Dynamics of emotional facial expression recognition in individuals with social anxiety

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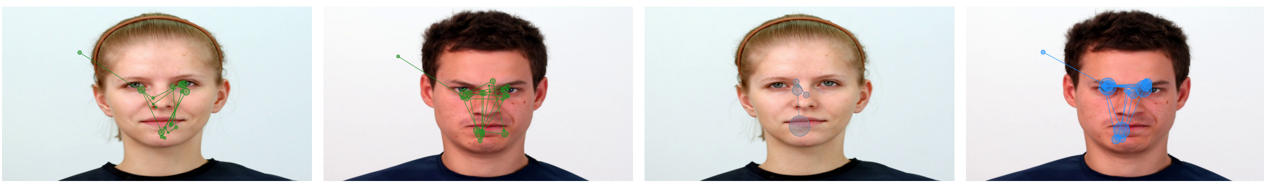

(a) happiness/anxious (b) anger/anxious (c) happiness/non-anxious (d) anger/non-anxious

Figure 1: Exemplary scanpaths over happy and angry faces by (a)–(b) anxious and (c)–(d) non-anxious participants.

ABSTRACT

This paper demonstrates the utility of ambient-focal attention and pupil dilation dynamics to describe visual processing of emotional facial expressions. Pupil dilation and focal eye movements reflect deeper cognitive processing and thus shed more light on the dynamics of emotional expression recognition. Socially anxious individuals ($N = 24$) and non-anxious controls ($N = 24$) were asked to recognize emotional facial expressions that gradually morphed from a neutral expression to one of happiness, sadness, or anger in 10-sec animations. Anxious cohorts exhibited more ambient face scanning than their non-anxious counterparts. We observed a positive relationship between focal fixations and pupil dilation, indicating deeper processing of viewed faces, but only by non-anxious participants, and only during the last phase of emotion recognition. Group differences in the dynamics of ambient-focal attention support the hypothesis of vigilance to emotional expression processing by socially anxious individuals. We discuss the results by referring to current literature on cognitive psychopathology.

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CCS CONCEPTS

• **Applied computing** → **Psychology**;

KEYWORDS

ambient/focal attention, pupil dilation, face scanning

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1 INTRODUCTION

As social animals, we have learned to rapidly and efficiently decode emotional information from facial expressions [Schyns et al. 2008]. One or two eye movements can be enough to recognize a face [Hsiao and Cottrell 2008] and not many more fixations are needed to recognize emotions [Schurgin et al. 2014]. Depending on the type of emotion and its intensity during recognition, some regions of the face elicit more attention than others, e.g., lips of happy faces or eyes of sad faces [Schurgin et al. 2014]. Importantly, visual patterns also depend on individual differences. Cognitive models of social phobia state that there are biases of social threat cue processing that underlie social anxiety [Rapee and Heimberg 1997]. In this paper we aim to examine differences in visual attention dynamics between socially anxious and non-anxious individuals, when decoding emotions from dynamically changing facial expressions.

2 BACKGROUND

Facial emotional expressions reflect an individual's motivational state. Happiness or anger may also reflect a person's intentions, e.g., towards another [Horstmann 2003]. Decoding facial expressions can be a rapid and useful source of information about another's behavior [Haxby et al. 2000]. Consequently, we tend to avoid people who express annoyance, and we are attracted to those who smile [Van Kleef et al. 2011]. Recent studies show that among the six classic facial expressions, four are innate and universal (happy, sad, fear/surprise, disgust/anger) [Jack et al. 2014], transmitting information deeply rooted in the perceptual expectations of others.

Facial expressions of basic emotions are produced with specific facial muscle constrictions leading to perceptual features needed for discriminating between different emotional expressions [Ekman 1978; Jack et al. 2014]. However, different regions of a face may contain differing amounts of information required for facial emotion recognition [Smith et al. 2005]. Furthermore, those signals are transmitted in specific sequences over time, which cause observers to dynamically scan for sufficient information over different regions of the face for successive categorization of emotion [Delis et al. 2016]. Despite these universalities, the question arises as to what extent are patterns of facial expression recognition modulated by individual differences, such as those stemming from social anxiety.

2.1 Attentional Biases in Social Anxiety

Early models of social phobia [Clark and Wells 1995; Rapee and Heimberg 1997] implicated the role of biased processing of socially threatening information in the maintenance of elevated social anxiety. These models made diverse predictions about the nature of the biases. Attentional biases in anxious individuals may reflect faster orienting (the vigilance hypothesis), and/or difficulty in disengaging attention from threat (the maintenance hypothesis) compared to non-anxious individuals [Weierich et al. 2008]. A meta-analysis of eye-tracking studies of affective disorders [Armstrong and Olatunji 2012] provided support for the vigilance rather than the maintenance hypothesis in anxious individuals [Holas et al. 2014].

Clark and Wells [1995] posited that people with social anxiety are more introverted, monitoring their own internal state, not attending to external threat signals. In contrast, Rapee and Heimberg [1997] claimed that socially anxious individuals simultaneously attend to internal cues and external stimuli potentially indicative of threat, such as angry facial expressions. In line with the model, social phobics have been found to exhibit greater *hyperscanning* of face stimuli than controls [Horley et al. 2003, 2004]. This hyperscanning strategy, reflected by an increase in scanpath length suggesting ambient processing, was observed across happy and angry faces.

A revised model of social phobia [Heimberg et al. 2010] emphasizes the relevance of fear of positive valence in addition to fear of negative valence in the maintenance of social anxiety. Thus, it is important to consider attentional biases to both negative and positive stimuli when studying social phobia. Several studies demonstrated biases in attention to both positive and negative facial expressions in social anxiety, with some reporting similar biases toward both expressions [Garner et al. 2006; Schofield et al. 2012]. Some studies indicate that social phobics disengage faster from positive social stimuli than controls [Chen et al. 2012; Schofield et al. 2013]. The latter result indicates that attention bias in social anxiety may be driven by a relative lack of biases seen in non-anxious participants.

2.2 Ambient and Focal Attention

The process of viewing is a dynamic interplay between fixations and saccades. Pannasch et al. [2008] showed a systematic increase in fixation durations and decrease of saccadic amplitudes over the time course of scene perception. This relationship appears very stable across a variety of studied conditions, including repeated presentation of similar stimuli, object density, emotional stimuli, and mood induction. Specifically, short fixations followed by long saccades are characteristic of *ambient* processing, while longer fixations followed by shorter saccades are indicative of *focal* processing [Unema et al. 2005]. Focal and ambient modes of visual information processing change dynamically. At early stages of visual perception, shorter fixations and longer saccades govern initial stimuli exploration. Once a target has been selected, longer fixations are followed by shorter saccades suggesting a change to focal processing [Irwin and Zelinsky 2002; Velichkovsky et al. 2005]. Focal attention is indicative of deeper information processing. This dynamic pattern of visual attention can be attributed to two modes of acquiring information: exploration and inspection.

Mathematical expressions relating fixation duration and saccadic amplitude immediately following a fixation have been proposed for analysis of static and dynamic viewing [Krejtz et al. 2012; Velichkovsky et al. 2005]. Holmqvist et al. [2011] review several means of operationalization of ambient/focal viewing, including thresholding on the ratio of fixation duration to saccade amplitude, among others. None of these approaches, however, explicitly consider dynamics of how the fixation duration/saccade amplitude ratio changes over time. Instead, we decided to use the $\mathcal{K}$ coefficient [Krejtz et al. 2012], which combines fixations and saccades into a single dynamic stream capturing the interplay of ambient and focal modes allowing for temporal analysis. Specifically, the ambient/focal $\mathcal{K}$ coefficient is calculated for each participant as the mean difference between standardized values (z-scores) of each saccade amplitude (a_{i+1}) and preceding i^{th} fixation duration (d_i),

$$\mathcal{K}_i = \frac{d_i - \mu_d}{\sigma_d} - \frac{a_{i+1} - \mu_a}{\sigma_a}, \quad \text{such that} \quad \mathcal{K} = \frac{1}{n}\sum_{n}\mathcal{K}_i, \quad (1)$$

where μ_d, μ_a are the mean fixation duration and saccade amplitude, respectively, and σ_d, σ_a are the fixation duration and saccade amplitude standard deviations, respectively, computed over all n fixations and hence n $\mathcal{K}_i$ coefficients (i.e., over the entire duration of stimuli presentation) [Krejtz et al. 2012, 2017, 2016]. Note that computed means (μ_d and μ_a) and standard deviations (σ_d and σ_a) in (1) refer to sample statistics and are computed over all conditions and for all participants. Values close to zero indicate relative similarity between fixation durations and saccade amplitudes (in terms of their distance from their means). Values of $\mathcal{K} > 0$ indicate relatively long fixations followed by short saccade amplitudes, suggesting focal processing. Analogously, $\mathcal{K} < 0$ refers to the situation when relatively short fixations are followed by relatively long saccades, suggesting ambient processing.

We use $\mathcal{K}$ to examine group differences in ambient/focal attention during recognition of dynamical facial expressions. We link ambient/focal attention with change in pupil dilation, an indicator of cognitive and emotional processing (see Duchowski et al. [2018] for a review of cognitive load and pupillometry).

2.3 Pupil Dilation

Pupil dilation is related to mental activity [Ahern and Beatty 1979; Hess and Polt 1960] and affect of the attended stimulus [Siegle et al. 2003]. Bradley et al. [2008] suggested that pupil dilation could be a physiological marker of the autonomic response associated with visual emotional processing. They observed that pupil responses to neutral images were smaller than to pleasant and unpleasant ones. Siegle et al. [2003] have shown larger pupil dilation among depressed individuals while attending to mood-congruent stimuli.

Pupil changes are also related to the decision-making process and its termination. de Gee et al. [2014] monitored pupil size while participants decided whether dynamic noise contained the presence or absence of an embedded visual signal. Pupil size significantly increased during formation of the decision. de Gee et al. [2014] concluded that the central neuromodulatory systems controlling pupil size are continuously engaged during decision-making. Urai et al. [2017] reported significantly smaller pupil dilation after correct decisions and larger pupil dilation after a wrong decision.

We examine characteristics of pupillary reaction during recognition of emotional faces among socially anxious and non-anxious individuals. Studies indicate that anxious people show decreased sustained pupil dilation to negative stimuli, possibly consistent with decreased regulatory control [Oathes et al. 2011; Price et al. 2013]. We expect that, during the time course of emotion recognition, pupil dilation combined with the distinction between ambient/focal attention will reveal group differences in dynamic processing of socio-emotional stimuli.

2.4 The Present Study

The present study investigates the dynamics of ambient/focal attention and pupil dilation during emotion recognition. Our aim is to to provide support for the hyperscanning [Horley et al. 2004] and maintenance hypotheses in anxiety [Weierich et al. 2008], in the context of dynamical stimuli. We offer substantial methodological improvements over previous work. To the best of our knowledge, only a few studies have evaluated attention to emotional expressions using dynamical faces [Torro-Alves et al. 2016] beyond three seconds of exposure [Armstrong and Olatunji 2012]. We use dynamical facial expressions displayed for a maximum of 10 seconds.

Recio et al. [2011] suggest that presentation of dynamic facial expressions increases attention to faces in a bottom-up way. We use this as a basis for observing differences between socially anxious and non-anxious groups during emotion recognition. The use of dynamic faces may reduce or eliminate the differences between individuals with high and low social anxiety in the recognition of facial emotions. For example, Torro-Alves et al. [2016] indicated that socially anxious participants recognized anger in static faces better than non-anxious participants, but no difference between groups was observed when emotions were dynamically displayed. Clearly, further understanding of differences between anxious and healthy controls requires research in which visual attention to specific emotions is examined simultaneously and dynamically.

Acknowledging research suggesting attentional biases in perception of static emotions [Horley et al. 2004; Weierich et al. 2008], we expect analogous effects for dynamical expressions. Specifically, our hypotheses are as follows.

(1) First, we predict that during early stages of facial expression recognition (first part of the trial), all participants will exhibit more ambient attention compared to later stages of emotion recognition. In the later stages of emotion recognition (before a decision), we expect both groups to switch to more focal attention.
(2) Second, we hypothesize that socially anxious individuals will actively scan faces for signs of emotional expressions. This hyperscanning will be reflected by averaged ambient attention among the socially anxious, a prediction derived from the early vigilance hypothesis.
(3) Third, during the emotion decoding process, we expect pupil dilation to increase. However, change in pupil dilation might be smaller in the anxious group reflecting decreased processing of facial signals, as we expect them to mentally avert their gaze away from emotional faces.
(4) Fourth, as Anderson et al. [2003] found that people can detect happy faces easier than angry faces, we expected that a happy face will be decoded faster than an angry or sad one.
(5) Finally, given the lack of studies with dynamically developing emotions, we do not have specific expectations concerning group differences in terms of recognition time.

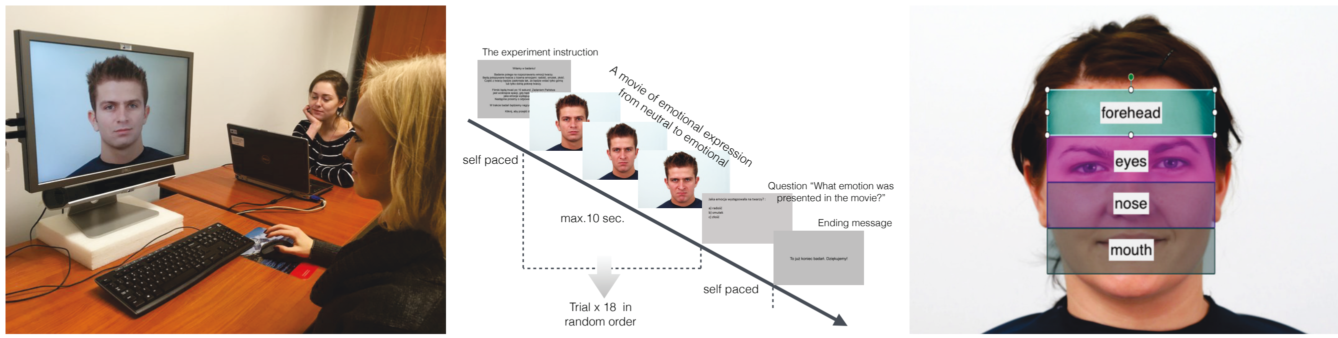
Both indicators of visual processing, ambient/focal attention and pupil dilation have not been measured before in unison in a dynamic emotion recognition task. We believe their union may be informative for processing of facial signals in social anxiety.

3 METHODOLOGY

The study consisted of two steps. During the first step participants were pre-screened into the either socially anxious or non-anxious group. In the second step, participants took part in the eye-tracking experiment. The experiment used a 2×3 mixed design. The first between-subjects factor was participants' social anxiety level (anxious vs. non-anxious/control group), the second within-subjects fixed factor was facial expression (happy vs. sad vs. angry).

Table 1: Descriptive statistics for socially anxious and non-anxious participants.

Variable	Control Group	Anxious Group	Group Differences Tests
Age	M = 26.00, SD = 6.64	M = 24.67, SD = 7.24	$t(45.66) = 0.66$, *n.s.*
Gender	17 females and 7 males	20 females and 4 males	$\chi^2(1) = 1.06$, *n.s.*
LSAS score	M = 32.83, SD = 13.44	M = 78.92, SD = 13.68	$t(45.99) = 11.77$, $p < 0.001$
CESD score	M = 15.75, SD = 8.62	M = 25.67, SD = 11.12	$t(43.31) = 3.45$, $p < 0.01$



(a) Experimental settings (b) Procedure schematic (c) Area Of Interest (AOI) definitions

Figure 2: Experimental setup (a), scheme of experimental main task (b), and Area Of Interest (AOI) definitions (c).

3.1 Participants

Forty-eight individuals (37 F, 11 M, aged between 18 and 45 years old, $M_{age} = 25.33$, $SD_{age} = 6.90$) participated in the study. They were pre-screened and divided into two groups based on their score on the Liebowitz Social Anxiety Scale (LSAS) [Liebowitz 1987]. They were divided into two groups based on the median-split of LSAS scores ($Me = 55$), compare with Holas et al. [2014]. Participants with LSAS score 56 and higher were considered as socially anxious and those with LSAS 54 and lower were assigned to the control group. The final sample consisted of 24 socially anxious participants and 24 non-anxious participants. Descriptive statistics and the results of mean difference tests are given in Table 1.

3.2 Experimental Procedure

In the first step participants completed an on-line version of the Liebowitz Social Anxiety Scale (LSAS), a self-reported scale assessing fear and avoidance of social situations [Liebowitz 1987], followed by the Center for Epidemiological Studies-Depression scale (CES-D), a 20-item inventory designed to measure depressive symptoms [Radloff 1977]. Based on their scores they were then invited to the laboratory for individual eye-tracking sessions. In the laboratory, participants started by signing a consent form and then performed a 5-point calibration task ($M = 0.45°$, $SD = 0.25$).

The main experimental task was the emotional expression recognition task. In this task participants were presented, in random order, with 18 video clips (each lasting max. 10 seconds). The clips showed steady close shots of facial expressions changing in time from neutral to either a happy, sad or angry expression. The participants' task was to press a space bar as soon as they recognized the displayed emotion. They were then presented with the question "What emotion did you recognize?" and answered by a mouse click on one of the three categories happiness, sadness, anger (see Figure 2b). Participants were debriefed at the end of the task.

3.3 Experimental Stimuli

Six Caucasian faces (3 F, 3 M) were selected from the Warsaw set of emotional facial expression pictures (WSEFEP) [Olszanowski et al. 2015]. For each face we selected their neutral, angry, sad, and happy expression. Video clips were created using FantaMorph 5 software by combining two source images of the neutral face and one with the full expression. Each image was marked with over 100 facial landmarks. In all, 18 clips (290 consecutive frames) were produced, each showing transition from neutral to emotional expression.

3.4 Apparatus

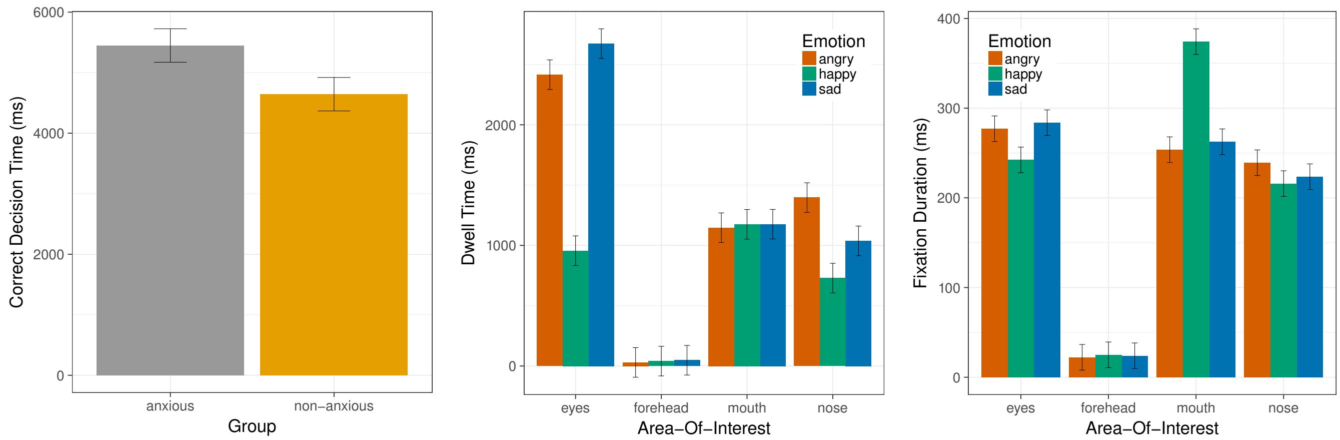
An SMI RED eye tracker was used to binocularly record eye movements at a sampling rate of 120 Hz. A stimuli presentation 22-inch monitor (with 1680×1050 px resolution, and 60 Hz refresh rate) was set at a viewing distance of 60 cm, see Figure 2a. The experiment took place in a dedicated laboratory room with no windows and constant ambient light.

4 RESULTS

Raw data collected by the eye tracker was processed with SMI's BeGaze software. SMI's standard BeGaze dispersion-based algorithm was used for detecting fixations and saccades. Fixations of duration within the range of 80–1200 ms were analyzed together with their following saccades of amplitude $< 10°$ (compare with Velichkovsky et al. [2005] or Krejtz et al. [2017]).

Data from each stimulus was categorized into four dynamic Areas of Interest (AOIs), drawn around the forehead, eyes, nose, and mouth of the faces presented, see Figure 2c. The complex nature of facial muscles movement during facial expressions on dynamical stimuli [Waters 1987] is related to anatomy of occurring facial emotion which emphasizes the significant role of facial signals around the eyes or mouth [Ekman 1993]. To differentiate the role of different facial regions in recognition of emotions, most studies distinguish AOIs around the eyes, mouth and nose [Bombari et al. 2013; Vassallo et al. 2009]. We decided to add to this set the "forehead" due to a role of the forehead muscles in expressing anger and sadness [Ekman 1993]. Note that all AOIs in the present study were of the same size (coverage of each AOI of the entire presentation screen was 5.9%). These AOIs were used as a within-subjects fixed factor in statistical analyses.

To analyze the dynamics of eye movements during scanning of dynamical facial expressions, the viewing duration of each stimulus, for every participant, was divided in two, creating two trial time periods (early and late). Since trial durations differed depending on



(a) Correct Decision Time (b) Dwell Time (c) Average Fixation Duration

Figure 3: Correct Decision Time difference between groups and interaction effects of emotional expression and attention allocation to different parts of the face: Dwell Time and Average Fixation Duration (error bars represent ±1SE).

participants' decision times, this division was made relative to each participant and trial, reflecting the relative early and late stages of visual processing. This variable was used as a within-subjects fixed factor for statistical analyses when needed.

The dependent variables used for the statistical analyses were created by averaging eye tracking data for six stimuli faces within each of the three emotional expressions (happy, sad, and angry).

All statistical analyses were performed in R [R Core Team 2017]. Analysis of Variance (ANOVA) was used for hypotheses testing, followed by post-hoc pairwise comparisons with HSD Tukey correction. For each ANOVA we give the significance level as well as effect size (generalized η^2).

4.1 Accuracy of Responses

We start by analyzing participants' accuracy and decision time for different facial expressions. Two analyses of variances were conducted with a 2×3 mixed design with group (anxious vs. non-anxious) as the between-subjects fixed factor and stimuli facial emotion (angry vs. sad vs. happy) as the within-subjects fixed factor.

The first analysis used the proportion of accurate decisions as the dependent variable. The effect of emotion was statistically significant, $F(1.63, 75.18) = 11.79$, $p < 0.001$, $\eta^2 = 0.14$. As expected, pairwise comparisons showed that the happy faces were recognized with significantly higher accuracy (M = 0.996, SE = 0.02) than sad (M = 0.88, SE = 0.02, $t(92) = 4.08$, $p < 0.001$), or angry faces (M = 0.87, SE = 0.02), $t(92) = 4.32$, $p < 0.001$.

The second analysis focused on correct decision time as the dependent variable. Consistent with the previous analysis, ANOVA showed a significant main effect of emotion, $F(1.80, 82.74) = 121.50$, $p < 0.001$, $\eta^2 = 0.37$, suggesting that the happy facial expression was recognized significantly faster (M = 3437.94, SE = 221.27) than the angry facial expression (M = 5777.82, SE = 221.27), $t(92) = 13.08$, $p < 0.001$ or the sad facial expression (M = 5923.55, SE = 221.27), $t(92) = 13.89$, $p < 0.001$.

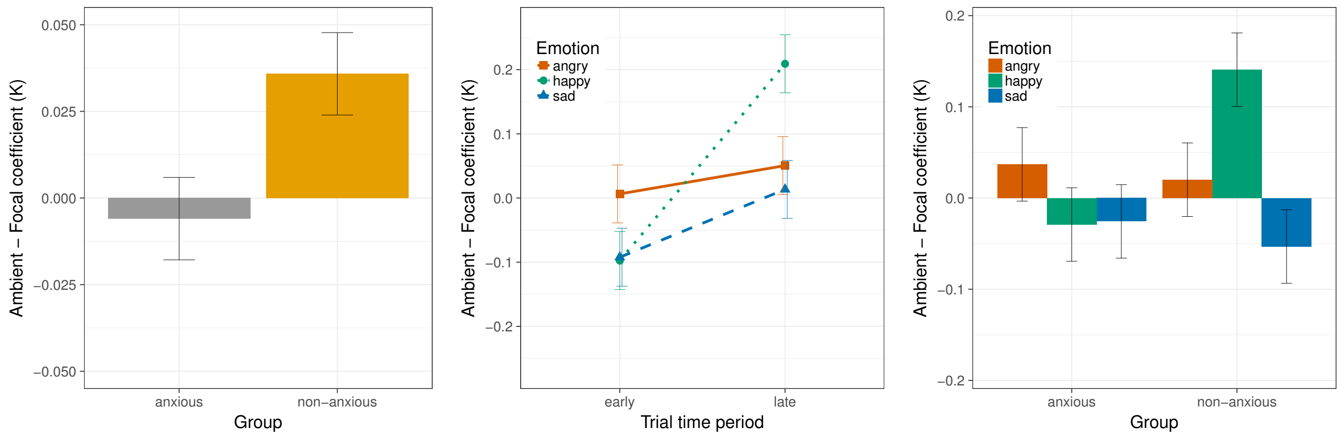
The main effect of group also reached statistical significance, $F(1, 46) = 4.23$, $p < 0.05$, $\eta^2 = 0.07$, see Figure 3a. The non-anxious group was faster (M = 4644.02, SE = 276.72) when making correct decisions than the anxious group (M = 5448.85, SE = 276.72).

4.2 Attention Distribution

To analyze attention distribution during recognition of emotional facial expressions, $2 \times 3 \times 4$ ANOVAs were conducted with group (anxious vs. non-anxious) as the between-subjects fixed factor, emotional expression (happy vs. angry vs. sad) as a within-subjects fixed factor, and AOI (forehead vs. eyes vs. nose vs. mouth) as a within-subjects fixed factor. We used AOI dwell time and fixation duration as dependent variables in the following analyses.

As expected, ANOVA of AOI dwell time revealed significant interaction between facial AOIs and emotional expression, $F(3.45, 158.51) = 48.81$, $p < 0.001$, $\eta^2 = 0.32$ see Figure 3b. The following post-hoc comparisons showed that while processing the happy face participants allocated the same amount of average dwell time to the eyes (M = 956.17 ms, SE = 260.36), mouth, (M = 1174.75 ms, SE = 260.36), $t(198.16) = 1.22$, *n.s.*, and nose (M = 728.74 ms, SE = 260.36), $t(198.16) = 1.27$, *n.s.*. In contrast, when processing both sad and angry facial expressions, the difference in dwell time allocated to the eyes (sad faces: M = 2672.97 ms, SE = 260.36, angry faces: M = 2415.51 ms, SE = 260.36) and mouth (sad faces: M = 1146.86 ms, SE = 260.36, angry faces: M = 1175.88 ms, SE = 260.36) was statistically significant in favor of the eyes (sad faces: $t(198.16) = 8.36$, $p < 0.001$; angry faces: $t(198.16) = 7.09$, $p < 0.001$).

The analysis also suggested a marginally significant effect of group, $F(1, 46) = 3.63$, $p = 0.063$, $\eta^2 = 0.01$. The mean dwell time on AOIs for the anxious group was longer (M = 1164.36 ms, SE = 71.06) than for the non-anxious group (M = 972.88 ms, SE = 71.06). We also observed a significant main effect of emotional expression, $F(1.87, 85.94) = 115.78$, $p < 0.001$, $\eta^2 = 0.08$. Dwell time on the AOIs of happy facial expression was significantly shorter (M = 725.08 ms, SE = 55.09) than on the sad expression (M = 1233.63 ms, SE = 55.09),



(a) Group difference on ambient/focal eye movements

(b) Interaction of emotional expression and time period

(c) Interaction of emotional expression and the group

Figure 4: Ambient/focal eye movements when processing emotional dynamical facial expressions (error bars represent ±1SE).

$t(92) = 13.00$, $p < 0.001$, or the angry expression, (M = 1247.16 ms, SE = 55.09), $t(92) = 13.35$, $p < 0.001$. The difference between angry and sad expressions was not statistically significant.

Analysis also revealed a main effect of AOI, $F(2.03, 93.49) = 49.50$, $p < 0.001$, $\eta^2 = 0.41$. On average, the longest dwell time was on the eyes (M = 2014.88 ms, SE = 111.56), compared to the mouth (M = 1165.83ms, SE = 111.56), $t(138) = 5.22$, $p < 0.001$, nose (M = 1054.32 ms, SE = 111.56), $t(138) = 5.91$, $p < 0.001$, or forehead (M = 39.44 ms, SE = 111.56), $t(138) = 12.15$, $p < 0.001$. Additionally, dwell time on the forehead was significantly shorter than any other AOI.

ANOVA of mean fixation duration showed an interaction effect of AOI and emotional expression, $F(2.32, 106.70) = 18.57$, $p < 0.001$, $\eta^2 = 0.08$. see Figure 3c. Post-hoc comparisons of means grouped by facial expression showed that the mean fixation duration difference between the eyes and mouth is significant only for happy faces (mouth: M = 374.14 ms, SE = 14.29; eyes: M = 242.27 ms, SE = 14.29), $t(253.42) = 6.64$, $p < 0.001$, but not for angry or sad faces.

A main effect of emotional expression was also significant, $F(1.54, 70.63) = 3.60$, $p < 0.05$, $\eta^2 = 0.006$. The longest mean fixation duration was on faces expressing happiness, (M = 214.32 ms, SE = 7.51) compared to angry faces (M = 198.03 ms, SE = 7.51), $t(92) = 2.35$, $p = 0.05$, and marginally longer than mean fixation time on sad faces (M = 198.46 ms, SE = 7.51), $t(92) = 2.35$, $p = 0.06$.

Similar to analysis of dwell time we observed a strong main effect of AOI on mean fixation duration, $F(2.18, 100.09) = 108.97$, $p < 0.05$, $\eta^2 = 0.55$. Fixations on the mouth lasted significantly longer (M = 296.80 ms, SE = 12.05) than those on the nose (M = 226.19 ms, SE = 12.05) $t(138) = 4.23$, $p < 0.001$ or forehead (M = 23.73 ms, SE = 12.05), $t(138) = 16.34$, $p < 0.001$. The mean fixation duration was also significantly longer on the eyes than on the forehead, $t(138) = 14.57$, $p < 0.001$, and marginally different from the mean fixation duration on the nose, $t(138) = 2.48$, $p = 0.07$. We also observed a significant difference between dwell time on the forehead and nose, $t(138) = 12.11$, $p < 0.001$.

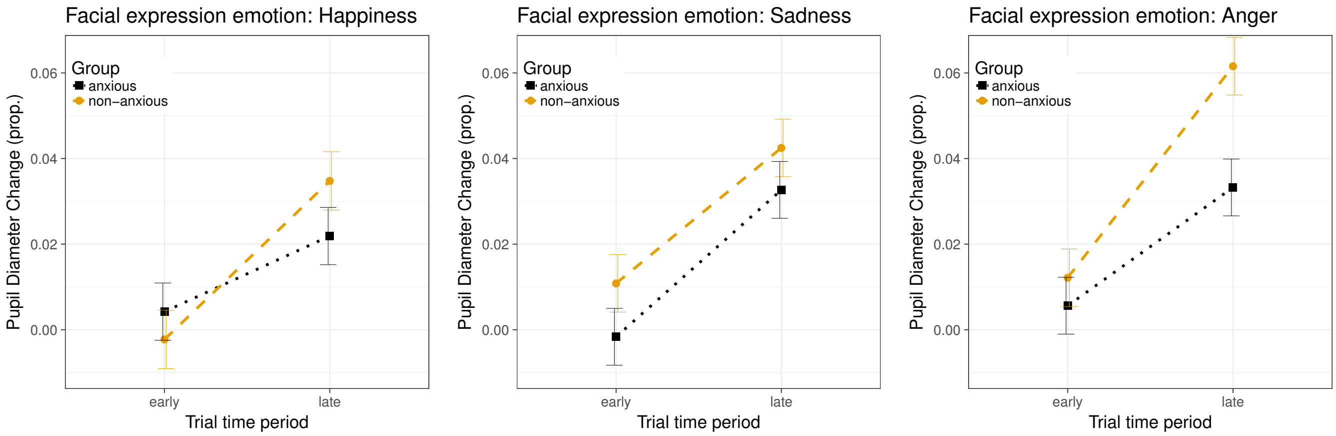
4.3 Dynamics of Ambient/Focal Attention

To capture the dynamics of ambient/focal attention during emotional expression recognition a series of ANOVAs was run on $\mathcal{K}$ as the dependent variable. Analyses used a $2 \times 2 \times 3$ mixed design with the following fixed factors: group (anxious vs. non-anxious) as the between-subjects factor, emotional expression (sadness vs. happiness vs. anger) as the first within-subjects factor, and time period (early vs. late) as the second within-subjects factor.

Consistent with expectations, a marginally significant interaction effect between group and emotional expression was observed, $F(1.59, 73.19) = 2.76$, $p = 0.08$, $\eta^2 = 0.02$, see Figure 4c. Post hoc comparisons revealed that the difference between anxious and non-anxious participants' ambient/focal attention was significant only for the expression of happiness, $t(108.4) = 2.98$, $p < 0.01$. Anxious participants exhibited ambient attention when examining happy faces (M = −0.03, SE = 0.04) while the non-anxious group was significantly more focal, (M = 0.14, SE = 0.04).

Interaction between emotional expression and time period was significant, $F(1.65, 76.04) = 3.85$, $p < 0.03$, $\eta^2 = 0.03$, see Figure 4b. The expected temporal ambient/focal shift was significant only during processing of happy faces. In the first stage of processing the happy face, participants on average used ambient attention (M = −0.1, SE = 0.05), then more focal during the later stage (M = 0.2, SE = 0.05), $t(138) = 4.38$, $p < 0.001$. The differences between early and late stages of processing was not significant for sad ($t(138) = 1.51, n.s.$) or for angry faces ($t(138) = 0.63, n.s.$), yet the pattern of means is consistent with expectations of a shift from ambient to focal processing, see Figure 4b. For exemplary eye movement visualizations of anxious and non-anxious participants scanning happy and angry faces see Figure 1.

A significantly varying pattern of ambient/focal attention dynamics was observed, $F(1, 46) = 14.06$, $p < 0.001$, $\eta^2 = 0.06$. Eye movements in the early stage of evaluating facial expressions were



(a) Time period by group for happy facial expressions

(b) Time period by group for sad facial expressions

(c) Time period by group for angry facial expressions

Figure 5: Interaction of time period, emotional expression, and group on PCPD in focal fixations (error bars represent ±1SE).

significantly more ambient, (M = −0.06, SE = 0.02) than during the later stage (M = 0.09, SE = 0.02).

Analyses also revealed a statistically significant main effect of group, $F(1, 46) = 6.17$, $p < 0.02$, $\eta^2 = 0.005$, see Figure 4a. On average, anxious participants’ eye movements were more ambient while processing emotional expressions, (M = −0.06, SE = 0.12) than the non-anxious group, (M = 0.04, SE = 0.12).

4.4 Dynamics of Pupillary Reaction

To test the hypothesis that participants with social anxiety would avoid deeper processing of emotional faces, analyses of pupil size dynamics were performed. We predicted the differences between anxious and non-anxious participants at the later stage of facial expression processing. Given the findings on ambient/focal processing, we expected that differences in depth of processing, indicated by pupil dilation, should be manifested within focal fixations. Thus in the following analyses we selected only focal fixations (those whose $\mathcal{K}$ was above median Me = 0.02). We employed a $2 \times 2 \times 3$ mixed design ANOVA (similar to the above analysis of K). The dependent variable was the percentage change of pupil diameter (PCPD) within focal fixations. PCPD was calculated as the difference between pupil size within every fixation and the average pupil size during the first 1000 ms of each trial. For each stimuli first approx. 1000 ms were presenting neutral facial expression. Analysis resulted in significant effects supporting the hypotheses.

First, a 3-way interaction between facial emotional expression, time period, and group was significant, $F(1.86, 74.26) = 3.93$, $p < 0.05$, $\eta^2 = 0.007$, see Figure 5. Pairwise comparisons revealed that the only significant difference between anxious and non-anxious participants in PCPD appeared in the later stage of processing of angry facial expressions $t(90.84) = 8.42$, $p < 0.001$. At this stage of angry facial expression processing, the pupil dilated half as much in the anxious group (M = 0.03, SE = 0.007) as in the non-anxious group (M = 0.06, SE = 0.007). Other pairwise comparisons were not statistically significant. Second, interaction between time period and emotional expression was statistically significant, $F(1.86, 74.26) = 3.93$, $p < 0.05$, $\eta^2 = 0.007$. In the early stage of facial expression processing, there were no significant differences in PCPD between emotions. A significant difference appeared only during the later stage of stimuli processing between angry (M = 0.05, SE = 0.005), and happy (M = 0.03, SE = 0.005), $t(143.18) = 4.41$, $p < 0.001$, and sad faces, (M = 0.04, SE = 0.005), $t(143.27) = 2.37$, $p < 0.05$. The difference between sad and happy faces was marginally significant, $t(143.18) = 2.14$, $p = 0.086$.

Third, a main effect of time period was significant, $F(1, 40) = 102.21$, $p < 0.001$, $\eta^2 = 0.22$. In general the pupil dilated significantly more at the later stage of facial processing (M = 0.04, SE = 0.004). compared to the early stage (M = 0.005, SE = 0.004).

Finally, a significant difference between emotional expressions was found, $F(1.75, 70.01) = 8.14$, $p < 0.001$, $\eta^2 = 0.04$. Pairwise comparisons showed that processing angry faces yielded significantly larger pupil dilations (M = 0.03, SE = 0.004) than happy faces (M = 0.01, SE = 0.004), $t(89) = 3.62$, $p < 0.001$.

5 SUMMARY & DISCUSSION

The present study focused on visual processing of dynamical facial expressions during recognition of emotion (anger, sadness and happiness) in socially anxious and non-anxious individuals. Here, we summarize the key findings and relate them to the current literature and theories of cognitive psychopathology in social anxiety.

5.1 Attentional Bias to Happiness

Our study provides support for the happiness superiority effect [Craig et al. 2014] among socially anxious and non-anxious individuals. Similar to previous studies showing recognition advantage for happy faces [Kret et al. 2013], we found that happy faces were more accurately and more quickly recognized than faces expressing negative emotions, i.e., both angry and sad. This finding is also supported by Silvia et al. [2006], who reported recognition advantage for happy faces and showed that people with low and high social anxiety recognized sad faces and angry faces equally quickly.

In line with the tendency to prioritize positivity [Leyman et al. 2011], observed eye movement characteristics support deeper visual processing of happy faces. Participants demonstrated longer average fixation duration when recognizing happiness in comparison to anger and sadness. Interestingly, while processing happy faces, attention was allocated equally to the eyes and mouth in terms of dwell time with longer average fixation duration on the mouth than on the eyes. These results suggest not only deeper but also more precise visual scanning when viewing happy faces.

Results are in line with recent theoretical accounts of social phobia [Cunningham and Wallraven 2009; Heimberg et al. 2010] which advocate the importance of including both fear of negative and positive evaluations as core mechanisms sustaining social anxiety. They are also congruent with empirical research showing attentional biases to both positive and negative facial expressions related to social anxiety [Garner et al. 2006; Schofield et al. 2012].

Present results do not support avoidance of the eyes in angry faces in the socially anxious group, as reported elsewhere [Horley et al. 2004]. However, the lack of attentional bias to threat in social anxiety is in line with most of the literature [Garner et al. 2006; Pineles and Mineka 2005]. Thus, evidence for attentional bias to threatening faces in social anxiety is far from established, with complex patterns of both vigilance and avoidance that is not limited to threatening expressions [Staugaard 2010]. Moreover, evidence for attentional bias to threatening static faces stems mainly from research examining social phobia (clinical social anxiety) [Horley et al. 2004]. Therefore, it is possible that attentional bias toward threat (anger) is simply not apparent in subclinical social anxiety [Staugaard 2010]. Unlike the majority of studies evaluating attentional bias to emotional expressions that used static facial stimuli, we used dynamical faces. We assumed that recognition of emotional expression on dynamically changing faces is more natural than presentation of a series of static facial images.

5.2 Dynamics of Visual Processing

As expected, the process of emotional face scanning followed a pattern of switching from ambient to focal attention. Focal eye movements dominated the later stage of face processing, shortly before recognition of emotional expression (decision). This dynamical pattern is consistent with literature [Krejtz et al. 2016; Pannasch et al. 2008; Unema et al. 2005; Velichkovsky et al. 2005]. This pattern was altered by the emotional expression. The pattern of shifting from ambient to focal attention was only evident during processing of happy faces. This finding may seem to contradict the lack of differences in the dynamics of different emotional image processing as reported by Pannasch et al. [2008]. Note that Pannasch et al. rooted their experiment in the presentation of static emotional images that did not include facial expressions. We believe that the switch from ambient to focal attention over happy faces provides further support for the tendency to prioritize positivity.

The process of facial expression recognition from early scanning to deep information processing is also reflected in the dynamics of pupil dilation. We found that during focal fixations participants' pupils dilated significantly more at the later stage of facial processing in comparison to the early stage. Moreover, at the later stage of stimuli processing the pupils dilated more when scanning angry rather than happy faces. Again this result may be in favor of the happiness superiority effect [Craig et al. 2014], meaning that at the later stage of facial expression processing, happy faces do not require extensive cognitive resource allocation for recognition.

5.3 Visual Processing Moderated by Anxiety

We demonstrated that socially anxious participants recognized emotional expressions (positive and negative) with the same accuracy as the non-anxious group. However, to reach the same accuracy, they needed significantly more time than the control group.

In line with expectations, the socially anxious group performed more ambient eye movements than the non-anxious group when processing emotional expressions. This difference may be interpreted as a sign of hypervigilance for emotional information in social anxiety, which is reflected in a more exploratory viewing pattern in the socially anxious group than in the non-anxious group. Similarly, in their eye-tracking studies, Horley et al. 2003; 2004 demonstrated a hyperscanning strategy across angry faces in social phobia patients. Furthermore, a more ambient attentional pattern in the socially anxious group may suggest that their visual processing of dynamical faces relies more on simple physical aspects (bottom-up features) than deep processing of emotions.

Consistent with this line of reasoning, results of the present study demonstrate that at the later stage of angry face processing anxious participants' pupils dilated significantly less than those of non-anxious ones. This may imply that anxious individuals avoid processing of anger at the very moment of recognition of the negative emotion. Withdrawing from processing anger serves as a defense mechanism and is a consequence of early vigilance to and later avoidance of angry faces. This interpretation is consistent with Clark and Wells's 1995 model of social anxiety, which emphasizes withdrawal of socially anxious individuals from processing of external information and focusing on internal feelings and thoughts.

Processing of dynamical facial expressions involves several aspects that are absent in static stimuli. Interpretation of present results is in line with neuropsychological literature indicating that people with social anxiety exhibit deficits in the functioning of brain regions responsible for the processing of changeable facial features [Allison et al. 2000; Iacoboni et al. 2005]. Dynamic presentation of facial expressions may boost their visual processing, requiring more ambient eye movements, presumably because motion diffuses attention in a reflexive, stimulus-driven way.

5.4 Conclusions

The main contribution of the present study is the dynamical approach to studying attentional processes underlying facial expression recognition. Specifically, to our knowledge, ambient processing of emotional faces in social anxiety has not yet been reported. We believe that our findings shed more light on the mechanism of attentional withdrawing from anger expressed on others' faces in social anxiety, revealing a general tendency to focus on happiness.

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