Author Manuscript

Faculty of Biology and Medicine Publication

Published in final edited form as:

Title: Eye gaze behavior during affective picture viewing: Effects of motivational significance, gender, age, and repeated exposure.

Authors: Gomez P, von Gunten A, Danuser B

Journal: Biological Psychology

Year: 2019 Jun 4

Issue: 146

Pages: 107713

DOI: 10.1016/j.biopsycho.2019.06.001

Eye gaze behavior during affective picture viewing: Effects of motivational significance, gender, age, and repeated exposure

Patrick Gomez

Institut universitaire romand de Santé au Travail (Institute for Work and Health), University of Lausanne and University of Geneva

Armin von Gunten

Service of Old Age Psychiatry, Department of Psychiatry, Lausanne University Hospital

Brigitta Danuser

Institut universitaire romand de Santé au Travail (Institute for Work and Health), University of Lausanne and University of Geneva

Highlights

- Fixation frequency and scanpath length increase with self-rated unpleasantness.
- Fixation frequency and scanpath length increase with self-rated arousal.
- Fixation frequency and scanpath length decrease within series of similar pictures.
- The decrease in eye movements within series of similar pictures is age-dependent.
- Women exhibit a more exploratory scanning behavior than men do.

ABSTRACT

How top-down and bottom-up factors combine to determine eye movements during affective picture viewing is far from being completely understood. We investigated how observers' fixation frequency and scanpath length – two indices of information seeking and intake – are related to self-reported valence (pleasantness) and arousal and depend on gender, age, and repeated exposure during affective picture viewing. We tracked the eye movements of 157 younger, middle-aged, and older adults when viewing 14 picture series each consisting of six thematically and affectively similar pictures. Participants' valence and arousal ratings were registered for each series. Fixation frequency and scanpath length increased with self-rated unpleasantness and arousal and decreased across the six pictures within series. This decrease was age- and arousal-dependent. Compared to men, women exhibited a more exploratory scanning behavior. These findings suggest that observers' affective appraisal, gender and age and repeated exposure to affective visual stimuli influence visual information seeking and intake.

Keywords: affective pictures; age differences; emotion; eye movements; gender differences

Eye gaze behavior during affective picture viewing: Effects of motivational significance, gender, age, and repeated exposure

1. Introduction

In humans, much information about the environment is gathered through the eye. Eye fixations and their breadth determined most of the information available for further processing. Therefore, measures of eye gaze behavior such as fixation frequency and scanpath length can provide insight into allocation of attentional resources when exposed to visual cues. These measures index the amount and breadth of information seeking and intake, with higher fixation frequency and longer scanpath indicating that more information from the visual array is sought and encoded (Bradley, Houbova, Miccoli, Costa, & Lang, 2011).

Understanding how top-down and bottom-up factors combine to determine eye movements is a significant challenge (Henderson, 2003). In the present study, we aimed to determine the effects of four factors on fixation frequency and scanpath length during affective picture viewing. These factors are the motivational significance of the visual stimuli operationalized in terms of self-rated valence and arousal, observer's gender, observer's age, and repeated exposure to similar contents. To this end, we tracked the eye movements of 157 younger, middle-aged, and older men and women when viewing 14 picture series each consisting of six thematically and affectively similar pictures.

Motivational significance can be conceived in terms of information that is processed and appraised as bearing relevance to the individual's goals. One model to understand motivational significance of environmental cues is provided by Lang and coworkers (Lang & Bradley, 2010). According to their model, two phylogenetically old motivational systems, appetitive and defensive, are activated in response to emotional stimuli. The appetitive system is activated primarily by cues signaling reward (e.g., appetizing food, attractive nudes) and is associated with positive valence (pleasantness) and approach motivation. The defensive system is activated primarily by cues signaling threat (e.g., attacking humans, blood) and is associated with negative valence (unpleasantness) and aversive motivation. The vigor/degree of activation within each of these systems is reflected by arousal, which ranges from low (calm) to high (excited). Brain, somatic, and autonomic responses of healthy individuals to pictures depicting natural scenes vary as a function of the valence and arousal level of the stimuli (e.g., Bradley & Lang, 2007; Gomez, von Gunten, & Danuser, 2016).

From an evolutionary perspective, heightened visual search for and processing of relevant information in the environment should facilitate the survival of individuals by increasing their chances of successful behavioral responses to both aversive and appetitive cues (Bradley et al., 2011; Lang & Bradley, 2010). Thus, we would predict that more salient stimuli (i.e., more relevant to the survival of the individuals) would prompt enhanced information seeking and intake. Because higher arousal is supposed to index enhanced appetitive and defensive motivation, a plausible hypothesis is that higher arousal is significantly related to higher fixation frequency and longer scanpath.

Eye movements when processing affective pictures could also be expected to vary as a function of pictures' valence. According to the principle of negativity bias in attention, negative as opposed to positive information has privileged access to attentional resources (Baumeister, Bratslavsky, Finkenauer, & Vohs, 2001; Pratto & John, 1991; Rozin & Royzman, 2001). Encephalographic and eye blink studies have provided support for this bias (Carretie, Mercado, Tapia, & Hinojosa, 2001; Gomez, Shafy, & Danuser, 2008; Merckelbach, Vanhout, Vandenhout, & Mersch, 1989; Omori, 2005; Smith, Cacioppo, Larsen, & Chartrand, 2003). From this evidence, we would predict that, compared to pleasant contents of similar arousal, unpleasant contents prompt enhanced information seeking and intake. Thus, a plausible hypothesis is that higher unpleasantness is significantly related to higher fixation frequency and longer scanpath.

In support of the arousal hypothesis, viewing both pleasant and unpleasant scenes of similar normative arousal was characterized by more fixations and longer scanpath than viewing neutral scenes (Bradley et al., 2011; Dietz, Bradley, Okun, & Bowers, 2011). Moreover, higher pictures' mean arousal as rated by the participants was positively associated with more fixations and longer scanpath (Bradley et al., 2011). In contrast to these findings, Madan, Bayer, Gamer, Lonsdorf, and Sommer (2018) reported that pictures' mean arousal as rated by the participants did not correlate with number of fixations and correlated negatively rather than positively with scanpath length. The valence hypothesis is supported by a study reporting more fixations and longer scanpath for unpleasant than pleasant images of similar normative arousal (Blakemore, Rieger, & Vuilleumier, 2016). However, Bradley and colleagues (Bradley et al., 2011; Dietz et al., 2011) observed no significant differences in eye gaze movements between pleasant and unpleasant pictures of similar normative arousal. Furthermore, Madan et al. (2018) found that pictures' mean pleasantness as rated by the participants did not correlate significantly with number of fixations and correlated positively rather than negatively with scanpath length. Finally, Simola, Le Fevre, Torniainen, and Baccino (2015) found that a priori-defined valence and arousal interacted with each other in predicting fixation frequency when processing emotionally salient regions embedded in real-world scenes. In conclusion, eye-tracking studies suggest that valence and arousal are significant determinants of visual attention to affective stimuli; yet, the relative contribution of these two dimensions as well as the direction of their effects on eye movements is still debated.

The influence of gender in emotion has attracted much attention because of the potential ramifications on our understanding of gender differences in disorders involving emotion dysregulation (e.g., Hyde, Mezulis, & Abramson, 2008). Scholars have investigated and discussed gender differences in emotion from different perspectives (e.g., biological, socio-cultural, evolutionary; Bradley, Codispoti, Sabatinelli, & Lang, 2001; Fischer, 2000; Rupp & Wallen, 2008; Troisi, 2001; Wood & Eagly, 2002). Some lines of research suggest that, across adulthood, men may exhibit a stronger disposition to engage the appetitive system when processing appetitive cues than women, whereas women may display a stronger disposition to engage the defensive system when exposed to aversive material than men (Andreano, Dickerson, & Barrett, 2014; Bradley et al., 2001; Gard & Kring, 2007; Gomez, von Gunten, & Danuser, 2013, 2016b; Grossman & Wood, 1993; Hamann, Herman, Nolan, & Wallen, 2004; Hillman, Rosengren, & Smith, 2004; Rupp & Wallen, 2008; Sabatinelli, Flaisch, Bradley, Fitzsimmons, & Lang, 2004; Stevens & Hamann, 2012). Whether there exist gender differences in eye movements during affective processing in line with this evidence remains to be determined. This is a goal of the present study.

Recent work has challenged long-held views on old age as a time of affective deterioration by showing that aging up to the seventh decade is associated with enhanced positive overall emotional well-being and with greater emotional stability (Carstensen, Pasupathi, Mayr, & Nesselroade, 2000; Carstensen et al., 2011; Charles & Carstensen, 2010). The socioemotional selectivity theory is a life-span theory of motivation, according to which there are age differences in motivational priorities as a function of perceived future time horizons with implications for the processing of affective information. The theory posits that younger adults perceive time as largely open-ended and consequently tend to prioritize goals that aim to shape their potentially long future such as acquiring novel information. In contrast, older individuals tend to perceive time left as narrow and consequently prioritize emotionally meaningful goals in the present moment – feeling good, avoiding negative feelings (Carstensen, 2006). One implication of these age-related motivational changes predicted by this theory is that preferences in terms of attention to and memory for affective information shift toward positive information in later life. This preferential processing of positive over negative stimuli observed in older adults compared to younger adults is known as the age-related positivity effect in attention and memory (Isaacowitz, Toner, Goren, & Wilson, 2008; Reed & Carstensen, 2012; Reed, Chan, & Mikels, 2014). Consistent with this effect, some eye-tracking studies have found that compared to younger adults, older adults look less at negative and/or more at positive stimuli (e.g., Isaacowitz, Wadlinger, Goren, & Wilson, 2006a,b; Isaacowitz & Choi, 2011). However, other studies have failed to confirm this effect (e.g., Allard & Isaacowitz, 2008; see Reed et al., 2014, for a meta-analysis). These studies have typically shown pairs of stimuli of different a priori-defined valences (e.g., neutral vs. happy faces) and measured how participants direct their attention to one or the other, or they have presented only one stimulus at a time and determined how younger and older adults differ in their eye gaze behavior towards less vs. more emotionally salient regions. In the present study, we investigate whether there is an age-related positivity effect in fixation frequency and scanpath length when participants view series of pictures.

A final potential effect on eye gaze behavior investigated in the present study is the effect of exposure to series of thematically and affectively similar contents. This question fits into issues regarding sensitization (i.e., increase in reactivity) and habituation (i.e., decrease in reactivity) of emotional responses when exposure to affective stimuli is prolonged (e.g., Bradley, Cuthbert, & Lang, 1996; Ferrari, Bradley, Codispoti, & Lang, 2011). For instance, activity of the corrugator muscle increases across a block of unpleasant pictures, whereas skin conductance habituates over time when viewing blocks of pleasant and unpleasant pictures (Bradley et al., 1996). Habituation and sensitization are behavioral processes seen throughout phylogeny, suggesting that their role is an important one in an organism's survival (Eisenstein, Eisenstein, & Smith, 2001). Habituation may be understood as a process that has emerged for filtering out stimuli of decreasing motivational significance. Habituation of eye gaze indices was observed by Bradley et al. (2011) who found that repeated presentation of the same pictures elicited significantly lower fixation frequency and shorter scanpath than novel pictures. To the extent that fixation frequency and scanpath length reflect orienting to novel visual stimulation, we might expect that processing of thematically and affectively similar pictures presented one after the other is associated with a gradual decrease in information seeking and intake because with each picture the series' content and affective tone become increasingly familiar to the observer. From the theoretical and empirical evidence just introduced, we derived the following hypotheses to guide our research. First, we hypothesized that higher self-reported unpleasantness and higher self-reported arousal would be significantly related to higher fixation frequency and longer scanpath. Second, we predicted that compared to men, women would exhibit a stronger association between self-rated unpleasantness and both eye gaze measures. This effect would be driven by men exhibiting higher fixation frequency and longer scanpath than women when looking at series rated as pleasant and by women showing higher fixation frequency and longer scanpath than men when looking at series rated as unpleasant (i.e., significant valence by gender interaction). Third, we expected that compared to younger adults, older adults would display a weaker association between self-rated unpleasantness and both eye gaze measures. This effect would be driven by younger adults exhibiting higher fixation frequency and longer scanpath than older adults when viewing series rated as unpleasant and by older adults exhibiting higher fixation frequency and longer scanpath than younger adults when looking at series rated as pleasant (i.e., significant valence by age interaction). Finally, we hypothesized that fixation frequency and scanpath length would linearly decrease across the six pictures forming each series. Whether this decrease depends on observers' affective ratings, gender, or age was treated as an exploratory issue.

2. Material and methods

2.1. Participants

Participants were 70 men and 87 women belonging to three age groups: younger (ages 20-34 years), middle-aged (ages 40-54 years), and older (ages 60-74 years). Data from 22 additional participants were unusable due to procedural flaws (four participants) or unsatisfactory quality of the calibration of the eye-tracking system (18 participants; see below for details). The study was approved by the ethics committee of the canton of Vaud, Switzerland.

Prospective volunteers completed a screening questionnaire. We included respondents who had scores lower than 11 on both the anxiety and depression scales of the Hospital Anxiety Depression Scale (Zigmond & Snaith, 1983, scale range: 0-21). This was done to avoid the experience of excessive emotional distress among vulnerable people. Furthermore, participants had to be proficient in French, report at least "satisfactory" current general health on a 5-point scale ranging from "very good" to "very bad", not be pregnant or breastfeeding, not use recreational/illicit drugs, have normal or corrected-to-normal vision, not suffer from color blindness, not have a cardiac pacemaker, and not be currently under medical treatment for any psychiatric disorder.

Table 1 shows that participants were well-functioning individuals. Anxiety and depression scores were low. Mental health, physical functioning, and general health perception were better than average scores of the general local population (Richard et al., 2000). Mean scores of verbal fluency were above average compared to normative data (Tombaugh, Kozak, & Rees, 1999).

2.2. Stimuli

Stimuli were 84 pictures selected from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005; see the supplementary material for the library number of the pictures). They were arranged into 14 series, each consisting of 6 different pictures. Each series represented a different thematic content. Six series were expected to be pleasant, six unpleasant, and two neutral. Moreover, the six pleasant and the six unpleasant series were expected to vary in arousal from relatively low to high. The six pleasant contents were appetizing food, erotic heterosexual couples, pleasant family scenes, pleasant nature, romantic heterosexual couples, and sport scenes. The unpleasant contents included environmental contamination, human loss, mutilated/burned bodies, physical violence, sick/injured human beings, and suffering/dead animals. The two neutral series showed household objects and neutral human activities. Categorization was based on previous work (Bradley et al., 2001; Gomez & Danuser, 2010). All pictures were landscape in orientation. All pictures were characterized in terms of several perceptual properties that have been shown to influence eye gaze behavior or have been controlled for in previous studies on emotion and eye gaze movements (e.g., Bradley, Hamby, Löw, & Lang, 2007, Bradley et al., 2011; Löw, Bradley, & Lang, 2013; Madan et al., 2018; Marin & Leder, 2013; Ni et al., 2011; Simola et al., 2015). These properties were brightness, contrast, complexity, and presence of people. Brightness was defined as the mean RGB (red green blue) value for each pixel, averaged across all pixels (Bradley et al., 2011; Ni et al., 2011). Values can range from 0 (black) to 255 (white) for each of the RGB components in a color picture. Mean brightness of nine pictures was modified using Adobe Photoshop such that mean brightness across picture series was very similar. Mean (*SD*) for brightness across the 84 pictures was 104 (26), with no significant differences between series ($F(13, 70) = 0.20$, $p = .99$). The standard deviation of the mean RGB scores computed across pixels was used as an index of contrast (Bradley et al., 2011). Mean (*SD*) for contrast across the 84 pictures was 68 (14), with no significant differences between series ($F(13, 70) = 0.71$, $p = .74$). Following previous work, we operationalized picture complexity in two ways; as number of bytes of compressed image file size in JPEG format (Ni et al., 2011; Simola et al., 2015) and as figure-ground compositions vs. scenes (Bradley et al., 2007, 2011; Löw et al., 2013). Applying algorithmic information theory (Donderi, 2006), less complex images contain more redundant information that can be represented by a shorter string of bits; this yields a smaller file size than more complex images (Marin & Leder, 2013). Thus, larger size is assumed to correspond to higher complexity. Mean (*SD*) for picture size across the 84 pictures was 187 kB (52), with no significant differences between series ($F(13, 70) = 0.23$, $p = .99$). Figure-ground compositions have a focal figure with a rather uniform/constant background, whereas scenes lack a clear central figure or constant background (Bradley et al., 2007). We classified 37 of the 84 pictures as either figure-ground composition or scene using classification by Bradley and colleagues (Bradley et al., 2007, 2011; Löw et al., 2013). The first authors and two research assistants classified the remaining 47 pictures applying Bradley and colleagues' definition and examples (Bradley et al., 2007, 2011; Löw et al., 2013). We classified 41 pictures as figure-ground compositions and 43 pictures as scenes. Finally, fifty-four pictures included one or more people, whereas 30 included none. Of the pictures depicting people, 26 were figure-ground compositions and 28 were scenes. Of the pictures without people, 15 were figure-ground composition and 15 were scenes.

2.3. Measures

2.3.1. Eye movements

Eye movements were monitored using a dark pupil remote eye-tracking system (iView X, SensoMotoric Instruments, Teltow, Germany), which allows free movement of the head and uses infrared illumination and computer-based image processing. Images of the eye are analyzed in real-time by detecting the pupil, calculating the center, and eliminating artefacts. Eye gaze was registered with a sampling rate of 50 Hz and a spatial resolution of 0.1°. Both eyes were tracked.

2.3.2. Valence and arousal ratings

Valence and arousal were collected with the pencil-and-paper version of the 9-point Self-Assessment Manikin (SAM, Lang et al., 2005, scale range: 1-9). We scored valence and arousal ratings so that higher values indicated more pleasant and more aroused, respectively.

2.3.3. Self-rated health

A few days prior to the experimental session, participants completed the Medical Outcomes Study 36-Item Short Form (SF-36, Ware & Sherbourne, 1992), which was used to determine mental health, physical functioning, and general health perception.

2.3.4. Verbal fluency

Verbal fluency was assessed with the Animal Naming Task (1 minute, Kertesz, 1982). This test shows a strong association with general intellectual ability and has been extensively used with older adults (Lindenberger, Mayr, & Kliegl, 1993).

2.3.5. Educational level

Educational level was divided into three categories: level I = no vocational training with or without practical on-the-job training; level II: completed vocational training equivalent to apprenticeship or a degree judged equivalent; level III: baccalaureate with or without later academic studies.

2.3.6. Physiological measures

Cardiovascular, respiratory, electrodermal, and pupillary variables were also measured. The results for these measures are reported in Gomez, Filippou, Pais, von Gunten, and Danuser (2016) and Gomez et al. (2016b).

2.4. Procedure

Participants were tested individually in a windowless room with the same lighting conditions during the entire session for all participants. First, the experimenter provided the participants with an outline of the experimental procedure and an explanation of the measurements. The experimenter explained that 14 series, consisting of 6 pictures each, would be displayed on the screen in front of them and that the pictures would depict life events, objects, and persons that could evoke positive and negative emotions. The specific themes of the pictures (e.g., physical violence) were not mentioned. Then, participants filled out an informed consent.

After attaching the physiological sensors, the rating procedure was explained to the participants. It was emphasized that the ratings should be performed quickly and spontaneously and reflect the emotions felt during picture viewing. Participants were also asked to avoid excessive body movements, in particular of the upper body and head throughout the picture series presentation in order to guarantee high quality recordings. Then, the eye-tracking system was calibrated using a 9-point calibration routine. Subsequently, participants were shown an exemplary series of mushroom images followed by the 14 series, each lasting 1 min (10 s per picture), with 75-s pauses between series. The pictures were displayed full-screen using Experiment Center Software (SensoMotoric Instruments, Teltow, Germany) on a 19-in. computer screen placed at a viewing distance of about 70 cm. A gray screen was shown between series. Participants gave one valence and one arousal rating after each series and then relaxed until the next series. We instructed participants to look at the monitor at all times except when rating the series.

The series were shown in six different presentation orders. These orders were constructed with the constraint that no more than two series of similar valence were presented consecutively.

Moreover, we made sure that over the six orders the same series was presented on average both at the beginning, in the middle, and in the final part of the experiment. The six orders were counterbalanced across gender and age groups. For each of the six orders of the 14 series, the six pictures within each series were presented in one specific order. Across the six presentation orders of the series, the same picture appeared in first, second, third, fourth, fifth, and sixth position, respectively.

Upon completing the picture viewing session, the physiological sensors were removed. After a 10-min break, the animal naming task was performed, together with other tasks that are irrelevant to the present study. Finally, the participants were debriefed, paid 100 Swiss francs, and thanked.

2.5. Data reduction of the eye-tracking data

We extracted eye gaze data with BeGaze^{TM} 3.4 (SensoMotoric Instruments, Teltow, Germany). Fixations were defined by a minimum duration of 80 ms and a maximal dispersion of 100 px (see Salvucci & Goldberg, 2000, for details on the dispersion-based algorithm). The first fixation was excluded from analyses because it is not actively chosen and influenced by the stimulus content (Holmqvist, Nyström, Andersson, Dewhurst, Jarodzka, & van de Weijer, 2011). We computed fixation frequency for each picture by dividing the number of fixations by the stimulus duration (10 s); thus, the reported fixation frequencies correspond to the number of fixations per second. Scanpath length was calculated as the sum of the distance between successive fixations in pixels (px).

Only good quality recordings defined as those pictures with a tracking ratio > 95% were included in the analyses. Tracking ratio is defined as the number of non-zero gaze positions divided by sampling frequency multiplied by run duration, expressed in percent (SensoMotoric Instruments, BeGaze Manual, version 3.4, 2014). Moreover, participants with deviations on the

X or Y axes for the gaze position accuracy of the calibration larger than 1.5° were excluded from all analyses.

We analyzed fixation frequency and scanpath length from both eyes. We only report the analyses of the left eye data because the results of the analyses of the data from the two eyes were qualitatively identical.

2.6. Statistical analyses

All analyses were performed using SPSS Statistics version 25 (IBM Corp., Armonk, NY, USA). An alpha level of .05 was used for all tests.

2.6.1. Main analyses

Two linear mixed models (LMM) with restricted marginal maximum likelihood estimation and using the Satterthwaite method of estimating degrees of freedom were fitted for fixation frequency and scanpath length, separately. Random intercepts for participants and for series within participants were included to take into account the multi-level structure of the data.

In model 1, we tested fixed main effects of the five factors valence, arousal, gender, age group, and picture position. We treated valence, arousal, and picture position as continuous variables and gender and age group as categorical variables. Valence and arousal are the subjective valence and arousal judgments given by the participants centered around the respective grand mean. Significant effects of valence and arousal in model 1 indicate significant linear (positive or negative) relationships between valence/arousal ratings and the eye gaze measures. Significant effects of gender and age group in this model indicate significant differences between genders and age groups in the average level of the eye gaze measures. Picture position refers to the position of the six pictures within each series (i.e., first, second, etc.). Significant effects of picture position indicate significant linear decreases or increases of the eye gaze variables across the six pictures of the 14 series taken together.

In model 2, we added to model 1 the ten possible two-way interactions between the five main predictors, i.e., valence x arousal, valence x gender, valence x age group, arousal x gender, arousal x age group, gender x age group, valence x picture position, arousal x picture position, gender x picture position, and age group x picture position. Significant two-way interactions mean that the effects of the two predictors depend on each other. For instance, an interpretation of a significant valence x gender interaction is that the relationship between valence and the outcome measure is significantly different for men and women. Testing main effects and interaction effects in two separate models is required because in LMM analyses the effects of lower-order factors (e.g., main effects of valence and gender) cannot be readily interpreted when higher-order factors (e.g., valence x gender interaction) are also included.

Control variables entered in all models were educational level, presentation order of the picture series, picture brightness, picture contrast, picture size, picture composition (figure-ground vs. scene), and presence of people in the picture (people vs. no people). For the sake of brevity, detailed statistics for these seven variables are not reported as they served only as control variables.

Follow-up analyses of significant interactions involving gender or age group tested the effects of valence/arousal/picture position for the different groups separately and the gender/age group effects for different values of valence/arousal/picture position. As a measure of effect size, we report for each model conditional R^2 ($R^2_{LMM(c)}$) as proposed by Nakagawa and Schielzeth (2013). $R^2_{LMM(c)}$ indicates the variance explained by the full model.

2.6.2. Secondary analyses

We used LMM to test effects of gender, age group, and their interaction for each series separately while including the same control variables as in the main analyses. This information help understand the origin of the observed effects in the main analyses and is valuable to those interested in gender and age differences in the eye gaze behavior to distinct thematic contents.

3. Results

3.1. Calibration quality and tracking ratio

Mean deviations on the X and Y axes for the eye tracking system calibration were 0.3° (*SD* = 0.3°) and 0.5° (*SD* = 0.3°), respectively. Mean tracking ratio of the stimuli included in the analyses was 98.7% (*SD* = 1.2%).

3.2. Main analyses

3.2.1. Fixation frequency

3.2.1.1. Effects of the main predictors

Estimates of fixed effects for models 1 and 2 are presented in Table 2. In model 1, there were significant main effects of valence, arousal, and picture position. In line with our hypotheses, fixation frequency significantly increased with both unpleasantness and arousal (see Fig. 1) and decreased across the six pictures of the series.

Model 2 revealed significant effects of the interactions valence x gender, arousal x picture position, and age group x picture position. Male participants showed a significant increase in fixation frequency with unpleasantness (valence estimate = -0.014, *SE* = 0.004, $p < .001$), whereas female participants did not (valence estimate = 0.001, *SE* = 0.003, $p = .71$). Men had significantly lower fixation frequency than women for self-rated valence scores from 7 to 9 (mean differences = 0.124-0.155, *SE*s = 0.057-0.059, *p*s = .009-.030; see Fig. 2).

The significant arousal x picture position interaction indicates that the effects of arousal and picture position depended on each other. Specifically, the picture position effect became progressively smaller along the arousal dimension (i.e., flatter line; see Fig. 3), and the arousal effect became progressively larger (i.e., steeper line) across the six pictures of the series (see Fig. S1 in the supplementary material).

The significant age group x picture position interaction indicates that the three age groups differed significantly in their decrease in fixation frequency across the six pictures of the series. As shown in Fig. 4, the decrease in fixation frequency was largest for older adults (estimate = -0.033, *SE* = 0.004, $p < .001$) and smallest for younger adults (estimate = -0.012, *SE* = 0.003, $p < .001$), with middle-aged adults falling in between (estimate = -0.025, *SE* = 0.004, $p < .001$). Younger adults' decrease was significantly less steep than both older adults' decrease (estimated mean difference = 0.022, *SE* = 0.006, $p < .001$) and middle-aged adults' decrease (estimated mean difference = 0.013, *SE* = 0.005, $p = .017$). The difference between older and middle-aged adults was not significant (estimated mean difference = 0.009, *SE* = 0.006, $p = .14$). No pairwise comparisons between age groups were significant for any picture position (*p*s > .054). $R^2_{LMM(c)}$ for model 1 and 2 were 0.475 and 0.476, respectively.

3.2.1.2. Effects of the control variables

Larger picture size was significantly associated with higher fixation frequency (estimate = 0.0009, *SE* = 0.0003, $p = .005$). The effects of the other six control variables were not significant (*p*s > .21).

3.2.2. Scanpath length

3.2.2.1. Effects of the main predictors

Estimates of fixed effects for models 1 and 2 are given in Table 2. In model 1, there were significant main effects of valence, arousal, picture position, and gender. As predicted, scanpath length significantly increased with both unpleasantness and arousal (see Fig. 1) and decreased across the six pictures of the series. On average, women had significantly longer scanpaths than men (see Fig. 2).

As for fixation frequency, Model 2 showed significant effects of the interactions valence x gender, arousal x picture position, and age group x picture position. Men exhibited a steeper increase in scanpath length with unpleasantness (valence estimate = -81, *SE* = 11, $p < .001$) than women (valence estimate = -39, *SE* = 11, $p < .001$). Women's scanpath was significantly longer than men's scanpath for all valence ratings, with the differences being larger for positive valence (mean differences = 436-760, *SE*s = 179-191, *p*s = <.001-.023; see Fig. 2).

The significant arousal x picture position interaction indicates that the effects of arousal and picture position depended on each other. Specifically, the picture position effect became progressively smaller along the arousal dimension (i.e., flatter line; see Fig. 3), and the arousal effect became progressively larger (i.e., steeper line) across the six pictures of the series (see Fig. S1 in the supplementary material).

The significant age group x picture position interaction indicates that the three age groups differed significantly in their decrease in scanpath length across the six pictures of the series. As shown in Fig. 4, the decrease in scanpath length was largest for older adults (estimate = -59, *SE* = 15, $p < .001$) and smallest for younger adults (estimate = -6, *SE* = 12, $p = .61$), with middle-aged adults falling in between (estimate = -27, *SE* = 13, $p = .043$). Younger adults' decrease was significantly less steep than older adults' decrease (estimated mean difference = 52, *SE* = 19, $p = .007$). The differences between middle-aged adults and younger adults (estimated mean difference = 22, *SE* = 18, $p = .23$) and between middle-aged adults and older adults (estimated mean difference = 30, *SE* = 20, $p = .14$) were not significant. No pairwise comparisons between age groups were significant for any picture position (*p*s > .058). $R^2_{LMM(c)}$ for model 1 and 2 were 0.452 and 0.456, respectively.

3.2.2.2. Effects of the control variables

Scanpath was significantly longer for scenes than for figure-ground compositions (mean difference = 676, *SE* = 242, $p = .008$). The effects of the other six control variables were not significant (*p*s > .12).

3.3. Secondary analyses

Significant gender and age group differences in fixation frequency and scanpath length for specific series are given in Table 3. There were no significant gender x age group interactions. Means and *SE*s of fixation frequency and scanpath length by gender and age group for the fourteen series are provided as supplementary material.

4. Discussion

In line with our predictions, we found that, across participants, higher self-reported unpleasantness and arousal were associated with higher fixation frequency and longer scanpath. Thus, fixation frequency and scanpath length were lowest for pictures rated as pleasant and low arousal and highest for pictures rated as unpleasant and high arousal. Because the affective tone of visual stimuli is processed within few milliseconds (Codispoti, Bradley, & Lang, 2001; Globisch, Hamm, Esteves, & Ohman, 1999; Smith et al., 2003), it is plausible to conclude that both experienced (un)pleasantness and arousal drive, to a certain extent, eye movements and thus information gathering. The general tendencies are that the more unpleasant and arousing pictures are appraised, the more information is also sought from them.

The relationships between higher self-reported unpleasantness and higher fixation frequency/longer scanpath can be understood within the principle of negativity bias. According to this principle, negative as opposed to positive information has a privileged access to attentional resources (e.g., Baumeister et al., 2001; Smith et al., 2003). Our findings are in accordance with and extend results by Blakemore et al. (2016) who reported greater number of fixations and longer scanpath for unpleasant than pleasant images of similar normative arousal. They also converge with results from work that has relied on eye blinking as an indicator of visual attention. When attention is oriented toward significant external stimuli, eye-blink rate is reduced, and this reduction appears to be proportional to the required attention (Campagne, Pebayle, & Muzet, 2005; Stern, Walrath, & Goldstein, 1984; Veltman & Gaillard, 1996). Unpleasant pictures are associated with less eye-blinking than pleasant ones (Merckelbach et al., 1989; Omori, 2005), and eye-blink rate decreases with increasing self-rated unpleasantness during picture viewing, when controlling for self-rated arousal (Gomez et al., 2008).

The positive association between self-rated arousal and both fixation frequency and scanpath length is in line with and extend reports by Bradley et al. (2011) and Dietz et al. (2011). Indirectly, our findings are also in keeping with studies showing that attentional interference effects are arousal dependent (Schimmack, 2005; Tipples & Sharma, 2000) and that eye-blink rate tends to decrease with increasing arousal (Gomez et al., 2008). Self-rated arousal is supposed to index the degree of activation of primary motivational systems rooted in defensive and appetitive neural circuits and, thus, reflects the degree of motivational mobilization in the service of the individual's survival goals (Lang & Bradley, 2010). Increased scanning in response to high-arousal contents as reflected by higher fixation frequency and longer scanpath is consistent with an interpretation that enhanced motivational mobilization by visual arrays elicits enhanced information seeking and intake.

Findings regarding the effects of valence and arousal on eye movements during affective picture viewing have been inconsistent (see Introduction). Differences in the experimental procedure and analytical approach might partly explain these discrepancies. For instance, participants in the study by Madan et al. (2018) were required to name as many semantic associates as possible after viewing each picture, whereas participants in the study by Bradley et al. (2011) had no other task than freely scan the pictures. Task demands are likely to affect scanning behavior (Castelhano, Mack, & Henderson, 2009). A contribution of the present study that sets it apart from all previous studies in this domain is that we investigated how each participant's eye gaze behavior related to his/her own self-reported, as opposed to normative, valence and arousal ratings. Affective ratings of specific contents can differ greatly between individuals, even when average ratings at the group level are in line with a priori classifications along the valence and arousal continua.

We wondered whether there would be gender differences in eye gaze behavior consistent with data suggesting greater reactivity to appetitive cues among men and greater reactivity to aversive cues among women (e.g., Andreano et al., 2014; Bradley et al., 2001; Gomez et al., 2016b; Stevens & Hamann, 2012). We found that gender was a significant qualifier of the aforementioned relationships between eye gaze indices and valence ratings (i.e., significant valence x gender interaction); yet, the gender effect was not in line with our prediction of a stronger association between self-rated unpleasantness and eye gaze parameters for women than for men. Men had significantly higher fixation frequency for unpleasant than pleasant pictures, whereas women's fixation frequency varied only as a function of self-rated arousal with no significant differences between pleasant and unpleasant pictures. Consequently, men's fixation frequency was highest for unpleasant high-arousal pictures, whereas women's fixation frequency was highest for both pleasant and unpleasant high-arousal contents. Both genders exhibited a significant relationship between self-rated valence and scanpath length, yet, men's relationship was significantly stronger than women's relationship. Thus, in terms of the relationship between self-rated valence and eye gaze behavior, these findings are consistent with an interpretation that men exhibited a stronger negativity bias in attention than women.

With regard to gender differences in the absolute values, women exhibited higher fixation frequency than men when self-rated valence was positive and longer scanpath across the entire valence-arousal space. A possible interpretation of these findings is that women exhibited a more exploratory eye gaze behavior than men. Findings of eye-tracking studies suggest that women are more exploratory than men (Coutrot, Binetti, Harrison, Mareschal, & Johnston, 2016; Mercer Moss, Baddeley, & Canagarajah, 2012; Rennels & Cummings, 2013; Shen & Itti, 2012). For instance, Coutrot et al. (2016) found that compared to men, women made shorter fixations and larger saccades, and their eye positions were more scattered over actors' faces with a neutral expression. Mercer Moss et al. (2012) reported that women's fixation distributions were more spread out than those of men when looking at stimuli depicting social scenes, landscapes, and art pieces. These gender differences in eye gaze behavior could be seen as being in accordance with the selectivity hypothesis of information processing. According to this hypothesis, males are selective processors considering only a subset of all available information in apprehending environmental cues as basis for judgement, whereas females are comprehensive processors engaging in more detailed elaboration of all available information (Darley & Smith, 1995; Meyers-Levy, 1989).

With regard to age, we were interested in determining whether there would be age effects on eye gaze behavior consistent with the age-related positivity effect in visual attention to affective stimuli (Reed & Carstensen, 2012; Reed et al., 2014). We did not obtain any significant valence by age group interaction that would support this hypothesis. Rather, we found that younger, middle-aged, and older adults were not significantly different from each other in the relationships between their affective ratings and their eye gaze movements. This contrasts with other eye-tracking studies that have provided support for the age-related positivity effect hypothesis in attention to affective stimuli (see Isaacowitz 2012, for a summary) but is in accordance with others who have failed to report age-related differences in eye gaze behavior consistent with the positivity effect hypothesis (see Reed et al., 2014, for a meta-analysis). These discrepancies could be explained by methodological aspects as results differed significantly when different paradigms were used to investigate the age-related positivity effect in visual attention (Isaacowitz et al., 2006b). Another explanation for the mixed findings of eye-tracking studies is that age differences in attention to affective cues may not depend on whether stimuli are pleasant or unpleasant but may rather be content/emotion specific. The analyses of the responses to the single series revealed that younger adults had significantly higher fixation frequency and longer scanpath than both middle-aged and older adults for the physical violence series. For no other series, the age effect was significant and consistent for both eye gaze measures. This finding would be in agreement with an interpretation that middle-aged and older adults were less willing than younger adults to explore specifically pictures showing physical violence. Interestingly, older adults fixated significantly less on afraid and angry faces than their younger counterparts but not on sad faces (Isaacowitz et al., 2006a,b). Afraid and angry faces are often the facial expressions of the victim and the perpetrator of physical violence, respectively. Investigating to what extent discrete emotions theories (e.g., Consedine, Magai, & King, 2004) as opposed to dimensional perspectives of emotion can help explain age differences in eye gaze behavior is an important area to pursue. Finally, the age-related positivity effect is reduced when experimental instructions to the participants impose goals that interfere with chronically activated goals (Reed et al., 2014). Instructions in the present study were minimal. Nevertheless, we cannot exclude that asking participants to look at the screen at all times and to provide affective ratings influenced participants' eye gaze behavior in such a way that age-related positivity effects were abolished.

As anticipated, fixation frequency and scanpath length decreased significantly across the six similar pictures forming each series. These findings extend previous work showing that fixation frequency and scanpath length are reduced when processing the exact same picture repeatedly as compared to processing novel pictures (Bradley et al., 2011) and contribute to the body of research regarding habituation of emotional responses when exposure to affective stimuli is prolonged (Ferrari et al., 2011). Our results are consistent with an interpretation that with presentation of each new stimulus that is thematically and affectively similar to the immediately preceding ones, information seeking decreases. Moreover, this decrease in scanning behavior was modulated by self-rated arousal and age. Specifically, the decrease in fixation frequency and scanpath length with repeated exposure was largest for series rated as low arousal and smallest for series rated as high arousal. This finding could be understood from the perspective of motivational significance. On average, high-arousal stimuli are supposed to bear more relevance to the observer’s goals (e.g., survival of the individual) than low-arousal stimuli. Heightened visual search for relevant information during prolonged exposure to high-arousal pictures as compared to low-arousal pictures would appear advantageous in order to guarantee appropriate behavioral responses to motivationally highly relevant cues and ultimately facilitate the survival of the individual.

The decrease in fixation frequency and scanpath length across the six pictures of the series was smallest among younger participants and largest among older participants. This finding is in accordance with an interpretation that information seeking and intake decreased more rapidly with prolonged exposure to thematically and affectively similar pictures among older adults than younger adults. There were no overall differences in fixation frequency and scanpath length between age groups. The age effect was specific to the decrease in scanning behavior within each series. Studies are needed to replicate this finding and explore plausible mechanisms for it. We tentatively suggest that this effect may reflect an age-related strategy aiming at optimizing allocation of attentional resources which may decrease with aging (Erel & Levy, 2016; Zanto & Gazzaley, 2014). Alternatively, this finding might be seen as being in accordance with tenets of the socioemotional selectivity theory, according to which gathering information is a future-oriented goal that young adults tend to prioritize more than older adults (Carstensen, 2006). Because the goal of acquiring information is less strongly activated in older than in younger adults, older adults might tend to disengage their attention more quickly than younger adults during repeated exposure to thematically and affectively similar information.

The findings of this study are qualified by the following limitations. Although the 14 series covered a broad range of real-life themes, and we adjusted for the effects of several properties of the pictures in our analyses, we cannot exclude that the observed effects are due to the specific pictures shown to the participants. Second, we showed 1-minute series of six images each and collected one valence and one arousal rating per series. It remains to be determined whether our findings are reproduced when pictures are shown separately and ratings are obtained for each picture. Third, we presented series each consisting of thematically and affectively similar pictures. Future work may investigate how eye gaze movements change across pictures that are affectively different but thematically similar or affectively similar but thematically different (Bradley et al., 1996). This would help determine to what extent the observed effects of picture position on eye gaze indices are due to the thematic or affective similarity of the pictures. Finally, interpretation of the results regarding age-related vs. cohort effects requires caution because of the cross-sectional study design.

In conclusion, we have shown that, across participants, fixation frequency and scanpath length increase with self-reported unpleasantness and arousal. The associations between self-rated valence and the eye gaze indices are weaker among women than men. Compared to men, women exhibit a more exploratory eye gaze behavior. With presentation of each new stimulus that is thematically and affectively similar to the immediately preceding ones, fixation frequency and scanpath length progressively decrease. This decrease is arousal- and age-dependent.

These results have implications for models of emotion and more applied fields such as clinical psychology and human-technology interaction. Fixation frequency and scanpath length could be valuable sources of information to assess a person's moment-by-moment affective state noninvasively and nonverbally. This information could be used to understand, diagnose, and treat various disorders (e.g., anxiety, autism; Armstrong & Olatunji, 2012; Wang, Jiang, Duchesne, Laugeson, Kennedy, Adolphas, & Zhao, 2015) and to build interactive systems that are able to recognize users' affective state and respond accordingly (Picard, 1997; Zimmermann, Guttormsen, Danuser, & Gomez, 2003).

Appendix A. Supplementary data

Supplementary data to this article can be found online at ….

Author note

Patrick Gomez, Institut universitaire romand de Santé au Travail (Institute for Work and Health), https://orcid.org/0000-0001-7463-1858; Armin von Gunten, Service of Old Age Psychiatry, Department of Psychiatry, Lausanne University Hospital, https://orcid.org/0000-0001-7852-3803; Brigitta Danuser, Institut universitaire romand de Santé au Travail (Institute for Work and Health), University of Lausanne and University of Geneva, https://orcid.org/0000-0003-2017-2232.

This research was supported by a grant of the Opo Stiftung (Zurich, Switzerland) to Patrick Gomez and Brigitta Danuser.

We acknowledge the contribution of Miryam Cornaz, Olivier Fortini, and Bérengère Philippon to data collection.

Correspondence concerning this article should be addressed to Patrick Gomez, Institut universitaire romand de Santé au Travail, Route de la Corniche 2, 1066 Epalinges-Lausanne, Switzerland. Phone: +41 21 314 49 88; E-mail: Patrick.gomez@hospvd.ch

Declarations of interest: none

References

Allard, E.S., Isaacowitz, D.M., 2008. Are preferences in emotional processing affected by distraction? Examining the age-related positivity effect in visual fixation within a dual-task paradigm. Neuropsychol. Dev. Cogn. B Aging Neuropsychol. Cogn. 15, 725-743. http://dx.doi.org/10.1080/13825580802348562.

Andreano, J.M., Dickerson, B.C., Barrett, L.F., 2014. Sex differences in the persistence of the amygdala response to negative material. Soc. Cogn. Affect. Neurosci. 9, 1388–1394. http://dx.doi.org/10.1093/scan/nst127.

Armstrong, T., Olatunji, B.O., 2012. Eye tracking of attention in the affective disorders: A meta-analytic review and synthesis. Clin. Psychol. Rev. 32, 704-723. http://dx.doi.org/10.1016/j.cpr.2012.09.004.

Baumeister, R.F., Bratslavsky, El., Finkenauer, C., Vohs, K.D., 2001. Bad is stronger than good. Rev. Gen. Psychol. 5, 323-370. http://dx.doi.org/10.1037/1089-2680.5.4.323.

Blakemore, R.L., Rieger, S.W., Vuilleumier, P. 2016. Negative emotions facilitate isometric force through activation of prefrontal cortex and periaqueductal gray. Neuroimage 124, 627-640. http://dx.doi.org/10.1016/j.neuroimage.2015.09.029.

Bradley, M.M., Lang, P.J., 2007. Emotion and motivation. In: Cacioppo, J.T., Tassinary, L.G., Berntson, G.G. (Eds.), Handbook of psychophysiology. Cambridge University Press, New York, NY, pp. 581–607.

Bradley, M.M., Cuthbert, B.N., Lang, P.J., 1996. Picture media and emotion: effects of a sustained affective context. Psychophysiology 33, 662-670. http://doi.org/10.1111/j.1469-8986.1996.tb02362.x.

Bradley, M.M., Codispoti, M., Sabatinelli, D., Lang, P.J., 2001. Emotion and motivation II: sex differences in picture processing. Emotion 1, 300–319. http://dx.doi.org/10.1037/1528-3542.1.3.300.

Bradley, M.M., Hamby, S., Low, A., Lang, P. J., 2007. Brain potentials in perception: picture complexity and emotional arousal. Psychophysiology 44, 364-373. http://doi.org/10.1111/j.1469-8986.2007.00520.x.

Bradley, M.M., Houbova, P., Miccoli, L., Costa, V.D., Lang, P.J., 2011. Scan patterns when viewing natural scenes: emotion, complexity, and repetition. Psychophysiology 48, 1544-1553. http://dx.doi.org/10.1111/j.1469-8986.2011.01223.x.

Campagne, A., Pebayle, T., Muzet, A., 2005. Oculomotor changes due to road events during prolonged monotonous simulated driving. Biol. Psychol. 68, 353–368. http://dx.doi.org/10.1016/j.biopsycho.2004.05.003.

Carretie, L., Mercado, F., Tapia, M., Hinojosa, J.A., 2001. Emotion, attention, and the ‘negativity bias’, studied through event-related potentials. Int. J. Psychophysiol. 41, 75–85. https://doi.org/10.1016/S0167-8760(00)00195-1.

Carstensen, L.L., 2006. The influence of a sense of time on human development. Science 312, 1913–1915. https://doi.org/10.1126/science.1127488.

Carstensen, L.L., Pasupathi, M., Mayr, U., Nesselroade, J.R., 2000. Emotional experience in everyday life across the adult life span. J. Pers. Soc. Psychol. 79, 644-655. http://dx.doi.org/10.1037/0022-3514.79.4.644.

Carstensen, L.L., Turan, B., Scheibe, S., Ram, N., Ersner-Hershfield, H., Samanez-Larkin, G.R., Brooks, K.P., Nesselroade, J.R., 2011. Emotional experience improves with age: evidence based on over 10 years of experience sampling. Psychol. Aging 26, 21-33. http://dx.doi.org/10.1037/a0021285.

Castelhano, M.S., Mack, M.L., Henderson, J.M., 2009. Viewing task influences eye movement control during active scene perception. J. Vis. 9, 1–15. http://dx.doi.org/10.1167/9.3.6.

Charles, S.T., Carstensen, L.L., 2010. Social and emotional aging. Annu. Rev. Psychol. 61, 383-409. http://dx.doi.org/10.1146/annurev.psych.093008.100448.

Chuk, T., Chan, A.B., Hsiao, J.H., 2014. Understanding eye movements in face recognition using hidden Markov models. J. Vis. 14, 1–14. http://dx.doi.org/10.1167/14.11.8.

Codispoti, M., Bradley, M.M., Lang, P.J., 2001. Affective reactions to briefly presented pictures. Psychophysiology 38, 474–478. http://dx.doi.org/10.1111/1469-8986.3830474.

Consedine, N.S., Magai, C., King, A.R., 2004. Deconstructing positive affect in later life: A differential functionalist analysis of joy and interest. Int. J. Aging Hum. Dev. 58, 49–68. http://dx.doi.org/10.1167/14.11.8.

Coutrot, A., Binetti, N., Harrison, C., Mareschal, I., Johnston, A., 2016. Face exploration dynamics differentiate men and women. J. Vis. 16, 1-19. http://dx.doi.org/10.1167/16.14.16.

Darley, W.K., Smith, R.E., 1995. Gender Differences in Information Processing Strategies: An Empirical Test of the Selectivity Model in Advertising Response. J. Advert. 24, 41-56. http://dx.doi.org/10.1080/00913367.1995.10673467.

Dietz, J., Bradley, M.M., Okun, M.S., Bowers, D., 2011. Emotion and ocular responses in Parkinson's disease. Neuropsychologia 49, 3247-3253. http://dx.doi.org/10.1016/j.neuropsychologia.2011.07.029.

Donderi, D.C., 2006. Visual complexity: a review. Psychol. Bull. 132, 73-97. http://dx.doi.org/10.1037/0033-2909.132.1.73.

Eisenstein, E.M., Eisenstein, D., Smith, J.C., 2001. The evolutionary significance of habituation and sensitization across phylogeny: A behavioral homeostasis model. Integrative Physiol. Behav. Sci. 36, 251-265. http://dx.doi.org/10.1007/Bf02688794.

Erel, H., Levy, D.A., 2016. Orienting of visual attention in aging. Neurosci Biobehav Rev 69, 357-380. http://dx.doi.org/10.1016/j.neubiorev.2016.08.010.

Ferrari, V., Bradley, M.M., Codispoti, M., Lang, P. J., 2011. Repetitive exposure: Brain and reflex measures of emotion and attention. Psychophysiology 48, 515–522. http://dx.doi: 10.1111/j.1469-8986.2010.01083.x.

Fischer, A.H., 2000. Gender and Emotion: Social Psychological Perspectives. Cambridge University Press, Cambridge, UK (331 pp.).

Gard, M.G., Kring, A.M., 2007. Sex differences in the time course of emotion. Emotion 7, 429–437. http://dx.doi.org/10.1037/1528-3542.7.2.429.

Globisch, J., Hamm, A.O., Esteves, F., Ohman, A., 1999. Fear appears fast: temporal course of startle reflex potentiation in animal fearful subjects. Psychophysiology 36, 66–75. https://doi.org/10.1017/S0048577299970634.

Gomez, P., Danuser, B., 2010. Cardiovascular patterns associated with appetitive and defensive activation during affective picture viewing. Psychophysiology 47, 540–549. http://dx.doi.org/10.1111/j.1469-8986.2009.00953.x.

Gomez, P., Shafy, S., Danuser, B., 2008. Respiration, metabolic balance, andattention in affective picture processing. Biol. Psychol. 78, 138–149. http://dx.doi.org/10.1016/j.biopsycho.2008.01.013.

Gomez, P., von Gunten, A., Danuser, B., 2013. Content-specific gender differences in emotion ratings from early to late adulthood. Scand. J. Psychol. 54, 451-458. http://dx.doi.org/10.1111/sjop.12075.

Gomez, P., Filippou, D., Pais, B., von Gunten, A., Danuser, B., 2016a. Breathing and affective picture processing across the adult lifespan. Biol. Psychol. 116, 101–111. http://dx.doi.org/10.1016/j.biopsycho.2016.07.011.

Gomez, P., von Gunten, A., Danuser, B., 2016b. Autonomic nervous system reactivity within the valence-arousal affective space: modulation by sex and age. Int. J. Psychophysiol. 109, 51–62.

Grossman, M., Wood, W., 1993. Sex differences in intensity of emotional experience: a social role interpretation. J. Pers. Soc. Psychol. 65, 1010–1022. http://dx.doi.org/10.1037/0022-3514.65.5.1010.

Hamann, S., Herman, R.A., Nolan, C.L., Wallen, K., 2004. Men and women differ in amygdala response to visual sexual stimuli. Nat. Neurosci. 7, 411–416. http://dx.doi.org/10.1038/nn1208.

Henderson, J. M., 2003. Human gaze control during real-world scene perception. Trends Cogn. Sci. 7, 498-504. http://dx.doi.org/10.1016/j.tics.2003.09.006.

Hillman, C.H., Rosengren, K.S., Smith, D.P., 2004. Emotion and motivated behavior: postural adjustments to affective picture viewing. Biol. Psychol. 66, 51–62. http://dx.doi.org/10.1016/j.biopsycho.2003.07.005.

Holmqvist, K., Nyström, M., Andersson, R., Dewhurst, R., Jarodzka, H., van de Weijer, J., 2011. Eye tracking – A comprehensive guide to methods and measures. Oxford University Press, New York, NY, 537 pp.

Hyde, J.S., Mezulis, A.H., Abramson, L.Y., 2008. The ABCs of depression: Integrating affective, biological, and cognitive models to explain the emergence of the gender difference in depression. Psychol. Rev. 115, 291–313. http://dx.doi.org/10.1037/0033-295X.115.2.291.

Isaacowitz, D.M., 2012. Mood regulation in real time: Age differences in the role of looking. Curr. Dir. Psychol. Sci. 21, 237–242. http://dx.doi.org/10.1177/0963721412448651.

Isaacowitz, D.M., Choi, Y., 2011. The malleability of age-related positive gaze preferences: training to change gaze and mood. Emotion 11, 90-100. http://dx.doi.org/10.1037/a0021551.

Isaacowitz, D.M., Wadlinger, H.A., Goren, D., Wilson, H.R., 2006a. Selective preference in visual fixation away from negative images in old age? An eye-tracking study. Psychol. Aging 21, 40–48. http://dx.doi.org/10.1037/0882-7974.21.1.40.

Isaacowitz, D. M., Wadlinger, H.A., Goren, D., Wilson, H.R., 2006b. Is there an age-related positivity effect in visual attention? A comparison of two methodologies. Emotion 6, 511-516. http://dx.doi.org/10.1037/1528-3542.6.3.511.

Isaacowitz, D.M., Toner, K., Goren, D., Wilson, H.R., 2008. Looking while unhappy: mood-congruent gaze in young adults, positive gaze in older adults. Psychol. Sci. 19, 848-853. http://dx.doi.org/10.1111/j.1467-9280.2008.02167.x.

Kertesz, A., 1982. Western Aphasia Battery. Psychological Corp, San Antonio, TX.

Lang, P.J., Bradley, M.M., 2010. Emotion and the motivational brain. Biol. Psychol. 84, 437–450. http://dx.doi.org/10.1016/j.biopsycho.2009.10.007.

Lang, P.J., Bradley, M.M., Cuthbert, B.N., 2005. International affective picture system (IAPS): digitized photographs, instruction manual and affective ratings. Technical Report A-6. The Center for Research in Psychophysiology, University of Florida, Gainesville (FL).

Lindenberger, U., Mayr, U., Kliegl, R., 1993. Speed and intelligence in old age. Psychol. Aging 8, 207–220. http://dx.doi.org/10.1037/0882-7974.8.2.207.

Löw, A., Bradley, M.M., Lang, P.J., 2013. Perceptual processing of natural scenes at rapid rates: effects of complexity, content, and emotional arousal. Cogn. Affect. Behav. Neurosci. 13, 860-868. http://dx.doi.org/10.3758/s13415-013-0179-1.

Madan, C.R., Bayer, J., Gamer, M., Lonsdorf, T.B., Sommer, T., 2018. Visual complexity and affect: Ratings reflect more than meets the eye. Front. Psychol. 8, 2368. http://dx.doi.org/10.3389/fpsyg.2017.02368.

Marin, M.M., Leder, H., 2013. Examining complexity across domains: relating subjective and objective measures of affective environmental scenes, paintings and music. PLoS One 8(8), e72412. http://dx.doi.org/10.1371/journal.pone.0072412.

Mercer Moss, F.J., Baddeley, R., Canagarajah, N., 2012. Eye movements to natural images as a function of sex and personality. PLoS One 7, e47870. http://dx.doi.org/10.1371/journal.pone.0047870.

Merckelbach, H., Vanhout, W., Vandenhout, M.A., & Mersch, P.P., 1989. Psychophysiological and subjective reactions of social phobics and normals to facial stimuli. Behav. Res. Ther. 27, 289–294. https://doi.org/10.1016/0005-7967(89)90048-X.

Meyers-Levy, J., 1989. Gender differences in information processing: a selectivity interpetation. In: Cafferata, P.C., Tybout, A.M. (Eds.), Cognitive and affective responses to advertising. Lexington Books, Lexington, MA, pp. 219–260.

Nakagawa, S., Schielzeth, H., 2013. A general and simple method for obtaining R2 from generalized linear mixed-effects models. Methods Ecol. Evol. 4, 133–142. http://dx.doi.org/10.1111/j.2041-210x.2012.00261.x.

Ni, J., Jiang, H., Jin, Y., Chen, N., Wang, J., Wang, Z., Luo, Y., Ma, Y., Hu, X., 2011. Dissociable modulation of overt visual attention in valence and arousal revealed by topology of scan path. PLoS One 6: e18262. http://dx.doi.org/10.1371/journal.pone.0018262.

Omori, Y. (2005). Spontaneous eyeblink activity during repetitive pleasant–unpleasant visual stimuli. Psychophysiology, 42, S97.

Picard, R.W., 1997. Affective computing. MIT Press, Cambridge, MA, 306 pp.

Pratto, F., John, O.P., 1991. Automatic vigilance: the attention-grabbing power of negative social information. J. Pers. Soc. Psychol. 61, 380–391. http://dx.doi.org/10.1037/0022-3514.61.3.380.

Reed, A.E., Carstensen, L.L., 2012. The theory behind the age-related positivity effect. Front. Psychol. 3, 339–347. http://dx.doi.org/ 10.3389/fpsyg.2012.00339.

Reed, A.E., Chan, L., Mikels, J.A., 2014. Meta-analysis of the age-related positivity effect: age differences in preferences for positive over negative information. Psychol. Aging 29, 1–15. http://dx.doi.org/10.1037/a0035194.

Rennels, J.L., Cummings, A.J., 2013. Sex differences in facial scanning: similarities and dissimilarities between infants and adults. Int. J. Behav. Dev. 37, 111-117. http://dx.doi.org/10.1177/0165025412472411.

Richard, J., Bouzourène, K., Gallant, S., Ricciardi, P., Sudre, P., Iten, A., Burnand, B., 2000. Validation et normes du SF-36 dans la population du canton Vaud. Institut universitaire de médecine sociale et préventive (Raison de santé, 28), Lausanne, Switzerland.

Rozin, P., Royzman, E.B., 2001. Negativity bias, negativity dominance, and contagion. Pers. Soc. Psychol. Rev. 5, 296–320. http://dx.doi.org/10.1207/s15327957pspr0504_2.

Rupp, H.A.,Wallen, K., 2008. Sex differences in response to visual sexual stimuli: a review. Arch. Sex. Behav. 37, 206–218. http://dx.doi.org/10.1007/s10508-007-9217-9.

Sabatinelli, D., Flaisch, T., Bradley, M.M., Fitzsimmons, J.R., Lang, P.J., 2004. Affective picture perception: gender differences in visual cortex? Neuroreport 15, 1109–1112. http://dx.doi.org/10.1097/00001756-200405190-00005.

Salvucci, D.D., Goldberg, J.H., 2000. Identifying fixations and saccades in eye-tracking protocols. In: Proceedings of the Eye Tracking Research and Applications Symposium, ACM Press, New York, NY, pp. 71-78.

Schimmack, U., 2005. Attentional interference effects of emotional pictures: threat, negativity, or arousal? Emotion 5, 55–66. http://dx.doi.org/10.1037/1528-3542.5.1.55.

SensoMotoric Instruments, 2014. BeGaze Manual, version 3.4, 388 pp.

Shen, J., Itti, L., 2012. Top-down influences on visual attention during listening are modulated by observer sex. Vision Res. 65, 62-76. http://dx.doi.org/10.1016/j.visres.2012.06.001.

Simola, J., Le Fevre, K., Torniainen, J., Baccino, T., 2015. Affective processing in natural scene viewing: valence and arousal interactions in eye-fixation-related potentials. Neuroimage 106, 21-33. http://dx.doi.org/10.1016/j.neuroimage.2014.11.030.

Smith, N.K., Cacioppo, J.T., Larsen, J.T., Chartrand, T.L., 2003. May I have your attention, please: electrocortical responses to positive and negative stimuli. Neuropsychologia 41, 171–183. https://doi.org/10.1016/S0028-3932(02)00147-1.

Stern, J.A., Walrath, L.C., Goldstein, R., 1984. The endogenous eyeblink. Psychophysiology 21, 22–33. https://doi.org/10.1111/j.1469-8986.1984.tb02312.x.

Stevens, J.S., Hamann, S., 2012. Sex differences in brain activation to emotional stimuli: a meta-analysis of neuroimaging studies. Neuropsychologia 50, 1578–1593. http://dx. doi.org/10.1016/j.neuropsychologia.2012.03.011.

Tipples, J., Sharma, D., 2000. Orienting to exogenous cues and attentional bias to affective pictures reflect separate processes. Br. J. Psychol. 91, 87–97. http://dx. doi.org/10.1348/000712600161691.

Tombaugh, T.N., Kozak, J., Rees, L., 1999. Normative data stratified by age and education for two measures of verbal fluency: FAS and animal naming. Arch. Clin. Neuropsychol. 14, 167–177. http://dx.doi.org/10.1016/S0887-6177(97)00095-4.

Troisi, A., 2001. Gender differences in vulnerability to social stress: a Darwinian perspective. Physiol. Behav. 73, 443–449.

Veltman, J.A., Gaillard, A.W.K., 1996. Physiological indices of workload in a simulated flight task. Biol. Psychol. 42, 323–342. https://doi.org/10.1016/0301-0511(95)05165-1.

Wang, S., Jiang, M., Duchesne, X.M., Laugeson, E.A., Kennedy, D.P., Adolphs, R., Zhao, Q., 2015. Atypical visual saliency in autism spectrum disorder quantified through model-based eye tracking. Neuron 88, 604-616. https://doi.org/10.1016/j.neuron.2015.09.042.

Ware Jr., J.E., Sherbourne, C.D., 1992. The MOS 36-item short-form health survey (SF-36). I. Conceptual framework and item selection. Med. Care 30, 473–483. http://dx.doi.org/10.1097/00005650-199206000-00002.

Wood, W., Eagly, A.H., 2002. A cross-cultural analysis of the behavior of women and men: implications for the origins of sex differences. Psychol. Bull. 128, 699–727.

Zanto, T.P., Gazzaley, A. 2014. Attention and ageing. In: Nobre, A.C., Kastner, S. (Eds.), The Oxford handbook of attention. Oxford University Press, New York, NY, pp. 927-971.

Zigmond, A.S., Snaith, R.P., 1983. The hospital anxiety and depression scale. Acta Psychiatr. Scand. 67, 361–370. http://dx.doi.org/10.1111/j.1600-0447.1983.tb09716.x.

Zimmermann, P., Guttormsen, S., Danuser, B., Gomez, P., 2003. Affective computing - a rationale for measuring mood with mouse and keyboard. Int. J. Occup. Saf. Ergon. 9, 539-551. https://doi.org/10.1080/10803548.2003.11076589.

Table 1

Participants' characteristics by gender and age group

Variable	Men				Women			
	Younger	Middle-aged	Older	All	Younger	Middle-aged	Older	All
Sample size (n)	29	24	17	70	35	26	26	87
Age (years)	26.5 (0.9)	46.7 (0.8)	65.8 (1.0)	43.0 (1.9)	26.9 (0.8)	46.3 (0.9)	65.7 (0.7)	44.3 (1.8)
Educational level (#)[a]								
Level I	0	1	1	2	0	3	6	9
Level II	4	14	8	28	12	12	11	35
Level III	25	9	8	42	23	11	9	43
Self-reported health								
Anxiety[b]	4.9 (0.4)	4.5 (0.5)	5.9 (0.4)	5.0 (0.3)	5.4 (0.4)	5.1 (0.4)	5.3 (0.5)	5.3 (0.2)
Depression[b]	1.4 (0.2)	2.7 (0.4)	3.1 (0.6)	2.3 (0.2)	1.8 (0.3)	1.8 (0.4)	2.2 (0.4)	1.9 (0.2)
Mental health[c]	71 (3)	74 (3)	71 (4)	72 (2)	71 (3)	71 (3)	77 (4)	73 (2)
Physical functioning[c]	99 (0)	97 (1)	94 (2)	97 (1)	98 (1)	94 (2)	82 (6)	92 (2)
General health[c]	82 (2)	81 (3)	74 (3)	80 (2)	82 (2)	82 (3)	82 (3)	82 (2)
Verbal fluency								
Animal naming task[d]	22.8 (1.0)	21.4 (1.1)	22.8 (1.3)	22.3 (0.6)	23.7 (1.0)	25.0 (1.3)	20.5 (1.2)	23.1 (0.7)

Notes for Table 1

[a] Educational level was divided into three categories: level I = no vocational training with or without practical on-the-job training; education level II: completed vocational training equivalent to apprenticeship or a degree judged equivalent; education level III: baccalaureate with or without later academic studies; values for age, self-reported health, and verbal fluency are means with *SE*s in brackets; [b] HADS (Zigmond & Snaith, 1983), scores between 0 and 21 with higher scores corresponding to more anxiety/depression; [c] SF-36 (Ware & Sherbourne, 1992), scores between 0 and 100 with higher scores corresponding to better health; [d] (Kertesz, 1982), number of animal names in 1 minute.

Table 2 Estimated linear mixed models for fixation frequency and scanpath length

	Fixation frequency						Scanpath length					
	Model 1			Model 2			Model 1			Model 2		
	Coeff.	*SE*	*p*	Coeff.	*SE*	*p*	Coeff.	*SE*	*p*	Coeff.	*SE*	*p*
Intercept	2.308	0.104	**< .001**	2.279	0.120	< .001	4629	333	**< .001**	4514	388	< .001
Valence	-0.005	0.002	**.023**	-0.010	0.005	.004	-56	8	**< .001**	-68	17	< .001
Arousal	0.009	0.003	**.001**	0.004	0.007	.001	23	9	**.011**	29	21	.007
Gender	0.084	0.055	.13	0.132	0.107	.10	566	176	**.002**	770	343	.001
Age group			.26			.23			.22			.23
Younger	0.020	0.070		0.105	0.106		137	225		329	342	
Middle-aged	-0.084	0.071		-0.089	0.108		-232	227		-118	349	
Picture position	-0.022	0.002	**<.001**	-0.036	0.005	<.001	-27	8	**.001**	-50	18	<.001
Valence x arousal				0.000	0.001	.85				6	3	.054
Valence x gender				0.016	0.005	**.002**				40	16	**.010**
Valence x age group						.32						.26
Younger				-0.009	0.006					-30	19	
Middle-aged				-0.006	0.006					-24	20	
Arousal x gender				-0.002	0.006	.67				-26	18	.15
Arousal x age group						.13						.25
Younger				0.014	0.007					30	22	
Middle-aged				0.007	0.008					-1	24	
Gender x age group						.39						.74
Younger females				-0.140	0.136					-338	439	
Middle-aged females				0.021	0.144					-188	465	
Valence x Picture position				0.001	0.001	.50				1	3	.75
Arousal x Picture position				0.002	0.001	**.018**				7	3	**.040**
Gender x Picture position				0.005	0.005	.24				-14	16	.35
Age group x Picture position						**<.001**						**.026**
Younger				0.022	0.006					52	19	
Middle-aged				0.009	0.006					30	20	

Notes for Table 2

Reference categories for gender and age group were men and older adults, respectively. For valence and arousal, coefficients express the change in fixation frequency/scanpath length per 1 point on the 9-point valence and arousal scales. For picture position, coefficients express the change in fixation frequency/scanpath length from one picture to the next one within series. Coeff. = estimated coefficient; *SE* = standard error; *p* = *p* value. The *p* values are from the Type III tests of fixed effects. Significant main effects in model 1 and significant interaction effects in model 2 are marked in bold.

Table 3 Significant gender and age group effects for fixation frequency and scanpath length of specific series

Dependent measures	Effects	Series
	Gender	
Fixation Frequency	♂ < ♀	P: appetizing food, pleasant nature, sport scenes
Scanpath length	♂ < ♀	P: appetizing food, pleasant family scenes, pleasant nature, romantic heterosexual couples, sport scenes; N: household objects, neutral human activities; U: environmental contamination, mutilated/burned bodies, sick/injured human beings, suffering/dead animals
	Age group	
Fixation Frequency	Y > M, O	U: physical violence
Scanpath length	Y > M	P: sport scenes; U: physical violence
	Y > O	U: physical violence
	O > Y, M	N: household objects

Notes for Table 3

♂: male participants, ♀: female participants, Y: younger adults, M: middle-aged adults, O: older adults, P: pleasant series, N: neutral series, U: unpleasant series. Reported gender and age group effects are significant at $p < .05$.

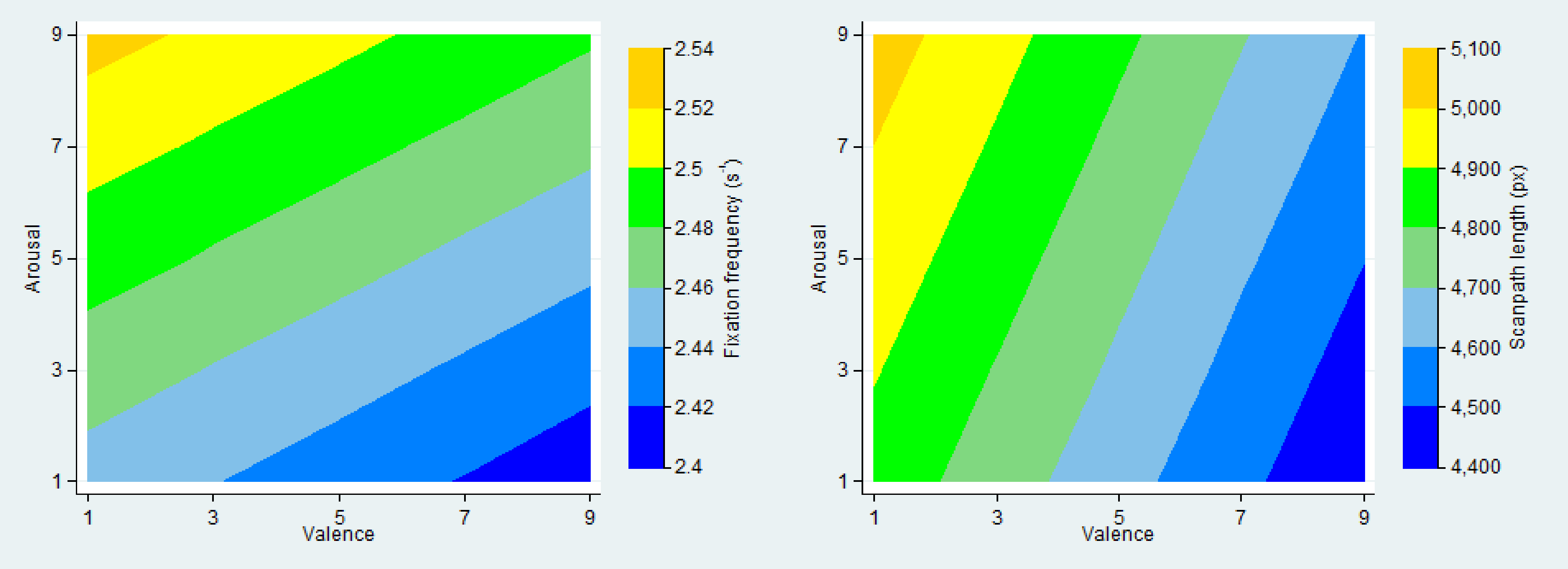
Arousal
Valence
Fixation frequency (s⁻¹)
2.54
2.52
2.5
2.48
2.46
2.44
2.42
2.4
Scanpath length (px)
5,100
5,000
4,900
4,800
4,700
4,600
4,500
4,400

Fig. 1

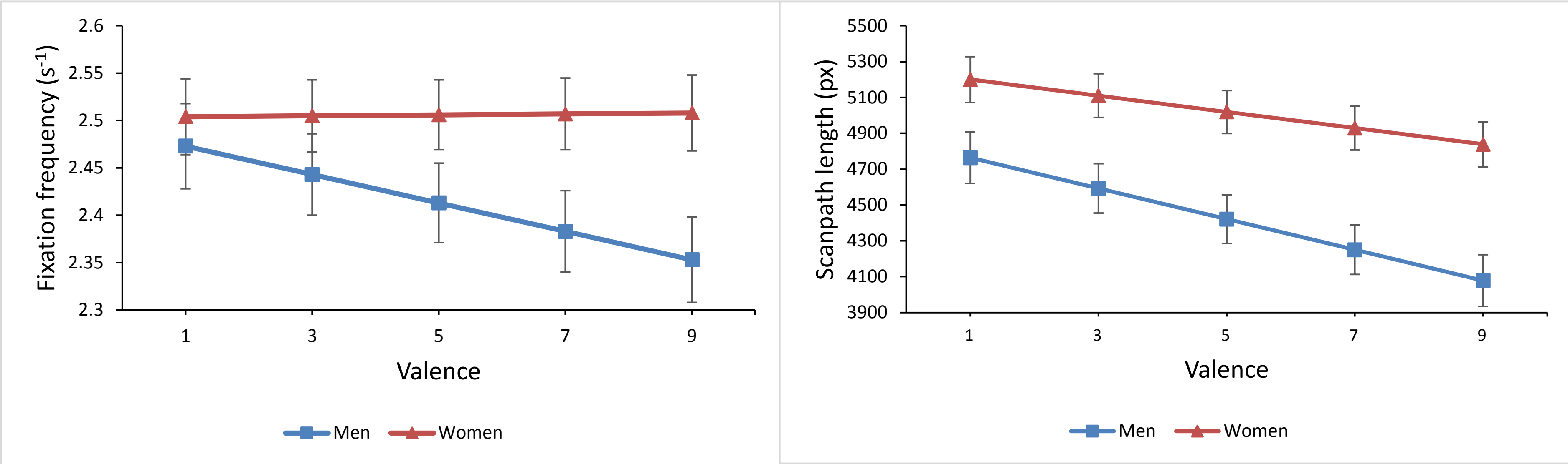
Fixation frequency (s-1)
2.6
2.55
2.5
2.45
2.4
2.35
2.3
1
3
5
7
9
Valence
Men
Women
Scanpath length (px)
5500
5300
5100
4900
4700
4500
4300
4100
3900
1
3
5
7
9
Valence
Men
Women

Fig. 2

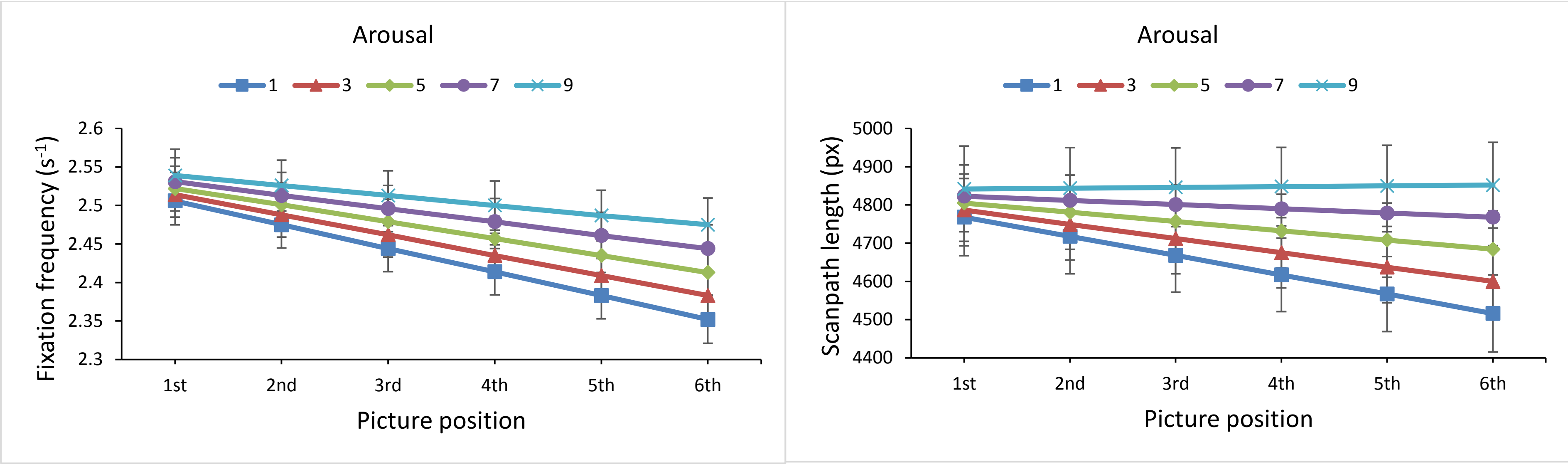
Arousal
1
3
5
7
9
Fixation frequency (s-1)
2.6
2.55
2.5
2.45
2.4
2.35
2.3
1st
2nd
3rd
4th
5th
6th
Picture position
Arousal
1
3
5
7
9
Scanpath length (px)
5000
4900
4800
4700
4600
4500
4400
1st
2nd
3rd
4th
5th
6th
Picture position

Fig. 3

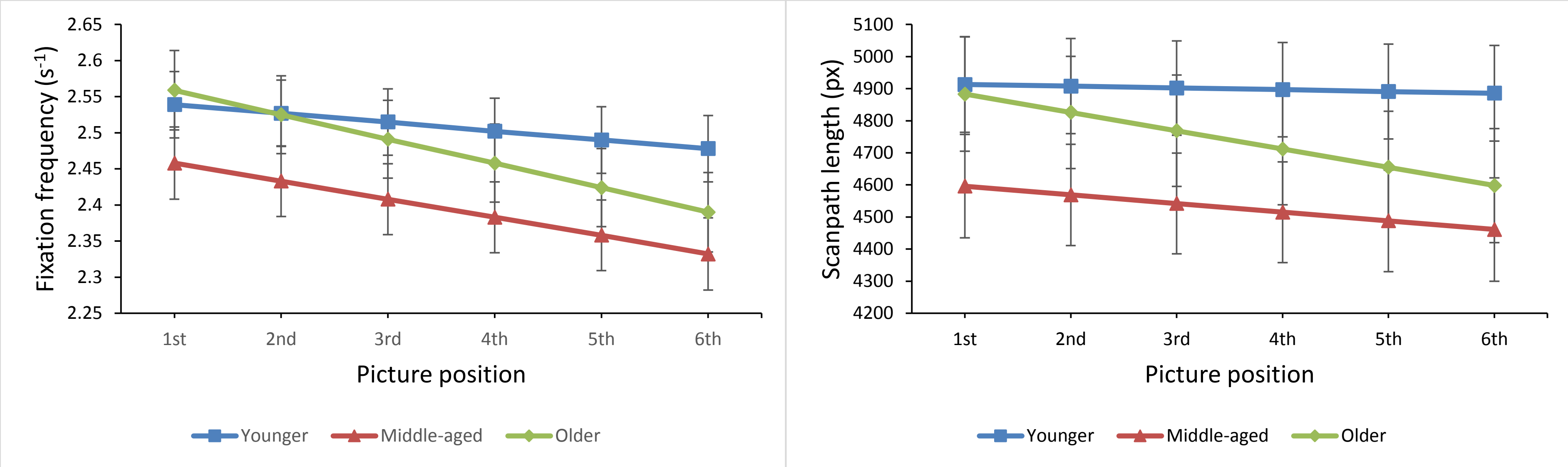
2.65
2.6
2.55
2.5
2.45
2.4
2.35
2.3
2.25
Fixation frequency (s-1)
1st
2nd
3rd
4th
5th
6th
Picture position
Younger
Middle-aged
Older
5100
5000
4900
4800
4700
4600
4500
4400
4300
4200
Scanpath length (px)
1st
2nd
3rd
4th
5th
6th
Picture position
Younger
Middle-aged
Older

Fig. 4

Figure captions

Fig. 1. Model-predicted estimated marginal means of fixation frequency (left) and scanpath length (right) in the space defined by valence ratings on the x-axis (1 = most negative valence, 9 = most positive valence) and arousal ratings on the y-axis (1 = lowest arousal, 9 = highest arousal) averaged across all participants (see Table 2 model 1 for predictors' estimates). *SE*s range from 0.028 to 0.035 for fixation frequency and from 90 to 110 for scanpath length.

Fig. 2. Model-predicted estimated marginal means (*SE*s) of fixation frequency (left) and scanpath length (right) along the valence dimension (1 = most negative valence, 9 = most positive valence) for men and women (see Table 2 model 2 for predictors' estimates).

Fig. 3. Model-predicted estimated marginal means (*SE*s) of fixation frequency (left) and scanpath length (right) across the six pictures of the series (1^{st} to 6^{th} position) for five arousal levels (1 = lowest arousal, 9 = highest arousal) (see Table 2 model 2 for predictors' estimates).

Fig. 4. Model-predicted estimated marginal means (*SE*s) of fixation frequency (left) and scanpath length (right) across the six pictures of the series (1^{st} to 6^{th} position) for younger, middle-aged, and older adults (see Table 2 model 2 for predictors' estimates).