

Emotional Scene Content Drives the Saccade Generation System Reflexively

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The authors assessed whether parafoveal perception of emotional content influences saccade programming. In Experiment 1, paired emotional and neutral scenes were presented to parafoveal vision. Participants performed voluntary saccades toward either of the scenes according to an imperative signal (color cue). Saccadic reaction times were faster when the cue pointed toward the emotional picture rather than toward the neutral picture. Experiment 2 replicated these findings with a reflexive saccade task, in which abrupt luminosity changes were used as exogenous saccade cues. In Experiment 3, participants performed vertical reflexive saccades that were orthogonal to the emotional–neutral picture locations. Saccade endpoints and trajectories deviated away from the visual field in which the emotional scenes were presented. Experiment 4 showed that computationally modeled visual saliency does not vary as a function of scene content and that inversion abolishes the rapid orienting toward the emotional scenes. Visual confounds cannot thus explain the results. The authors conclude that early saccade target selection and execution processes are automatically influenced by emotional picture content. This reveals processing of meaningful scene content prior to overt attention to the stimulus.

Keywords: attention, emotion, eye movements, scene perception

The attentional system ensures that the brain prioritizes the processing of highly salient and unexpected stimuli at the expense of other ongoing neural activity and behavior (Corbetta & Shulman, 2002). As the size of the foveal field of vision providing detailed visual information is limited, the eyes must be constantly moved in order to update our knowledge of the scenes we are currently surveying. Thus, a crucial question in oculomotor research is the degree to which the eyes are automatically guided by different visual and semantic features of the environment. Most of the models of visual attention and eye movements during scene perception assume that physical features such as salient low-level characteristics mainly determine where the initial fixations land on a novel scene. Recent studies, however, have provided increasing support for the notion that parafoveally or peripherally perceived surprising or semantically incongruent objects can affect eye movements during the initial 5–10 s of scene viewing (Becker, Pashler, & Lubin, 2007; De Graef, 2005; Gordon, 2004; Underwood, 2005). However, there is currently little evidence of seman-

tic scene properties influencing the very early (i.e., the initial 500 ms or the very first saccade) stages of saccade programming and execution.

Both neuropsychological and behavioral studies suggest that emotional stimuli are highly salient, are recognized rapidly, and consequently are especially likely to capture attention (for reviews, see Compton, 2003; Vuilleumier, 2005). This implies that early stages of eye movement guidance might be automatically influenced by emotional content. In the present series of four experiments, we used a prosaccade task as well as saccade trajectory measurements to determine whether emotional content of complex pictorial scenes engages the oculomotor system automatically and results in reflexive saccade execution during the earliest (< 500 ms) stages of scene perception. We show that both the reflexive and voluntary saccade generation systems automatically orient the eyes toward emotionally significant content even when such content is completely task irrelevant.

The Role of Visual and Semantic Features in Eye Movement Guidance During Scene Perception

The models of visual attention based on saliency maps, as originally suggested by Koch and Ullman (1985), rely on the assumption that attention is drawn by changes in the low-level visual characteristics of the environment. Thus, a composite description (so-called master saliency map) of changes from one area of an image to another will provide the elementary predictions of where the eyes land during scene inspection (Itti & Koch, 2001). The models of eye guidance in scene perception based on the

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saliency mapping framework (Findlay & Walker, 1999; Henderson, Weeks, & Hollingworth, 1999) assume that the magnocellular, rod-based visual system, providing information of low-level physical differences between scene parts, is responsible for the initial guidance of eye movements. The initial saliency map (i.e., one obtained during the first fixation on a scene) is constructed on the basis of low-level visual information and the gist of the scene contents that are accessible to the magnocellular visual system. Before a certain location or its nearby regions have been foveally fixated at least once, the control of eye movements is determined mainly by visual rather than semantic factors (Henderson et al., 1999), although top-down guidance can modulate the spatial distribution of the very first fixations made upon a scene (Torralba, Oliva, Castelhana, & Henderson, 2006). Consequently, the initial sampling of scene information, based on visual features, can build up a minimal or global (i.e., gist) semantic representation of the scene content that will subsequently guide the semantic analysis of the scene features.

Although observers generally tend to spend more time fixating informative regions of a visual scene than less informative regions (for a review, see Henderson & Hollingworth, 2003; Henderson et al., 1999), there is disagreement whether semantic information influences where the eyes land initially on a scene. A seminal study of Loftus and Mackworth (1978) provided evidence supporting early semantic guidance. Surprising objects that did not fit in the scene (e.g., a lawnmower in the kitchen) were more likely to be fixated following the first saccade within the scene than scene-consistent objects (e.g., a toaster on the kitchen table). However, more recent studies of Henderson et al. (1999) and De Graef, Christiaens, and d'Ydewalle (1990) could not replicate this early inconsistency effect. According to these studies, observers were not more likely to launch the initial saccade to an inconsistent than to a consistent object. Yet, the most recent studies of Underwood (2005), De Graef (2005), and Becker et al. (2007) have obtained evidence that seems to support the early findings of Loftus and Mackworth. They demonstrated that anomalous or inconsistent objects indeed attract an early fixation with a greater likelihood than nonanomalous or consistent objects.

Saccades can be triggered reflexively by events in the environment or voluntarily by observers' goals and intentions. The neural and cognitive systems responsible for these two saccade types are at least partially segregated (Findlay & Walker, 1999; Grosbras, Laird, & Paus, 2005). An important question that still remains unanswered is how reflexively or automatically semantic scene content governs the programming of the initial saccades. In the studies of Underwood (2005) and Becker et al. (2007), participants did not usually land the initial fixation on an anomalous object. Instead, the rank order of the first fixation landing on an object was lower for anomalous than for nonanomalous objects (Becker et al., 2007) or for inconsistent than for consistent objects (Underwood, 2005). Thus, these studies do not support the notion that anomalous or inconsistent objects attract attention in a reflexive fashion. However, using a probe recognition paradigm, Gordon (2004) recently showed that attention is very rapidly and automatically drawn toward objects that are inconsistent with the overall scene gist. Similarly, De Graef (2005) has provided evidence that the first fixation on a scene lands with a higher likelihood on inconsistent than on consistent objects. In sum, on the basis of the available evidence, it is not clear whether the initial eye fixation on

a scene is primarily guided by low-level visual factors or whether knowledge-based (semantic) guidance also influences early eye movements. A potential reason for these mixed findings is that the incongruity effects (both semantic and object intrinsic) are essentially very subtle. Additionally, semantic incongruity is most likely conveyed by high spatial frequency information, especially in the studies employing line drawings (De Graef et al., 1990; Henderson et al., 1999; Loftus & Mackworth, 1978). Thus, parafoveal or peripheral perception of the incongruent features may be difficult or even impossible. Accordingly, semantic content that has stronger attention-capturing qualities and that can be conveyed by low spatial frequency information accessible to the magnocellular pathway might exert more robust effects on initial eye movement guidance.

Does Emotional Content Influence Early Stages of Saccade Programming?

Three lines of evidence suggest that emotional scene content might influence the initial guidance of eye movements in a reflexive fashion even when the scenes are initially perceived in parafoveal-peripheral vision. First, studies using event-related potentials (ERPs) have demonstrated that discrimination between emotional and neutral visual information occurs early in the visual processing stream and that emotional content might have privileged access to the visual system. ERPs measured from the visual cortices differentiate between emotional and neutral facial expressions as early as 70–120 ms from stimulus onset (Eger, Jedynak, Iwaki, & Skrandies, 2003; Pourtois, Thut, Grave de Peralta, Michel, & Vuilleumier, 2005) and around 250 ms from stimulus onset for complex emotional scenes (Junghöfer, Bradley, Elbert, & Lang, 2001).

Second, ERP studies have demonstrated that the magnocellular pathway (projecting also from parafoveal-peripheral retina) might be more involved in the processing of emotional facial expressions (Pourtois, Dan, Grandjean, Sander, & Vuilleumier, 2005) and complex emotional scenes (Carretié, Hinojosa, López-Martín, & Tapia, 2007) than the parvocellular pathway. These studies have orthogonally manipulated the spatial frequency (low vs. high) and emotional valence (neutral vs. emotional) of the stimuli and demonstrated that ERPs (with a latency around 130 ms) measured from the visual cortex is modulated by the interaction of valence and spatial frequency. More specifically, low-pass filtered fearful faces and unpleasant scenes elicited larger amplitudes than the corresponding low-pass filtered neutral stimuli. Similarly, a functional magnetic resonance imaging study by Vuilleumier, Armony, Driver, and Dolan (2003) showed that amygdala responses (traditionally attributed to processing of fear; see Adolphs, 2002) for centrally presented fearful versus neutral faces were greater for faces comprising low rather than high spatial frequencies. The magnocellular pathway provides coarse spatial information rapidly to the amygdala (Vuilleumier et al., 2003), a subcortical group of nuclei associated with early assessment of emotional qualities of stimuli (see Vuilleumier, 2005). The amygdala further projects to the visual cortices and can modulate the subsequent visual processing of the emotional stimuli. It can therefore be assumed that emotional valence of scenes might be coded coarsely by the magnocellular pathway and subsequently influence the allocation of covert and overt attention (i.e., eye movements).

This hypothesis is supported by studies that have employed stimulus eccentricity manipulations. These studies show that emotional meaning of stimuli can be reliably extracted from parafoveal and peripheral vision. Fearful versus neutral faces presented outside participants' foveal vision increase amygdala activity (Vuilleumier, Armony, Driver, & Dolan, 2001). Similarly, when emotional visual scenes exceeding the area of foveal vision were presented 1.3° away from the fixation point, Keil, Moratti, Sabatinelli, Bradley, and Lang (2005) found enhanced occipito-temporal and parietal cortical activation for emotional scenes in comparison with neutral scenes. The claim that a finer-grained discrimination between unpleasant versus pleasant emotional scenes can be performed in parafoveal vision is further supported by a recent study of Calvo and Nummenmaa (2007). They demonstrated that emotional valence of singly presented complex scenes (unpleasant vs. pleasant) can be encoded parafoveally and that parafoveally presented unpleasant and pleasant prime scenes facilitated the affective categorization of foveally presented, affectively congruent probe pictures. As the priming effect occurred even with short (150 ms) prime durations and under gaze-contingent foveal masking, the findings suggest that affective (unpleasant vs. pleasant) parafoveal discrimination can be undertaken without overt attention.

Third, eye movement recordings have shown that overt attention is biased toward both unpleasant and pleasant emotional content presented to parafoveal or peripheral vision. When unpleasant, neutral, and pleasant photographic scenes were presented simultaneously with neutral control pictures under free viewing conditions, the initial fixation was more likely to land on the unpleasant and pleasant picture than on the neutral picture (Calvo & Lang, 2004; Nummenmaa, Hyönä, & Calvo, 2006, Experiment 1). A similar pattern also emerges when the paired emotional and neutral scenes are presented for brief durations (300–900 ms; Calvo, Nummenmaa, & Hyönä, 2007, 2008). This suggests that at least the emotional meaning (or gist) is processed rapidly outside the focus of overt attention (see Calvo et al., 2008), and the detection of emotional content results in an attentional shift toward the location occupied by the emotional scene.

There is also evidence suggesting that such attentional capture might be reflexive in nature. Nummenmaa, Hyönä, and Calvo (2006, Experiment 2) presented emotional and neutral pictures simultaneously and asked participants to look only at either the emotional or the neutral picture. The results demonstrated that despite the instruction to attend to the neutral picture, the emotional pictures were still more likely to be fixated first. However, in this study, speeded responses were not required, and accordingly the studies reported relatively long (nearly 500 ms) latencies for the initial saccade. Thus, these studies do not reveal how emotional scene content influences the earliest stages of the saccade programming.

The Current Study

The current study aimed at determining the role of semantic picture content on early eye movement guidance. In four experiments, participants were presented simultaneously with two distracter scenes. On each trial, a neutral scene was displayed together with an unpleasant or a pleasant scene. The pictures were presented to parafoveal vision, and participants performed voluntary (Experiment 1) or reflexive (Experiments 2 and 4) saccades toward

either of the pictures or reflexive saccades orthogonal to the picture locations (Experiment 3). Saccade direction was specified by either a foveally presented color cue (Experiment 1) or an abrupt luminosity onset in parafovea or visual periphery (Experiments 2–4). Importantly, the content of the pictures was completely task irrelevant in all the experiments, and the pictures belonging to the different content categories (i.e., unpleasant, neutral, and pleasant) were equated with respect to low-level physical features, such as luminosity and contrast density.

By comparing effects of emotional and neutral picture distracters on reflexive and voluntary task-instructed saccades at variable stimulus onset asynchronies (SOAs), we aimed at determining (a) whether parafoveally perceived emotional content influences the voluntary and reflexive saccade generation systems and (b) what the time course of the potential emotional content bias is in eye movement planning and execution. If emotional content automatically influences the saccade generation system, we expected the saccades to be initiated faster when the imperative signal pointed toward the emotional versus neutral picture in Experiments 1 and 2. Additionally, more misdirected saccades were expected when the imperative signal pointed toward the neutral picture (i.e., emotional scenes would trigger reflexive saccades against the task instructions). Further, we hypothesized that an automatic saccade program initiated toward an emotional picture in Experiment 3 would cause the saccade endpoint to deviate away from the saccade target due to oculomotor inhibition.

Experiment 1

In Experiment 1, participants performed voluntary horizontal saccades from a central fixation point according to an imperative signal (color change of the fixation point) while their eye movements were recorded. When the fixation point changed to orange, the participant had to make a saccade to the picture at the right side, whereas when it changed to green, the left picture was to be saccaded to (for half of the participants the color-direction pairing was reversed). Pairs of emotional and neutral pictures were presented to parafoveal–peripheral vision either 150 ms before or 150 ms after the imperative signal, thus resulting in SOAs of ± 150 ms. The onset of the distracter pictures was time-locked to the presentation of the imperative signal. Crucially, the imperative signal pointed toward either an unpleasant, a neutral, or a pleasant picture. If we assume that the goal of the task (e.g., Treue, 2003) and the semantic content of the scene can influence weights for the master saliency map, three saliency weights (in addition to visual saliency) would compete for attracting the initial fixation: (a) the location defined by the color cue, (b) the location of the emotional picture, and (c) the location of the neutral picture. If emotional picture content exerts a reflexive influence on saliency mapping and subsequently on saccade generation, a successful performance in the task (i.e., making a saccade to the cued location) would require voluntary inhibition of the saliency weight resulting from the emotional picture appearing at the nontarget location, and accompanying cortical inhibition of the neurons in the superior colliculus (SC) before (–150-ms SOA) or after (150-ms SOA) the imperative signal appears. Accordingly, if emotional picture content influences saccade generation in a bottom-up fashion, longer saccadic latencies and more saccadic errors can be expected when

the imperative signal points toward a neutral rather than an emotional picture.

Method

Participants. A mainly female sample of 30 students (23 women, 7 men) with a mean age of 23 years from the University of Turku participated in the experiment as part of a completion of an introductory psychology course. Participants' visual acuity was tested with a standard Snellen chart to ensure normal visual acuity.

Apparatus. Stimuli were presented on a 20-in. (50.8-cm) ViewSonic monitor (150-Hz refresh rate) with a 2-GHz Pentium IV computer. Participants' eye movements were recorded with an EyeLink II eyetracker (SR Research, Mississauga, Ontario, Canada) connected to a 2-GHz Pentium IV computer. The sampling rate of the eyetracker was 500 Hz, and the spatial accuracy was better than 0.5° , with a 0.01° resolution in the pupil tracking mode.

Materials. The stimuli (see Figure 1 for illustrations) were 128 pictures selected from the International Affective Picture System (Center for the Study of Emotion and Attention, 2005). There were 32 unpleasant, 32 pleasant, and 64 neutral pictures (see Appendix). The unpleasant pictures represented people suffering serious threat or harm. The pleasant pictures portrayed people showing or experiencing positive affect. The neutral pictures depicted people in daily nonemotional activities. Valence and arousal ratings (ranging from 1 to 9; see Table 1) for each picture were obtained in norming studies (Lang, Bradley, & Cuthbert, 2005). Valence (unpleasantness vs. pleasantness) reflects the dominant motive system activated (avoidance or approach). Arousal reflects the intensity of the motive system activation, from calm to tension. For the stimuli used in the current study, a one-way analysis of variance (ANOVA) yielded an effect of stimulus type on valence ratings, $F(2, 127) = 492.68, p < .001, \eta_p^2 = .93$, with significant differences between all three stimulus categories (all post hoc comparisons, $ps < .001$; Bonferroni corrected). There was also a stimulus type effect on arousal ratings, $F(2, 127) = 91.11, p < .001, \eta_p^2 = .80$, with significantly higher ratings for the unpleasant and the pleasant stimuli than for the neutral stimuli (both $ps < .001$), but no difference between the pleasant and unpleasant stimuli. To control for potential confounds resulting from low-level visual properties of the images, basic image statistics (see Table 1) including mean luminosity, standard deviation of luminosity, contrast density (root-mean-square contrast; Peli, 1990), complexity (JPEG file size; see Donderi, 2006), skewness, kurtosis, and energy were computed through MATLAB 7.0 (MathWorks, Natick, MA). The one-way ANOVAs showed no significant differences between the valence categories in any of the image characteristics (all $F_s \leq 1.60, p \geq .10$), $F(2, 125) = 3.90, p \geq .072$ (for energy,

after Bonferroni corrections for multiple contrasts). To obtain a reasonable number (16) of trials per condition, each stimulus scene was presented twice during the experiment.

Stimulus displays. See Figure 2 for illustrations of stimulus displays. The initial display consisted of an initial fixation target and two saccade target areas. The initial fixation target was a white circle with a black center and a diameter of 1.5° . The saccade target areas were white rectangles subtending $10.54^\circ \times 7.98^\circ$ of visual angle. They were centered on the central horizontal axis, and the distance between the innermost edges of the target areas from the center of the fixation circle was 2.5° . The imperative signal was a change in color (to orange or green) of the fixation circle. The size of the distracter pictures was $10.24^\circ \times 7.68^\circ$. The distracter displays consisted of an emotional (either pleasant or unpleasant) and a neutral picture.

Design. The design was a 2 (SOA: -150 ms vs. 150 ms) \times 2 (Visual field of emotional picture: left vs. right) \times 3 (Emotional content of target area picture: unpleasant vs. neutral vs. pleasant) fully within-subjects design.

Procedure. Upon arriving at the laboratory, participants were given an informed-consent form to sign, and their visual acuity was tested. Participants were then seated in front of the monitor and given instructions on how to perform the experimental trials. The study was presented as a voluntary eye movement task, in which they had to perform horizontal saccades according to the color change (from white to green or orange) of the central fixation point. The participants were told that on each trial they were also going to see two pictures appearing on the initially empty placeholders, but it was stressed that the pictures were unrelated to the eye movement task and should simply be ignored. Next, the eyetracker was calibrated. The calibration was accepted if the average error was less than 0.5° . After 10 practice trials, the eyetracker was recalibrated.

Each trial (see Figure 2 for events on trials) began with a drift correction. A fixation circle appeared on the center of the screen with the saccade target areas (white rectangle frames), and the participant had to focus his or her gaze at the center of the circle. When the participant's eye was fixated on the circle, the experimenter initiated the trial. A random delay of 0–100 ms was appended at the beginning of all trials to prevent anticipatory saccades. On trials with -150 -ms SOA, the pictures first appeared at the target areas for 150 ms, after which the fixation circle changed color to either green or orange, and then the circle and the pictures were displayed for 1,350 ms. On trials with 150-ms SOA, the order of the events was reversed: The fixation circle first changed its color, and after 150 ms the distracter pictures appeared at the target areas and stayed on the screen with the fixation circle



Figure 1. Examples of (A) unpleasant, (B) neutral, and (C) pleasant stimuli used in Experiments 1–4. Note that these example pictures were not among the experimental stimuli.

Table 1
Means and Standard Deviations of Stimulus Characteristics of the Unpleasant, Neutral, and Pleasant Stimuli Used in Experiments 1–4

Image characteristic	Unpleasant		Neutral		Pleasant	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Valence rating	2.60 _a	0.64	5.27 _b	0.59	7.20 _c	0.53
Arousal rating	5.59 _a	1.00	3.58 _b	0.55	5.45 _a	1.03
Luminance (average)	99.35 ^a	19.66	101.06	19.55	109.22 ^a	22.46
Luminance (<i>SD</i>)	73.72	12.49	67.22	13.52	73.17	13.57
Root-mean-square	0.76	0.14	0.68	0.17	0.70	0.21
Skewness	0.57	0.48	0.54	0.50	0.39	0.58
Kurtosis	2.36	0.67	2.57	1.17	2.27	0.86
Energy ($\times 10^{-7}$)	7,226	2,930	8,394	3,079	6,767	1,669

Note. Subscripts indicate significant differences between scene categories. If two scores share an identical subscript, they are equivalent.

for 1,350 ms. Participants were instructed to ignore the pictures and concentrate on performing a saccade as fast as possible anywhere on the target area designated by the imperative signal and to maintain a fixation in the area until the screen changed to black. After an intertrial interval of 500 ms, the fixation point reappeared and the next trial was initiated by the experimenter when the participant fixated the circle.

The first experimental block consisted of 64 trials in random order. After the first block, a short break was held, and the eyetracker was recalibrated. In the second block, the same emotional and neutral pictures were presented in random order. In the second block, each scene was presented in the opposite visual field and randomly paired with a different picture. The color coding of the imperative signal, that is, whether the green or orange fixation circle indicated a leftward or rightward saccade, was counterbalanced across participants. After the experiment, the participants were debriefed about the purposes of the study.

Results

Saccadic reaction times (RTs), amplitudes, and velocities were computed for correctly directed saccades. On average, partici-

pants performed misdirected saccades on 11% of the trials. Prior to the analyses, anticipations (RTs < 80 ms) and retardations (RTs two standard deviations above the participant's mean) were filtered out. These accounted for 5% of the trials. Frequency distributions of saccade latencies as a function of emotional valence and SOA are presented in Figure 3. Mean saccadic RTs, amplitudes, and velocities and number of misdirected saccades were computed for each condition and subjected to a 2 (SOA: -150 ms vs. 150 ms) \times 2 (Visual field of emotional picture: left vs. right) \times 3 (Emotional content of target area picture: unpleasant vs. neutral vs. pleasant) repeated measures ANOVA. In this and all the subsequent analyses, only statistically significant or borderline ($p < .10$) results are presented, and all multiple comparisons are Bonferroni corrected. For saccadic RTs (see Figure 4A), there were main effects of SOA, $F(1, 29) = 79.51$, $p < .001$, $\eta_p^2 = .73$, and picture content, $F(2, 58) = 4.12$, $p = .01$, $\eta_p^2 = .12$. RTs were faster for -150-ms SOA than for 150-ms SOA (320 ms vs. 348 ms, respectively). Multiple comparisons revealed that saccades made toward unpleasant, $F(1, 29) = 8.01$, $p < .001$, $\eta_p^2 = .22$, and pleasant, $F(1, 29) = 3.53$, $p = .05$, $\eta_p^2 = .12$, pictures were faster than those made toward neutral pictures. RTs for saccades made toward unpleasant and pleasant pictures were similar ($F < 1$, $p = .44$). The saccade amplitudes and velocities were not influenced by SOA, picture content, or their interaction ($F_s < 3.2$).

For the number of misdirected saccades (see Figure 4B), the analysis yielded main effects of SOA, $F(1, 29) = 27.01$, $p < .001$, $\eta_p^2 = .48$, and picture content, $F(2, 58) = 3.91$, $p = .02$, $\eta_p^2 = .13$. More errors were made with -150-ms SOA than with 150-ms SOA (17 % vs. 14%, respectively). Additionally, multiple comparisons revealed that more errors were made when the imperative signal pointed toward neutral than toward unpleasant, $F(1, 29) = 6.26$, $p = .02$, $\eta_p^2 = .18$, or pleasant, $F(1, 29) = 5.04$, $p = .03$, $\eta_p^2 = .15$, pictures. Error rates were similar for trials in which the imperative signal pointed toward unpleasant or pleasant pictures ($F < 1$).

Discussion

The main finding of Experiment 1 was that emotional scene content influenced the programming and execution of the initial saccade. The latencies of voluntary saccades were faster when the

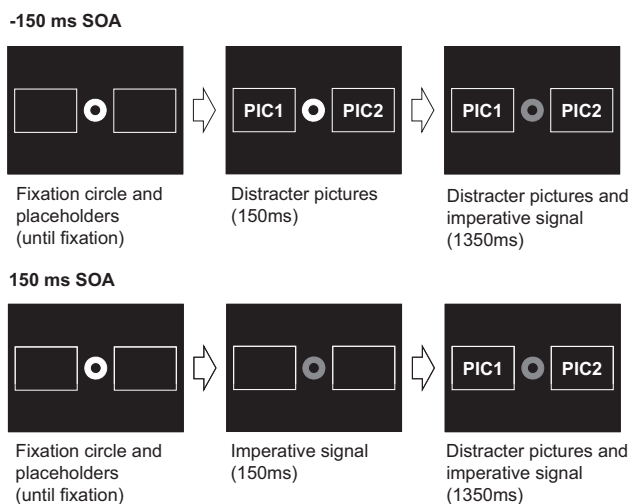


Figure 2. A trial sequence with -150-ms stimulus onset asynchrony (SOA) and 150-ms SOA in Experiment 1.

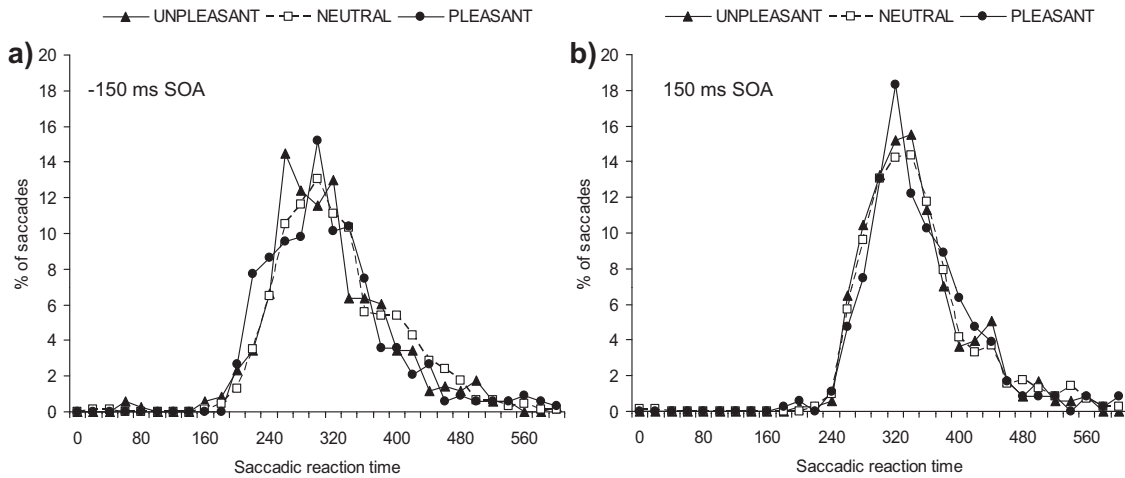


Figure 3. Frequency distributions (20-ms time bins) of saccade latencies as a function of emotional valence for (A) -150-ms stimulus onset asynchrony (SOA) and (B) 150-ms SOA in Experiment 1.

imperative signal pointed toward emotional than toward neutral pictures, when the pictures were presented either 150 ms before or 150 ms after the imperative signal. This occurred even though the distracter pictures were completely task irrelevant and were presented at an eccentric location (over 2.5° away from the fixation) and under resource-consuming conditions involving the encoding of the directional meaning of the imperative signal (color cue). The pattern of error rates was highly similar to that for the saccadic RTs. More saccadic errors were made when the imperative signal pointed toward neutral than toward emotional pictures. In other words, when the imperative signal pointed away from the emotional picture, the parafoveally perceived emotional content tended to override the voluntarily generated saccade program, resulting in an erroneous saccade toward the emotional scene. However, although the negative SOA speeded up the saccadic RT, it increased the error rate. This is likely to reflect the fact that the prolonged exposure to and encoding of the scenes will simply increase the

likelihood of an erroneous, stimulus-driven saccade. Importantly, as low-level visual features of the emotional and neutral pictures were matched and two simultaneous abrupt onsets occurred in the opposite visual fields due to the picture presentation, the results provide strong evidence that the affective meaning of scenes can be perceived parafoveally (Calvo & Nummenmaa, 2007) and that this information results in an elevated saliency weight for the location occupied by the emotional scene.

An inspection of the frequency distributions (see Figure 3) of the saccadic latencies reveals that for -150-ms SOA, there are more saccades with latencies around 220–300 ms made toward emotional than toward neutral scenes, whereas the corresponding latency range for 150-ms SOA is 300–340. Thus, the latency modulation by emotional scenes is not due to participants making more ultra-rapid (low latency; cf. Kirchner & Thorpe, 2006) voluntary saccades toward the emotional scenes. Instead, this suggests that the emotionality effects in saccade programming emerge for

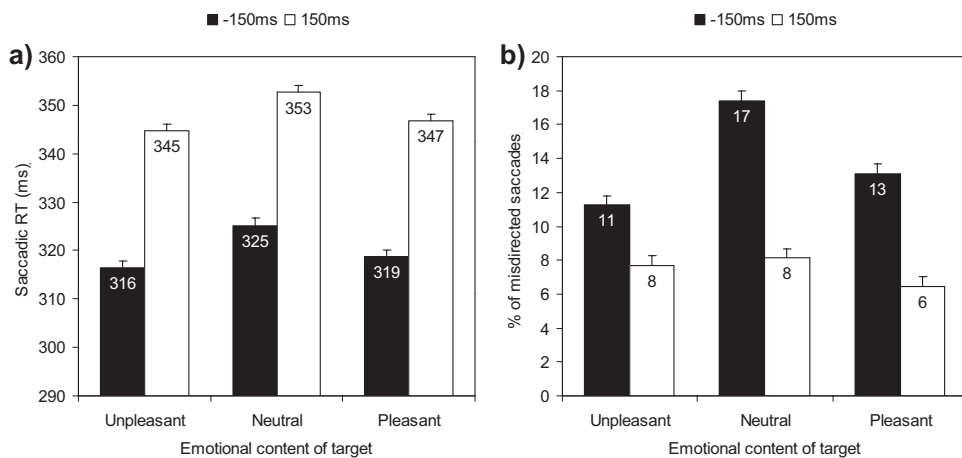


Figure 4. Means and pooled 95% confidence intervals of (A) saccadic latency and (B) proportion of errors as a function of stimulus onset asynchrony and emotional valence of the picture at the saccade target location in Experiment 1. RT = reaction time.

saccades with latency close to the mean value of the distribution. The effect of emotional content on saccadic RTs was of comparable magnitude at both SOAs. This is a striking finding given that voluntarily triggered saccades take a minimum of about 150–250 ms to program (Carpenter, 1988). The mean saccadic latency in the 150-ms SOA condition (in which distracter pictures were presented after the imperative signal) was 348 ms. Thus, this leaves around 200 ms for the processing of the emotional content of the parafoveally perceived picture and the programming of the subsequent emotion-driven saccade after presentation of the emotional pictures. In other words, the rise of the activity in the saccade neurons in the SC due to programming a task-induced saccade did not seem to exceed the threshold for triggering a saccade during the initial 150 ms and could thus still be influenced by a competing input that specified the emotional picture as a saccade goal. This suggests that the encoding of the emotional content must occur relatively early in the visual processing stream. As noted in the introduction, ERPs recorded from the visual cortices demonstrate very early (around 70–90 ms from stimulus onset) differences between schematic emotional and neutral faces (Eger, Jedynak, Iwaki, & Skrandies, 2003), whereas the latencies of scalp ERPs are around 250 (Junghöfer, Bradley, Elbert, & Lang, 2001) from stimulus onset for complex emotional scenes. In line with intracranial recordings from the ventromedial prefrontal cortex (Kawasaki et al., 2001) and the extracranial ERP data on facial expression perception (e.g., Pourtois, Thut, et al., 2005), our data show that the processing of the emotional valence of complex visual scenes must occur at least 100 ms earlier than suggested by Junghöfer et al. (2001). The scalp ERPs do not thus show the earliest time point when the processing of emotional and neutral scenes differs (see Kirchner & Thorpe, 2006, for similar results on semantic categorization).

But which stage of saccade programming was influenced by the emotional scene content? A wealth of neuroimaging data (for a review, see Grosbras et al., 2005) provides support for a distinction between two classes of saccades: stimulus driven (or reflexive) and voluntary, which are subserved by separable but partially overlapping neural circuits. Reflexive saccades are thought to be programmed by a corticotectal pathway from the parietal eye fields in the intraparietal sulcus (IPS) projecting to the SC, which further projects to the brainstem saccade generator, whereas voluntary saccades are thought to rely more heavily on the inputs from the frontal eye field (FEF) and supplementary eye field to the SC (Schall, 1995). In Experiment 1, participants performed voluntary saccades according to a color cue. Accordingly, the effects obtained in Experiment 1 may index only an interference of the frontocortical voluntary saccade control due to the presence of emotional pictures, thus contradicting our claim about the reflexive nature of the observed oculomotor response. If so, similar effects would not be expected for reflexive saccades. Experiment 2 was conducted to test this possibility.

Experiment 2

Experiment 2 was aimed at determining whether the reflexive saccade generation system is influenced by parafoveal perception of emotional content. Experiment 2 was identical to Experiment 1 with two important modifications. First, instead of centrally presented color cues, peripheral abrupt onset cues (bright square

around one of the distracter pictures) designated where a saccade was to be made. Second, SOAs of -150 ms and 0 ms were used. Given that the latency of reflexive saccades is usually around 150 ms (Rayner, 1998), no interference effects may be found at an SOA of 150 ms, as participants could be expected to have already programmed a saccade within 150 ms. Thus, we reasoned that by using SOAs of -150 ms and 0 ms, we could assess the effects of emotional scenes that precede (-150 -ms SOA) or coincide (0 -ms SOA) with the presentation of the reflexive saccade cue (the white frame around the picture area turned orange).

Method

Participants and procedure. A mainly female sample of 30 students (24 women, 6 men) with a mean age of 23 years from the University of Turku participated in the experiment as part of a completion of an introductory psychology course. Participants' visual acuity was assessed similarly as in Experiment 1; all participants had visual acuity within the normal limits. See Figure 5 for the sequence of events in a trial. The procedure was identical to that in Experiment 1 with the following exceptions. The fixation circle remained black-and-white throughout the trial. The imperative signal was an abrupt luminosity change (from white to bright orange) in one of the two frames surrounding the saccade target area. SOAs of -150 ms and 0 ms were used.

Results

Frequency distributions of saccade latencies as a function of emotional valence and SOA are presented in Figure 6. Mean saccadic RTs, amplitudes, and velocities and number of misdirected saccades (see Figure 7) were subjected to a 2 (SOA: -150 ms vs. 0 ms) \times 2 (Visual field of emotional picture: left vs. right) \times 3 (Emotional content of target area picture: unpleasant vs. neutral vs. pleasant) repeated measures ANOVA. For saccadic RTs, there were main effects of SOA, $F(1, 29) = 32.00$, $p < .001$, $\eta_p^2 = .53$, and picture content, $F(2, 58) = 9.10$, $p < .001$, $\eta_p^2 = .24$.

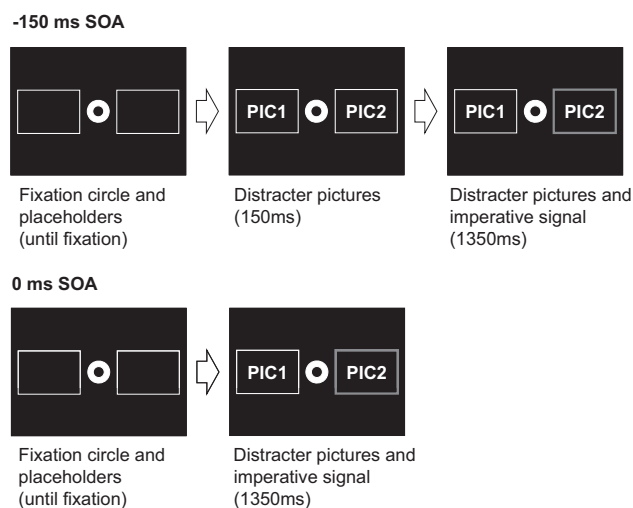


Figure 5. A trial sequence with -150 -ms stimulus onset asynchrony (SOA) and 0 -ms SOA in Experiment 2.

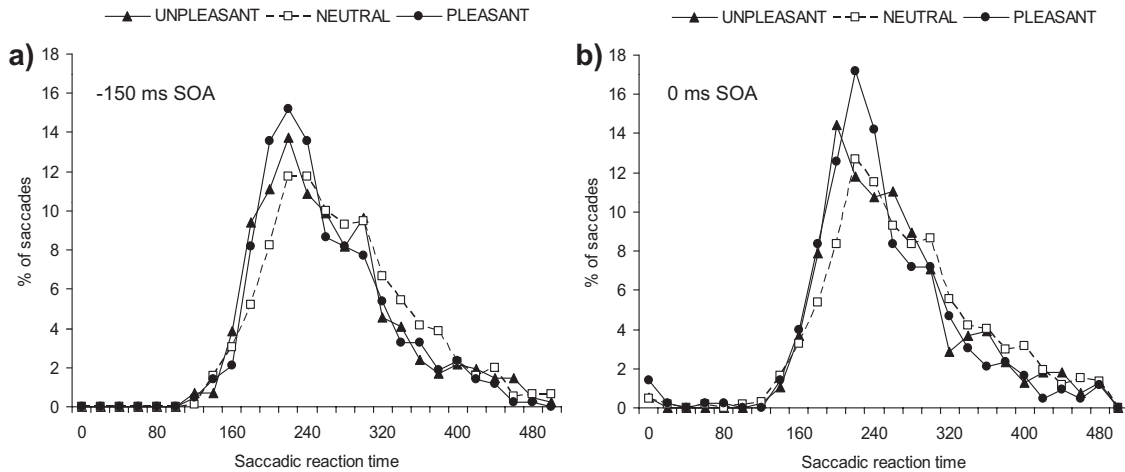


Figure 6. Frequency distributions (20-ms time bins) of saccade latencies as a function of emotional valence for (A) -150 -ms stimulus onset asynchrony (SOA) and (B) 0 -ms SOA in Experiment 2.

RTs were faster for trials with -150 -ms SOA than with 0 -ms SOA (246 ms vs. 261 ms, respectively). Multiple comparisons revealed that RTs were faster when the imperative signal pointed toward unpleasant, $F(1, 29) = 11.38, p < .001, \eta_p^2 = .28$, and pleasant, $F(1, 29) = 16.00, p < .001, \eta_p^2 = .36$, pictures than toward neutral pictures. No significant differences in RTs were observed for saccades initiated toward unpleasant versus pleasant pictures ($F = 2.90, p = .10$).

For the saccade amplitudes, the ANOVA yielded a significant main effect of picture content, $F(2, 58) = 11.32, p < .001, \eta_p^2 = .28$, resulting from unpleasant scenes triggering longer saccades than neutral scenes, $F(1, 29) = 25.46, p < .001, \eta_p^2 = .47$. There was also a tendency for the pleasant scenes to trigger longer saccades than the neutral scenes, but this effect did not reach significance ($p = .11$). Analysis of the saccade velocities yielded highly similar results. There was a main effect of picture content, $F(2, 58) = 4.33, p = .02, \eta_p^2 = .13$. Contrast tests revealed that this resulted from the unpleasant scenes triggering saccades with higher velocity than the neutral scenes, $F(1, 29) = 7.80, p = .01, \eta_p^2 = .28$. Numerically, saccade velocities were larger for pleasant versus neutral scenes, but this difference did not reach significance ($p = .12$).

For the number of misdirected saccades, the analysis yielded significant main effects of SOA, $F(1, 29) = 32.00, p < .001, \eta_p^2 = .53$, and picture content, $F(2, 58) = 9.10, p < .001, \eta_p^2 = .24$. More errors were made with -150 -ms SOA than with 0 -ms SOA (17% vs. 12%, respectively). Multiple comparisons revealed that participants made more errors when the imperative signal pointed toward neutral than toward unpleasant, $F(1, 29) = 35.70, p < .001, \eta_p^2 = .55$, or pleasant, $F(1, 29) = 75.44, p < .001, \eta_p^2 = .72$, pictures. Additionally, more errors were made when the imperative signal pointed toward pleasant than toward unpleasant pictures, $F(1, 29) = 14.00, p < .001, \eta_p^2 = .33$.

Discussion

Experiment 2 essentially replicated the results of Experiment 1 with a reflexive saccade task. Saccadic RTs were faster when

the saccade target area contained an emotional rather than a neutral picture. Similarly, more errors were made when the saccade target area contained a neutral rather than an emotional picture. The emotional valence also influenced saccade velocities and amplitudes, but these effects were restricted to the unpleasant pictures, although there was a statistically nonsignificant tendency for the pleasant pictures to influence saccade amplitudes and velocities as well. Together these data suggest that the saccade program resulting from the presence of an emotional picture interfered or competed with the program resulting from the reflexive saccade cue. The interference due to the emotional picture content was observed at both SOAs. The finding that interference was observed even when the emotional picture was presented 150 ms before the imperative signal suggests that the emotional scenes result in relatively long-lasting changes in the activity of the saccade generation systems that can override or at least influence the stimulus-driven saccades elicited by the imperative signal. The error rate was surprisingly high (26%) when the imperative signal pointed toward a neutral picture, in contrast to that (around 10%–15%) typically observed in the relatively demanding antisaccade task (see Munoz & Everling, 2004). This underlines the strong bottom-up influence of the emotional pictures. This provides further support for the notion that emotional content captures visual attention automatically and subsequently biases saccade target selection in a reflexive manner (Nummenmaa et al., 2006, Experiment 2). As the interference effects resulting from the emotional distracters are relatively similar for reflexive (Experiment 2) and voluntary (Experiment 1) saccades, this implies that the emotional content influences saccade programming at a processing stage that is common for the neural circuits involved in reflexive and voluntary saccade generation, projecting relatively directly to the subcortical oculomotor systems (see General Discussion).

On the assumption that reflexive saccades are programmed within 150 ms, the observed saccade latencies seem to be relatively long for reflexive saccades. However, as stated by Rayner

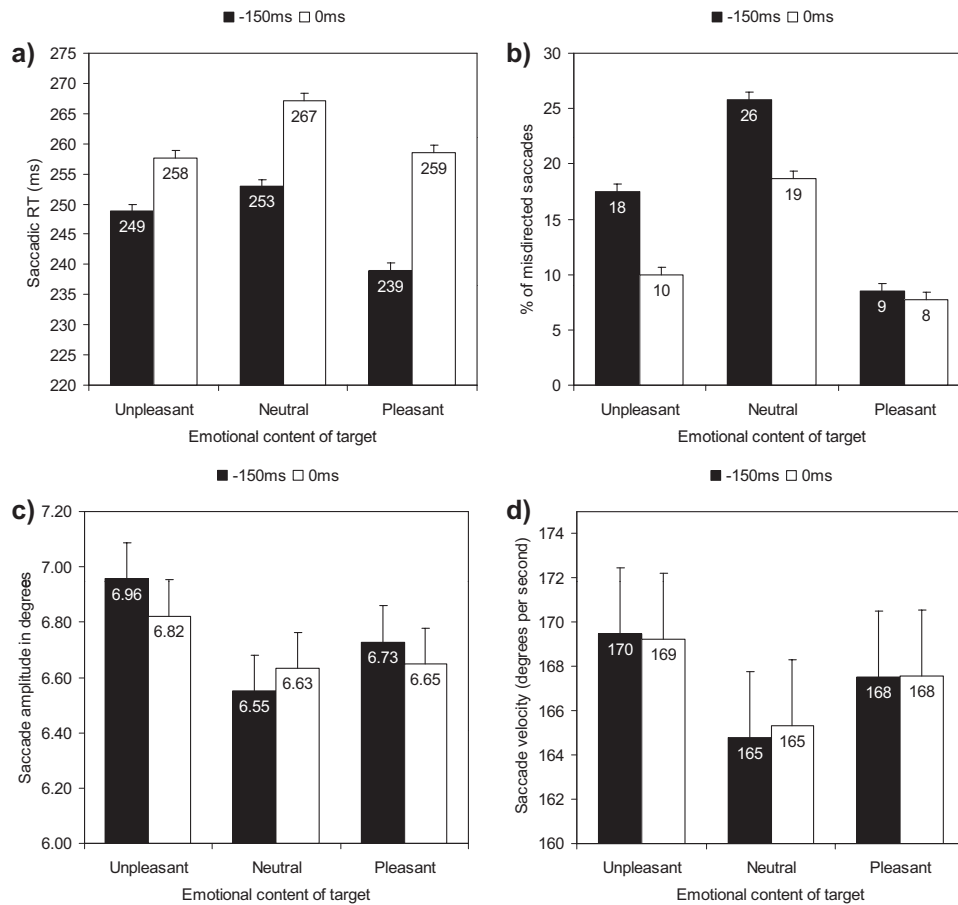


Figure 7. Means and pooled 95% confidence intervals of (A) saccadic latency, (B) proportion of errors, (C) saccade amplitude, and (D) saccade velocity as a function of stimulus onset asynchrony and emotional valence of the picture at the saccade target location in Experiment 2. RT = reaction time.

(1998, p. 374), reflexive saccades are not usually initiated with latencies below 150 ms “even if uncertainty about when or where to move the eyes is eliminated”; this number is rather the lower limit of the minimal saccadic latency. Additionally, as the saccades in Experiment 2 had over 80-ms shorter latencies than the voluntary saccades in Experiment 1 (254 ms vs. 334 ms, respectively), we feel that the saccade task was successful in eliciting reflexive saccades.

The most rapid saccades were made toward the emotional scenes. Figure 6 reveals that for both SOAs, already for saccades with latencies exceeding 170 ms, the majority of saccades are triggered toward the emotional scenes. This implies that the valence encoding must be undertaken rapidly. This would suggest a 170-ms lower limit for the latency for emotional valence encoding. Even this figure is likely an overestimate given the time taken to output the information regarding the saccade goal to the brainstem neurons responsible for saccade generation.

However, the results of Experiment 2 are open to an alternative explanation not involving the saccade generation system. The quick encoding of emotional content and subsequent bias in attentional orienting has been explained in terms of a two-route model; the routes are (a) from thalamus to primary visual cortex

(V1) and (b) from thalamus via amygdala to V1 (see Vuilleumier, 2005). Essentially, coarse magnocellular inputs might reach the amygdala quickly, thus enabling early crude assessment of emotional content (emotional gist). Subsequently, the projections from amygdala to V1 can further modulate the processing in the retinotopic location occupied by the emotional content in V1. Accordingly, the faster saccadic RTs observed in Experiment 2 for emotional content might be due to the fact that the emotional pictures trigger a covert shift of attention to the location occupied by the emotional picture, which subsequently increases the sensory gain at that location. This would in turn boost the detection of the saccade signal (a luminosity onset in the frame surrounding the picture area), and consequently the luminosity onset occurring around an emotional scene would be able to initiate a saccadic response faster than the luminosity onset occurring around a neutral picture.

To test these alternative interpretations, in Experiment 3 a different paradigm was implemented, which allowed us to examine whether the observed facilitation in reflexive saccade RTs toward emotional target area is due to reflexive shifts of covert attention only or to reflexive programming of saccades.

Experiment 3

In Experiment 3, we assessed whether the subcortical oculomotor system is automatically engaged by emotional content. To this end, we measured the endpoint deviation and trajectory curvature of task-induced saccades executed while emotional and neutral distracters were presented simultaneously with or after the saccade target cue. Paired emotional and neutral distracter pictures were presented to parafoveal vision, aligned along the central horizontal axis. Participants were instructed to ignore the pictures and perform vertical saccades from the central fixation point to target crosses appearing abruptly at the visual periphery.

It is known that saccades deviate away from irrelevant distracters presented in the visual periphery (Doyle & Walker, 2001, 2002; Godijn & Theeuwes, 2004) as well as in the center of the screen (Nummenmaa & Hietanen, 2006). This curvature can be used to index the activity of the oculomotor system (for a review, see Van der Stigchel, Meeter, & Theeuwes, 2006): The curvature or deviation away from the distracter is explained by the competing interactions that operate in the neural map that specifies the saccade goal (e.g., Godijn & Theeuwes, 2002). Competing stimuli activate separate populations of neurons. If a distracter is presented whose spatial location is irrelevant for the saccade task, the inhibition of the saccadic response to the spatial location occupied by the distracter reduces the activity of neurons associated with the programming of the response to the distracter, below the baseline level. Consequently, the task-induced saccade curves away from the distracter. Importantly, as the distracter location is orthogonal to the demanded saccadic response, this paradigm is not confounded with the facilitated detection of the saccade targets due to covert shifts of attention.

Intracranial recordings in primates suggest that the saccade goal inhibition causing the deviation in the saccade endpoint and/or saccadic curvature might occur in the SC (McPeck, Han, & Keller, 2003). As the saccadic curvature reflects a reduction in the activity of neurons associated with the programming of the saccade to the location occupied by the distracter, we expected the saccades to deviate away from the visual hemifield in which the emotional picture was presented.

Method

Participants and stimulus displays. Fifteen students (10 women, 5 men) with a mean age of 23 years from the University of Turku participated in the experiment as part of a completion of an introductory psychology course. Participants' visual acuity was assessed as in Experiments 1 and 2; all participants had visual acuity within the normal limits. The stimulus displays (see Figure 8) were similar to those used in Experiment 1 with the exception that saccade target placeholders were now presented at the top and bottom of the screen. These were white squares measuring $1.6^\circ \times 1.6^\circ$ of visual angle and located on the central vertical axis at a distance of $\pm 10.5^\circ$ from the central horizontal axis (and the central fixation point). The imperative signal (i.e., the saccade target) was a white cross (diameter 1.4°) presented in either of the saccade target placeholders. The initial fixation circle stayed white throughout the trial.

Design. As every trial involved the presentation of paired emotional, and neutral pictures and the to-be-performed saccades

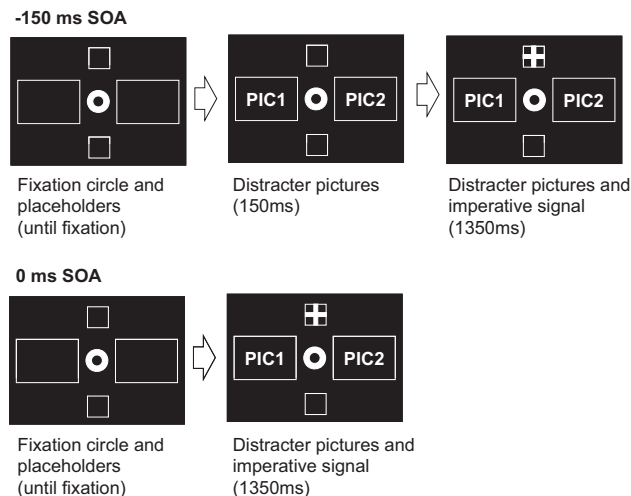


Figure 8. A trial sequence with -150 -ms stimulus onset asynchrony (SOA) and 0 -ms SOA in Experiment 3.

in this task were orthogonal to the location of the distracters (i.e., saccades did not have to be made toward the emotional or neutral pictures), this resulted in a 2 (SOA: -150 ms vs. 0 ms) \times 2 (Visual field of emotional picture: left vs. right) \times 2 (Emotional content: unpleasant vs. pleasant) fully within-subjects design.

Procedure. The procedure was similar to that in Experiment 2 with the following modifications. Before each trial (see Figure 8), the initial fixation circle, the distracter placeholders, and the saccade target placeholders were displayed. After a drift correction, a cross (i.e., the saccade target) appeared randomly at either the upper or the lower target placeholder. The paired emotional and neutral distracter pictures were presented either 150 ms before (-150 -ms SOA) or simultaneously (0 -ms SOA) with the saccade target. Participants were instructed to ignore the pictures, perform a saccade to the target cross as soon as it appeared, and maintain a fixation until the imperative signal disappeared. After $1,350$ ms, the display turned black for 500 ms and the next trial was initiated.

The experiment began with 10 practice trials followed by a recalibration of the eyetracker. This was followed by two blocks of 64 experimental trials. The visual field in which each picture was presented was counterbalanced as in Experiments 1 and 2, and the direction (up vs. down) of the task-instructed saccades was counterbalanced across blocks for each picture.

Data analysis. The eye movement data were processed as follows: First, anticipations (saccadic latencies < 80 ms) and retardations (latencies over two standard deviations above the participant's mean) were omitted from the analysis. Saccades made to a wrong target or falling more than 4° away from the center of the target area were labeled as errors; those with amplitudes less than 10° were considered undershoots; both erroneous saccades and saccadic undershoots were omitted from the analysis. These accounted for 8% of the trials.

The influence of emotional content on saccade programming was measured by two metrics (see Ludwig & Gilchrist, 2002, for details): (a) signed (negative vs. positive) *saccade endpoint deviation*, that is, the discrepancy between the actual saccade endpoint and the center of the saccade target cross; and (b) signed *saccadic*

curvature (see Figure 9). The endpoint deviation was computed as follows: First, a leftward deviation was given a negative sign, and a rightward deviation, a positive sign. To adjust for the potential effect of saccadic amplitude on the endpoint deviation, the endpoint deviations were divided by the saccade amplitude to obtain a ratio value of deviation per amplitude (see Doyle & Walker, 2001). Thus, the signed endpoint deviation represents how much and into which direction the distracter caused the saccades to deviate. The signed saccadic curvature was computed as the peak deviation of the saccade trajectory from the interpolated direct start-to-end route (see Figure 9). Saccades with a curvature to right were given a plus sign, and those with a curvature to left, a minus sign. The signed curvature measure was divided by the saccade amplitude to obtain a ratio value of curvature per unit of amplitude.

Results

The results are summarized in Figure 10. The saccadic latencies, signed endpoint deviations, and signed saccadic curvatures were subjected to a 2 (SOA: 0 ms vs. -150 ms) \times 2 (Visual field of emotional picture: left vs. right) \times 2 (Emotional content: unpleasant vs. pleasant) within-subjects ANOVA. The saccadic latencies were influenced only by SOA, $F(1, 14) = 139.00$, $p < .01$, $\eta_p^2 = .90$, with shorter latencies for -150-ms SOA than for 0-ms SOA (RTs: 218 ms vs. 290 ms, respectively). The analysis of the signed endpoint deviation yielded a main effect of the visual field of emotional picture, $F(1, 14) = 8.22$, $p = .01$, $\eta_p^2 = .35$. As expected, the saccade endpoints deviated away from the visual field in which the emotional picture was presented. Importantly, the endpoint deviations were similar for both SOAs ($F < 1$, $p = .38$) and for unpleasant and pleasant pictures ($F < 1$, $p = .40$). For the signed saccadic curvatures, none of the main effects reached significance, but the SOA \times Visual Field of Emotional Picture interaction reached significance, $F(1, 14) = 5.40$, $p = .03$, $\eta_p^2 = .26$. Multiple comparisons demonstrated that at the -150-ms SOA, the saccades curved away from the emotional scenes, $F(1, 14) = 4.32$, $p = .04$, $\eta_p^2 = .24$, whereas for the 0-ms SOA, there was no statistically significant effect of scene content ($F = 2.5$, $p = .10$).

Discussion

The results of Experiment 3 provide direct evidence that the oculomotor system is reflexively engaged by the perception of emotional content. Both the saccadic curvature and the saccade endpoint deviated away from the emotional distracter. A bulk of previous studies have demonstrated that voluntary (Rizzolatti, Riggio, & Sheliga, 1994; Sheliga, Riggio, Craighero, & Rizzolatti, 1995) and reflexive orienting of covert attention by illumination onsets (Doyle & Walker, 2001, 2002; Godijn & Theeuwes, 2004), as well as centrally presented social cues (Nummenmaa & Hietanen, 2006), can influence the curvature or endpoint deviation of reflexive and voluntary saccades. In Experiment 3, the endpoint deviation away from the emotional scene was observed at both SOAs, whereas the curvature away from the emotional scenes was observed only at the -150-ms SOA. However, although the analysis of the endpoint deviations resulted only in a main effect of the visual field of the emotional picture, an inspection of Figure 10A reveals that the effect of emotional scenes on endpoint deviation seems greater at the -150-ms SOA. Thus, the curvature and endpoint deviation results imply that the interference due to the presence of emotional pictures is slightly greater when the distracter scenes are presented 150 ms prior to the imperative signal. Prior studies measuring saccadic curvature resulting from task-irrelevant luminosity onsets have reported significant effects when the distracters have been presented with SOAs of 0 ms (Doyle & Walker, 2001, 2002, Experiment 2) and -100 ms (Doyle & Walker, 2002, Experiment 3; Godijn & Theeuwes, 2004, Experiment 1). However, as the deviation and curvature effects resulting from the emotional scenes are contingent on the somewhat time-consuming process of encoding the valence of the distracter scene, it is plausible that the more complex emotional distracter scenes produce the deviation effect with a slightly longer latency than simple luminosity onsets.

To our knowledge, Experiment 3 of the present study is the first study reporting saccade endpoint deviation and curvature resulting from a higher level representation of complex visual scenes, which implies that the perception of emotional scene content does indeed influence the oculomotor system reflexively. As the parafoveally presented, task-irrelevant emotional pictures caused saccades to deviate away from the visual hemifield in which the emotional picture appeared, the results suggest that the oculomotor system is reflexively engaged during the perception of emotional pictures. These data complement those obtained in Experiments 1 and 2 in two ways. First, as saccade endpoints deviated away from the emotional scenes when the emotional pictures were presented at locations orthogonal to the saccade target locations (i.e., participants never had to make a saccade toward the emotional picture), the results provide further evidence for the view that the findings of Experiment 2 were due to oculomotor activation instead of enhanced sensory processing of targets due to a shift of covert attention. Taken together, these data suggest that the reflexive saccade generation system is automatically engaged when emotional content is perceived in parafovea. Second, the saccadic deviation away from the distracter presumably results from an inhibition of the oculomotor response to the spatial location occupied by the distracter, which reduces the activity of neurons associated with the programming of a saccadic response toward a distracter (Godijn & Theeuwes, 2002). Accordingly, under these

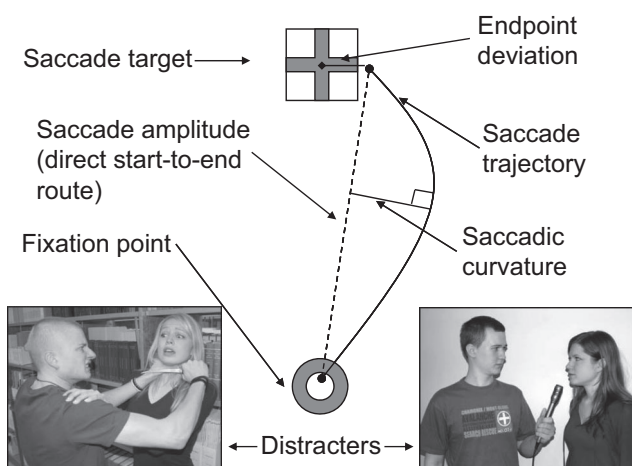


Figure 9. Graphical illustration of computing saccade endpoint deviation and saccadic curvature in a typical stimulus display in Experiment 3.

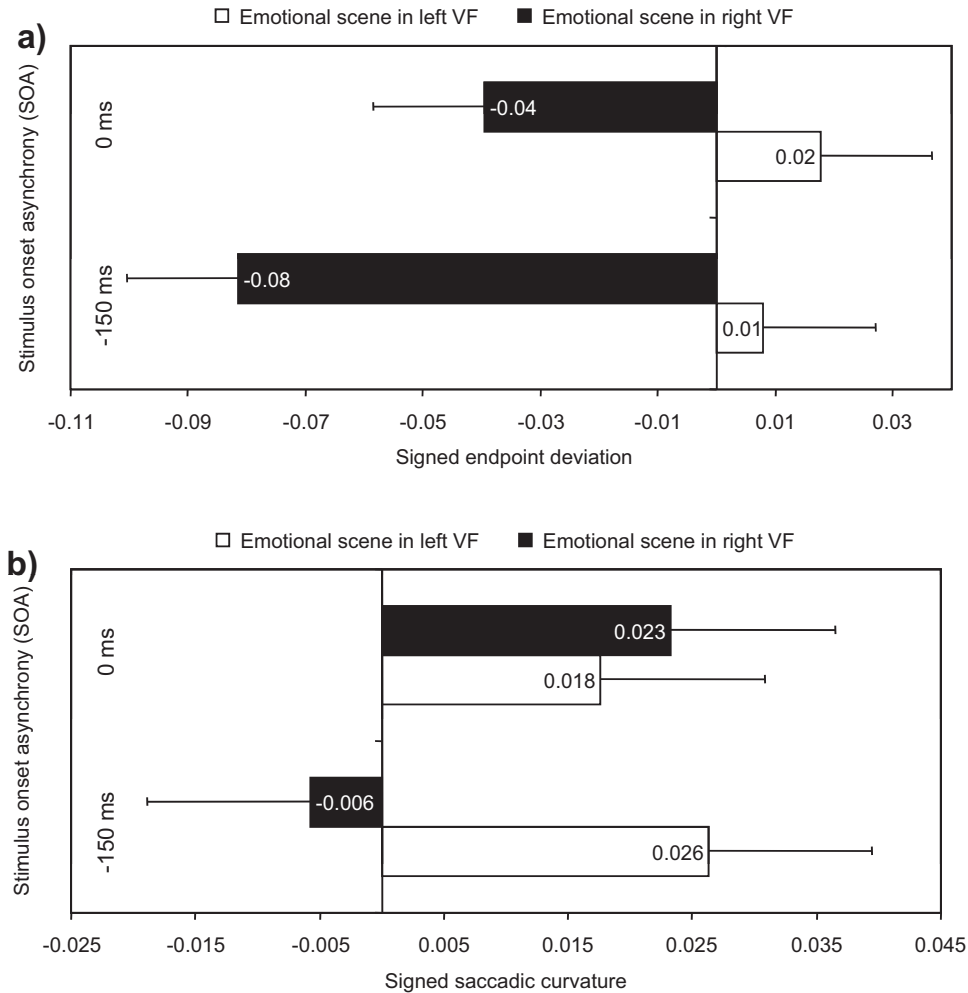


Figure 10. Means and pooled 95% confidence intervals of (A) signed saccade endpoint deviation and (B) signed saccadic curvature (in degrees per saccadic amplitude) as a function of stimulus onset asynchrony and visual field (VF) of the emotional picture, pooled across unpleasant and pleasant pictures, in Experiment 3. Negative values index deviation or curvature to left; positive values index deviation or curvature to right.

premises, the results of Experiment 3 provide strong evidence for the bottom-up nature of this phenomenon, as the emotional pictures were totally task irrelevant and did not share response compatibility with the saccade target.

Experiment 4

Although we had controlled for various low-level image statistics between the stimulus categories, this does not completely rule out the possibility of some physical image feature being responsible for the observed rapid orientation toward the emotional scenes. Namely, it is possible that each feature in isolation does not account for orienting because the visual system may combine the measured properties in a nonlinear fashion. To test this alternative, Experiment 4 combined a stimulus orientation manipulation with a computational modeling approach. First, we replicated Experiment 2 (where the largest RT effects were observed) with an additional manipulation of stimulus orientation (upright vs. inverted). Inversion interferes with object and face recognition (see, e.g., Maurer,

LeGrand, & Mondloch, 2002) but does not influence low-level image statistics. Hence, if the effects observed in Experiments 1–3 are due to emotional instead of physical characteristics, emotional scenes should trigger faster saccades in upright but not in inverted orientation.

Second, we computed stimulus-driven visual saliency maps of our stimulus displays involving one neutral and one emotional scene using the Neuromorphic Vision Toolkit (iNVT) developed by Itti and Koch (2000; see also Itti, 2006; Navalpakkam & Itti, 2005). The saliency map represents the relative visual conspicuity of the different parts of the image. Various models have proposed that saliency influences the initial shifts of covert and overt attention (see Torralba et al., 2006). Importantly, studies have shown that particularly the initial distribution of fixations on a picture is determined by the saliency weights of the different parts of the image (e.g., Parkhurst, Law, & Niebur, 2002; Underwood, Foulsham, van Loon, Humphreys, & Bloyce, 2006). Accordingly, if visual saliency is responsible for the rapid orienting responses

toward the emotional scenes, the emotional scenes should have greater saliency values than the respective neutral scenes.

Method

Participants, stimuli, and procedure. A mainly female sample of 20 students (19 women, 1 man) with a mean age of 22 years from the University of Turku participated in the experiment. The stimuli were the same as in the previous experiments with the exception that the stimuli were also presented in inverted (upside-down) orientation. The procedure was similar to that in Experiment 2 with the exception that SOA was not manipulated. Instead, we manipulated the orientation of the images (upright vs. inverted) and presented the imperative signal with a 0-ms SOA. The stimulus orientation was blocked and counterbalanced across participants, as it has been shown that parafoveal emotional processing is facilitated by prior foveal or parafoveal presentation of the emotional scenes, which allows perceptual identification and association of perceptual features with affective value (Calvo & Nummenmaa, 2007). Hence, even if emotional processing is influenced by scene inversion, seeing an image first in the upright orientation might facilitate its recognition when the image is subsequently perceived upside down (thus reducing the effects of inversion), whereas initial precept of an upside-down scene would not influence its subsequent processing in the upright orientation.

Computational modeling of visual saliency. A purely stimulus-driven saliency map was computed for each stimulus display containing an emotional and a neutral scene through the iNVT (Itti & Koch, 2000). This neuromorphic model simulates which elements (and in which order) in a given scene attract attention of human observers. Briefly, the visual input is first decomposed and processed by feature (e.g., local contrast, orientation, energy) detectors mimicking the response properties of retinal neurons, lateral geniculate nucleus, thalamus, and V1. These features are integrated for a neural saliency map, which is a graded representation of the visual conspicuity of each pixel in the image. Salient areas (or objects) thus stand out from the background and from other surrounding objects. A winner-takes-it-all (WTA) neural network determines the point of highest saliency and draws focus of attention to this point.

To allow attention to shift to the next most salient location, an inhibition of return (IOR) is triggered for the currently attended location, reducing its saliency weight and resulting in a modified

saliency map. The interplay between WTA and IOR ensures that the saliency map is scanned in order of decreasing saliency, thus simulating the temporal order of the allocation of visual attention. As applied to our stimulus displays, we computed the initial (i.e., before the first IOR) saliency map and the maximum and mean saliency values (ranging from 0 to 255) of the areas occupied by the emotional and neutral scenes.

Results

Computational model. The means and standard deviations of the maximal saliency values were as follows: pleasant scenes: $M = 218.61$, $SD = 46.25$; neutral scenes: $M = 205.86$, $SD = 56.21$; and unpleasant scenes: $M = 210.44$, $SD = 50.18$. We compared the maximal categorywise visual saliencies with a one-way ANOVA. This showed that there were no differences in the maximum visual conspicuity of the unpleasant, neutral, and pleasant scenes ($F < 1$, $p = .53$). Although the neuromorphic model (Itti & Koch, 2000) that was employed for computational modeling of visual saliency is based on the WTA principle (i.e., the maximum saliency value in the map determines where attention is allocated), we also assessed whether mean saliency of the distracter scenes would differ as a function of picture content, as this would constitute the “typical” conspicuity of a given scene. Means and standard deviations of the initial visual saliencies were as follows: unpleasant scenes: $M = 15.40$, $SD = 5.10$; neutral scenes: $M = 13.18$, $SD = 5.00$; and pleasant scenes: $M = 15.30$, $SD = 5.83$; with no statistically significant differences between stimulus categories ($F = 2.60$, $p = .11$).

Human observers. Mean saccadic RTs and the proportion of misdirected saccades (see Table 2) were subjected to a 2 (Order: inverted first vs. upright first) \times 2 (Orientation: upright vs. inverted) \times 3 (Emotional content of target area picture: unpleasant vs. neutral vs. pleasant) mixed ANOVA, with order being the only between-subjects factor. For saccadic RTs, there were main effects of orientation, $F(1, 18) = 4.74$, $p = .04$, $\eta_p^2 = .21$, and emotional content, $F(2, 36) = 15.44$, $p < .001$, $\eta_p^2 = .46$, as well as an interaction of order and emotional content, $F(2, 36) = 3.95$, $p = .04$, $\eta_p^2 = .16$ (see Figure 11). Simple effects tests revealed that for the group that saw the distracter scenes initially in an inverted orientation, there was only a main effect of orientation, $F(1, 9) = 5.70$, $p = .04$, $\eta_p^2 = .39$, with inversion slowing down the saccadic RTs (M_{inverted} : 285 ms, M_{upright} : 265 ms). Main effect of emotional

Table 2
Means and Standard Deviations of Saccadic Reaction Times and Proportion of Errors as a Function of Order of Presentation, Stimulus Valence, and Stimulus Orientation in Experiment 4

Effect	Upright first						Inverted first					
	Unpleasant		Neutral		Pleasant		Unpleasant		Neutral		Pleasant	
	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>	<i>M</i>	<i>SD</i>
Reaction time (ms)												
Upright	256	14	271	14	255	12	261	14	271	15	263	17
Inverted	268	10	284	12	253	12	289	24	288	22	278	23
Proportion of errors (%)												
Upright	8.13	3.10	18.13	2.86	6.88	1.73	12.50	3.49	21.56	4.00	6.24	2.08
Inverted	8.13	2.47	15.00	2.83	7.50	2.76	8.13	2.96	19.06	4.19	6.88	3.14

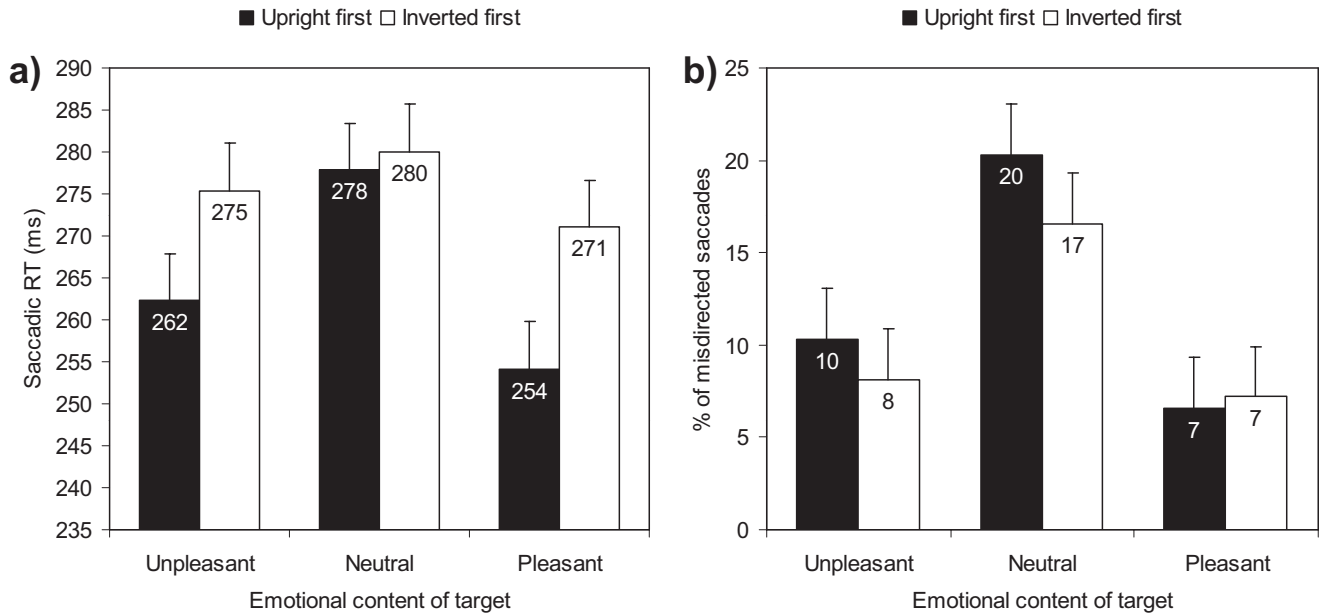


Figure 11. Means and pooled 95% confidence intervals of (A) saccadic latency and (B) proportion of errors as a function of picture orientation in the first and second blocks (upright vs. inverted scenes first) and emotional valence of the picture at the saccade target location in Experiment 4. RT = reaction time.

content did not reach significance ($F = 2.3, p = .16$), although there was a numerical trend for shorter saccade latencies toward the unpleasant and pleasant versus neutral upright scenes (see Table 2).

For the group that saw the scenes initially in an upright orientation, there was a main effect of emotional content, $F(2, 18) = 15.84, p < .001, \eta_p^2 = .64$. Planned comparisons revealed that saccadic RTs were faster when the imperative signal pointed toward unpleasant, $F(1, 9) = 28.20, p < .001, \eta_p^2 = .76$, or pleasant, $F(1, 9) = 21.99, p < .001, \eta_p^2 = .71$, versus neutral pictures. For the proportion of misdirected saccades, the ANOVA yielded only a significant main effect of emotional content, $F(2, 36) = 4.42, p = .05, \eta_p^2 = .21$, with more errors being made when the imperative signal pointed toward neutral than toward unpleasant, $F(1, 18) = 52.92, p < .001, \eta_p^2 = .74$, or pleasant, $F(1, 18) = 55.44, p < .001, \eta_p^2 = .75$, scenes. It was further verified that the inverted emotional scenes influenced the error rates when the inverted scenes were presented initially or after an upright presentation ($F_s > 3.6, p_s < .05, \eta_p^2_s = .28$).

Discussion

The results of Experiment 4 suggest that visual confounds cannot explain the rapid attentional orienting toward emotional scenes, as the influence of emotional content on the saccadic RTs was contingent on the orientation and order (upright first vs. inverted first) of the stimulus presentation. No emotional content effects were observed when the scenes were initially presented in an inverted orientation. However, emotional content of the distracter scenes influenced saccadic RTs when (a) the participants saw the scenes initially in an upright orientation and (b) they subsequently saw the scenes in an inverted orientation. As in Experiments 1 and 2, the saccades were faster when the imperative

signal pointed toward the emotional scenes. This finding is in line with the results of Calvo and Nummenmaa (2007), who showed that repeated exposures facilitate encoding of emotional valence of scenes perceived in the parafoveal vision. Our data extend those of Calvo and Nummenmaa by showing that once the emotional valence of an upright scene has been initially assessed, this can facilitate the affective processing of the corresponding scene even when it is presented upside down. Thus, it is likely that some relatively low-level (or gist-level) visual features are initially associated with the affective valence of a scene, and subsequent detection of these features serves as a shortcut for detecting the emotional valence and programming of eye movements toward the scene even when its processing is disrupted by inversion.

There were no differences in the computationally modeled visual saliency between the unpleasant, neutral, and pleasant scenes. This evidence should be interpreted with some caution, as it is essentially based on lack of observable differences in the visual saliency of the different stimulus categories. The computational model (iNVT) is not a perfect representation of the human visual system, and it is possible that it does not capture some visual feature combinations that could be crucial for the rapid orienting toward certain scenes. It is nevertheless important to note that the *lack* of visual saliency differences occurred in the *presence* of observed differences in human observers' saccadic latencies toward emotional versus neutral scenes. Hence, this is not merely a null finding in absolute, noninformative terms. Additionally, the neuromorphic model used for computing the saliency weights predicts purely stimulus-driven shifts of visuospatial attention remarkably well (see review in Itti & Koch, 2000). Furthermore, this model has been successfully applied to predict human observers' initial orienting of overt attention (i.e., first fixation probability and localization times) to emotional facial expressions as a function of

differences in visual saliency of target faces in a visual search task (Calvo & Nummenmaa, 2008). Accordingly, its complete failure to account for the rapid orienting (and error rates; see below) toward emotional scenes in the current study supports our argument that the rapid eye movement programming toward emotional scenes cannot be explained by merely visual differences between the scene categories.

Nevertheless, it is slightly surprising that scene inversion did not have a statistically significant effect on the error rates. This implies that visual factors could, after all, contribute at least partially to our effects—mainly for those associated with erroneous saccades—although it must be stressed that the data from Experiment 4 show that emotional valence must make a unique contribution as well, as evidenced by the effects of inversion and presentation order on saccadic latencies toward unpleasant and pleasant scenes. It is noteworthy that inversion only disrupts, but does not completely abolish, various face and object recognition processes (Maurer et al., 2002). As our distracter stimuli depicted various complex affective and neutral scenes, it is of particular interest that scene inversion has been found to result in no penalties (Wright & Roberts, 1996) or in penalties that are substantially smaller than those resulting from face inversion (Yin, 1969). Although all the emotional and neutral distracter scenes contained humans, this does not necessitate that the encoding of their affective valence would be contingent on the visual stream dedicated to facial expression perception, especially because the faces in some of the pleasant (e.g., romantic couples with faces occluded) and unpleasant (e.g., dead or mutilated bodies) scenes did not convey facial expressions at all. It is thus possible that some affective features of the inverted scenes that are not contingent on face-specific processing may have been recognized by similar inversion-insensitive neural mechanisms that encode scenes in general, and the affective valence associated with these features would have subsequently been retrieved from the long-term memory (cf. Calvo & Nummenmaa, 2007) to facilitate rapid orienting. Such partial reliance on the neurocognitive mechanisms for scene perception could thus provide a possible explanation for the lack of inversion effects in error rates.

General Discussion

The present set of experiments was aimed to study how emotional scene content influences early programming and execution of saccadic eye movements. Although previous studies of the effects of scene content on eye movement behavior have relied on the manipulation of the relationship (e.g., semantic congruency) of the target object and the scene background, our methodology involved a simultaneous presentation of two complex scenes that served as distracters to the primary saccade task. In four experiments, participants performed voluntary (Experiment 1) or reflexive (Experiments 2 and 4) saccades toward the location of emotional or neutral distracter pictures or toward a location that was never occupied by the distracter pictures (Experiment 3). The pictures were located in parafoveal and peripheral vision with their inner edges 2.5° away from a central fixation point. The results of the four studies showed that perception of emotional visual content in parafoveal–peripheral vision influences both the reflexive and the voluntary saccade generation systems. In Experiments 1 and 2, voluntary and reflexive saccades were initiated faster toward the

location of emotional pictures than toward that of neutral, simultaneously presented pictures. In addition, in Experiment 3, saccades executed orthogonally to the emotional and neutral picture locations deviated away from the visual field in which the emotional picture appeared. In Experiment 4, the RT advantage for saccades made toward emotional scenes disappeared when the scenes were inverted, essentially ruling out the influence of low-level visual features.

Effective visual perception relies on the visual system's ability to acquire detailed information from the environment. As the region of the foveal field of vision is small (around 2°; see Wandell, 1995), this system must be complemented by a perceptual mechanism that uses parafoveally and peripherally perceived scene content to determine where to guide the foveal fixations. Models of scene perception assume that upon encountering a novel scene, the initial distribution of fixations is determined by physical rather than semantic factors (Henderson et al., 1999). Our findings suggest that high-level semantic information (emotional valence) can be acquired via the magnocellular, rod-based mechanisms, and this information is subsequently used to generate saccades reflexively toward the emotional scenes. We next discuss the implications of the findings regarding (a) reflexive guidance of eye movements by emotional content and (b) the neural systems involved in programming eye movements toward emotional scenes.

Reflexive Saccade Guidance by Emotional Content

From an evolutionary viewpoint, it makes sense to assume that the cognitive system is supported by attentional mechanisms that facilitate the processing of semantically highly salient and novel information even when it is perceived outside foveal vision. Previous studies have shown that emotional valence of scenes can be detected (Bradley, Mogg, Falla, & Hamilton, 1998; Calvo & Lang, 2004; Mogg & Bradley, 1999; Nummenmaa et al., 2006) and even discriminated (e.g., pleasant vs. unpleasant; Calvo & Nummenmaa, 2007) from the parafovea. Eye-tracking studies have also demonstrated a voluntary and an involuntary attentional bias toward emotional pictures of both pleasant and unpleasant valence (Calvo & Lang, 2004; Nummenmaa et al., 2006). The current study extends these findings by demonstrating that the bias is not only due to bias in attentional selection. Instead, it results from automatic programming and execution of saccades toward the parafoveally perceived emotional scenes.

In Experiments 1, 2, and 4, emotional and neutral pictures were presented simultaneously to saccade target areas in parafoveal and peripheral vision. As the low-level visual features of the different picture categories were equated, the emotional content of the pictures is a relevant candidate that can account for the differences in the saccadic RTs and the number of misdirected saccades. In Experiments 1 and 2, saccadic RTs were faster when the imperative signal pointed (endogenously or exogenously) toward an emotional picture than when it pointed toward a concurrent neutral picture. In Experiment 4, this effect was observed only when the scenes were presented initially in an upright orientation. This suggests that the perception of emotional content triggered a saccade program that facilitated the execution of a task-appropriate saccade but interfered with the execution of a task-inappropriate saccade.

The proportion of misdirected saccades in Experiments 1 and 2 showed a consistently similar pattern. Participants made more erroneously directed saccades when the imperative signal pointed toward a neutral picture (i.e., participants fixated the emotional picture) than when it pointed toward an emotional picture (i.e., they fixated the neutral picture). This effect was especially robust in Experiment 2, in which participants performed reflexive saccades toward luminosity onsets appearing abruptly to the visual periphery. Nevertheless, we acknowledge that the error rates were not influenced by the inversion of the scenes in Experiment 4; thus we cannot completely rule out the possibility that visual factors could contribute to the orienting effects to some extent. However, the effects of inversion on saccadic RTs in Experiment 4 show that the emotional scene content must have a unique, strong contribution to the saccade programming.

The present findings thus indicate that emotional meaning of parafoveally or peripherally perceived scenes can govern the saccade generation systems in an automatic fashion. This is in line with the findings demonstrating an effect of parafoveally or peripherally perceived semantic scene content on eye movement guidance (Becker et al., 2007; Loftus & Mackworth, 1978; Underwood, 2005). However, these studies have only reported the time taken to land a fixation (not necessarily the first one) on an anomalous object. Thus they only provide data on saccade target selection in the later stages of scene perception, that is, when the participants may have already sampled various scene regions by means of foveal vision. Our data go one step further by demonstrating that parafoveal perception of an emotional scene can trigger a reflexive saccade toward the scene (in the case of erroneous saccades) or influence the latency of the initial (correct) saccade. This indicates that the semantic scene content can influence the programming of even the very first saccade made to the scene (see also De Graef, 2005), which further implies that semantic content is extracted before the scene is fixated. This is consistent with Calvo and Lang's (2005) findings that semantic analysis of emotional scenes can begin in parafoveal vision in advance of foveal fixation. Accordingly, this suggests that the models of eye movement guidance during scene perception must be accommodated to account for the early eye movement guidance by semantic content: Even during the initial fixation on a scene, semantic representations of the parafoveal-peripheral scene content are acquired alongside the low-level physical information of the scene structure. Thus both purely physical or visual saliency and "semantic saliency" are rapidly integrated into the topographical master saliency map for determining where the eyes will be moved.

It must nevertheless be noted that our data do not imply that emotional scene content is analyzed without attention. The current paradigms allowed for covert attention to the scenes, although overt attention was generally (i.e., prior to the task-instructed saccade) restricted. It is likely that the scenes were covertly attended and that the advantage of emotional scenes in saccade latencies resulted from their prioritized processing by covert attention. Therefore, our findings do not stand in conflict with the view (Calvo & Nummenmaa, 2007) that parafoveally perceived emotional scenes must be attended—either covertly or overtly—in order to encode their affective valence.

Programming Reflexive Eye Movements Toward Emotional Scenes

How does the saccade goal specified by the imperative signal interact with the emotional content of the scenes? The models based on the WTA principle of saccade generation (e.g., Findlay & Walker, 1999; Trappenberg, Dorris, Munoz, & Klein, 2001) assume that saccades are programmed in a serial manner, with the saccade always being programmed toward the target with the highest visual or behavioral salience. Alternatively, the models based on competitive integration (e.g., Godijn & Theeuwes, 2002) suggest that exogenous and endogenous saccades compete on a common topographical neural map that defines the saccade goal (see also Walker & McSorley, 2006, for recent evidence). The present results of Experiments 1 and 2 are consistent with the competitive integration model. In Experiment 1, the endogenous (color of the imperative signal) and exogenous (emotional picture) saccade cues resulted in additive, facilitative effects on saccadic RTs, when both cues pointed toward the *same* direction. If reflexive and voluntary saccades are programmed in parallel in the same neural map, the combined activation peaks in the map resulting from the emotional picture and the endogenous cue pointing toward the emotional picture will reach the threshold for saccade initiation quickly. On the contrary, when the endogenous cue points *away* from the emotional picture, the activation related to these two locations (i.e., one indicated by the cue, another by the presence of an emotional scene) would inhibit each other, thus slowing down the initiation of the task-appropriate saccade.

Similarly, the lateral inhibition of the saccade toward the location of the emotional picture and the subsequent endpoint deviation observed in Experiment 3 are in line with the predictions of the competitive integration model: As the participants never had to make a saccade toward the emotional scenes, the peak in the topographical map resulting from the emotional scene must be inhibited. Due to overinhibition, the neurons coding saccades away from the emotional scene become relatively more active, thus resulting in a deviation away from the emotional scene. In sum, the faster saccadic responses toward emotional scenes in Experiments 1, 2, and 4 result from an activation peak in the topographical saccade target map caused by the emotional scene; in Experiment 3, an overinhibition of this saccade goal brings about a deviation away from the emotional distracter.

A further important question is how the visual system is able to rapidly categorize the stimuli as emotional versus neutral and initiate a reflexive saccade program toward an emotional target picture. The FEF and IPS are considered as the core systems responsible for saccade target selection (Dietrich & Brandt, 2000; Grosbras et al., 2005); the projections from the FEF and IPS to the SC contribute to determining the saccade goal. The voluntary saccade task (Experiment 1) most likely involves the FEF and IPS, whereas the FEF is not involved in the reflexive task-instructed saccades in Experiments 2 and 3. As Experiments 2 and 3 demonstrate that emotional scene content also influences RTs (Experiment 2) and endpoint deviation (Experiment 3) of reflexive saccades (not involving FEF), a potential explanation is that the interference caused by the emotional pictures could occur at IPS, as it is involved in generating both reflexive and voluntary saccades.

The effect of emotional scene content on saccade RTs and endpoint deviations observed in the present study must be contingent on the recognition of emotional valence. Kirchner and Thorpe (2006) have demonstrated that when saccadic responses are made in a visual categorization task (animal vs. no animal) with peripherally presented pictures, the responses can be initiated in less than 120 ms (although the reported median RT was 228 ms). This voluntary saccade task is assumed to involve the ventral visual pathway. Both FEF and IPS receive substantial input from numerous areas of the ventral visual pathway involved in object recognition, and Kirchner and Thorpe have suggested that the cortical eye fields accumulate evidence from ventral stream areas to determine where the saccade should be launched. This account could probably explain our findings as well, although the extrageniculostriate pathway involving the SC, pulvinar thalamus, and amygdala (involved in emotional face perception; Morris, Öhman, & Dolan, 1999) has also been implicated in the early encoding of the emotional valence of the scenes.

Although emotional content (neutral vs. aversive) of visual scenes can modulate intracranially measured amygdala responses as early as 50–150 ms from stimulus onset (Oya, Kawasaki, Howard, & Adolphs, 2002), emotional modulation of the activity of the ventromedial prefrontal cortex has also been observed within a similar time window (120–160 ms; Kawasaki et al., 2001). However, scalp potentials differentiate between emotional (unpleasant and pleasant) and neutral pictorial scenes as late as around 250 ms (Junghöfer et al., 2001) or 500 ms (Keil et al., 2001). As saccade latencies in the 150-ms SOA condition of Experiment 1 were relatively short ($M = 348$ ms), leaving about 200 ms for emotional content to affect saccade programming, the cortical differentiation (as measured by scalp electrodes) between emotional and neutral scenes seems to occur too late to account for the observed effects of the emotional scenes on saccadic RT. It is therefore likely that the latency of emotional versus neutral differentiation reported by the extracranial ERP studies is an overestimate of the cortical latency of emotional scene processing. ERP studies using facial stimuli show differentiation between liked and disliked faces (Pizzagalli et al., 2002) as well as emotional versus neutral facial expressions (Eger et al., 2003; Pourtois, Thut, et al., 2005) around 120 ms from stimulus onset. This latency range is more in line with that obtained in the current study. As all our distracter scenes involved humans, it is reasonable to assume that the cortex can differentiate emotional valence of complex visual scenes in less than 200 ms, at least when the scenes involve human bodies and faces.

The current data, however, cannot answer why the emotional scenes are semantically salient and prone to trigger reflexive eye movements. Although the idea that the scenes contain phylogenetically relevant material that is processed by specialized neural systems is intuitively appealing, it is also plausible that long-term learning of affective associations with the pictorial scenes is responsible for the effect. In other words, it is possible that long- and medium-term adaptation processes can modify the saliency representation of images and their features. In accordance with this, it has been shown that stimuli with intrinsic or biological (e.g., snakes) and learned (e.g., guns or syringes) affective values are detected equally fast among distracters in a visual search task (Blanchette, 2006).

Conclusions

Taken together, our data demonstrate that semantic saliency weights are elevated for complex pictorial scenes conveying emotional meaning, which results in rapid eye movement responses toward such stimuli, in comparison with neutral scenes. These responses are automatic, and they can even override a reflexive saccade program resulting from a sudden illumination change in the visual environment. In addition, our data suggest that parafoveally encoded semantic content is capable of influencing eye movement guidance to a greater extent than has been thought. However, as emotional content of stimuli may be detected by specialized cortical and subcortical neural systems (Vuilleumier, 2005), our results might be restricted to this special content class of stimuli. It should also be noted that we do not argue that specific semantic content is necessarily extracted from emotional pictures. Instead, our contention is that observers can readily perceive the gist of the scenes, that is, whether or not a scene contains emotionally arousing (something good or bad for well-being) material. The current findings do suggest, however, that emotional valence of complex pictorial scenes is automatically analyzed even from outside the focus of overt attention and that this semantic information is used to guide the eyes in a reflexive fashion.

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Appendix

The International Affective Picture System (IAPS) Numbers for the Stimulus Pictures

Neutral pictures: 2037, 2102, 2190, 2191, 2191.1, 2200, 2220, 2221, 2270, 2272, 2272.1, 2305, 2312, 2312.1, 2357, 2372, 2383, 2389, 2393, 2393.1, 2394, 2396, 2397, 2397.1, 2410, 2491, 2493, 2512, 2513, 2513.1, 2515, 2560, 2560.1, 2575, 2575.1, 2579, 2593, 2593.1, 2594, 2594.1, 2595, 2595.1, 2598, 2598.1, 2635, 2635.1, 2745.1, 2745.2, 2749, 2749.1, 2840, 2850, 2870, 5410, 7493, 7496, 7496.1, 7550, 7550.1, 7620, 7620.1, 9070, 9210, and 9210.1. *Unpleasant pictures:* 2399, 2399.1, 2683, 2691, 2703, 2716, 2718, 2722, 2799, 2800, 2811, 2900, 3051, 3180, 3181, 3225, 3300, 3350, 6010, 6250, 6313, 6315, 6550, 6560, 8480, 8485, 9250, 9254, 9410, 9415, 9423, and 9435. *Pleasant pictures:* 2040, 2070, 2160, 2165, 2311, 2332, 2352, 2540, 2550, 4599, 4610, 4624, 4647, 4658, 4660, 4669, 4676, 4680, 4687, 4694, 4700, 5621, 5831, 5836, 7325, 8021, 8080, 8161, 8186, 8200, 8490, and 8499.

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