (0.24)	-0.27 (0.26)	-0.18 (0.17)	-0.15 (0.17)	-0.07 (0.12)	-0.08 (0.22)	-0.10 (0.14)
Happy	-0.20 (0.35)	-0.11 (0.28)	-0.27 (0.34)	-0.23 (0.23)	-0.10 (0.13)	-0.09 (0.12)	-0.08 (0.20)	-0.03 (0.22)
Neutral	-0.18 (0.35)	-0.11 (0.26)	-0.22 (0.21)	-0.19 (0.22)	-0.11 (0.14)	-0.07 (0.14)	-0.07 (0.19)	-0.07 (0.24)

Table 5.

Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in the *upright* conditions in Experiment 3 (in degrees, with standard deviations); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

Distractor emotion	LVF target				UVF target			
	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	-0.16 (0.17)	-0.15 (0.14)	-0.15 (0.19)	-0.20 (0.17)	-0.19 (0.21)	-0.05 (0.21)	-0.08 (0.25)	0.02 (0.28)
Happy	-0.04 (0.22)	-0.16 (0.14)	-0.12 (0.17)	-0.10 (0.11)	-0.20 (0.22)	-0.05 (0.26)	-0.09 (0.19)	0.02 (0.22)
Neutral	-0.07 (0.19)	-0.14 (0.16)	-0.18 (0.23)	-0.09 (0.13)	-0.11 (0.21)	-0.03 (0.28)	-0.11 (0.19)	-0.03 (0.15)

Table 6.

Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in the *inverted* conditions in Experiment 3 (in degrees, with standard deviations); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

Distractor emotion	LVF target				UVF target			
	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	-0.14 (0.16)	-0.10 (0.22)	-0.16 (0.20)	-0.08 (0.12)	-0.08 (0.12)	-0.10 (0.14)	-0.09 (0.22)	-0.13 (0.15)
Happy	-0.26 (0.18)	-0.05 (0.18)	-0.21 (0.17)	-0.08 (0.16)	-0.07 (0.13)	-0.07 (0.13)	-0.09 (0.19)	-0.11 (0.21)
Neutral	-0.20 (0.17)	-0.08 (0.18)	-0.27 (0.21)	-0.13 (0.20)	-0.09 (0.11)	-0.04 (0.16)	-0.08 (0.12)	-0.08 (0.23)

Table 7.

Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in the *upright* conditions in Experiment 4 (in degrees, with standard deviations); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

Distractor emotion	LVF target				UVF target			
	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	-0.15	-0.10	-0.22	-0.22	-0.01	-0.08	0.01	0.05
	(0.33)	(0.40)	(0.29)	(0.31)	(0.21)	(0.13)	(0.20)	(0.15)
Happy	-0.18	0.01	-0.21	-0.16	-0.13	0.02	-0.09	0.03
	(0.19)	(0.37)	(0.22)	(0.22)	(0.22)	(0.12)	(0.14)	(0.16)
Neutral	-0.11	-0.09	-0.24	-0.17	-0.11	-0.09	0.00	0.04
	(0.17)	(0.33)	(0.32)	(0.32)	(0.15)	(0.11)	(0.17)	(0.23)

Table 8.

Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in the *inverted* conditions in Experiment 4 (in degrees, with standard deviations); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

Distractor emotion	LVF target				UVF target			
	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	-0.06	0.05	-0.12	-0.13	-0.03	-0.03	0.26	0.16
	(0.24)	(0.42)	(0.29)	(0.32)	(0.15)	(0.12)	(0.22)	(0.24)
Happy	-0.03	0.06	-0.19	-0.05	-0.02	0.04	0.29	0.16
	(0.24)	(0.34)	(0.25)	(0.20)	(0.13)	(0.17)	(0.39)	(0.33)
Neutral	0.00	0.01	-0.11	-0.05	-0.02	0.02	0.25	0.15
	(0.17)	(0.45)	(0.19)	(0.33)	(0.12)	(0.22)	(0.19)	(0.22)

Table 9.

Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in the *noun* conditions in Experiment 5 (in degrees, with standard deviations); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

Distractor emotion	LVF target				UVF target			
	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	-0.10 (0.22)	-0.01 (0.18)	-0.03 (0.17)	0.04 (0.14)	-0.01 (0.13)	0.02 (0.12)	-0.03 (0.13)	0.03 (0.12)
Happy	-0.05 (0.14)	0.04 (0.19)	-0.06 (0.18)	-0.02 (0.18)	-0.01 (0.11)	0.02 (0.09)	-0.04 (0.11)	0.02 (0.11)
Neutral	-0.07 (0.16)	0.05 (0.17)	-0.08 (0.23)	0.01 (0.14)	-0.01 (0.13)	0.02 (0.12)	-0.06 (0.16)	0.02 (0.11)

Table 10.

Mean curvature scores (i.e., difference in curvature relative to the corresponding no-distractor baseline condition) in the *verb* conditions in Experiment 5 (in degrees, with standard deviations); positive values indicate curvature towards the distractor, negative values indicate curvature away from the distractor; UVF (upper visual field), LVF (lower visual field).

Distractor emotion	LVF target				UVF target			
	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	-0.01 (0.18)	-0.07 (0.14)	-0.01 (0.25)	-0.04 (0.19)	-0.06 (0.10)	0.01 (0.14)	-0.07 (0.12)	-0.01 (0.17)
Happy	0.00 (0.22)	0.03 (0.20)	-0.03 (0.19)	-0.03 (0.20)	0.01 (0.12)	0.02 (0.22)	-0.02 (0.15)	0.07 (0.16)
Neutral	-0.01 (0.13)	0.02 (0.15)	-0.03 (0.26)	0.00 (0.16)	-0.04 (0.12)	0.04 (0.24)	-0.04 (0.23)	0.06 (0.14)

Appendix D

Mean saccade latencies in Experiment 1, 2, 3, 4, and 5

Table 11.

Mean saccade latencies in Experiment 1 (in milliseconds, with standard deviations); UVF (upper visual field), LVF (lower visual field).

Horizontal distractor location	LVF target		UVF target	
	LVF distractor	UVF distractor	LVF distractor	UVF distractor
left	264 (53)	279 (64)	255 (80)	236 (57)
right	271 (61)	285 (60)	249 (56)	234 (61)

Table 12.

Mean saccade latencies in Experiment 2 (in milliseconds, with standard deviations); UVF (upper visual field), LVF (lower visual field).

Distractor emotion	LVF target				UVF target			
	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	239 (48)	241 (52)	255 (47)	255 (53)	225 (35)	221 (37)	213 (31)	212 (35)
Happy	232 (51)	240 (51)	247 (48)	248 (49)	222 (39)	227 (50)	214 (46)	212 (49)
Neutral	236 (46)	236 (40)	258 (46)	250 (39)	220 (39)	219 (36)	205 (33)	212 (27)

Table 13.

Mean saccade latencies in the *upright* conditions in Experiment 3 (in milliseconds, with standard deviations); UVF (upper visual field), LVF (lower visual field).

	LVF target				UVF target			
Distractor emotion	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	248 (42)	257 (51)	257 (40)	265 (30)	234 (33)	229 (38)	222 (43)	215 (38)
Happy	244 (37)	250 (41)	262 (44)	262 (36)	238 (47)	238 (47)	223 (38)	227 (47)
Neutral	246 (37)	249 (41)	268 (37)	266 (43)	233 (47)	236 (38)	229 (36)	221 (38)

Table 14.

Mean saccade latencies in the *inverted* conditions in Experiment 3 (in milliseconds, with standard deviations); UVF (upper visual field), LVF (lower visual field).

	LVF target				UVF target			
Distractor emotion	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	257 (47)	250 (34)	270 (42)	263 (41)	239 (31)	238 (27)	228 (27)	220 (28)
Happy	257 (40)	255 (32)	267 (39)	257 (33)	239 (29)	230 (23)	224 (25)	229 (34)
Neutral	256 (41)	255 (35)	267 (35)	265 (31)	236 (30)	228 (24)	225 (25)	230 (34)

Table 15.

Mean saccade latencies in the *upright* conditions in Experiment 4 (in milliseconds, with standard deviations); UVF (upper visual field), LVF (lower visual field).

	LVF target				UVF target			
Distractor emotion	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	184 (20)	184 (15)	196 (19)	194 (27)	175 (21)	174 (16)	163 (16)	161 (12)
Happy	177 (15)	183 (9)	193 (24)	194 (15)	173 (23)	173 (23)	168 (14)	165 (21)
Neutral	184 (17)	180 (14)	199 (21)	190 (14)	172 (26)	169 (21)	168 (24)	164 (19)

Table 16.

Mean saccade latencies in the *inverted* conditions in Experiment 4 (in milliseconds, with standard deviations); UVF (upper visual field), LVF (lower visual field).

	LVF target				UVF target			
Distractor emotion	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	188 (18)	191 (14)	193 (30)	192 (20)	177 (22)	172 (28)	163 (24)	166 (21)
Happy	182 (18)	183 (19)	199 (26)	198 (17)	176 (31)	174 (28)	166 (24)	170 (27)
Neutral	181 (17)	188 (20)	200 (19)	199 (18)	175 (30)	176 (25)	162 (24)	170 (22)

Table 17.

Mean saccade latencies in the *noun* conditions in Experiment 5 (in milliseconds, with standard deviations); UVF (upper visual field), LVF (lower visual field).

Distractor emotion	LVF target				UVF target			
	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	325 (78)	338 (83)	341 (84)	347 (81)	316 (80)	311 (71)	308 (74)	303 (77)
Happy	338 (83)	329 (77)	335 (87)	340 (82)	312 (73)	318 (66)	323 (90)	317 (91)
Neutral	331 (79)	337 (78)	330 (77)	336 (76)	310 (80)	310 (70)	309 (90)	310 (77)

Table 18.

Mean saccade latencies in the *verb* conditions in Experiment 5 (in milliseconds, with standard deviations); UVF (upper visual field), LVF (lower visual field).

Distractor emotion	LVF target				UVF target			
	LVF distractor		UVF distractor		LVF distractor		UVF distractor	
	left	right	left	right	left	right	left	right
Angry	321 (74)	335 (69)	339 (90)	332 (80)	330 (97)	305 (71)	311 (75)	306 (78)
Happy	338 (93)	324 (70)	331 (74)	337 (75)	316 (73)	320 (72)	306 (74)	305 (65)
Neutral	328 (83)	330 (72)	327 (69)	346 (91)	303 (67)	325 (89)	313 (82)	230 (73)