Emotion modulation of the pupil response in psychopathy

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Keywords: Psychopathy, interpersonal-affective, emotion, pupillometry
Abstract

Psychopathy is a form of personality disorder associated with a deficit in emotional processing. However, there is debate whether this deficit applies to all emotions, or exists only for negative emotions. The pupil dilates rapidly in response to emotional stimuli, allowing a time-sensitive index of emotional processing. Across three experiments using: (1) visual images of real-world scenes, (2) auditory sound-clips, and (3) videos of dynamic facial expressions, we measured emotional modulation of the pupil response to both negative and positive stimuli. Participants were 82 male mentally disordered offenders. Psychopathy was measured using the Psychopathy Checklist-Revised (PCL-R) to produce factor scores of interpersonal-affective traits (Factor 1) and lifestyle-antisocial traits (Factor 2). Participants with high Factor 1 scores showed reduced emotional modulation of the pupil response to negative images and angry faces, but not to any of the positive stimuli. These effects only occurred shortly after the emotion was presented (< 2000 ms) suggesting delayed processing of negative affective stimuli in Factor 1 psychopathy. Factor 2 scores were not associated with any changes in pupil response. There were no effects of psychopathy on the pupil response to the affective sound-clips. The results support a specific psychopathic deficit in the processing of negative stimuli related to the interpersonal-affective dimension of psychopathy. We argue that pupillometry is a powerful and non-invasive tool to investigate emotional processing in clinical populations.

Keywords: Psychopathy, interpersonal-affective, emotion, pupillometry
Emotional modulation of pupil diameter in psychopathy

Affective Processing in Psychopathy

Psychopathy is a form of personality disorder that is associated with pervasive anti-social behavior. Many theories of psychopathy propose an affective deficit, where stimuli that contain affective content fail to induce normative affective states, behavioral responses, or physiological reactions (Hare, 2003). However, the evidence for the nature of this emotional deficit underpinning psychopathy is inconsistent (Brook, Brieman, & Kosson, 2013; Dawel, O’Kearney, McKone, & Palermo, 2012). A general emotional deficit perspective argues that psychopathy is linked to a blunted capacity for experiencing all emotions (Cleckley, 1941). There is some evidence to support such a position. For instance, Verona, Patrick, Curtin, Bradley, and Lang (2004) found that psychopathy was related to a deficit in galvanic skin responses to affective sounds for both negatively-valenced and positively-valenced sounds. Others, however, suggest that psychopathy is associated with a problem in processing only negative emotions such as sadness and fear. For example, the low-fear hypothesis (Lykken, 1957) proposes that psychopathy is characterised by a reduced capacity for activating fear systems leading to an insensitivity to fearful cues.

There is evidence to support a negative-specific deficit within psychopathy. For example, Benning, Patrick, and Iacono (2005) reported that individuals high in psychopathy evidenced deficient skin conductance magnitudes only in response to aversive images. Further, Patrick, Bradley, and Lang’s (1993) seminal work examined how the startle response to a loud stimulus is altered when viewing affective images. For individuals low in psychopathy, aversive pictures increased the magnitude of the startle response whilst positive images decreased the startle reflex. However, for those with high psychopathy scores, the aversive images did not produce the expected increase in the startle response (and
may even have caused a decrease). In contrast, the positive images produced a typical
decrease in startle reflex. Hence, this experiment points to a selective deficit in processing
the aversive affective content of stimuli for individuals high in psychopathy.

However, Brook et al. (2013) concluded in their review that the “overall pattern of
findings is not clearly consistent with any of the dominant theoretical perspectives of
emotion processing in psychopathy” (p. 979). It seems probable that different experimental
paradigms, which use different stimulus-types (e.g., image-based, auditory, facial stimuli
etc.) and that have different task-demands, have all contributed to this inconsistent pattern
of results. Therefore, it seems pertinent to explore a basic autonomic response to affective
cues (both negative and positive) across a range of stimulus modalities to further evaluate
the nature of emotional processing impairments associated with psychopathy.

**Pupillometry**

The pupil is known to be sensitive to the affective content of a stimulus. Whilst some
evolved early studies suggested that negative stimuli cause a constriction of the pupil and positive
stimuli cause a dilation (Hess & Polt, 1960), many recent studies show that both negative
and positive stimuli produce a significant dilation and this has been demonstrated for visual
images, sound-clips, and facial stimuli (Bradley, Miccoli, Escrig, & Lang, 2008; Bradley,
Sapigao, & Lang, 2017; Burley, Gray, & Snowden, 2017; Snowden et al., 2016; Partala &
Surakka, 2003). Hence, it appears that it is not the valence of a stimulus that causes the
dilation but instead the arousal induced by the stimulus. However, the exact nature of which
affective stimuli produce pupil dilation is still debated. Some studies have looked at how
people’s subjective ratings of a stimulus is related to pupil dilation (O’Farrel, 2016; Bradley
et al., 2017). Whilst there is a relationship between subjective rating and pupil dilation, it is
also clear that some stimuli that are subjectively rated as arousing do not give rise to a
corresponding degree of pupil dilation (such as pictures of cute animals, babies, etc.). Instead, it is those stimuli that would normally demand immediate action if encountered in real-life (e.g., threats, sex, violence) that cause the greatest pupil dilation. This has led to the suggestion that the degree of pupil dilation is related to the extent with which the stimulus engages the fundamental defensive or appetitive motivational systems (Bradley et al., 2017).

At a physiological level, pupil diameter is mediated via the activity of two groups of muscles: the sphincter pupillae and the dilator pupillae. The sphincter pupillae are controlled by the parasympathetic nervous system and activation serves to constrict the pupil. The dilator pupillae are innervated by the sympathetic nervous system and activation of these muscles serves to dilate the pupil. It is this sympathetically mediated dilation that is being detected in experiments using affective stimuli (Bradley et al., 2017). The sympathetic activity arises from activation of the amygdala and pupil dilation is considered to reflect amygdala activity (Davis, 1992). Indeed, direct stimulation of the amygdala leads to pupil dilation (Koikegami & Yoshida, 1953) and there is evidence for the co-occurrence of both pupil dilation and increased amygdala activity (Siegle, Steinhauer, Thase, Stenger, & Carter, 2002).

It is clear that the amygdala plays a major role in the processing of threat stimuli, the mediation of fear, and is important in fear conditioning (Phelps & LeDoux, 2005). Hence, a dysfunction in the amygdala may cause someone to lack fear and to fail to learn from punishment. Not surprisingly, dysfunction of the amygdala has been put forward as a possible neurophysiological explanation of many features of psychopathy (e.g., Blair, 2003). However, the amygdala is also sensitive to many other stimuli, including positively valenced stimuli. For example, Hamann, Ely, Hoffman, and Kilts (2002) showed strong activity in the amygdala, via positron emission topography, to a mixture of positive images showing nudes,
appealing animals, infants and foods. They also showed that the amygdala was responsive to unusual or interesting images. Such findings suggest the amygdala is involved in processing the “motivational salience” of stimuli (Cunningham & Brosch, 2012) including both negative and/or positive stimuli. Therefore, the pupil offers a non-invasive index of amygdala activity, which is valuable to investigate the emotional deficit underpinning psychopathy given the proposed link between psychopathy and abnormal amygdala structure and function (Moul, Killcross, & Dadds, 2012).

There are several pragmatic advantages to pupillometry compared to other measures of sympathetic activity, such as skin conductance response (SCR). Firstly, pupil dilation is far more dynamic than the slow response of the palmar sweat glands and may provide a more time-sensitive psychophysiological tool to explore autonomic reactivity to emotional stimuli. In addition, the pupil response is a more reliable measure of emotional arousal. Bradley et al. (2017) reported that 92% of their sample of healthy volunteers had significantly larger pupils to emotional images compared to neutral images, whereas only 67% of participants evidenced greater SCR to the same images. Importantly, the pupil’s reaction to the affective component of stimuli is automatic and is not influenced by habituation or attention (Snowden et al., 2016).

There has been one previous study examining the effects of psychopathy on the emotional modulation of the pupil response (Burley et al., 2017), but this did not demonstrate any significant effects of psychopathy on pupil responsivity to negative and positive stimuli across a range of stimulus types. However, this study used an undergraduate sample and measured psychopathy using a self-report questionnaire. We aimed to build upon this study to investigate the emotional deficits in psychopathy by measuring psychopathy using the
Psychopathy Checklist-Revised (PCL-R; Hare, 2003) in a forensic population where a proportion of individuals were expected to show elevated levels of psychopathic traits.

Factors and Facets of Psychopathy

Psychopathy has been traditionally considered as a unitary construct with a single underlying cause (Neumann, Hare, & Newman, 2007), but research suggests that this approach may mask the contribution of underlying dimensions and, therefore, psychopathy has been explored as a multi-faceted disorder. The PCL-R, the instrument most often used within offender/criminal samples and in clinical settings, is thought to be underpinned by two-factors: Factor 1 (interpersonal-affective) capturing features such as grandiosity, lack of guilt and callousness, and Factor 2 (lifestyle-antisocial) capturing impulsive and disinhibited antisocial behavior. Factor 1 has been found to be associated with deficits in processing emotions, including blunted physiological responses to affective stimuli. For example, in the study of Patrick et al. (1993) described above, the lack of potentiated startle to the aversive stimuli was only associated with Factor 1 and not Factor 2 (see also Vaidyanathan, Hall, Patrick, & Bernat, 2011; Vanman, Mejia, Dawson, Schell, & Raine, 2003). More recent models have further separated the PCL-R factors into a 4-facet model of psychopathy (Hare, 2003) with interpersonal (Facet 1), affective (Facet 2), lifestyle (Facet 3) and antisocial facets (Facet 4). This highlights the importance of carefully considering both factor and facet models of psychopathy when investigating the nature of the emotional processing deficit underpinning psychopathy.

Current Study

The current study aimed to define the nature of emotional processing impairments associated with psychopathy by measuring pupil responses to negative, positive and neutral stimuli across three different modalities (images, sounds, and dynamic facial expressions)
within a population of offenders with a mental disorder. Psychopathy was indexed via the clinician-rated PCL-R. We hypothesized that Factor 1 of the PCL-R would be related to reduced pupil dilation to negative (and possibly positive) stimuli, whereas Factor 2 would be unrelated to pupil responses to emotional stimuli.

Theories of affective deficits (Blair et al., 2005) or of attentional deficits (Newman & Lorenz, 2003) in psychopathy both predict a reduction in affective processing that could be overcome if the stimulus was presented for a sufficient time or at a sufficient intensity (Hamilton, Hiatt Racer, & Newman, 2015). Hence, it seems likely that deficits due to psychopathy might be more evident “early” in the response to a stimulus, with the deficit weakening or disappearing at a “late” time period, although the precise definition of early and late is not possible as this is likely to vary with factors such as stimulus intensity and modality. Nevertheless, we hypothesised that deficits are more likely in an early period than in a later period. Indeed, several studies have found that psychopathic individuals demonstrate attenuated physiological responses to emotional stimuli early in the sequence of responses (up to around 2000 ms), but normal later responses (Levenston, Patrick, Bradley, & Lang, 2000; Sutton, Vitale, & Newman, 2002; Justus & Finn, 2007). Hence, all analyses examined the effects of emotional content on pupil response over the time-course of each stimulus with the hypothesis that the effects of psychopathy would be stronger earlier in the pupil response.

**Method**

**Participants**

Eighty-two men (mean age = 38.6, SD = 12.8) were recruited from low and medium secure psychiatric hospitals in the UK. The majority had a diagnosis of a personality disorder (n = 68, 83%), with other common diagnoses being schizophrenia, schizotypal and
delusional disorders \((n = 40, 49\%)\) and mood disorders \((n = 8, 10\%)\). Table 1 presents their demographic information.

Sample size was based on an \textit{a priori} power calculation for a linear multiple regression including two predictor variables (Factor 1 and Factor 2) with 80\% power \((\alpha = .05)\) to detect a medium effect size \((f^2 = 0.15)\). Participants gave written informed consent to participate in the experimental procedures and for the research team to access their hospital medical records. They were paid for their participation. All experimental procedures were given NHS ethical approval (REC reference: 14/SC/1198).

Participants were eligible to take part in the study if they had the ability to give informed consent and were not currently psychotic. The Responsible Clinician\(^1\) for each patient made these judgments. Only participants with an IQ above 70 took part. Participants were free from any documented history of head injury (defined as a loss of consciousness for more than one hour), spoke English as their first language, and had normal/corrected-to-normal vision. Random drugs tests carried out by the hospitals during the research period to test for illicit substance misuse were negative for all cases.

It was recorded whether participants were taking anti-psychotic, anti-anxiety and/or anti-depressant medication with 32.9 \% of the sample being medication-free. Across the sample, 61.0\% of the participants were taking anti-psychotic medication (atypical only = 46.3\%; typical only = 11.0\%; both atypical and typical = 3.7\%), 26.8\% of the sample were taking benzodiazepines, while 20.7\% of participants were taking anti-depressant medication (see Supplementary Materials for further details).

\(^{1}\) The Responsible Clinician has overall responsibility for care and treatment for service users being assessed and treated under the Mental Health Act.
**Materials and Design**

Affective images, affective sounds, and dynamic facial expressions were presented across three independent tasks in this set order. Stimulus presentation order within each task was randomized. Participants were read these instructions prior to each task, “You are now going to be presented with some images/sound-clips/video-clips. Your task is to pay attention to them, and keep your eyes on the screen while keeping your head as still as you can”.

**Affective images.**

Thirty images from the International Affective Picture System (IAPS; Lang, Bradley & Cuthbert, 2008) were selected. Ten were negative (mean valence/arousal based on IAPS ratings = 2.91, 6.20), 10 positive (7.60, 5.89), and 10 neutral images (5.17, 3.10). All images were presented in grey-scale and matched for luminance and contrast. Each image was presented for 2000 ms and was preceded by an equiluminant grey screen displaying a fixation cross (for 2000 ms) and was followed by a similar plain grey screen for 5000 ms.

**Affective sounds.**

Thirty sound-clips were selected from the International Affective Digital Sounds (IADS; Bradley & Lang, 2007) consisting of 10 negative (mean valence/arousal = 2.87, 7.09), 10 positive (7.17, 6.76), and 10 neutral (5.06, 5.05). The sound-clips did not differ (ps > .25) across valence categories for average ($M = -22.61, SD = 2.52$) or maximum root-mean-square decibel level ($M = -11.61, SD = 2.65$). Sound-clips were played to participants at a comfortable set volume through headphones. The sound-clips were presented for 6000 ms and presentation order was randomized. A grey fixation slide was displayed throughout and was presented for another 10,000 ms post offset of auditory stimulus. This recovery time
was based on preliminary pilot work and allowed for the pupil to return to baseline levels before the next trial began.

**Dynamic facial emotions.**

Forty-eight video-clips were selected from the Amsterdam Dynamic Facial Expression Set (ADFES; van der Schalk, Hawk, Fischer, & Doosje, 2011) comprising four male and four female actors simulating facial expressions of fear, happiness, neutral, and anger. We chose to use dynamic facial stimuli as previous research has shown that these are more effective than static emotional expressions of faces for portraying emotions (Alves, 2013). The videos were presented for 4000 ms and depicted an actor displaying a neutral face before changing into the target expression commencing 500 ms post video-clip onset and taking 500-1000 ms to reach full expression (van der Schalk et al., 2011). Screenshots were taken from the end of each video-clip and luminance, contrast and color showed no differences between valences ($p > .35$). All actors were presented facing forwards and with direct gaze. Each video-clip was preceded for 2000 ms and followed for 5000 ms by a grey-screen luminance-matched to the video-clips.

**Psychopathy Checklist-Revised**

The PCL-R (Hare, 2003) is a clinician-rated measure of psychopathy. Factor 1 represents interpersonal-affective psychopathy traits (e.g., grandiosity, callousness/lack of empathy, shallow affect), whereas Factor 2 reflects the lifestyle-antisocial dimension of psychopathy (e.g., impulsivity, parasitic lifestyle, and criminal versatility). PCL-R also provides facet level scores across the interpersonal (Facet 1), affective (Facet 2), lifestyle (Facet 3) and antisocial facets (Facet 4).

Across the sample, 31.7% of participants had been assessed within the last 5 years using both interview and file-review by a trained clinical/forensic psychologist. The remaining
68.3% of participants were assessed on the PCL-R through a collateral file review. Reliable and valid PCL-R ratings can be made on the basis of file information alone that are in-line with scores obtained from full PCL-R assessments (Hare, 2003). The rater (D.B.) was trained on the administration of the PCL-R and had completed the Darkstone Post-Workshop training programme with an inter-class correlation of .87. As a check of inter-rater reliability, the rater conducted a file-review on three participants who had been previously been assessed using the full PCL-R assessment achieving an intra-class correlation of .96 for total PCL-R score. Within the current sample, Factor 1 and Factor 2 demonstrated high internal consistency (Factor 1, $\alpha = .84$; Factor 2, $\alpha = .78$) although item scores were not available for six participants.

**Wechsler Abbreviated Scale of Intelligence**

Intelligence was measured using the two-subtest form of the WASI (Wechsler, 1999) that gives an estimate of full-scale IQ. Twenty-six participants had previously completed the WAIS-III or WAIS-IV (Wechsler, 2014) and so this score was recorded from their patient notes as a more comprehensive assessment of intelligence. IQ scores were similar across WASI ($M = 90.14, SD = 12.88$) and WAIS-III/WAIS-IV ($M = 87.50, SD = 11.60$) with no difference between the abbreviated and full version scores ($p = .38$).

**Data Acquisition and Analyses**

A Tobii X2-60 Hz eye tracker recorded pupil diameter. Pictures were viewed from 57 cm on a 39.6 cm laptop monitor in a dark and quiet room. Data were analyzed using Matlab (MathWorks, version 8.5). We removed any pupil diameter increase or decrease of 0.375 mm within one data reading and deleted the first data point that followed missing data. Data were smoothed using a low-pass filter for a span of 5 readings (83 ms). Pupil size was determined by calculating the mean diameter across both eyes. Pupil diameter for each trial
in the period 200 ms prior to stimulus-onset was subtracted from subsequent pupil size to establish baseline-corrected pupil diameter (Snowden et al., 2016).

Trials with fewer than 50% data points were omitted. Participants were excluded if they had less than 50% valid data across all trials, leading to the removal of three participants for the affective images ($n = 79$), five for the affective sounds ($n = 77$) and four for the dynamic facial expressions ($n = 78$). Split-half reliability estimates using the Spearman-Brown correction revealed good internal consistency for mean pupil diameter across tasks (affective images, $r = .95$; affective sounds, $r = .84$; dynamic facial expressions, $r = .86$).

**Statistical Analyses**

To identify modulation of pupil diameter we calculated the Emotional Modulation of the Pupil Response (EMPR): The differences in pupil diameter between the affective stimulus and the neutral stimulus. This was calculated over 1000 ms epochs throughout stimulus presentation. To investigate the effects of psychopathy on the EMPR we performed separate analyses of variance (ANOVA) for Factor 1 and Factor 2. Each ANOVA included a between-subjects factor of psychopathy score (as a continuous variable), and within-subject factors of stimuli valence (e.g., negative, positive), and time (over each 1000 ms epoch). Where interactions were found they were further examined by planned correlations between psychopathy and EMPR (separately for each valence). Where a significant relationship between a PCL-R factor and EMPR was identified, we ran supplemental analyses separating the PCL-R factors down into their facet components.

To explore the role of potential confounding variables, we examined the influence of psychotropic medication dosage, age, IQ and substance misuse (see Supplementary Materials). The inclusion of these variables did not alter the general pattern of findings in relation to our main hypotheses (see Supplementary Analyses 1 in Supplementary
Materials). We also examined significant relationships between PCL-R scores and EMPR scores by repeating the analyses using only patients without a diagnosis of psychotic disorder (see Supplementary Analyses 2 in Supplementary Materials). Two-tailed statistical analyses were conducted throughout. We reported 95% confidence intervals for all correlational analyses and 90% confidence intervals for ANOVAs (Steiger, 2004).

Results

The sample had a mean PCL-R total score of 20 (SD = 8.0), with 33% of the sample having a score greater than 25 and 15% a score greater than 30. PCL-R scores as a function of diagnosis are given in the Supplementary Materials (Table 1).

Affective Images

Figure 1a shows the change in pupil size post-stimulus presentation in response to the images. We observed a pupillary constriction reflex from around 300 ms, before larger pupil diameter emerged from around 500 ms in response to the negative and positive images relative to neutral images. As our major aim was to investigate whether this affective dilation was altered by psychopathic traits, we first examined if there were any changes in the pupil response to neutral stimuli as a function of any psychopathy score (factors and facets). None of these correlations approached significance ($p$s > .15). We then quantified the emotional modulation of the pupil response (EMPR) by calculating the difference between the pupil diameter to affective and neutral images.

Two ANOVAs (for Factor 1 and Factor 2 separately) on the EMPRs were conducted with factors of psychopathy score (as a continuous variable), valence (negative, positive), and time epoch (0-1000ms, 1000-2000 ms).
For Factor 1, there was a significant 3-way interaction, $F(1, 77) = 6.40, p = .01, \eta^2 = .08, 90\% \text{ CI} [.01, .18]$. This interaction was examined by looking at the correlation between Factor 1 and EMPR for each time-window. Factor 1 was inversely related to EMPR for negative images, $r(79) = -.23, 95\% \text{ CI} [-.43, -.01], p = .02$, for the 1000-2000 ms time window. No other correlations were significant. The supplementary analysis on only those patients without a diagnosis of psychosis (see Supplementary Materials) also showed a significant relationship for Factor 1 and negative images at 1000-2000 ms, $r(39) = -.55, 95\% \text{ CI} [-.74, -.29], p < .001$.

We also conducted a supplemental analysis separating the PCL-R Factor 1 down into its facet components. The interpersonal facet (Facet 1) was negatively correlated with EMPR for the negative images at 1000-2000 ms, $r(79) = -.23, 95\% \text{ CI} [-.43, -.01], p = .04$, while Facet 2 (Affective) produced a similar effect size but this was not statistically significant, $r(79) = -.18, 95\% \text{ CI} [-.39, .04], p = .11$.

To graphically illustrate these results, we split the participants according to Factor 1 score. The high Factor 1 group ($n = 25$) had a score of $\geq 10$ (proportional to 25 for total PCL-R score; Cooke, Michie, Hart, & Clark, 2005), and the low Factor 1 group ($n = 27$) had a score of $\leq 4$ (proportional to 10 for total PCL-R score). These groups approximately represented the top and bottom third of Factor 1 scorers. Figure 2a & b illustrates the pupil size change for each affective stimulus (negative, positive, and neutral) for the low Factor 1 score and high Factor 1 scorers respectively. We also calculated the EMPR for the negative and positive stimuli and these are plotted in Figure 2c & d. For the low Factor 1 group both the negative and positive images caused an increase in pupil size in comparison to the neutral images. For the high psychopathy group, the positive images caused pupil dilation in comparison to the neutral images, whereas the negative images do not.
Affective Sounds

Figure 1b shows the change in pupil size post-stimulus presentation in response to the sound-clips with larger pupil diameter observed in response to negative and positive sound-clips. Psychopathy was not related to pupil response to the neutral sounds ($p_s > .15$).

We quantified the EMPR by calculating the difference between pupil diameter to the affective and neutral sounds. ANOVAs did not reveal any significant interactions between valence (negative and positive) and time for both Factor 1 and Factor 2 and so no further analyses are reported. However, the data are illustrated in Figure 3 a-d.

Dynamic Facial Expressions

Figure 1c shows the change in pupil size post-stimulus presentation in response to the dynamic faces. The initial presentation of the face produced the expected pupillary light reflex. The expression appeared on the face from around 500 ms and took up to 1000 ms to complete (see shaded area), before greater pupil dilation to affective expressions emerged around 1500 ms. In order to ease comparison to the other stimuli, we defined our time windows relative to the onset of the emotional expression (approx. 1000 ms). There were no correlations ($p_s > .15$) between any psychopathy measure and pupil response to the neutral stimuli.

For Factor 1, an ANOVA showed a significant interaction between valence (fear, happiness, anger) and time on the EMPR, $F(4.24, 301.31) = 4.40, p < .001, \eta^2 = .06, 90\% CI [.01, .09]$. Factor 1 was negatively related to EMPR for the angry facial expressions over both the 0-1000 ms, $r(76) = -.24, 95\% CI [-.44, -.02], p = .02$, and the 1000-2000 ms time windows, $r(76) = -.20, 95\% CI [-.41, .03], p = .04$. The supplementary analysis on only those
patients without a diagnosis of psychosis (see Supplementary Materials) also showed a significant relationship for Factor 1 and angry expressions at 0-1000 ms, $r(39) = -.36$, 95% CI [-.60, -.05], $p = .03$, and 1-2 s, $r(39) = -.33$, 95% CI [-.58, -.02], $p = .04$. No correlations were significant for the fear expressions.

Finally, for the happy expressions, Factor 1 was positively correlated with EMPR in the 2000-3000 ms time-window, $r(76) = .34$, 95% CI [.13, .53], $p = .002$. The supplementary analysis on only those patients without a diagnosis of psychosis (see Supplementary Materials) also showed a significant relationship for Factor 1 and happy expressions at 2000-3000, $r(39) = .46$, 95% CI [.17, .68], $p = .004$.

The facet analysis showed that the interpersonal facet (Facet 1) was negatively related to EMPR for angry faces over 0-1000 ms, $r(76) = -.24$, 95% CI [-.44, -.01], $p = .02$, and 1000-2000 ms, $r(76) = -.22$, 95% CI [-.42, .01], $p = .03$. Facet 2 (Affective), however, only showed a trend-level relationship to EMPR at 0-1000 ms, $r(76) = -.19$, 95% CI [-.40, .04], $p = .05$, and no relationship at 1000-2000 ms, $r(76) = -.13$, 95% CI [-.34, .10], $p = .14$. Both the interpersonal facet (Facet 1) and the affective facet (Facet 2) were positively associated with EMPR for happy faces over 2000-3000 ms, Facet 1: $r(76) = .33$, 95% CI [.12, .52], $p = .003$; Facet 2: $r(76) = .29$, 95% CI [.07, .48], $p = .01$.

Figure 4a & b illustrates the results for low and high Factor 1 scores with the associated EMPRs in Figure 4c & d. For the low Factor 1 group, the angry stimuli produced the most pupil dilation (the fearful faces produced very similar results but have been omitted to improve the clarity of the figure), with the happy stimuli producing the least dilation. However, for the high Factor 1 group, there appeared to be little difference in pupil dilation in response to the angry faces compared to neutral, and it was the happy faces that produced the greatest dilation.
The ANOVA for Factor 2 showed no significant effects.

**Time course of psychopathic deficit**

We hypothesised that the effects of psychopathy might be greater during the early response to the affective stimulus. To test this idea, we plotted (Figure 5) the correlation coefficient between Factor 1 score and the EMPR for the negative stimuli across the three experiments (angry expressions were used for the facial stimuli) as a function of the time since emotional stimulus onset. The correlation coefficients were consistently negative for time epochs of 2000 ms and earlier, while the correlations were small for later time periods.

**General Discussion**

As expected, the pupil showed greater dilation when presented with emotional stimuli in comparison to neutral stimuli across all three types of stimuli. Our main hypothesis was that this emotional modulation would be reduced for individuals high in interpersonal-affective psychopathy. In line with this, individuals scoring high on Factor 1 (interpersonal-affective) of the PCL-R showed reduced pupil dilation to negatively-valenced images. However, levels of psychopathy did not alter the response elicited by positive images. Factor 2 (lifestyle-antisocial) scores did not moderate pupil responses to affective images. A similar pattern of responses occurred in relation to the facial expressions with clear evidence of reduced pupil dilation to angry faces for those with high Factor 1 scores. However, we did not show significant effects of psychopathy on the pupil response to auditory stimuli containing affective content.

**General vs Negative-Specific Deficit**

Our findings appear consistent with the Brook et al. (2013) review that asserted that across the diverging research literature on autonomic reactivity “psychopathy appears to be
associated with reduced autonomic responsiveness to negatively valenced/aversive stimulation” (p. 991). However, across varying paradigms (behavioral, psychophysiological, brain imaging and self-report) Brook and colleagues also noted that psychopathy was at times associated with a generalised deficit across all emotions.

Perhaps the most germane research findings in respect to the present study are those that have examined other measures of sympathetic nervous system activity in response to affective stimuli. Some studies are supportive of the negative-specific deficit. For example, Benning et al. (2005) used affective images and found that individuals high in interpersonal-affective psychopathy traits showed normal SCRs to positive images, but smaller SCRs to negative images, in a community sample where psychopathy was defined via self-report. In contrast, Verona et al. (2004) measured SCRs to affective sounds (from the IADS) within an offender sample. They found that those high on Factor 1 showed a reduced response to all stimuli (including the neutral stimuli) and reduced differentiation between affective vs neutral stimuli, which was similar in magnitude for both negatively and positively-valenced sound-clips. Clearly, this result, a deficit for both negative and positive stimuli, contrasts with the present findings. The findings of Verona et al. (2004) are complicated by the overall lack of response in the high psychopathy group to the neutral stimuli, which makes comparison of low and high psychopathic groups hard to interpret. The present study does not seem to have this complication as the autonomic responses to the neutral stimuli (across all three tasks) were not associated with any measure of psychopathy. For completeness, it should be noted that other studies have failed to find any effect of psychopathy on the emotional modulation of the SCR to affective stimuli (Pastor, Molto, Vila, & Lang, 2003; Patrick et al., 1993), similar to the results found in the current study in response to auditory stimuli.
Auditory Stimuli

The absence of a significant effect of psychopathy on pupil dilation to negative auditory stimuli is puzzling. Auditory stimuli from the IADS vary in intensity over time and the nature of the affective content may take some time to become apparent. It may be that this “complexity” serves to reduce the psychopathic deficit by some mechanism. However, we note that for visual stimuli the reduction in aversive-potentiated startle response due to psychopathy is greater for more complex stimuli (Sadeh & Verona, 2012). Alternatively, these auditory stimuli may be more “psychologically intense” than the visual stimuli and therefore able to overcome an emotion processing deficit. It might be possible to demonstrate a psychopathy-related deficit by using stimuli that are less intense or by distracting attention away from the auditory stimuli in order to reduce people’s ability to process these stimuli. Clearly, this is an area that requires further research.

Factors and Facets

The interpersonal-affective dimension of psychopathy has been suggested to reflect a dispositional fearlessness caused by an insensitive defensive motivation system (Lilienfeld, Watts, Francis Smith, Berg, & Latzman, 2015) and appears hyporesponsive to negative stimuli. The association between reduced pupil responsivity, as indexed by emotional modulation to negative stimuli, and Factor 1, but not Factor 2, supports the idea of distinct factors underpinning psychopathy.

We also divided Factor 1 into the separate facets of Interpersonal (Facet 1) and Affective (Facet 2), according to the four facet models of psychopathy (Hare, 2003). However, this analysis did not produce strong evidence that one of these facets was more powerful than the other in accounting for the hypo-responsivity to negative stimuli, although the results for Facet 1 (Interpersonal) reached statistical significance, whereas those for Facet 2 (Affective)
did not. We note that Verona et al. (2004) showed a similar pattern where Facet 1 produced stronger modulation of SCRs than Facet 2.

**Time Course of Emotional Modulation**

The time-sensitive response of the pupil allowed us to explore autonomic reactivity over the course of stimulus presentation. We observed reduced pupil responses to negative stimuli during the first 2000 ms following the onset of the affective stimulus, with little evidence for deficits over later time periods. This illustrates that there are greater effects of psychopathy early in the time window. Such a pattern of results suggests that the ability to process negative affect in psychopathy is not completely impaired, but rather takes more time or is delayed. Our results highlight that other researchers should consider the effects of time as a factor that might moderate possible deficits for those high in psychopathy.

**Pupil Responses to Happy Facial Expressions**

We found evidence that the interpersonal-affective dimension of psychopathy (and the interpersonal and affective facets individually) were associated with increased pupil dilation to happy faces. Examination of Figure 4 shows that the happy faces produced a reduction in pupil size (in comparison to the neutral stimuli) for the low psychopathy participants, but an increase in pupil size for the high psychopathy participants. This finding was unexpected. One possibility is that individuals who score highly on the interpersonal-affective dimension have a lack of interpersonal trust and could react suspiciously to the expression of someone smiling, thus causing arousal. Alternatively, we note that individuals who scored low in Factor 1 demonstrated elevated pupil response to neutral compared to happy facial expressions. Previous research has shown that “neutral” faces are often perceived as somewhat hostile (Phillips et al., 1997). Hence, the greater pupil dilation observed to the neutral face than to the happy face for individuals scoring low in psychopathy may reflect a
negative perception of this neutral face. Clearly, these ideas are speculative and the finding needs replication and further exploration.

Limitations and Considerations

As is typical in forensic psychiatric settings, our sample had a variety of mental health diagnoses (see Table 1). Some of these diagnoses are associated with complex disturbances of emotional functioning that may serve to compromise our ability to isolate affective deficits specific to psychopathy (Taylor et al., 2012). For example, schizophrenia is associated with attenuated autonomic activity. We attempted to reduce such effects by only recruiting patients who were currently non-psychotic. We also re-ran our statistical analyses using only participants without a history of psychotic disorder (see Supplementary Materials). The results of these analyses obtained similar (and even larger) effects of Factor 1 on pupil dilation for negatively-valenced stimuli. Further, the same pattern of results occurred (see Supplementary Materials) when we statistically controlled for possible effects of psychotropic medication. We also note that previous drug and alcohol misuse cannot explain our current results (see Supplementary Materials).

A second limitation was that we used historically (up to 5 years old) gathered PCL-R information for around one third of the offenders, whilst the other PCL-R scores were assessed through an up-to-date file review. The use of historic measurement is not ideal. However, psychopathy scores on the PCL-R are fairly stable (Hare, 2003) and it seems unlikely that significant changes would occur within this time period for a person in a secure setting. However, future studies should aim to calculate PCL-R scores using the same method for consistency.
Conclusions

Using the rapid reaction of the pupil to stimuli with affective content, the current data support the hypothesis that psychopathy, specifically Factor 1 (interpersonal-affective) traits, are associated with a deficit in processing negatively-valenced affective information. Further, these effects of psychopathy were greatest shortly after the presentation of the affective stimuli, suggesting slowed affective processing rather than a global persistent insensitivity. No similar impairment was observed in response to positively-valenced stimuli. Factor 2 (lifestyle-antisocial) scores were unrelated to the pupil’s response to emotional stimuli. The current pupillometry paradigm has obvious practical applications as a fast, time-sensitive, and non-intrusive measure to identify individuals who have problems in processing affective information.

Acknowledgements

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References


O'Farrel, K. (2016). *Assessment of emotional processes and psychopathy among offenders using both behavioural and physiological measures* (PhD), Cardiff University.


Table 1. Detailed demographic description of the participant sample

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<tr>
<th>Variable</th>
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<td>Assault and grievous bodily harm b</td>
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<td><strong>Previous substance abuse</strong></td>
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*a* Older qualifications were categorised equivalent to their contemporary level

*b* Including threats

*c* Including attempted murder

*d* All mental health diagnoses are reported as many patients experienced co-occurring mental health disorders
Figure 1. Baseline-corrected pupil diameter as a function of the time since stimulus onset in response to: a) images, b) sound-clips, and c) dynamic facial expressions. Shaded area in part c represent period over which facial expression changes from neutral to expressive.
Figure 2. Baseline-corrected pupil diameter as a function of the time since stimulus onset in response to positive, negative, and neutral images for: a) high Factor 1, and b) low Factor 1 groups. Emotional modulation of the pupil response (EMPR; the difference in pupil diameter to positive/negative images compared to neutral images) is plotted for both high and low Factor 1 groups for c) negative images and d) positive images.
Figure 3. Baseline-corrected pupil diameter as a function of the time since stimulus onset in response to positive, negative, and neutral sounds for: a) high Factor 1, and b) low Factor 1 groups. Emotional modulation of the pupil response (EMPR; the difference in pupil diameter to positive/negative sounds compared to neutral sounds) is plotted for both high and low Factor 1 groups for c) negative sounds and d) positive sounds.
Figure 4. Baseline-corrected pupil diameter as a function of the time since stimulus onset in response to happy, anger and neutral dynamic facial expressions for: a) high Factor 1, and b) low Factor 1 groups (data from the fearful face is not plotted in order to simplify the figure, but followed the pattern for anger expressions closely). Emotional nodulation of the pupil response (EMPR, the difference in pupil diameter to happy/anger dynamic facial expressions compared to neutral dynamic facial expressions) is plotted for both high and low Factor 1 groups for c) angry facial expressions and d) happy facial expressions. Shaded areas represent period over which facial expression changes from neutral to expressive.
Figure 5. The correlation coefficient between PCL-R Factor 1 score and the Emotional modulation of the pupil response (EMPR) in response to negative stimuli across images, sound-clips and dynamic facial expressions (angry faces were used for the dynamic facial expressions) as a function of the time since emotional stimulus onset (the onset for the emotional dynamic faces was taken as 1000 ms which is approximately the mid-point of the transition from neutral to expressive).