

Scan patterns when viewing natural scenes: Emotion, complexity, and repetition

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Abstract

Eye movements were monitored during picture viewing, and effects of hedonic content, perceptual composition, and repetition on scanning assessed. In Experiment 1, emotional and neutral pictures that were figure-ground compositions or more complex scenes were presented for a 6-s free viewing period. Viewing emotional pictures or complex scenes prompted more fixations and broader scanning of the visual array, compared to neutral pictures or simple figure-ground compositions. Effects of emotion and composition were independent, supporting the hypothesis that these oculomotor indices reflect enhanced information seeking. Experiment 2 tested an orienting hypothesis by repeatedly presenting the same pictures. Although repetition altered specific scan patterns, emotional, compared to neutral, picture viewing continued to prompt oculomotor differences, suggesting that motivationally relevant cues enhance information seeking in appetitive and defensive contexts.

Descriptors: Emotion, Oculomotor, Normal volunteers, Eye movements, Orienting

For the highly visual human, sensory cues that warn of danger or signal the possibility of reward are often first accessed through vision. During visual exploration, the eye moves in discrete steps, fixating for a period of time before moving to another spatial location. Both sensory information and semantic/task relevance can affect the nature, duration, and temporal dynamics of eye movement behavior during scene perception (e.g., Castelano, Mack, & Henderson, 2009; Einhäuser, Rutishauser, & Koch, 2008; Itti & Koch, 2001; Unema, Pannasch, Joos, & Velichkovsky, 2005). In two studies, we explored effects of hedonic content, perceptual composition, and repetition in a free viewing task on eye movements when viewing affective and neutral pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008).

Previous studies have outlined differences in autonomic, somatic, and neural activity when viewing these emotionally engaging cues (e.g., Lang, Greenwald, Bradley, & Hamm, 1993; see Lang & Bradley, 2010, for an overview). The goal of the current study is to provide a qualitative and quantitative description of scanning behavior when healthy people look at a sample of emotional and neutral pictures in the IAPS (Lang et al., 2008) in order to (a) elucidate how perceptual and memorial factors affect eye movements when viewing affective pictures; and (b) provide a foundation database for studying eye move-

ments during affective picture viewing in studies that explore effects of psychopathological, neurological, and other individual differences in emotionality.

Although the pattern of eye movements during visual perception is highly stereotypical, with periods of repose (fixations) interspersed with rapid movement (saccades), eye movement activity is affected by the type of visual stimulus as well as by its semantic relevance. For instance, Henderson and Hollingworth (1999) found longer fixation durations as well as greater saccade lengths when participants viewed scenes, compared to reading. Not surprisingly, eye movements are also influenced by sensory features of the visual array, including contrast, edges, complexity, etc. (e.g., Itti & Koch, 2001; Parkhurst, Law, & Niebur, 2002; Peters, Iyer, Itti, & Koch, 2005). Nonetheless, the importance of perceptual information in understanding a scene strongly affects eye movement behavior as well (e.g., Loftus and Mackworth, 1978). For instance, Henderson, Weeks, and Hollingworth (1999; see also Henderson & Hollingworth, 1999) presented line drawings of real-world scenes, varying whether the same object was consistent (e.g., uninformative) or inconsistent (e.g., informative) in different scenes. When an object was informative, it received more fixations than if it was not informative. Moreover, when participants are instructed to view a natural scene in anticipation of a later memory test, saccade length increases, compared to target search, suggesting a broader scan of the visual image when the entire image is the focus of processing (Castelano et al., 2009).

We have hypothesized that emotionally engaging cues activate primary motivational systems, implemented in appetitive and defensive neural circuits that direct attention to the eliciting cue, engage sensory processing, and arouse the organism to action

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(e.g., Lang, Bradley, & Cuthbert, 1997). In particular, we have suggested that affective cues engage natural selective attention (Bradley, 2009), in which activation of appetitive or defensive motivational systems reflexively enhances information intake, as evidenced by heightened cardiac deceleration and other indices of orienting and attention. Eye movements represent a sensitive measure of information intake during visual perception, as the sensory information available for further processing is almost solely determined by eye fixations, their duration, and their extent.

Thus, in two experiments, eye movements were measured throughout a sustained (6-s) interval in which participants viewed emotional (pleasant or unpleasant) and neutral pictures. In addition to hedonic content, Experiment 1 manipulated the perceptual composition of natural scenes by presenting pictures that depicted either simple figure-ground compositions or more complex scenes. We expected that perceptual complexity would affect eye movements, based on the amount and spatial distribution of information in the picture. Nonetheless, because indices of emotional engagement are similar regardless of whether a picture depicts a figure-ground composition or a more complex scene (Bradley, Hamby, Löw, & Lang, 2007), we expected to find effects of emotionality regardless of perceptual composition if emotion affects eye movements. In both experiments, participants were instructed to simply look at each picture while it was on the screen. A free viewing context is optimal not only because it most closely mimics the mode in which visual images are often viewed, but also because specific tasks and instructions can alter eye movements to meet specific goals (e.g., visual search; Einhäuser, Rutishauser, & Koch, 2008).

Among the dependent measures that we assessed were the number of discrete fixations during picture viewing and the total scan path, defined as the sum of the lengths of the distance between successive fixations. Together, these two indices characterize the amount and breadth of information intake from a visual array. Based on studies showing that important or informative cues elicit a greater number of fixations, we hypothesized that emotional pictures would prompt a greater number of fixations than neutral pictures. If more information is also sought from the visual array, we expected longer scan paths for emotional, compared to neutral, pictures. Although complex visual scenes were expected to be associated with an increase in the number of fixations and total scan path, if emotion alone similarly heightens scanning behavior, a main effect of emotion was also expected.

We also assessed the temporal dynamics of eye movements, measuring the duration of fixations and the distance between fixations (termed “saccade length or amplitude”) as these measures varied across the viewing interval. Using a relatively long (20-s) free viewing interval, Unema et al. (2005) found that fixation duration slows across the viewing interval, and that saccade length decreases—scan patterns that are consistent with Buswell’s (1935) original observation that fixations are initially rapid and broadly distributed, but slow and narrow later in the viewing interval as interesting information is identified and processed. Unema et al. (2005) included a measure of perceptual complexity (e.g., 8 or 16 objects depicted in the scene), finding that pictures with a greater number of objects generally shortened fixation durations. Assuming that complex natural scenes similarly include more information than figure-ground compositions, we expected shorter fixation durations when viewing complex scenes, compared to simple figure-ground compositions.

Eye movements are a key component of orienting to novel visual stimuli in primates, including humans, for whom visual stimulation is central. To the extent that specific scan patterns or eye movement indices primarily reflect initial orienting to novel stimulation, we expected to attenuate effects when pictures were no longer novel. Thus, in Experiment 2, we presented emotional and neutral pictures that were either novel or repeated. Effects of emotion that primarily reflect heightened initial orienting to novel stimulation are expected to be attenuated or eliminated with repetition. On the other hand, several indices of affective engagement persist following picture repetition, including modulation of the late positive potential and the startle reflex (Bradley, Lang, & Cuthbert, 1993; Ferrari, Bradley, Codispoti, & Lang, 2011). To the extent that specific eye movement differences reflect motivational significance, independent of novelty, effects of emotion should persist.

Experiment 1

Method

Participants. Twenty-four participants (13 male) from a University of Florida General Psychology course signed a consent form and participated for course credit.

Materials and design. Stimuli were 192 color photographs selected from IAPS¹ (Lang et al., 2008) to include 64 pleasant, 64 neutral, and 64 unpleasant pictures. Half of the pictures (i.e., $n = 32$) of each hedonic content depicted relatively simple figure-ground compositions, defined as a picture with a focal figure and a constant or uniform background, and half depicted more complex scenes, which included multiple objects and a varied background. Differences in perceptual composition were validated by the ratings of an independent group of participants who rated each picture using a 0–9 point scale in which “figure-ground” or “scene” were the anchors. Mean rated composition for figure-ground compositions was 1.52, and for scenes, 5.14. Mean pleasure and arousal ratings were equated for figure-ground compositions and scenes (see Bradley et al., 2007, for more details). Pictures were arranged in blocks of six, with two pictures of each hedonic content and three depicting either figure-ground or scene composition in each block. Pictures were viewed in one of two different orders in which a specific picture was viewed in either the first or the second half of the study, across orders.

Each trial consisted of a 6-s picture viewing period, and a 2.5-s interpicture interval. A central fixation cross was on the screen

1. IAPS pictures were: Figure-Ground: Pleasant: 1500, 1610, 2304, 2510, 2650, 4608, 4640, 4651, 4653, 5000, 5030, 5300, 5480, 5890, 7260, 7270, 7330, 7352, 7400, 7460, 7470, 8041, 8120, 8161, 8200, 8280, 8300, 8320, 8330, 8465, 8502, 8531. Neutral: 2190, 2200, 2210, 2214, 2215, 2221, 2230, 2270, 2271, 2280, 2440, 2495, 2516, 2570, 2810, 2830, 6150, 7010, 7100, 7110, 7130, 7140, 7150, 7175, 7190, 7211, 7224, 7233, 7235, 7490, 7705, 7950. Unpleasant: 1050, 1120, 1300, 1930, 2120, 2520, 2800, 3030, 3100, 3168, 3170, 3181, 3266, 3400, 3550, 5970, 6020, 6230, 6250, 6260, 6300, 6370, 9006, 9008, 9010, 9180, 9405, 9432, 9440, 9560, 9561, 9800. Scenes: Pleasant: 1340, 1850, 1920, 2208, 2501, 2560, 2791, 4617, 4666, 4681, 4687, 5200, 5600, 5621, 5779, 7280, 7282, 7284, 7286, 7289, 7350, 7481, 8080, 8090, 8116, 8162, 8180, 8370, 8380, 8400, 8420, 8510. Neutral: 2206, 2381, 2383, 2410, 2480, 2514, 2518, 2580, 2749, 2752, 2850, 2870, 3210, 5120, 5395, 5455, 5731, 6000, 7180, 7205, 7234, 7495, 7496, 7500, 7510, 7550, 7560, 7590, 7595, 7700, 9210, 9700. Unpleasant: 1051, 1280, 1303, 2205, 2590, 2691, 2730, 3015, 3064, 3500, 3530, 5971, 6211, 6212, 6821, 6830, 6831, 6838, 7380, 9001, 9090, 9102, 9181, 9252, 9290, 9300, 9470, 9480, 9592, 9611, 9912, 9921.

during the interpicture interval, and participants were instructed to look at the central fixation cross whenever a picture was not on the screen.

Pictures were displayed using a LCD projector on a 127 (50 in) \times 95.5 (37.5 in) cm screen at a distance of 250 cm (98 in) from where the subject was seated, subtending $28^\circ \times 22^\circ$ of visual angle.

Eye movements were recorded using an ASL model 504 eye-tracker system (Applied Science Laboratories, Bedford, MA), which allows free movement of the head, and consists of a video camera and an infrared light source pointed at the participant's right eye. A magnetic sensor, attached to a headband, tracked and adjusted for head movement. The recording video camera was located in a box in front of the subject covered by a red translucent screen that obscured it from view. Eye position was sampled at 60 Hz for 2 s prior to picture onset and for 6 s following picture onset; spatial resolution was approximately $.25^\circ$ and accuracy 1° .

Procedure. Upon arrival at the laboratory, each participant signed a consent form and was seated in a small, sound-attenuated, dimly lit room. The eye tracking headband was attached, and eye movements were calibrated using a procedure that requested that the participant fixate a series of 9 dots arrayed in different spatial locations. Following calibration, each participant was instructed that a series of pictures would be displayed and that each picture should be viewed the entire time it was on the screen. Following a few practice trials, the set of pictures was presented. The experimenter subsequently debriefed and paid the participant.

Data reduction. For each trial, fixations were determined using ASL Eysenal software in which a fixation was defined as the eye remaining within 1° of visual angle for at least 100 ms. Figure 1 illustrates the number of fixations identified over all trials and participants from the 2 s preceding picture onset to 6 s following picture onset. A clear increase in the number of fixations occurs around 225 ms after picture onset. Accordingly, picture fixations included those occurring from 225 ms postpicture onset to those that began prior to picture offset. For each trial, the reduction software output the number of fixations, the duration of each

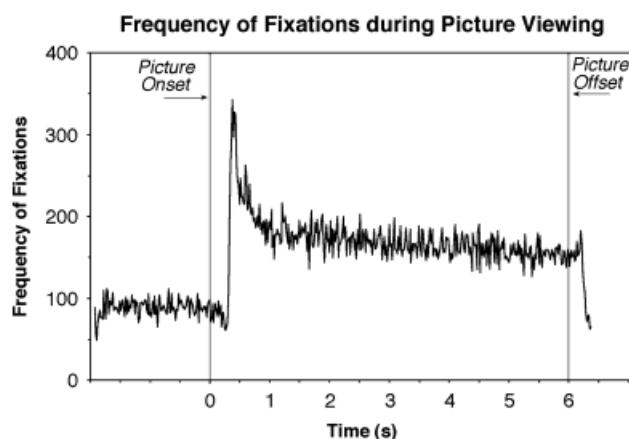


Figure 1. A histogram illustrating the number of fixations occurring at each sampling point (60 Hz) across all participants and trials from 2 s before picture onset to 6 s after picture onset illustrates the time-locked increase in eye movements approximately 225 ms after picture onset, Experiment 1.

fixation, and the distance (in degree of visual angle) between successive fixations (i.e., saccade length). Dependent measures using all of the data from each trial included (a) the number of fixations; and (b) total scan path,² defined as the sum of individual saccade lengths in degrees. For each of these measures, multivariate analyses (Wilks' lambda) that included hedonic content (pleasant, neutral, unpleasant) and perceptual composition (figure-ground, scene) as repeated measures were conducted; reported effect sizes are η_p^2 (partial eta squared).

To assess the temporal dynamics of eye movement behavior, fixation duration and saccade length across the viewing interval were analyzed. Because not all participants made an equivalent number of eye movements on each trial, these analyses included the first 10 fixations/saccades for each subject and each picture content. Based on the raw data for each measure, the data were smoothed by averaging adjacent samples between end points.³

To additionally determine whether emotionality affects eye tracking measures, we conducted ANOVAs using the picture as the unit of analysis, and assessed effects due to rated emotional arousal (from the IAPS, Lang et al., 2008) after effects due to brightness, contrast, spatial frequency, and rated perceptual composition were removed. In these analyses, brightness was defined as the mean RGB (red green blue) value for each pixel, averaged across all pixels. For contrast, the standard deviation of the mean RGB values was computed across pixels for each column, and the standard deviation of these was used as an index of contrast. For spatial frequency, the frequency of the median fast Fourier transform power was determined for each row and column in the image and then averaged. For rated perceptual composition, an independent group of participants rated each picture using a 0–9 point scale in which “figure-ground” and “scene” were anchors. Ratings of emotional arousal were from the IAPS (Lang et al., 2008).

Results

Number of fixations. As illustrated in Figure 2, and as expected, more complex scenes elicited more discrete fixations than simple figure-ground compositions, $F(1,23) = 40.5$, $p < .0001$, $\eta_p^2 = .64$.⁴ More importantly, hedonic content, $F(2,22) = 22$, $p < .0001$, $\eta_p^2 = .67$, also affected the number of fixations (see Figure 2). Emotionally engaging pictures—whether pleasant or unpleasant—elicited more discrete fixations than did neutral pictures, quadratic $F(1,23) = 44.3$, $p < .0001$, $\eta_p^2 = .66$; pleasant vs. neutral, $F(1,23) = 41$, $p < .0001$, $\eta_p^2 = .64$; unpleasant vs. neutral, $F(1,23) = 33.4$, $p < .0001$, $\eta_p^2 = .59$. Pleasant and unpleasant pictures did not significantly differ in the number of

2. Total scan path could be a misleading index of the breadth of scanning if, for instance, a participant only viewed two distant points successively. Following Castelano et al. (2009), an additional measure of spatial dispersion was computed in which the percentage of the picture in the field of view across the entire viewing interval was estimated by placing a circular filter with a 13° radius (to approximate the information available to the macula) over each fixation and summing the areas on each trial. Results were identical to those reported here for total scan path. Moreover, using narrower (3° or 1°) filters also produced identical results.

3. Statistical analyses and figures using all 10 fixations/saccades were similar in all respects to those conducted following smoothing.

4. The latency of the first fixation (mean = 393 ms) did not differ as a function of hedonic content or complexity, either when using only fixations that began after 225 ms or when using all fixations (e.g., 0 ms postpicture).

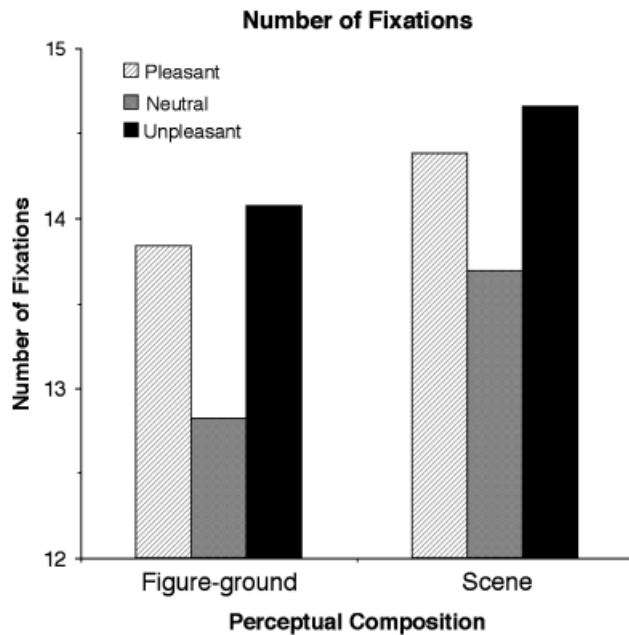


Figure 2. Emotional (pleasant or unpleasant) pictures prompt more eye fixations during picture viewing than neutral pictures for both simple figure-ground compositions and for more complex scenes, Experiment 1.

fixations. Emotional pictures prompted more fixations than neutral pictures whether pictures comprised figure-ground compositions, $F(2,22) = 13.5$, $p < .0001$, $\eta_p^2 = .55$, quadratic $F(1,23) = 27.6$, $\eta_p^2 = .55$, or scenes, $F(2,22) = 16.5$, $p < .0001$, $\eta_p^2 = .60$, quadratic $F(1,23) = 34$, $p < .0001$, $\eta_p^2 = .60$. Importantly, the interaction of hedonic content and perceptual composition was not significant ($F < 1$).

Fixation duration. As illustrated in Figure 3, the average duration of each fixation increased significantly across the viewing interval $F(5,19) = 50.8$, $p < .0001$; $\eta_p^2 = .93$. Significant linear $F(1,23) = 164$, $p < .0001$, $\eta_p^2 = .88$ and quadratic trends $F(1,23) = 43$, $p < .0001$, $\eta_p^2 = .22$ indicated a scan pattern in which initially brief durations lengthened across the viewing interval and then flattened out. Follow-up tests indicated that the

fixation duration significantly increased between fixations until the final two fixations (see Figure 3). As illustrated in Figure 3, this scan pattern was similar regardless of hedonic content or perceptual composition as indicated by the lack of any effects involving fixation and these variables.

Not surprisingly, given the greater number of fixations (and the fixed viewing interval), fixation duration was overall significantly shorter when viewing emotional (pleasant or unpleasant) pictures, compared to neutral pictures ($F[2,22] = 12.6$, $p < .0001$, $\eta_p^2 = .53$; quadratic $F[1,23] = 25.3$, $p < .0001$, $\eta_p^2 = .52$), as well as when viewing complex scenes, compared to simple figure-ground compositions ($F[1,23] = 24$, $p < .0001$, $\eta_p^2 = .53$). Pleasant and unpleasant pictures did not differ in fixation duration, and the interaction of hedonic content and perceptual composition was not significant.

Saccade length. The distance the eyes moved between successive fixations varied systematically across the viewing interval, $F(5,19) = 5.2$, $p = .004$, $\eta_p^2 = .58$. As illustrated in Figure 4, saccade length initially increased and then decreased across the viewing interval, prompting a significant quadratic trend $F(1,23) = 22.9$, $p < .0001$, $\eta_p^2 = .50$. This scan pattern was similar regardless of perceptual composition (see Figure 4, left panel) or hedonic content (see Figure 4, right panel) and there were no interactions involving either factor with ordinal saccade.

The total scan path across all fixations was significantly longer for scenes, compared to simple figure-ground compositions, as expected, (see Table 1; $F[1,23] = 214$, $p < .0001$, $\eta_p^2 = .90$). Importantly, the total scan path was also longer for emotional (pleasant or unpleasant), compared to neutral, pictures $F(2,22) = 36.9$, $p < .001$, $\eta_p^2 = .77$; quadratic $F(1,23) = 76.2$, $\eta_p^2 = .77$. Emotional pictures prompted longer scan paths than neutral pictures whether pictures were figure-ground compositions ($F[2,22] = 42.3$, $p < .001$, $\eta_p^2 = .79$) or scenes ($F[2,22] = 10.7$, $p < .002$, $\eta_p^2 = .49$). A significant interaction of hedonic content and perceptual composition $F(2,22) = 11.2$, $\eta_p^2 = .51$ simply indicated a larger effect of hedonic content on total scan path for figure-ground pictures (see Table 2 and Figure 4).

Picture analysis. Using the data from each picture as the unit of analysis (i.e., $n = 192$), we reassessed effects of emotion on eye

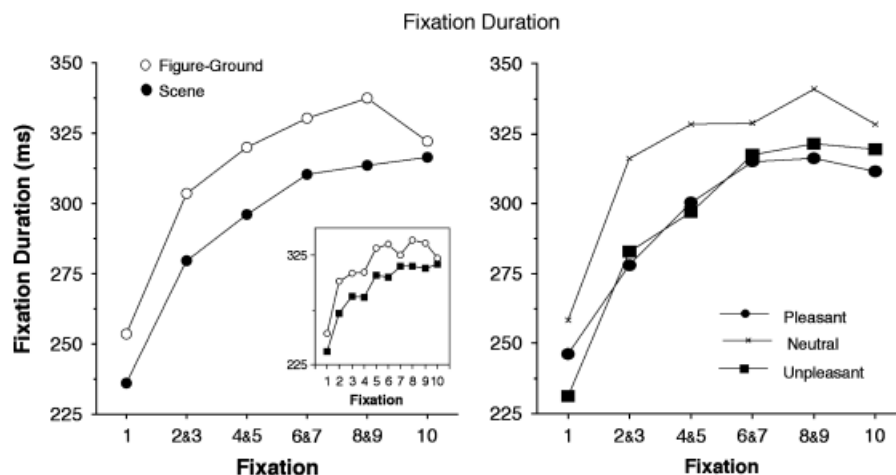


Figure 3. For all picture contents, fixation duration initially increases across the first few fixations and then levels off. Overall, emotionally arousing pictures (right panel) prompt shorter fixation durations than neutral pictures and perceptually more complex scenes prompt shorter fixation durations than simple figure-ground compositions (left panel), Experiment 1.

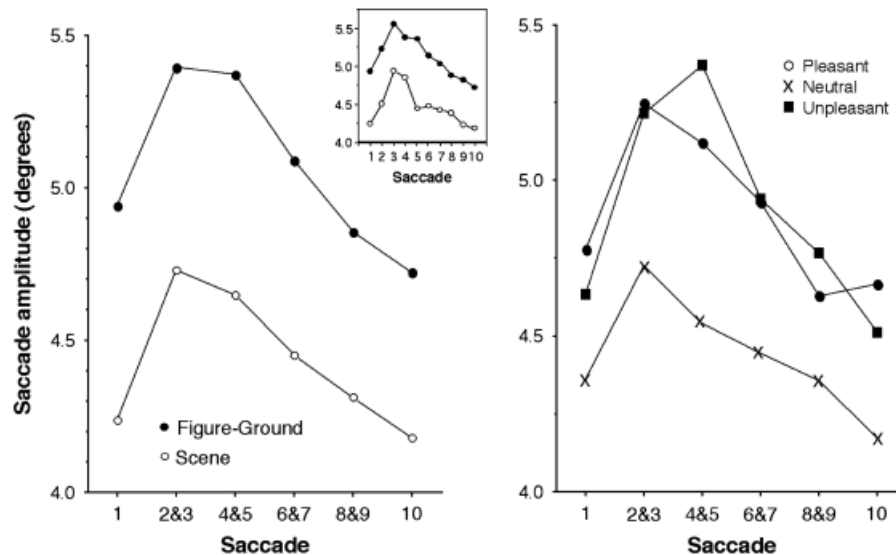


Figure 4. Saccade length initially increases and then decreases over the viewing interval regardless of perceptual composition (left panel) or hedonic content (right panel). Overall, saccade length is larger when viewing emotional (pleasant or unpleasant) pictures, compared to neutral pictures and when viewing complex scenes, compared to figure-ground compositions, Experiment 1.

tracking using the mean rated arousal of each picture from the IAPS as a continuous measure of emotionality (Lang et al., 2008), and using, as continuous measures of physical differences for each picture, the mean brightness, contrast, spatial frequency, and rated picture composition. Of most interest in these analyses is whether emotion continues to modulate eye tracking behavior when other potential modulators are removed. In these regression analyses, effects due to brightness, contrast, spatial frequency, and rated composition were removed, and effects of emotional arousal determined using the residuals for each measure. Results were identical to those already described. For the number of fixations, emotional arousal was highly significant after removing effects due to brightness, contrast, spatial frequency, and rated perceptual composition, $F(1,190) = 34.9$, $p < .0001$. Moreover, emotional arousal remained a significant predictor after removing effects of brightness, contrast, spatial frequency, and rated perceptual composition for total scan path $F(1,190) = 24.1$, $p < .0001$, fixation duration $F(1,190) = 9.9$, $p < .001$, and saccade length, $F(1,190) = 11.1$, $p < .0001$.

Experiment 2

During initial viewing, both the duration of eye fixations and saccade length showed significant differences across the viewing interval that are consistent with the interpretation of an initial series of brief eye fixations that increase in breadth to compre-

hensively scan the visual stimulus, and then lengthen in duration and decrease in breadth, perhaps as informative or interesting material is identified. This scan pattern was similar across all picture contents. To the extent that these scan patterns reflect eye movements when orienting to novel stimuli, we expected to attenuate or change these patterns when pictures were no longer novel. In Experiment 2, we tested this hypothesis by presenting both novel and repeated pictures that varied in emotionality, measuring the same eye movement parameters as in Experiment 1.

Emotional and neutral pictures were repeated four times, either in a row (massed repetition) or separated by other pictures (distributed repetition). Massed repetitions should be the least perceptually novel, and provide the strongest test of whether repetition affects eye movements. Indeed, in a recent study we found that the amplitude of the frontal N2 component of the cortical event-related potential, often interpreted as reflecting novelty, is drastically attenuated following the first massed repetition of a picture (Ferrari, Bradley, Codispoti, & Lang, 2009). And, although distributed repetitions include a temporal lag between presentations, memory for IAPS pictures presented only once is quite accurate on a later recognition test (Bradley, Greenwald, Petry, & Lang, 1992), suggesting distributed repetition could also affect scanning behavior.

Experiment 2 also provides an opportunity to replicate the effects of emotion found when viewing novel pictures in Experiment 1, using highly arousing pictures. Thus, pictures in

Table 1. Total Scan Path (in Degrees) for Pictures Viewed in Experiment 1

	Hedonic content			
	Pleasant	Neutral	Unpleasant	Mean
Figure-ground	59.6 (2.3)	47.5 (2.9)	61.7 (2.0)	56.2 (2.3)
Scene	67.9 (2.3)	62.9 (2.3)	69.5 (2.2)	66.8 (2.1)
Mean	63.7 (2.2)	55.2 (2.5)	65.6 (2.0)	

Note. Standard errors are in parentheses.

Table 2. Total Scan Path (in Degrees) for Pictures Viewed in Experiment 2

	Emotional	Neutral	Mean
Novel	41.3 (1.0)	36.3 (1.0)	38.9 (0.9)
Distributed repetition	32.0 (0.9)	28.0 (0.9)	30.3 (0.8)
Massed repetition	30.6 (0.8)	28.2 (0.9)	29.5 (0.8)
Mean	34.9 (0.8)	30.9 (0.9)	

Note. Standard errors are in parentheses.

Experiment 2 were simple figure-ground compositions that were either high in emotional arousal (i.e., erotica or violence) or neutral (people). Moreover, in Experiment 2, we presented pictures in grayscale to determine whether any of the effects due to hedonic content in Experiment 1 were influenced by differences in color composition (Castelhano & Henderson, 2008). If the scan patterns and effects found when viewing novel pictures in Experiment 1 are reliable, we expected to replicate these effects of emotion on scanning behavior when participants viewed novel pictures in Experiment 2.

Methods

Participants. Sixty-four (37 female) participants from a University of Florida General Psychology course participated for course credit.

Materials and design. Stimuli were 72 pictures selected from the IAPS⁵ (Lang et al., 2008) arranged in two sets of 36 pictures. Each participant saw one set. In each set of 36, there were 18 emotional pictures (9 pleasant, 9 unpleasant) and 18 neutral pictures that were presented in 16-bit grayscale. Pleasant pictures depicted erotica and romance (mean pleasure and arousal = 6.6, 6.3), unpleasant pictures depicted mutilation and threat (mean pleasure and arousal = 2.3, 6.6), and neutral pictures depicted neutral people (mean pleasure and arousal = 5.2, 3.5). Arousal ratings were significantly higher for emotional (mean = 6.5), compared to neutral pictures (mean = 3.5; $F[1,71] = 704$, $p < .0001$), and emotional and neutral pictures did not differ in rated perceptual composition (mean emotional = 3.5; neutral = 3.7).

Of the 18 pictures of each content, 6 were presented once (novel), 6 were presented 4 times in a row (massed repetition), and 6 were presented 4 times distributed across the study (distributed repetition), resulting in 108 total trials. Across participants, approximately half of the participants viewed each set of 36 pictures, and for each set of pictures, counterbalancing orders were constructed such that each of the 36 pictures was viewed in the novel, massed repetition, or distributed repetition condition across participants, and each picture was viewed early, middle, or late in the picture sequence.

Apparatus. Pictures were displayed for 6 s (10–15 s interpicture interval) on a 1024 × 768 (19 in) monitor (Samsung SyncMaster 191T), with a distance of approximately 112 cm from the participant's eye to the screen, subtending $19^\circ \times 14^\circ$ of visual angle. Eye movements were recorded as in Experiment 1.

Procedure. The procedure was the same as described in Experiment 1 with participants instructed to look at each picture while it was on the screen and to look at the fixation cross when a picture was not on the screen.

Dependent measures were the same as those described in Experiment 1. Multivariate analyses (Wilks' lambda) used hedonic

content (emotional, neutral) and repetition (novel, massed, distributed) as repeated measures; reported effect sizes are η_p^2 (partial eta squared).

Results

Number of fixations. Replicating Experiment 1, viewing emotional pictures was associated with a greater number of fixations than neutral pictures, $F(1,63) = 63.2$, $p < .0001$, $\eta_p^2 = .50$, as illustrated in Figure 5. A main effect of repetition $F(2,62) = 51.3$, $p < .0001$, $\eta_p^2 = .62$ indicated that repeated pictures elicited significantly fewer fixations than novel pictures and that the decrease in the number of fixations with repetition was similar regardless of whether the repetitions were massed or distributed ($F < 1$). On the other hand, emotional pictures prompted significantly more fixations than neutral pictures whether pictures were novel ($F[1,63] = 32.6$, $p < .0001$, $\eta_p^2 = .34$), distributed ($F[1,63] = 38$, $p < .0001$, $\eta_p^2 = .38$, or massed ($F[1,63] = 12.6$, $p = .001$, $\eta_p^2 = .17$), resulting in no interaction between emotion and repetition.

Fixation duration. Figure 6 (top panel, inset) illustrates fixation duration across the viewing interval for novel pictures and those that were repeated. Differences are clearly apparent as a function of repetition, supported by a significant interaction between repetition and fixation, $F(10,54) = 5.5$, $p < .0001$, $\eta_p^2 = .51$. Replicating Experiment 1, for novel pictures a main effect of fixation $F(5,59) = 10.1$, $\eta_p^2 = .46$ showed a scan pattern in which durations were initially brief, and then lengthened and flattened out across the viewing interval (linear $F(1,63) = 24.5$, $p < .0001$, $\eta_p^2 = .28$; quadratic $F(1,63) = 21.2$, $p < .0001$, $\eta_p^2 = .25$). For distributed repetition, a main effect of fixation, $F(5,59) = 2.4$, $p = .05$, $\eta_p^2 = .17$, indicated that, following an initial increase, duration did not significantly differ across the viewing interval, quadratic trend $F(1,63) = 7.4$, $p = .008$, $\eta_p^2 = .11$. For massed repetition, a main effect of fixation $F(5,59) = 4.7$, $p = .001$, $\eta_p^2 = .28$ indicated that, following an initial increase, duration significantly decreased across the viewing interval (linear

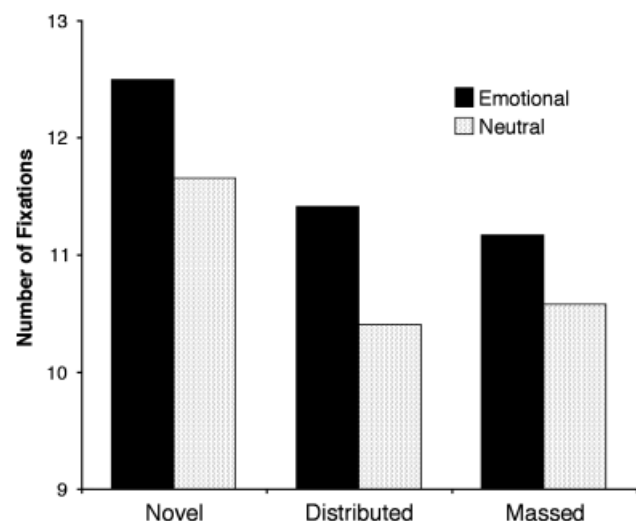


Figure 5. Emotional pictures prompt more discrete eye fixations during picture viewing than neutral pictures, whether pictures are novel or repeated. Repeated pictures prompt fewer fixations than novel pictures, Experiment 2.

5. IAPS (Lang et al., 2008) numbers for pictures in Experiment 2 included, for Emotional: 1050, 1120, 1300, 1304, 3030, 3053, 3068, 3069, 3140, 3160, 3170, 3191, 3500, 3530, 4604, 4611, 4619, 4641, 4653, 4658, 4659, 4660, 4668, 4669, 4687, 4690, 4693, 4694, 4695, 4697, 4800, 6212, 6520, 6550, 6560, and for Neutral: 2102, 2104, 2190, 2191, 2210, 2221, 2272, 2305, 2312, 2372, 2377, 2383, 2390, 2393, 2394, 2400, 2410, 2411, 2435, 2493, 2495, 2500, 2506, 2511, 2512, 2513, 2515, 2579, 2593, 2594, 2595, 2630, 2850, 7550.

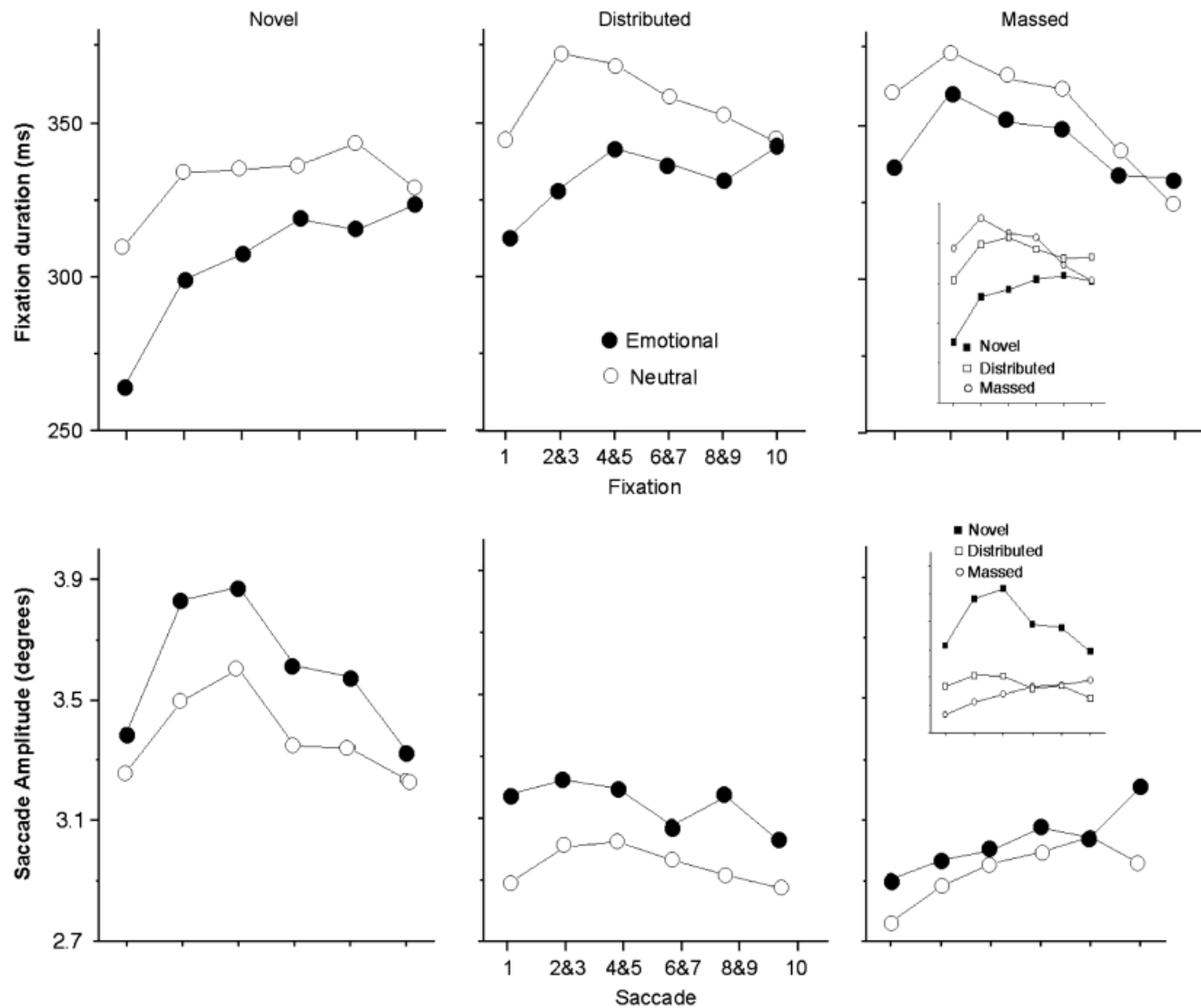


Figure 6. The temporal dynamics of scanning behavior when viewing novel pictures in Experiment 2 are identical to those found when viewing novel pictures in Experiment 1 for both fixation duration (top left) and saccade length (bottom left), whereas the temporal dynamics of both eye movement indices are strongly affected by either distributed (top and bottom middle panel) or massed (top and bottom right panels) repetition. Top inset: Fixation duration averaged across emotional and neutral pictures that were novel or repeated (i.e., massed or distributed). Bottom inset: Saccade length averaged across emotional and neutral pictures that were novel or repeated (i.e., massed or distributed).

$F[1,63] = 10.6$, $p = .002$, $\eta_p^2 = .14$; quadratic $F[1,63] = 10.7$, $p = .002$, $\eta_p^2 = .15$). When effects of repetition were tested at each point across the viewing interval, viewing novel pictures was associated with briefer fixation durations than repeated pictures at each of the first four points, (see Figure 3, top panel, inset; F s $[2,62] = 22.9, 24.8, 19.18, 9.13$, $ps < .001$). On the other hand, fixation duration when viewing massed and distributed repetitions did not significantly differ from each other at any sample point.

Replicating Experiment 1, fixation duration was shorter for emotional, compared to neutral, pictures, $F(1,63) = 30.8$, $p < .0001$, $\eta_p^2 = .33$. Duration was also shorter for novel, compared to repeated pictures, $F(2,62) = 26$, $p < .0001$, $\eta_p^2 = .46$ and an Emotion \times Repetition interaction, $F(5,59) = 2.81$, $p = .024$, $\eta_p^2 = .19$, indicated more reliable effects of emotion on fixation duration for distributed, $F(1,63) = 17.7$, $p < .0001$, $\eta_p^2 = .22$, compared to massed repetition, $F(1,63) = 3.96$, $p = .051$, $\eta_p^2 = .06$.

Saccade length. As illustrated in Figure 6 (bottom inset), the length of the saccades between fixations again varied across the viewing interval, $F(5,59) = 5.87$, $\eta_p^2 = .33$. The sequence of saccade changes differed as a function of repetition, however, Repetition \times Fixation, $F(10,54) = 4.5$, $p < .0001$, $\eta_p^2 = .45$. Replicating Experiment 1, for novel pictures, a main effect of fixation $F(5,59) = 15.5$, $p < .0001$, $\eta_p^2 = .57$ indicated that saccade length again first increased and then decreased across fixations, prompting a significant quadratic trend, $F(1,63) = 37.7$, $p < .0001$, $\eta_p^2 = .37$. For repeated pictures, whether massed or distributed, saccade length did not significantly vary across the viewing interval. As illustrated in Figure 6 (bottom), saccade length was overall longer when viewing emotional, compared to neutral, pictures, $F(1,63) = 14.5$, $p < .001$, $\eta_p^2 = .19$, and longer for novel, compared to repeated, pictures, $F(2,62) = 84.3$, $p < .0001$, $\eta_p^2 = .73$.

Thus, viewing emotional pictures prompted longer average scan paths than viewing neutral pictures (see Table 2;

$F[1,63] = 60, p < .0001, \eta_p^2 = .49$), and scan paths were significantly longer when viewing novel, compared to repeated, pictures, $F(2,62) = 122, p < .0001, \eta_p^2 = .80$. Scan paths were longer when viewing emotional pictures regardless of whether they were novel, $F(1,63) = 57, p < .0001, \eta_p^2 = .48$, distributed, $F(1,63) = 29.2, p < .0001, \eta_p^2 = .32$, or massed, $F(1,63) = 12.1, p = .001, \eta_p^2 = .16$ (Table 1; see also Figure 6, bottom). A significant interaction of emotion and repetition $F(2,62) = 4.4, p = .02, \eta_p^2 = .13$, indicated that, whereas emotional pictures prompted longer scan paths when repetitions were distributed, compared to massed $F(1,63) = 6.95, p = .01, \eta_p^2 = .10$, scan paths for neutral pictures did not differ as a function of whether repetitions were massed or distributed (see Table 1; $F < 1$)

General Discussion

In two experiments, emotionally engaging cues (whether pleasant or unpleasant) prompted a greater number of discrete fixations (of briefer duration) and a longer total scan path, compared to neutral pictures. When perceptual differences between pictures, including brightness, contrast, spatial frequency, and rated picture composition, were excluded using regression, analysis of the residuals continued to show highly significant modulation of all scanning parameters as a function of emotional arousal. These differences are consistent with an interpretation that activation of appetitive or defensive motivational systems by visual cues prompts enhanced information-seeking and information intake.

There were no reliable differences when participants viewed unpleasant, compared to pleasant, pictures. These data join many other measures in which, compared to neutral pictures, emotionally arousing scenes—regardless of hedonic valence—prompt differential activity, including skin conductance, viewing time, memory performance, pupil diameter, and others (e.g., Bradley & Lang, 2007; Bradley, Miccoli, Escrig, & Lang, 2008; Lang & Bradley, 2010). Although a broader attentional focus in positive information processing has received both empirical and theoretical support (e.g., see Derryberry & Tucker, 1992; Rowe, Hirsh, & Anderson, 2007), negative affect has more often been linked to a narrowing of attentional focus (e.g., Christianson, Loftus, Hoffman, & Loftus, 1991; Derryberry & Reed, 1998; Easterbrook, 1959). Often, however, negative affect is operationalized as an individual state or trait personality factor (e.g., high anxiety), which differs from aversive perception. Although Christianson et al. (1991) proposed attentional narrowing when viewing an unpleasant picture, a single unpleasant picture was tested in that study, making it difficult to generalize more broadly. From an evolutionary perspective, heightened processing of threat cues is clearly adaptive for both animals and humans.

We have suggested (Bradley, 2009; Lang et al., 1997) that activation of either appetitive or defensive motivational systems prompts heightened orienting to the eliciting cue, increased information-seeking and intake, and preparation for action in the service of sustaining and protecting life. In the current study, the differences in eye movements found when viewing emotional cues is consistent with an interpretation of motivated vigilance—a continued search of the visual array for relevant information—driven by goal-oriented defensive or appetitive motivation to act adaptively. Thus, the sensory array is repeatedly and broadly scanned: Is a predator attack imminent? Is prey approaching or receding? Scanning behavior presumably

evolved in the service of survival goals, and this pattern of heightened attention and information intake persists in human emotional perception.

In Experiment 1, viewing complex scenes prompted more fixations and longer scan paths than simple figure-ground compositions, regardless of hedonic content. The common effects of perceptual and affective variables on scanning behavior support an interpretation that both reflect heightened scanning and information intake. In the case of perceptual composition, information seeking is presumably initiated by the demands of the sensory array. Previous studies have determined, for instance, that fixations rarely land on spatial locations in which the information is constant or uniform (e.g., Henderson, 2003)—a defining feature of the figure-ground compositions presented in Experiment 1—and consistent with finding fewer fixations for figure-ground compositions. Moreover, saccade length increases as picture size increases (von Warburg et al., 2007), and, although pictures were equivalent in size in Experiment 1, informative information was more focal in figure-ground compositions, which could functionally reduce the size of the critical visual array. On the other hand, using pictures of textures, Groner, Groner, and vaon Muhlenen (2008) reported longer durations and shorter saccades when viewing high, compared to low, spatial frequency stimuli, which is opposite to the pattern reported here, and suggests that spatial frequency is not mediating the pattern of eye movements found when viewing complex natural scenes.

In Experiment 2, novel picture viewing elicited a greater number of fixations and longer scan paths than when viewing repeated pictures, which is additional support for an interpretation that these indices are associated with information-seeking and intake. Nonetheless, despite repetition, emotional pictures continued to prompt more fixations and longer scan paths than neutral pictures. The persistence of these eye movement differences, despite repetition, make it unlikely that sensory or perceptual differences between emotional and neutral pictures are the critical mediators of these effects. Moreover, the fact that there were very few differences in eye movement indices whether repetitions were massed or distributed also suggests that these effects are not due to physical differences. Rather, particularly after viewing the same picture four times in a row, one would expect effects primarily prompted by differences in the sensory array to be greatly dampened, if not eliminated, as recent memory would provide a salience map that can attenuate effects due primarily to sensory differences (Hollingworth, 2004). Rather, the data suggest that, when cues activate fundamental motivational systems of appetite and defense, enhanced information seeking is engaged, even if the cue is not perceptually novel.

Effects of hedonic content on eye movements have previously been investigated with an emphasis on initial fixation. For instance, a number of studies have found that, when pictures are presented in pairs, emotionally arousing pictures are more likely to draw the first fixation (e.g., Calvo & Lang, 2005; Nummenmaa, Hyönä, & Calvo, 2006). In the current study, a single picture was the focus of processing and, for all pictures, an initial rapid scan of the image was found, as evidenced by initially brief fixation durations that increased in saccade length over the first few fixations. In both Experiments 1 and 2, we replicated Unema et al. (2005) who reported a scan pattern consisting of initially brief fixation durations that lengthen over the course of the viewing interval. In all of these experiments, viewing time was relatively lengthy (i.e., 6 s or greater), and effects of shorter

viewing intervals on the temporal dynamics of scan behavior remains an interesting area to pursue.

On the other hand, Unema et al. (2005) found that saccade length decreased across the viewing interval whereas, in both Experiments 1 and 2, saccade length first increased and then decreased across the viewing interval. This pattern was surprisingly consistent when viewing novel pictures of any content. Interestingly, using pictures of indoor and outdoor natural scenes, Castelhamo et al. (2009) found not only the same increasing/decreasing pattern of saccade length as found here, but also found the same pattern of changes in fixation duration over the viewing interval. One critical difference lies in the visual images used by Unema et al. (2005), which were computerized architectural drawings of shelves containing different objects. For natural scene viewing, both the current data and that of Castelhamo et al. (2009) suggest that saccade length first increases, and then decreases across the viewing interval, a pattern consistent with an initial broad scan of the picture, followed by a spatial focus on the more interesting or informative information.

Experiment 2 indicated that the temporal dynamics of scanning are drastically altered by repetition. Regardless of whether repetitions were massed or distributed, the initially brief fixations and longer saccade lengths found over the first few fixations when viewing novel pictures were eliminated. Rather, for repeated pictures, initial fixation durations were generally long and saccade lengths short, compared to when viewing novel pictures. Moreover, the reliable changes across the viewing interval found when viewing novel pictures in both Experiments 1 and 2 were absent or changed when viewing repeated pictures. Thus, scan patterns were clearly indicative of prior presentation (potentially providing a new measure of memory performance), and perhaps even allow discrimination of whether repetitions were massed or distributed. Although differences in temporal dynamics as a function of the type of repetition (i.e., massed or distributed)

were few, fixation duration linearly decreased across the viewing interval for massed repetitions, whereas, for distributed repetitions, fixation duration was flat following the initial fixation. The briefer and briefer fixations for pictures repeatedly presented in a row (i.e., massed repetition) might reflect an active search for novel (more interesting?) information, whereas the pattern of fixation duration for distributed repetitions was more similar to that found for novel pictures, although with a much earlier asymptote.

Pictures were repeated only four times in Experiment 2, raising the question of whether further repetition would eliminate differences in scanning behavior between emotional and neutral pictures. It is possible that, with more repetitions, eye movements would cease to differentiate between emotional and neutral stimuli. On the other hand, even following 30 massed repetitions of the same picture, affective modulation of the startle reflex remains intact (Ferrari et al., 2011) and, following 90 repetitions, the late positive potential of the brain event-related potential continues to be enhanced when viewing emotional, compared to neutral, pictures (Codispoti, Ferrari, & Bradley, 2007). One hypothesis is that affective cues retain motivational significance (which we define as activation of the neural systems mediating appetite and defense) until their associative links to these neural systems are changed or weakened through new learning (Bradley, 2009).

Taken together, the data from the current studies indicate that eye movements and scan patterns reflect differences in emotionality, complexity, and memory when perceiving natural scenes, and therefore comprise an important tool in the study of emotional visual perception. Moreover, these studies identify reliable, replicable patterns of oculomotor and scanning behavior when viewing affective, compared to neutral, pictures, which supports their use in studying emotional reactivity as it varies with psychopathology, brain trauma, aging, and other individual difference factors.

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