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Gaze-fixation and pupil dilation in the processing of emotional faces: The role of rumination

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Sustained attentional processing of negative information plays a significant role in the development and maintenance of depression. The present study examines the relationships between rumination, a relevant factor in information processing in depression, and the attentional mechanisms activated in individuals with different levels of depression severity when attending to emotional information (i.e., sad, angry, and happy faces). Behavioural and physiological indicators of sustained processing were assessed in 126 participants (39 dysphoric and 87 non-dysphoric) using eye-tracking technology. Pupil dilation and total time attending to negative faces were correlated with a global ruminative style in the total sample once depression severity was controlled. Furthermore, in dysphoric participants the brooding component of rumination was specifically associated with the total time attending to sad faces. Finally, bootstrapping analyses showed that the relationships between global rumination and pupil diameter to emotional faces were accounted by total time attending to emotional faces, specifically for participants reporting lower levels of depression severity. The results support the idea that sustained processing of negative information is associated with a higher ruminative style and indicate differential associations between these factors at different levels of depressive symptomatology.

Keywords: Depression; Rumination; Emotional information processing; Selective attention; Pupil dilation.

According to cognitive models (Beck, 1967; Bower, 1981; Teasdale, 1988), depression is caused and maintained by biases in the processing of mood-congruent information. A key prediction of these models is that depressed individuals selectively attend to mood-congruent information. Moreover, this dysfunctional processing bias is presumed to last beyond the depressive episode, representing a stable vulnerability factor for depression onset and recurrence.

Using attention allocation paradigms, such as the dot-probe task, research has shown that both
currently depressed individuals (e.g., Donaldson, Lam, & Mathews, 2007; Gotlib, Krasnoperova, Yue, & Joormann, 2004; Joormann & Gotlib, 2007; Leyman, De Raedt, Schacht, & Koster, 2007) and formerly depressed individuals (e.g., Joormann & Gotlib, 2007) are characterised by attentional biases to negative stimuli (words and facial expressions) when they are presented with negative stimuli for 1000 milliseconds (ms), but not when they are presented with negative stimuli for brief durations (14 ms). It has been suggested that these results indicate that these individuals do not initially direct their attention to negative information more frequently than control participants do, however, once this negative information attracts their attention, they maintain their focus of attention on it for longer periods of time (e.g., Gotlib & Joormann, 2010). Recent research into attentional biases has tested this hypothesis using eye movement recording, which allows continuous monitoring of the focus of visual orienting. Most of the research on depression and visual attention has found that free viewing tasks may be more sensitive than visual search tasks to detect attentional biases (Armstrong & Olatunji, 2012). In free viewing paradigms attentional biases are not measured in relation to performance and participants can deploy their visual attention without restrictions across stimuli. Eye-tracking studies have shown that depressed individuals do not differ from control individuals in terms of frequency (number of times that they direct and redirect attention to negative information), but, when compared to control participants, they do spend significantly more total time looking at these stimuli (e.g., Eizenman et al., 2003; Ellis, Beevers, & Wells, 2011; Kellough, Beevers, Ellis, & Wells, 2008). Furthermore, these biases have been found to predict increases in depressive symptoms in college students 7 and 13 weeks later (Beevers & Carver, 2003; Osinsky, Loesch, Hennig, Alexander, & MacLeod, 2012). Overall, these studies suggest that attentional biases consisting of a sustained visual processing of negative stimuli may play an important role in the development and maintenance of depression (Gotlib & Joormann, 2010).

The evaluation of sustained processing of emotional information has also involved pupilometry methods (Bradley, Miccoli, Escrig, & Lang, 2008), referred to as the assessment of changes in pupil diameter during the processing of information. The pupil dilates under conditions of high attentional allocation and it is a reliable indicator of sustained information processing (Beatty, 1982; Beatty & Lucero-Wagoner, 2000)—see Steidtmann, Ingram, and Siegle (2010). Moreover, the pupil dilates in response to emotional information (Janisse, 1973), including pictures (Bradley et al., 2008), sounds (Partala & Surakka, 2003), words (Siegle, Steinhauer, Carter, Ramel, & Thase, 2003), and even monetary rewards (Chiew & Braver, 2013). It has been suggested that pupil dilation is indicative of a range of brain mechanisms associated with emotional information processing, including amygdala (Siegle, Steinhauer, Thase, Stenger, & Carter, 2002), dorsolateral prefrontal cortex (Siegle, Steinhauer, Stenger, Konecky, & Carter, 2003) and anterior cingulate cortex activity (Critchley, Tang, Glaser, Butterworth, & Dolan, 2005), and it is also sensitive to complex interactions of neurotransmitter systems (Savine & Braver, 2010). Recent research has implemented eye-tracking techniques to measure pupil diameter at the time that individuals are attending to emotional information, to test whether depression is associated with higher pupil dilation for mood-congruent information. These studies have shown that depressed individuals display higher sustained pupil dilation to emotional information than controls (Siegle, Granholm, Ingram, & Matt, 2001) and that this is particularly the case for mood-congruent information (Siegle et al., 2003). Steidtmann et al. (2010) found that formerly depressed compared to never depressed individuals showed a greater pupil diameter for negative information, although this physiological response was only found before individuals received a negative mood induction and not afterwards. Moreover, Siegle, Steinhauer, Friedman, Thompson, and Thase (2011) found that increased sustained pupillary responses to negative stimuli before treatment were associated
with lower remission rates after 20 sessions of cognitive therapy.

Overall, sustained visual processing of negative information, as measured by both eye-movement and pupil diameter indicators, is thought to play a role in depression. However, research evaluating the mechanisms behind this sustained processing of negative information is still scarce. It has been suggested that this continuous bias might be due to malfunctioning inhibitory processes (Disner, Beevers, Haigh, & Beck, 2011; Gotlib & Joormann, 2010). Recent proposals postulate that difficulties in inhibiting the processing of negative information are a central mechanism that contributes to the continuous processing of negative information observed in depressed individuals, such as rumination (Koster, De Lissnyder, Derakshian, & De Raedt, 2011). Ruminative responses are defined as “behaviors or thoughts that focus an individual’s attention on his or her depressed mood and [on] the possible causes and consequences of that mood” (Nolen-Hoeksema, Morrow, & Fredrickson, 1993, p. 90). Rumination has been found to be associated with more severe and prolonged depressive symptoms, as well as heightened vulnerability to experiencing major depressive episodes (see Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008 for review).

Using a dot-probe paradigm, Donaldson et al. (2007) showed an association between a ruminative style and attentional biases to depression-related information. Morrison and O’Connor (2008) reported an interaction between attentional biases to depression-related information and rumination to predict increases in depressive symptoms in college students. Furthermore, research on pupil size has also revealed a link between higher sustained pupil dilation for negative information and rumination. Siegle et al. (2003) reported that pupil dilation to negative emotional information shown by depressed individuals, correlated with self-report measures of rumination. In addition to the evidence that has been gathered on the relation between sustained emotional processing and global ruminative style, there has also been a growing interest in analysing the role of distinct subtypes of rumination. Treynor, Gonzalez, and Nolen-Hoeksema (2003) conducted a factor analysis using the Ruminative Response Scale (RRS), which is the most commonly used rumination assessment scale, identifying two distinct components (i.e., brooding and reflection), which have different functional relationships with depression. Brooding is considered as “a passive comparison of one’s current situation with some unachieved standard” and is positively correlated with depression in the short and long run, whereas reflection is defined as “a purposeful turning inward to alleviate one’s depressive symptoms” and is associated with more depression concurrently but with less depression over time (Treynor et al., 2003, p. 256).

These results suggest that rumination could be distressing in the short term because it leads to negative effect, but adaptive in the long term because it leads to effective problem solving. Several studies have confirmed this distinction and have demonstrated that brooding and reflection can be considered as independent components of rumination with differential contributions to depression (Burwell & Shirk, 2007; Joormann, Dkane, & Gotlib, 2006; Raes & Hermans, 2008). Interestingly, an initial study tested the association between separated rumination components and attention bias to negative faces in depressed individuals, using a dot-probe task (Joormann et al., 2006). These authors showed that depressed individuals’ attention bias to sad faces was related specifically to brooding but not to reflection, even after controlling for severity of depressive symptoms.

Despite these encouraging results, further research is necessary to clarify the role of sustained visual processing of negative information in depression, by considering its relation to a ruminative style. Studies considering the analyses of both behavioural and physiological indicators of sustained processing of emotional information simultaneously are still scarce in this field (e.g., Allard, Wadlinger, & Isaacowitz, 2010). As noted above, pupil diameter is thought to be an indicator of the deployment of attentional resources (Kahneman, 1973; Iqbal, Zheng, & Bailey, 2004), as a physiological index of the sustained processing of information. However, there have been no studies that have tested the association of pupil size with direct measures of sustained visual attention during the processing of emotional information.
Based on previous results showing that pupil dilation can be considered as a reliable index of emotional and motivational aspects of the information processed (Chiew & Braver, 2013), our first hypothesis was that pupil diameter to emotional information would be associated with the total time attending to emotional information across the stimuli presentation. Stimuli used in this study were facial expressions of different emotional content (sad, angry and happy faces) which convey an important amount of social and emotional information and are more likely to be ecologically valid than words (Gross, 2005). Facial expressions have been used in other similar studies (Leyman, De Raedt, Vaeyens, & Philippaerts, 2011; Mogg, Millar, & Bradley, 2000) as they attract easily the attention due to their higher interpersonal relevance showing emotional state of others. Previous evidence of the relation between sustained visual processing and rumination has been gathered from dot-probe tasks (e.g., Gotlib et al., 2004; Joormann & Gotlib, 2007), which assess the allocation of attention indirectly from response latencies to the probes. Eye-tracking techniques can overcome this limitation, by allowing patterns of visual processing during the stimulus presentation to be continually assessed. In the present study, our second hypothesis was that sustained processing of negative information, as measured by a direct eye-tracking indicator (i.e., the total time attending to emotional information across the stimuli presentation), would be associated with a higher ruminative style. Moreover, based on previous findings on the distinct associations between attention to negative information and rumination components in depressed individuals (Joormann et al., 2006), we expected that this relation would specifically be found for the brooding component in individuals reporting higher levels of depressive symptoms.

METHOD

Participants

A sample of 126 undergraduate students (82% female) received course credits for their participation in the study. Their mean age was 22.04 (SD = 2.37). All participants had normal or corrected-to-normal vision and were allowed to wear their glasses or contact-lenses, if required.

Psychological measures

Depressive symptoms

Participants completed the Beck Depression Inventory-II (BDI-II; Beck, Steer, & Brown, 1996), a 21-item self-report measure of depressive symptom severity. Respondents reported the severity of their experience for each depression symptom on a four-point scale, ranging from 0 to 3. BDI-II total scores can range from 0 to 63. This measure has shown excellent reliability and validity (Beck et al., 1996). In the current study, there was good internal consistency (α = .90). Participants’ scores on the BDI-II were used to classify participants into dysphoric (n = 39) and non-dysphoric (n = 87) groups, according to BDI-II cut-off scores provided by Dozois, Dobson, and Ahnberg (1998): 0–12, non-dysphoric; 13 or above, dysphoric. These criteria have yielded a correct correspondence rate of 91% (sensitivity = 81%; specificity = 92%) in previous research (Dozois et al., 1998).

Ruminative style

Participants completed the RRS (Nolen-Hoeksema & Morrow, 1991). This is a 22-item scale with a 4-point scale (from almost never to almost always) that assesses how participants tend to respond to sad feelings and symptoms of dysphoria. The RRS
assesses responses to dysphoric moods that are focused on the self (e.g., You think about all your shortcomings, failings, faults, mistakes), on symptoms (e.g., You think about how hard it is to concentrate) or on possible consequences and causes of moods (e.g., You analyze recent events to try to understand why you are depressed). The score range varies from 22 to 110. Two subscales were derived from the RRS, the Brooding scale and the Reflection scale (Treynor et al., 2003). The Brooding subscale measured preoccupation with depressing, morbid, or painful memories or thoughts, whereas the Reflection subscale measured rumination in the context of engaging in contemplation. Previous research has demonstrated that the scale has good reliability and validity (Just & Alloy, 1997; Nolen-Hoeksema et al., 1993). In the current study, there was good internal consistency for the ruminative style scale (α = .91), as well as for both the Brooding and Reflection subscales (α = .72, and α = .77, respectively).

### Attention task

#### Overview

The experimental task used in this study involved asking participants to freely view emotional and neutral information. After a central fixation cross on a computer screen was displayed, and a secondary numeric task to maintain that central fixation was performed, pairs of stimuli were presented, with one presented on the left and the other presented on the right of this central fixation point. Stimulus pairs comprised of a facial expression of a different emotion (i.e., happiness, anger, sadness) paired with a neutral expression of the same actor/actress. Eye-tracking was used to monitor and register both participants’ attention behaviour and pupil dilation during the presentation of the stimulus.

#### Stimulus material

The stimuli consisted of pairs of pictures comprising of an emotional and a neutral facial expression of the same person. Faces were selected from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist, Flykt, & Öhman, 1998). Following the procedures used by Williams, Moss, Bradshaw, and Mattingley (2005) and Calvo and Lundqvist (2008), original KDEF frontal view pictures were framed with an oval window. The hair, neck and surrounding parts of the images were darkened to remove non-informative aspects of the faces.

Stimuli selection was based on two parameters: (1) the emotional prototypicality of the faces for the corresponding emotion and (2) their emotional intensity (for a description of different emotional parameters, see for instance Schaefer, Nils, Sanchez, & Philippot, 2010). The selection was made on a previous validation study of the KDEF emotional pictures (Sánchez & Vazquez, 2013). Based on these results, 28 happy, 28 angry and 28 sad expressions (14 men and 14 women for each emotional category) were selected and matched with the corresponding neutral expression of the same actors for the current study.1

#### Apparatus

Attention performance and pupil diameter were recorded using an ASL model 504 eye-tracker system (Applied Science Laboratories, Bedford, MA), which consists of a video camera and an infrared light source pointed at the participant’s left eye. This system employs a Pupil-Centre Corneal Reflection (PCCR) method (Mason, 1969) to calculate pupil size and to track the eye gaze location at 60 Hz (i.e., every 16.7 ms). Data collection was managed using Eyenal software.

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1 Analyses showed that there were not significant differences among the three types of faces in prototypicality, $F(2, 81) = 1.21$, n. s., $\eta^2 = .029$, and intensity, $F(2, 81) = 1.39$, n. s., $\eta^2 = .03$. The mean scores for emotional prototypicality for the happy, angry and sad expressions were 5.53 (SD = .39), 5.39 (SD = .52) and 5.32 (SD = .62), respectively. Mean intensity scores were 5.55 (SD = .51), 5.86 (SD = .58) and 5.76 (SD = .94), respectively.
Procedure

The attention task was completed after consent forms were signed and a questionnaire pack was filled in, including BDI-II and RRS. The experimental task comprised of 84 trials (28 happy, 28 angry and 28 sad expressions, each of them paired with their corresponding neutral expression of the same actor/actress), which were randomly presented to each participant. Emotional and neutral expressions were presented just as often on both the left and right side of the screen. The task also included six practice trials, followed by a brief break (1 min), before starting the actual trials.

The stimuli were displayed using a beam projector on a 147 cm (width) × 110 cm (height) screen. The size of each face was 21 cm (width) × 27 cm (height). Pictures were presented on the right and on the left of the screen at a distance of 21 cm from the centre of each photograph to the centre of the screen. Participants were seated approximately 226 cm from the screen's centre, resulting in a visual angle of approximately 5.5° between each picture's centre and the centre of the screen. The participants' head position was kept comfortably stable using an anatomic chair, with a distance between the eyes and the eye-tracker capture of approximately 60 cm.

The stimuli presentation was controlled by National Instruments software and the eye-tracking system automatically synchronised with this program at the beginning of each trial. Each trial started with a black screen for 500 ms, followed by a white fixation cross displayed in the middle of a black screen for 500 ms, which participants were to fixate their gaze. Immediately afterwards, a white random 1-digit number (ranging from 1 to 9) replaced the fixation cross, appearing for 1000 ms. Participants were instructed to pay attention to the number and say it aloud as quick as possible, since their response times would be recorded. This procedure has been used previously by Calvo and Avero (2005) to ensure that the participants' attention was focused on the centre of the screen before the face pairs appeared. Immediately after the offset of the 1-digit number, a pair of faces (either happy-neutral, angry-neutral or sad-neutral) was presented for 3500 ms and participants were told to watch the screen freely, without any constrains, until the next trial, which was indicated by the appearance of the next trial.

![Figure 1. Representation of a trial sequence. Each trial starts with a black screen for 500 ms, followed by the display of a central fixation cross for 500 ms. A white random 1-digit number replaces the central fixation cross then for 1000 ms. After the offset of the 1-digit number, a pair of faces (either happy-neutral, angry-neutral or sad-neutral) is presented for 3500 ms.](image-url)
fixation cross (see Figure 1). Free watching of face pairs was implemented to encourage naturalistic information processing (Issacowitz, 2005).

Data preparation and sustained visual processing indices

Eyenal software was used to define two areas of interest (AOI) in each trial; one corresponding to the neutral face area and the other corresponding to the emotional face on the screen. Fixation data recorded with the eye-tracker for each AOI were used to estimate sustained visual processing indices. Visual fixations were defined as keeping one’s gaze on a specific location on the screen for at least 100 ms and a maximum fixation radius of 1°, as employed in previous research (e.g., Bradley, Mogg, & Millar, 2000; Caseras, Garner, Bradley, & Mogg, 2007).

Sustained visual processing indices involved the pupil diameter and the total time attending to each type of emotional face (i.e., happy, angry and sad) across the trials. Total time attending to each face was obtained by estimating the fixation time to each AOI, referred to as the total time that participants fixate on the emotional face area and on the neutral face area during the 3500 ms period. This indicator has been employed in previous research (e.g., Kellough et al., 2008). Pupil diameter was sampled for visual fixations in each of the two AOIs across the trials, and comprised of the average dilation for fixations made to each face over the 3500 ms period. Pupil diameter data were corrected for baseline by subtracting tonic, baseline pupil diameter (1 s prior to each trial onset; Bradley et al., 2008; Partala & Surakka, 2003) from the following average pupil diameter for the emotional face and the neutral face across the trial.

Pupil diameter and total time attending to emotional faces indices were obtained by subtracting the corresponding score obtained for the neutral face from the corresponding score obtained for the emotional faces. Following this procedure, we obtained difference score indices for each emotional condition (i.e., happy, angry and sad faces). These difference score indices have been employed in previous research (Bradley, Mogg, & Lee, 1997; Donaldson et al., 2007). Pupil diameter and total time attending difference scores greater than zero, indicate a greater pupil diameter to emotional than to neutral pictures and a preference to look at the emotional pictures rather than the neutral pictures across the trials, respectively. Thus, indices of pupil diameter and total time attending to emotional faces were calculated to estimate sustained visual processing for each emotional condition.

Data analysis plan

Demographic and clinical variables were analysed by Pearson chi-square tests for qualitative variables, and by two-tailed independent-samples t-tests for quantitative variables.

A series of zero-order correlation analyses were conducted to test our hypotheses, examining the relationships between behavioural and physiological indicators of sustained processing of emotional information, as well as the relationships between these indicators and rumination components. In order to test specific relationships between variables for individuals reporting different levels of depression severity, we ran these analyses for the total sample, as well as for each separate group (i.e., dysphoric and non-dysphoric groups).

A common problem when studying associations between rumination and emotional processing indices is that the RRS has a number of items with embedded depressive content, which makes it difficult to establish conclusions on the specific contribution of rumination. Moreover, previous research has reported high correlations between RRS scores and depression severity (e.g., Joormann et al., 2006). Further analyses were conducted to examine whether correlations between rumination and behavioural and physiological indicators could be explained by the severity of depressive symptoms. Thus, partial correlation analyses controlling for BDI-II scores were conducted for the total sample, as well as for each separate group. This strategy has been previously used in similar studies analysing associations between rumination and attention processing of emotional information in participants with different levels of depression severity (Donaldson et al.,
and in samples of individuals with major depression (Joormann et al., 2006).

Finally, a series of bootstrapping analyses were conducted to test indirect effects between rumination and behavioural and physiological indicators of emotional processing, according to the guidelines proposed by Mathieu and Taylor (2006).

RESULTS

Participant characteristics

Table 1 shows the mean values and standard deviations of the variables measured in the study for the total sample, as well as for each group. Statistical analyses revealed significant gender differences in brooding in the total sample. Women ($M = 11.26, SD = 3.49$) reported significantly more brooding than men ($M = 9.39, SD = 3.19$), $t(123) = -2.36, p < .05$. No significant gender differences were found for global ruminative style, reflection, depressive symptoms, pupil diameter and total time attending to emotional faces.2

Regarding group differences, dysphoric and non-dysphoric groups did not differ significantly with respect to the proportion of females, $\chi^2 (1, n = 126) = .004, p = .95$, or age, $t(124) = -.93, p = .35$. Dysphoric compared to non-dysphoric participants reported higher depression severity, $t(47.67) = -11.67, p < .05$, as well as greater levels of global rumination, $t(124) = -3.32, p < .05$ and brooding, $t(124) = -2.54, p < .05$, whereas there were no significant group differences in reflection, $t(124) = -1.62, p = .11$.

Relations among sustained visual processing indices

A series of correlation analyses were conducted to test our first hypothesis, namely that pupil diameter to emotional stimuli would be associated with behavioural measures of sustained visual processing (i.e., the total time attending to emotional stimuli). Table 2 shows zero-order correlation coefficients. In the total sample, all correlations between indices were significant, except for the relation between pupil diameter to angry expressions and total time attending to happy expressions. In the non-dysphoric group, all correlations between indices were significant, except for the relation between total time attending to happy faces and pupil diameter to sad and angry expressions. Pupil diameters to happy, angry and sad faces were positively associated with total time attending to happy, angry and sad faces. Interestingly, pupil diameter to sad expressions was also positively correlated with total time attending to angry faces. Similarly, total time attending to sad expressions was also related to higher pupil diameter to angry faces, and with lower pupil diameter to happy faces. In the dysphoric group, only three correlations were significant: pupil diameter to happy faces and total time attending to happy faces, pupil diameter to angry faces and total time attending to angry faces, and pupil diameter to sad faces and total time attending to happy faces. Subsequent partial correlation analyses controlling for BDI-II (see Table 3), showed that results did not differ from those obtained in the zero-order correlation analyses. Thus, hypothesis 1 was only partially confirmed. Pupil diameter to each type of emotional stimuli was associated with total time attending to the corresponding type of emotional stimuli, but these associations were significant in all the emotional categories only in the total sample and non-dysphoric group. Furthermore, we found a “cluster effect” between sad and angry faces (i.e., sad and angry processing indices were inter-correlated both in the total sample and non-dysphoric group), revealing an absence of emotional specificity.

Rumination and sustained processing of emotional information

In order to test our second and third hypotheses, zero-order and partial correlations controlling for current depressive symptoms were used to explore

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2 Given the significant gender differences found in brooding, we examined whether statistically controlling for gender affected any of the reported results. The findings from these analyses were similar to those reported below.
Table 1. Means and standard deviation of the variables included in the study

<table>
<thead>
<tr>
<th></th>
<th>Total sample</th>
<th>Non-dysphoric group</th>
<th>Dysphoric group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>M</td>
<td>SD</td>
</tr>
<tr>
<td>Age</td>
<td>126</td>
<td>22.04</td>
<td>2.37</td>
</tr>
<tr>
<td>Males, N (%)</td>
<td>126</td>
<td>25 (18%)</td>
<td></td>
</tr>
<tr>
<td>Clinical measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Depressive symptoms (BDI-II)</td>
<td>126</td>
<td>9.14</td>
<td>8.08</td>
</tr>
<tr>
<td>Rumination total score (RRS)</td>
<td>126</td>
<td>48.36</td>
<td>12.80</td>
</tr>
<tr>
<td>Brooding (RRS)</td>
<td>126</td>
<td>10.90</td>
<td>3.69</td>
</tr>
<tr>
<td>Reflection (RRS)</td>
<td>126</td>
<td>10.92</td>
<td>3.50</td>
</tr>
<tr>
<td>Visual processing indices</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total time (ms)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Happy faces (ms)</td>
<td>125</td>
<td>468.10</td>
<td>417.92</td>
</tr>
<tr>
<td>Angry faces (ms)</td>
<td>126</td>
<td>−33</td>
<td>487.27</td>
</tr>
<tr>
<td>Sad faces (ms)</td>
<td>126</td>
<td>−9.7</td>
<td>436.48</td>
</tr>
<tr>
<td>Pupil diameter (mm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Happy faces (mm)</td>
<td>126</td>
<td>$1.12 \times 10^{-1}$</td>
<td>$2.85 \times 10^{-1}$</td>
</tr>
<tr>
<td>Angry faces (mm)</td>
<td>126</td>
<td>$7.62 \times 10^{-5}$</td>
<td>$1.56 \times 10^{-1}$</td>
</tr>
<tr>
<td>Sad faces (mm)</td>
<td>126</td>
<td>$2.86 \times 10^{-5}$</td>
<td>$1.41 \times 10^{-1}$</td>
</tr>
</tbody>
</table>

Note: M, mean; SD, standard deviation; BDI, Beck depression inventory-II; RSS rumunative response scale.
the relations between rumination components and sustained visual processing of emotional information indices (see Tables 4 and 5, respectively).

Our second hypothesis was supported. In the total sample, total time attending to negative information (i.e., angry and sad faces) was positively associated with a global ruminative style. Furthermore, total time attending to sad and angry faces was also positively associated with a higher global ruminative style in the non-dysphoric and dysphoric groups after controlling for severity symptoms (see Table 5). With regard to rumination components, in the non-dysphoric group, reflection was positively associated with total time attending to sad and angry faces, and negatively associated with total time attending to happy faces. These relations were not significant in the dysphoric group. However, the brooding component was significantly associated with the total time attending to sad faces in the dysphoric group. These associations remained significant even after controlling for severity of depressive symptoms.3

Regarding the relations between pupil diameter to emotional information and rumination, our third hypothesis only received partial support. We found an association between pupil diameter to sad faces and both global ruminative style and brooding in the total sample (see Table 4). However, when depressive symptoms were controlled, this association was only significant for global rumination, whereas the relation to the brooding component did not reach significance (see Table 5). Moreover, when correlations were performed separately for the dysphoric and non-dysphoric groups, the association between pupil diameter to sad faces and global ruminative style or brooding did not reach significance for any group. No other significant associations between rumination components and pupil dilation to emotional faces were found, except for a negative relation between reflection and pupil diameter to happy faces. This significant relation was found in the total sample and also in the non-dysphoric group.

**Indirect effects analyses**

Correlation analyses showed that the only rumination factor associated with both behavioural and physiological indices of sustained processing of negative information was the global ruminative style and this relation was only significant for the total sample. However, due to the numerous significant associations found in both groups of participants between (1) global ruminative style and total time attending to emotional information indices and (2) total time attending and pupil diameter for emotional information indices, we conducted a series of analyses to test whether global ruminative style influenced pupil diameter indices via total time attending to emotional information indices in each group.

Following analytic guidelines by Mathieu and Taylor (2006), to exam these indirect effects we used a bootstrapping method, with 5000 bootstrap resamples (Hayes, 2013).

According to this rationale, three different analyses were conducted in the non-dysphoric group (Table 6). In the first analysis, pupil

3 Further analyses were conducted to test whether a more general association between rumination and total time fixating on faces (both emotional and neutral) per se, could account for specific relations between rumination components and total time fixating on emotional faces. Overall percentage of time spent fixating on emotional faces was 70% of the total time fixating on faces (non-dysphoric participants: happy-neutral faces trials: 69.7%, angry-neutral faces trials: 69.9%, sad-neutral faces trials: 69.7%; dysphoric participants: happy-neutral faces trials: 70.7%, angry-neutral faces trials: 70.3%, sad-neutral faces trials: 70%). Both zero-order and partial correlation analyses controlling for current depressive symptoms did not show any significant association between indices of overall time fixating on faces and global ruminative style, brooding or reflection (all r’s < .162; all p’s > .05) in the total sample. Furthermore, no significant zero-order or partial correlations were found for the dysphoric (all r’s < .165; all p’s > .05) nor the non-dysphoric group (all r’s < .198; all p’s > .05), separately. Thus, our analyses indicated that rumination did not contribute to a general sustained processing of information per se, but it contributed to a specific sustained processing of emotional information.
Table 2. Bivariate correlations between visual sustained processing indices

<table>
<thead>
<tr>
<th></th>
<th>Total sample (n = 126)</th>
<th>Non-dysphoric group (n = 87)</th>
<th>Dysphoric group (n = 39)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pupil diameter to happy faces (mm)</td>
<td>Pupil diameter to angry faces (mm)</td>
<td>Pupil diameter to sad faces (mm)</td>
</tr>
<tr>
<td></td>
<td>.49**</td>
<td>−.14</td>
<td>−.21*</td>
</tr>
<tr>
<td>Total time attending to</td>
<td>−.37**</td>
<td>.44**</td>
<td>.31**</td>
</tr>
<tr>
<td>happy faces (ms)</td>
<td>−.38**</td>
<td>.33**</td>
<td>.32**</td>
</tr>
</tbody>
</table>

Note: *p < .05; **p < .001.

Table 3. Partial correlations between visual sustained processing indices (controlling for BDI-II)

<table>
<thead>
<tr>
<th></th>
<th>Total sample (n = 126)</th>
<th>Non-dysphoric group (n = 87)</th>
<th>Dysphoric group (n = 39)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pupil diameter to happy faces (mm)</td>
<td>Pupil diameter to angry faces (mm)</td>
<td>Pupil diameter to sad faces (mm)</td>
</tr>
<tr>
<td></td>
<td>.49**</td>
<td>−.13</td>
<td>−.20**</td>
</tr>
<tr>
<td>Total time attending to</td>
<td>−.37**</td>
<td>.44**</td>
<td>.31**</td>
</tr>
<tr>
<td>happy faces (ms)</td>
<td>−.38**</td>
<td>.33**</td>
<td>.32**</td>
</tr>
</tbody>
</table>

Note: *p < .05; **p < .001.
<table>
<thead>
<tr>
<th></th>
<th>Total sample (n = 126)</th>
<th>Non-dysphoric group (n = 87)</th>
<th>Dysphoric group (n = 39)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Depressive symptoms</td>
<td>Global rumination</td>
<td>Reflection</td>
</tr>
<tr>
<td>Total time attending to happy faces (ms)</td>
<td>−.18**</td>
<td>−.17</td>
<td>−.12</td>
</tr>
<tr>
<td>Total time attending to angry faces (ms)</td>
<td>−.02</td>
<td>.21*</td>
<td>.18*</td>
</tr>
<tr>
<td>Total time attending to sad faces (ms)</td>
<td>.02</td>
<td>.30**</td>
<td>.25**</td>
</tr>
<tr>
<td>Pupil diameter to happy faces (mm)</td>
<td>−.00</td>
<td>−.11</td>
<td>−.23**</td>
</tr>
<tr>
<td>Pupil diameter to angry faces (mm)</td>
<td>.06</td>
<td>.15</td>
<td>.15</td>
</tr>
<tr>
<td>Pupil diameter to sad faces (mm)</td>
<td>.03</td>
<td>.20*</td>
<td>.07</td>
</tr>
</tbody>
</table>

Note: *p < .05; **p < .01.
diameter to sad faces was the criterion variable, global ruminative style the antecedent variable, and total time attending to sad faces the potential mediator. BDI-II scores were included as covariate. True indirect effect was estimated to lie between .0002 and .0027. In the second analysis, pupil diameter to angry faces was the criterion variable, global ruminative style the antecedent variable, and total time attending to angry faces the mediator. BDI-II scores were included as covariate. True indirect effect was estimated to lie between .0002 and .0035. Finally, in the third analysis, pupil diameter to happy faces was the criterion variable, ruminative style the antecedent variable, and total time attending to happy faces the mediator. BDI-II scores were included as covariate. True indirect effect was estimated to lie between $-0.0086$ and $-0.0003$. Since zero is not in the 95% confidence interval for the three analyses, we can conclude that the indirect effects were significantly different from zero at $p < .05$, and that pupil diameter is influenced by global ruminative style via total time attending to sad, angry and happy faces, respectively.

In line with Baron and Kenny (1986), we also explored the validity of three reversed indirect effect models, in which total time attending to emotional faces indices were the criterion variables and pupil diameter to emotional faces indices the potential mediators (Table 6). In these analyses, global ruminative style remained as antecedent variable. For sad, angry and happy faces, true effects were estimated to lie between $-0.0001$ and $-0.0068$, $-0.22$ and $0.09$, and $-0.06$ and $0.25$, respectively. Since zero is not in the 95% confidence interval for sad faces, we can conclude that the indirect effect was significantly different from zero at $p < .05$ (i.e., the reversed model in that total time attending to sad faces is influenced by global ruminative style via pupil diameter was supported). However, for angry and happy faces, since zero is in the 95% confidence interval, we can conclude that pupil diameter to emotional faces did not account the relationship between global ruminative style and total time attending to angry and happy faces.
Table 6. Bootstrap analyses of the magnitude and statistical significance of indirect effects for global rumination (controlling for BDI-II scores) in the non-dysphoric group. (Pathways in bold are significant)

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Mediator variable</th>
<th>Dependent variable</th>
<th>B</th>
<th>Mean indirect effect</th>
<th>SE of mean</th>
<th>95% CI mean indirect effect (lower and upper)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global rumination</td>
<td>TotalTimeSad</td>
<td>PupilSad</td>
<td>.0010</td>
<td>.0006</td>
<td></td>
<td>.0002 and .0027</td>
</tr>
<tr>
<td>Global rumination</td>
<td>TotalTimeAngry</td>
<td>PupilAngry</td>
<td>.0015</td>
<td>.0008</td>
<td></td>
<td>.0002 and .0035</td>
</tr>
<tr>
<td>Global rumination</td>
<td>TotalTimeHappy</td>
<td>PupilHappy</td>
<td>−.0031</td>
<td>.0020</td>
<td></td>
<td>−.0086 and −.0003</td>
</tr>
<tr>
<td>Reversed models</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global rumination</td>
<td>PupilSad</td>
<td>TotalTimeSad</td>
<td>.0024</td>
<td>.0017</td>
<td></td>
<td>.0001 and .0068</td>
</tr>
<tr>
<td>Global rumination</td>
<td>PupilAngry</td>
<td>TotalTimeAngry</td>
<td>.0028</td>
<td>.0022</td>
<td></td>
<td>−.0009 and .0079</td>
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<tr>
<td>Global rumination</td>
<td>PupilHappy</td>
<td>TotalTimeHappy</td>
<td>−.0025</td>
<td>.0018</td>
<td></td>
<td>−.0070 and .0001</td>
</tr>
</tbody>
</table>

Note: TotalTimeSad, Total time attending to sad faces; PupilSad, Pupil diameter to sad faces; TotalTimeAngry, Total time attending to angry faces; PupilAngry, Pupil diameter to angry faces; TotalTimeHappy, Total time attending to happy faces; PupilHappy, Pupil diameter to happy faces.

Table 7. Bootstrap analyses of the magnitude and statistical significance of indirect effects for global rumination (controlling for BDI-II scores) in the dysphoric group

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Mediator variable</th>
<th>Dependent variable</th>
<th>B</th>
<th>Mean indirect effect</th>
<th>SE of mean</th>
<th>95% CI mean indirect effect (lower and upper)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect effects</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global rumination</td>
<td>TotalTimeSad</td>
<td>PupilSad</td>
<td>.0013</td>
<td>.0016</td>
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<td>−.0013 and .0050</td>
</tr>
<tr>
<td>Global rumination</td>
<td>TotalTimeAngry</td>
<td>PupilAngry</td>
<td>.0017</td>
<td>.0012</td>
<td></td>
<td>−.0001 and .0053</td>
</tr>
<tr>
<td>Global rumination</td>
<td>TotalTimeHappy</td>
<td>PupilHappy</td>
<td>.0015</td>
<td>.0019</td>
<td></td>
<td>−.0016 and .0061</td>
</tr>
<tr>
<td>Reversed models</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Global rumination</td>
<td>PupilSad</td>
<td>TotalTimeSad</td>
<td>.0014</td>
<td>.0022</td>
<td></td>
<td>−.0011 and .0088</td>
</tr>
<tr>
<td>Global rumination</td>
<td>PupilAngry</td>
<td>TotalTimeAngry</td>
<td>.0023</td>
<td>.0029</td>
<td></td>
<td>−.0006 and .0119</td>
</tr>
<tr>
<td>Global rumination</td>
<td>PupilHappy</td>
<td>TotalTimeHappy</td>
<td>−.0014</td>
<td>.0040</td>
<td></td>
<td>−.0114 and .0052</td>
</tr>
</tbody>
</table>

Note: TotalTimeSad, Total time attending to sad faces; PupilSad, Pupil diameter to sad faces; TotalTimeAngry, Total time attending to angry faces; PupilAngry, Pupil diameter to angry faces; TotalTimeHappy, Total time attending to happy faces; PupilHappy, Pupil diameter to happy faces.
Using the same criteria as outlined above, indirect effects models were also tested in the dysphoric group for sad, angry and happy faces (Table 7). When pupil diameter to sad, angry and happy faces were included as criterion variables, global ruminative style as antecedent variable and total time attending to emotional faces as mediator variable, true indirect effects were estimated to lie between \(-0.0016\) and \(0.0061\). Since zero is in the 95% confidence interval for the three analyses, we can conclude that the indirect effects were not significantly different from zero at \(p < 0.05\). Thus, indirect effects models were not supported for this group. The reversed models, using total time attending to sad, angry and happy faces as criterion and pupil diameter to emotional faces as mediator, were not supported either (Table 7).

Given the lack of direct association between antecedent (ruminative style) and criterion (pupil diameter indices) in both groups, dysphoric (all \(r's < 0.18; \) all \(p's > 0.05\)) and non-dysphoric (all \(r's < 0.21; \) all \(p's > 0.05\)), other alternative models to test full or partial mediation were not conducted.

**DISCUSSION**

The present study investigated the relations between behavioural and physiological indicators of sustained visual processing of emotional information and their association with rumination. Our first hypothesis (namely, that pupil diameter to emotional information would be associated with total time attending to emotional information) was partially supported. Pupil diameter indices were associated with direct measures of total time attending to emotional information across the total sample. These associations were also found separately for participants at different levels of depression severity, with the exception of the association between total time attending and pupil dilation to sad faces in the dysphoric group. However, we found a “cluster effect” between sad and angry processing indices showing a lack of emotional specificity. Overall, results are consistent with the assumption that pupil size changes may reflect a physiological response associated with sustained attentional processing (Iqbal et al., 2004; Kahneman, 1973).

Regarding the associations between sustained emotional processing indices and rumination, our second hypothesis was supported. Total time attending to negative information (i.e., angry and sad faces) was associated with a higher global ruminative style across the total sample. These relationships were also found for the two subgroups of dysphoric and non-dysphoric participants once depression severity was controlled. The present findings are consistent with previous dot-probe research, which found that attentional biases to negative information were positively correlated with a global ruminative style (Donaldson et al., 2007). The eye-tracking methodology employed in the present study overcomes the limitations of dot-probe research, replicating and extending previous findings to show that rumination is linked to a sustained processing of negative information. Recent proposals postulate that difficulties in inhibiting the processing of negative information are a central mechanism that contributes to the continuous processing of negative information (Koster et al., 2011). Koster et al. (2011) have argued that sustained processing of negative information leads to persistent rumination and prolonged negative mood, which in turn reinforces a sustained processing of negative aspects. Our results are consistent with this assumption and suggest that rumination and sustained processing of negative information may be interrelated factors involved in the development and maintenance of depression.

Importantly, besides this general association between global ruminative style and sustained processing of negative information, brooding and reflection showed specific associations with sustained negative processing for dysphoric and non-dysphoric participants. This pattern of results suggests differential contributions of rumination components in emotional information processing depending on the depression severity condition. As hypothesised, we found that sustained processing of sad faces was specifically associated with brooding but not with reflection for dysphoric participants. This finding is consistent with a
previous dot-probe study which found that attention to depression-related information was specifically associated with the brooding component in a subsample of currently depressed participants (Joormann et al., 2006). Taken together, the results suggest that brooding may play a maintaining role in depression by favouring a sustained processing of depression-related information which, in turn, might contribute to a prolonged negative mood in these individuals.

Interestingly, for the non-dysphoric participants, the only factor significantly related to sustained processing of negative information (i.e., sad and angry faces) was reflection, which was also associated with lower sustained processing of positive information (i.e., happy faces). According to Nolen-Hoeksema et al. (2008), reflection may be an emotionally distressing response style in the short term, thus affecting concurrent emotional processing. Our results support this assumption, suggesting that, for non-dysphoric participants, a higher use of reflection seems to contribute to a concurrent sustained processing of negative information and a reduced processing of positive information. However, research has also shown that although the use of reflection in non-clinical samples may be maladaptive in the short term, it predicts depression decreases over time (e.g., Treynor et al., 2003). Further longitudinal research is warranted to clarify the role of the association between reflection and sustained emotional processing in predicting depression changes over time. Despite the hypothesised adaptive role of reflection in non-dysphoric individuals (Nolen-Hoeksema et al., 2008), more recent research has shown that both a sustained processing of negative information and a reduced processing of positive information may be linked to the generation of persistent sad mood states (e.g., Sánchez, Vazquez, Gomez-Baya & Joormann, 2014; Sánchez, Vazquez, Marker, LeMoult, & Joormann, 2013). Thus, further research should clarify whether attentional processing associated with reflection in non-dysphoric participants may be protective or, on the contrary, confer vulnerability to developing depression over time. Current results do not allow us to respond to this issue.

With regard to the associations between rumination and pupil dilation to emotional information, our third hypothesis was only partially supported. Pupil diameter resulting from the visualisation of sad faces was associated with a higher global ruminative style across the total sample. This finding is consistent with results found in Siegle et al. (2003), who reported a positive association between multiple self-report measures of rumination and sustained pupil size to negative personally relevant information. However, when we considered this association separately for dysphoric and non-dysphoric participants, it did not reach significance for any group. Moreover, although zero-order correlation analyses showed a significant association between brooding and pupil diameter to sad faces in the total sample, this association did not reach significance once controlled for current depressive symptoms and it was not specifically significant for the dysphoric group. Thus, the unique factor associated with both behavioural and physiological indices of sustained negative processing, was the global ruminative style and this relation was only significant across the total sample.

A possible explanation for the limited support in the association between rumination and pupil dilation is that rumination may be indirectly linked to physiological responses to emotional information through its influence on the sustained attentional processing of that information. We tested this indirect effect model in each group for those types of emotional information where significant associations between factors were found. The results for the non-dysphoric group support this model, showing that rumination had an indirect effect on pupil diameter via total time attending to the corresponding type of emotional information (i.e., happy, angry and sad faces). A reversed indirect effect model, in which rumination had an indirect effect on total time attending to emotional faces via pupil dilation, was also supported for sad faces. However, this reversed model was not supported for angry and happy faces. Overall, these results suggest that rumination may be linked to pupil changes in response to emotional information due to its influence in
sustained attentional processing. However, this indirect effect model should be considered cautiously, as an inverse relation between pupil size and total time attending to sad faces was also supported in this group.

Moreover, the role of sustained attentional processing of negative information between rumination and pupil dilation was not supported for the dysphoric group. The differences in support of the indirect effect model in each group might be due to the role of depression severity in the associations between sustained processing indices. For instance, correlation analyses showed a non-significant association between total time attending and concurrent pupil dilation to sad faces in the dysphoric group. Thus, with regard to high depression severity levels, although a global ruminative style is linked to a higher sustained processing of negative information, this sustained processing may not result in concurrent higher pupil dilation. Pupil diameter is indicative of a range of cortical and subcortical brain mechanisms (e.g., amygdala, dorso-lateral prefrontal cortex and anterior cingulate cortex activity) involved in attentional processing of emotional information. Current cognitive and neurobiological findings (for a review see, for instance, De Raedt & Koster, 2010) show that sustained negative information processing in depressed compared to non-depressed participants is linked to a decrease in activity in prefrontal areas, associated with an impaired attenuation of subcortical regions, resulting in prolonged activation of the amygdala. Differential results by group concerning the association between the factors in our study may reflect differential patterns of cortical and subcortical activity in response to the sustained processing associated with rumination, depending on the depression severity condition.

However, differential results by group on the indirect effect model of rumination influence in pupil dilation should be considered cautiously. For instance, the absence of statistical support for the indirect effect model in dysphoric participants could be affected by the relatively small sample size for this group in our study. Further research should examine interactions between rumination and behaviour and physiological indicators of sustained processing in larger dysphoric samples, to clarify the role of depression severity in these associations. Moreover, our study is somewhat limited in the sense that it was conducted using a non-clinical sample and DSM-IV diagnoses of current depressive disorders were not assessed. Furthermore, the analysis of the relation between rumination components and sustained processing of emotional information in our study was correlational and some correlations were modest-to-medium. Although our analyses and the magnitude of our results are similar to the ones used in previous analogous studies (e.g., Joormann et al., 2006), further research is necessary to clarify these relations. For instance, more direct evidence of a causal role of the components of rumination in emotional processing will require studies that examine whether inductions of different types of rumination responses (i.e., brooding vs. reflection) lead to specific changes in sustained processing of emotional information at different levels of depression severity.

Despite these limitations, the current study should be noted for its methodological rigour. The eye-tracking methodology employed allowed the processing of emotional information to be monitored continuously and this is not possible for other tasks such as the dot-probe test. Moreover, the present findings support the assumption that pupil size changes can be reliably considered as a psychophysiological response associated with sustained attentional processing (Iqbal et al., 2004) and the findings suggest that this may vary as a function of depression severity. Hence, this study replicates and extends previous evidence of the relation between behavioural and physiological indicators of the processing of emotional information and their association with rumination components. These findings may help to increase our understanding of the cognitive mechanisms involved in the development and maintenance of depression.
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