

RESEARCH ARTICLE

As Far as the Eye Can See: Relationship between Psychopathic Traits and Pupil Response to Affective Stimuli

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Abstract

Psychopathic individuals show a range of affective processing deficits, typically associated with the interpersonal/affective component of psychopathy. However, previous research has been inconsistent as to whether psychopathy, within both offender and community populations, is associated with deficient autonomic responses to the simple presentation of affective stimuli. Changes in pupil diameter occur in response to emotionally arousing stimuli and can be used as an objective indicator of physiological reactivity to emotion. This study used pupillometry to explore whether psychopathic traits within a community sample were associated with hypo-responsivity to the affective content of stimuli. Pupil activity was recorded for 102 adult (52 female) community participants in response to affective (both negative and positive affect) and affectively neutral stimuli, that included images of scenes, static facial expressions, dynamic facial expressions and sound-clips. Psychopathic traits were measured using the Triarchic Psychopathy Measure. Pupil diameter was larger in response to negative stimuli, but comparable pupil size was demonstrated across pleasant and neutral stimuli. A linear relationship between subjective arousal and pupil diameter was found in response to sound-clips, but was not evident in response to scenes. Contrary to predictions, psychopathy was unrelated to emotional modulation of pupil diameter across all stimuli. The findings were the same when participant gender was considered. This suggests that psychopathy within a community sample is not associated with autonomic hypo-responsivity to affective stimuli, and this effect is discussed in relation to later defensive/appetitive mobilisation deficits.

Introduction

Psychopathy, or psychopathic personality, is a dangerous and costly disorder that has a substantial harmful effect on society. The disorder is characterised by interpersonal (e.g., callousness, manipulative, grandiose), emotional (e.g., lack of remorse and empathy, blunted emotional experience) and behavioural traits (e.g., impulsivity, irresponsibility). Psychopathy

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has been associated with abnormal emotional processing; research has identified that psychopathic individuals show reduced recognition of affective faces [1–5], attenuated emotional modulation of behavioural responses [6–9], deficient physiological anticipatory anxiety [10, 11], autonomic hypo-responsivity to emotion [11–15], abnormal emotional modulation of the startle response [13, 16–22], as well as abnormal brain responses to emotion [23–34]. Furthermore, these deficits exist across both negative and positive affect, although greater emotional abnormalities may occur in response to aversive cues [35, 36].

Psychopathy increasingly is being viewed as a dimensional construct rather than as a taxon [37–44] allowing researchers to investigate psychopathy within normal community samples, rather than relying on samples where the prevalence of psychopathy is high (e.g. offender or forensic psychiatric populations). Psychopathic traits in community samples have been associated with an attenuated fear-potentiated startle reflex [22, 45, 46], deficient fear conditioning [12, 47], reduced anticipatory autonomic responses [48], and reduced amygdala response to affective stimulus [15, 49–51]. Furthermore, the majority of this research has linked this hypo-responsivity to the interpersonal/affective components of psychopathy rather than the life-styles/antisocial features [22, 45, 47–49, 52, 53], which parallels work in offender samples [13, 14, 16].

Evidence, however, is somewhat inconclusive to the nature of autonomic responses to the simple presentation of affective stimuli in psychopathy. Studies have found that psychopathy is associated with hypo-responsivity to negative stimuli only [15, 54], hypo-responsivity to all affective stimuli (both negative and positive) [55], overall smaller response magnitudes regardless of valence (including neutral images) [18, 19], or no psychopathic response deficit [16, 56]. However, it is important to delineate psychopathy into its differing dimensions given that affective deficits have been typically linked to the interpersonal/affective component of psychopathy rather than to the lifestyle/antisocial dimension.

Benning et al [45] measured skin conductance response (SCR) to moderately arousing negative and highly arousing positive images within a male community sample. The fearless dominance dimension of the Psychopathic Personality Inventory–Revised (PPI-R) [57], thought to relate to the interpersonal/affective dimension of psychopathy, was negatively associated with SCR to aversive images in comparison to neutral images, suggesting a hypo-responsivity to the affective content of the stimuli. However, the impulsive-antisocial scale, representing the lifestyle/antisocial component of psychopathy, was negatively associated with response to all images (including affectively neutral stimuli) suggesting an overall hypo-responsivity rather than a deficit specific to affective image content. Verona et al [14] presented male inmates with emotionally arousing sound-clips and found that offenders scoring high on Factor 1 (interpersonal/affective) of the Psychopathy Checklist–Revised (PCL-R) [58] had attenuated unpleasant–neutral and pleasant–neutral electrodermal differentiation, as well as reduced overall response magnitudes to all stimuli. Bate et al [59] reported that, within a male and female undergraduate sample, the interpersonal/affective dimension of psychopathy was negatively associated with SCR to negative and positive images (combined), whilst the lifestyle/antisocial factor was positively related to this emotional response, although this effect only occurred for participants lower in intelligence. Sutton et al [60] found psychopathy was related to overall SCR hypo-responsivity to all stimuli in a sample of offenders, but was unrelated to the affective content of the stimuli. Ragsdale et al (2013) [61] reported that, within a male and female community sample, both PPI-R factors and total scores were unrelated to electrodermal responses to emotionally arousing and neutral images. Therefore, while there is some evidence that psychopathy, in particular the interpersonal/affective component of the disorder, is associated with attenuated autonomic responses to the emotional content of stimuli, the presence and nature of this impairment needs further investigation.

Most studies of psychopathy have measured autonomic responses by indexing electrodermal or cardiovascular reactivity, but pupillometry offers an objective measure of emotional response that is fast, easy to administer and non-invasive (no wires are attached to the participant). The pupil is a hole located in the centre of the iris. It has a contractile structure consisting of two muscles groups controlled by opposing divisions of the autonomic nervous system: a circular group called the sphincter (or constrictor) muscle which is innervated by the parasympathetic nervous system, and the radially-arranged dilator muscle group that is activated by the sympathetic nervous system. The dynamic 'push-pull' between the activities of these two iris muscles determines pupil diameter. Therefore, pupil dilation can occur through both excitation of the sympathetic division or inhibition of the parasympathetic system, with the opposing activity leading to pupil constriction [62–64]. Thus, pupil diameter can act as an objective measure of autonomic arousal.

It has been proposed that affective stimuli lead to increased autonomic arousal that reflects increased defensive or appetitive motivational activation [65, 66]. Indeed, influential work by Bradley et al [63] demonstrated that the pupil is sensitive to emotion, showing greater pupil size in response to affective images of both negative and positive valence, a finding that has been replicated repeatedly [67–74]. Moreover, Bradley and colleagues [63] reported that increases in pupil diameter to emotional images is positively related to SCR, a sympathetically-mediated process [75], suggesting that affective modulation of pupil diameter indexes sympathetic excitation. Therefore, affective pupil reactivity can be viewed as an indicator of emotional processing and has been successfully applied to explore emotional processing within clinical populations [76–82], although this technique has not as yet been explored in relation to psychopathic traits.

Current study

The present study aimed to extend previous emotion and psychopathy research by exploring whether psychopathic traits in a community sample were associated with autonomic hypo-responsivity to emotionally arousing cues using pupillometry. Psychopathy was measured using the Triarchic Psychopathy Measure (Tri-PM; [83]) a self-report measure that differentiates psychopathy into three phenotypic personality traits: Boldness, Meanness and Disinhibition. Boldness refers to the nexus of social dominance, low stress reactivity and fearlessness; Meanness reflects cruelty, lack of empathy, and excitement seeking; Disinhibition entails impulsiveness, irresponsibility, as well as impaired regulation of behaviour and affect.

The present study extends previous work by investigating pupil size to emotion across a range of stimuli types that have previously only been explored independently. First, pupil diameter was measured in response to affective images, which, as discussed earlier, has been investigated many times in normal healthy samples. However, the depiction of emotion in such scenes involves participant to process complex images which are hard to match in terms of physical properties across valences.

Second, facial expressions are thought to represent unique social and emotional stimuli [84] that are processed by a highly specialised system [85] and there is a lot of evidence that psychopathy is associated with poor processing of facial affect [86]. Facial stimuli are advantageous for pupillometry as the stimuli depicting the different valences are highly similar in terms of luminance and contrast. A number of studies have measured pupil diameter to static or morphed facial affect for adults [87–89] and children [68, 76, 81, 90]. The current study examined pupil size to facial affect by presenting images of fearful, happy, disgusted, angry and sad faces, as well as an emotionally neutral expression for comparison.

Third, while static images of faces have proved valuable affective stimuli in many studies, facial expressions are actually dynamic [91–95]. We also tested using video-clips of facial affect as they are thought to be more ecologically valid and represent the dynamic, complex, and subtle changing expressions of real-life emotion more accurately [91–95]. In addition, to our knowledge, no study has previously examined pupil response to video-clips of facial affect in adults.

Finally, we also measured pupil response to sound-clips; this is advantageous as sound is an emotionally-evocative stimulus and it removes any visual influence on the pupil, yet few studies [72, 78] have examined pupil reactivity to affective and neutral sound-clips.

Given that the pupil is thought to index emotional arousal [63], our predictions for the images and sound-clips reflected subjective arousal ratings (taken from the manuals for these stimuli). No ratings were available for the facial stimuli. We expected greater pupil diameter to the negative images and sound-clips than to pleasant or neutral stimuli. As we chose to not match the positive and negative images and sound-clips respectively on arousal, and instead chose stimuli that were unambiguously unpleasant or pleasant, this resulted in the negative valence images having greater arousal ratings than the positive images. Pleasant stimuli are hard to match to negative stimuli on arousal unless erotic cues are included [96–100], and the present study was concerned to omit erotic stimuli given future ethical concerns of showing such images to offenders. We also expected larger pupil diameter to pleasant compared to neutral images, but no difference in pupil diameter between pleasant and neutral sound-clips reflecting arousal ratings. We also predicted that the amount of dilation would be positively related to the subjective arousal-rating for the images and sound-clips. For the static and dynamic facial expressions, it was expected that negative faces would lead to larger pupil diameter than pleasant expressions as previous research has highlighted elevated autonomic responses for negative compared to happy faces suggestive of increased emotional arousal [101–104], but pleasant facial affect was still predicted to produce greater pupil size than neutral expressions.

Our main hypothesis, with regard to psychopathy, was that psychopathy would be associated with hypo-responsivity to the emotional content of the stimuli. This would be most associated with the Boldness and Meanness, but not Disinhibition, scales of the Tri-PM. This hypothesis was based on the theoretical conceptualisation of the Tri-PM dimensions of Boldness and Meanness as phenotypical expressions of fearlessness [83], alongside previous research identifying hypo-responsivity to affective stimuli being associated with interpersonal/affective traits [14, 45]. A secondary question was whether hypo-responsivity to affective stimuli was specific to negative valence, or was present for both positive and negative valences. Given the wide-range of previous findings related to this issue (see [discussion](#) above), we did not make a specific hypothesis on this matter. Finally, we also predicted that psychopathy, in particular the lifestyle/behaviour component, here represented by the Disinhibition scale, was associated with hypo-responsivity to stimuli irrespective of its affective content [14].

Materials and Methods

Participants

One-hundred and two participants were recruited (52 female) with a mean age of 21.08 (S.D. = 3.57) from the School of Psychology participant panel at Cardiff University from May 2014 –February 2016. Participant sample size was based on a power calculation (G*Power 3.1; [105]) for a bivariate correlation with 95% power ($\alpha = .05$) to detect a moderate effect size consistent with previous research exploring the relationship between psychopathy and autonomic hypo-responsivity [106]. All participants had normal or corrected-to-normal vision.

Participants were requested to not consume caffeine or smoke 60-minutes prior to testing. Participants were either paid money or given research credits as part of their psychology undergraduate course.

All experimental procedures were given ethical approval by the ethical committee of the School of Psychology, Cardiff University. All participants gave written informed consent to participate in the experimental procedures, and were fully debriefed at the end of the session.

Design

Each stimuli type was presented as a separate task and every participant took part in the tasks in the same order (images, static facial expressions, dynamic facial expressions and affective sound-clips). Trials in each task began with a grey slide displaying a fixation cross (2 s) composed of alternating light and dark grey pixels whose overall luminance matched the slide luminance. The stimulus was then presented (matched for luminance to the grey slide) for a period of time (2–6 s depending on experiment) and then the grey slide (now without fixation cross) was presented until the end of the trial (total trial length 8–10 s). For the auditory sound-clip task, a blank grey screen was presented throughout the whole task with the same fixation cross displayed as described previously.

Each experiment consisted of a number of conditions that differed according to the valence of the image (for the IAPS and IADS experiments there were three conditions: unpleasant, neutral and pleasant) or the facial expression (for the static and dynamic face experiments there were 6 conditions: fear, disgust, anger, sadness, neutral, and happy).

Measures and stimuli

Psychopathy measure. The Triarchic Psychopathy Measure (Tri-PM; [107]) is a 58-item self-report measure that gives participants score along the dimensions of Boldness, Meanness and Disinhibition. Meanness has been found to correlate positively with both Boldness and Disinhibition, with no relationship between Boldness and Disinhibition [108–112]. This was replicated in the present study: Meanness was positively related to Boldness, $r(102) = .43, p < .001$, and Disinhibition, $r(102) = .53, p < .001$, with no significant relationship evidenced between Boldness and Disinhibition, $r(102) = .14, p = .18$. The Tri-PM has shown good construct validity relating to psychopathy scores on the Psychopathy Checklist-Revised (PCL-R [58]), the most widely used psychopathy measure for assessing psychopathy within clinical populations, with Boldness and Meanness associated to Factor 1 (Affective/Interpersonal deficits) [112]. The Tri-PM is also correlated with alternative self-report psychopathy measures [113–117] including the Psychopathic Personality Inventory (PPI-R; [57]). The Tri-PM's utility within community samples has been previously supported [116]. Moreover, the Tri-PM has been associated with good internal consistency [115, 116] and test-retest reliability [118]. The present study found that Boldness ($M = 29.44, S.D. = 8.73$), Meanness ($M = 12.60, S.D. = 8.52$) and Disinhibition ($M = 14.18, S.D. = 7.50$) all showed good internal reliability (Cronbach's α : Boldness = .86; Meanness = .91; Disinhibition = .85).

Affective images. Thirty images were selected (Unpleasant: 1301, 1304, 1525, 1930, 2811, 6260, 6250, 6263, 6370, 6510; Pleasant: 1440, 1441, 1460, 1463, 1710, 1721, 1750, 2070, 4641, 8380; Neutral: 2036, 7009, 7010, 7020, 7042, 7045, 7052, 7150, 7179, 7205) from the International Affective Picture System (IAPS; [119]). We selected images that were unambiguously regarded as fear, neutral or happy based on Barke et al's [120] affective categorisation of the IAPS images. The three conditions differed on valence using the ratings from the IAPS manual: (unpleasant = 2.94, neutral = 5.18, pleasant = 7.87; all $ps < .001$). The IAPS also provides ratings of subjective arousal for these images. The unpleasant images had the greatest arousal

rating (arousal = 6.53), then the pleasant images (arousal = 4.74), with the neutral images rated least arousing neutral images (arousal = 2.90) (all $ps < .001$).

Due to the large variations in RGB colour space between the original IAPS images, all images were converted to grey-scale and equated for overall luminance using Adobe Photoshop Elements 12. Image contrast, defined as the standard deviation of all pixel values [121], was adjusted for each image and was therefore matched across valence categories. Pictures were presented on a computer display monitor and each participant was sat 57 cm from this monitor. The images subtended 50 by 30 deg. Participants were asked to simply pay attention to the images. Stimulus presentation order was randomised. Each image was presented for 2 s because we wanted a brief presentation that allowed us to assess initial emotional reaction to the stimulus while still gathering sufficient data following an expected initial stimulus-onset constriction [122].

Static facial expressions. Images of posed facial expression images were selected from the Radboud Faces Database [123] consisting of four male and four female actors (models chosen were 01, 02, 03, 04, 05, 07, 09 and 12). The facial expressions presented were fear, happiness, neutral, disgust, anger and sadness (48 images in total). Affective expressions showed comparable luminance and contrast values as each actor demonstrated each facial expression. There were little differences between images in RGB colour space and, therefore, facial expressions were presented in colour. All actors were presented facing forwards and with direct gaze. The images of facial affect were presented for 2 s and presentation order was randomised.

Dynamic facial expressions. Forty-eight video-clips were selected from the Amsterdam Dynamic Facial Expression Set (ADFES; [124]) comprised of four male and four female actors (models selected were F01, F02, F03, F05, M02, M03, M04 and M08) pulling facial expressions to fit the emotional categories of fear, happiness, neutral, disgust, anger and sadness. The videos were presented for 4 s and they depicted an actor displaying a neutral face before changing into the target expression at approximately 1.3–1.4 s post video-clip onset. Screenshots were taken from the end of each video-clip and valences showed similar luminance and contrast values). Images were similar in RGB colour space and so all video-clips were presented in colour. All actors were presented facing forwards and with direct gaze. Presentation order was randomised.

Affective sound-clips. We selected 30 sound-clips (Unpleasant: 106, 276, 277, 286, 291, 424, 625, 699, 711, 712; Pleasant: 110, 151, 220, 226, 230, 353, 810, 811, 815, 820; Neutral: 114, 120, 246, 320, 364, 368, 410, 425, 701, 723) from the International Affective Digitalised Sounds (IADS; [125]) consisting of 10 unpleasant sound-clips. We selected affective sound-clips that had been previously classified clearly as fearful or happy sound-clips [126], and neutral sound-clips based on their normative valence ratings: (unpleasant = 2.66, neutral = 4.90, pleasant = 7.40; all $ps < .001$). The IADS also provides ratings of subjective arousal for these images. The unpleasant images had the greatest arousal rating (arousal = 7.25) which was significantly higher ($ps < .001$), than the pleasant images (arousal = 5.52) or the neutral images (arousal = 5.52). The pleasant and neutral images did not differ significantly on arousal ratings ($p = .33$).

Sound-clips were matched across the emotional categories for maximum and average root mean square decibel level ($ps > .05$), and played to all participants at a comfortable set volume. The sound-clips were presented for 6 s and presentation order was randomised.

Data acquisition and cleaning

A Tobii X2-60 Hz eye tracker recorded pupil data throughout each trial and allowed free movement of the head during the task. The eye trackers were calibrated to each participant's eyes before each task using a 5-point calibration screen. The experiment took place in a dim, sound-proof room within the university.

Data was cleaned and analysed using Matlab (MathWorks, version 8.5). We removed pupil diameter increases or decreases of 0.0375 cm within a 0.02 s interval as these are thought to be artefacts [72]. We also deleted the first data point that followed missing data to avoid abnormal readings. Data for each pupil was smoothed using a low-pass Savitzky-Golay filter [127] for a span of 5 readings (over a period of approximately 0.083 s). Pupil size was determined by calculating the mean across both eyes.

Data analysis

Trials were omitted if there was less than 50% data for the selected time window and participant means for a given emotion were only calculated if there was valid data for at least 50% of trials. Participants were excluded if they recorded less than 50% valid data across all trials during stimulus presentation. Participant's data was identified as an outlier and removed if their data for a given valence was outside the interval defined as three times the interquartile range [128]. The sample size varied between each experiment based on the number of participants excluded with missing/outlier data (n : Affective images = 97; Static facial expressions = 95; Dynamic facial expressions = 92; Affective sound-clips = 97).

The baseline pupil size for each trial was calculated over the period 0.2 s prior to image-onset. For every trial, this baseline pupil diameter was subtracted from subsequent pupil size to establish baseline-corrected pupil diameter. Mean baseline-corrected pupil size was calculated over a specified time period for each task to indicate the degree of physiological responsivity.

For the affective images and static faces tasks, mean pupil size was determined from 1–2 s post-image onset. This response window period followed the initial constriction response and terminated at the end of image presentation. For the dynamic faces task we used a response window of from 3–4 s post-video-clip onset as all faces started out with a neutral expression and then began moving to the emotional expression at 1.4 s post stimulus onset (with this movement last seconds). For the affective sound-clips, no initial pupil constriction was expected as there was no visual influence on the pupil and so pupil size was calculated over the entirety of sound-clip presentation for an early (0–2 s), middle (2–4 s) and late time window (4–6 s).

Repeated measures ANOVAs were run to assess the effect of condition on pupil diameter, and planned comparison t -tests were conducted between each affective condition to the neutral condition. We also examined the role of participant gender by re-running the ANOVAs with gender entered as a between-subjects variable. For this gender analysis, we adopted a conservative alpha level within each task of $\alpha = .01$ as we made no specific gender predictions.

In order to test if psychopathy was associated with reduced emotional modulation of the pupil response, we created an 'emotional index' for each emotion by subtracting mean neutral pupil diameter from mean pupil diameter for each affective condition. Larger values were indicative of greater emotional modulation of pupil diameter.

The relationship between Tri-PM Boldness, Meanness and Disinhibition and each emotional index was explored by conducting Pearson's zero-order correlations and multiple linear regressions to assess the unique contribution of each dimension. Additionally, to explore the role of participant gender on psychopathy effects, we conducted hierarchical regression analyses with the dichotomous variable gender (0 = male, 1 = female) and the centred variable Tri-PM subscales entered at the first step, and the interactions between gender and each dimension entered at the second step [129]. The predicted variable was the pupil diameter emotional index across each experiment. Again, we corrected our alpha level to be more conservative ($\alpha = .01$) within each regression as we made no specific gender predictions.

Table 1. Mean (and standard deviations) of the pupil diameter across the response windows for the four experiments.

		Unpleasant	Pleasant	Neutral			
		<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>	<i>M (SD)</i>
Affective images		- 0.27 (0.28)	- 0.39 (0.29)	- 0.34 (0.24)			
		Fear	Happy	Neutral	Disgusted	Angry	Sad
Static facial expressions		- 0.31 (0.29)	- 0.36 (0.29)	- 0.36 (0.32)	- 0.30 (0.30)	- 0.32 (0.29)	- 0.32 (0.29)
Dynamic facial expressions		0.16 (0.20)	0.13 (0.20)	0.13 (0.21)	0.17 (0.20)	0.17 (0.19)	0.18 (0.20)
Affective sound-clips		Unpleasant	Pleasant	Neutral			
	Early	0.13 (0.09)	0.10 (0.09)	0.10 (0.08)			
	Middle	0.28 (0.16)	0.17 (0.16)	0.17 (0.14)			
	Late	0.24 (0.20)	0.14 (0.16)	0.10 (0.16)			

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Results

Table 1 displays mean baseline-corrected pupil diameter in response to affective and neutral stimuli for the response analysis window/s across each task. Split-half reliability checks were run finding good internal consistency for pupil size for each task with odd and even trials being highly positively related for all the visual stimuli (all $ps < .001$; Pearson's r : Affective images = .81; Static facial expressions = .96; Dynamic facial expressions = .86) but were lower for the auditory stimuli (all $ps < .001$; Pearson's r : Early = .40; Middle = .59; Late = .44).

Affective images

Fig 1 shows the pupil response to the presentation of the images. There was an initial pupil constriction with an approximate latency of 0.3 s and a nadir of -0.45 mm occurring at around 0.8 s post-image onset. The pupil then increased in size until the offset of the stimulus, where there was a smaller secondary constriction, which again occurred with a latency of around 0.3 s after image-offset before recovery back to baseline pupil diameter.

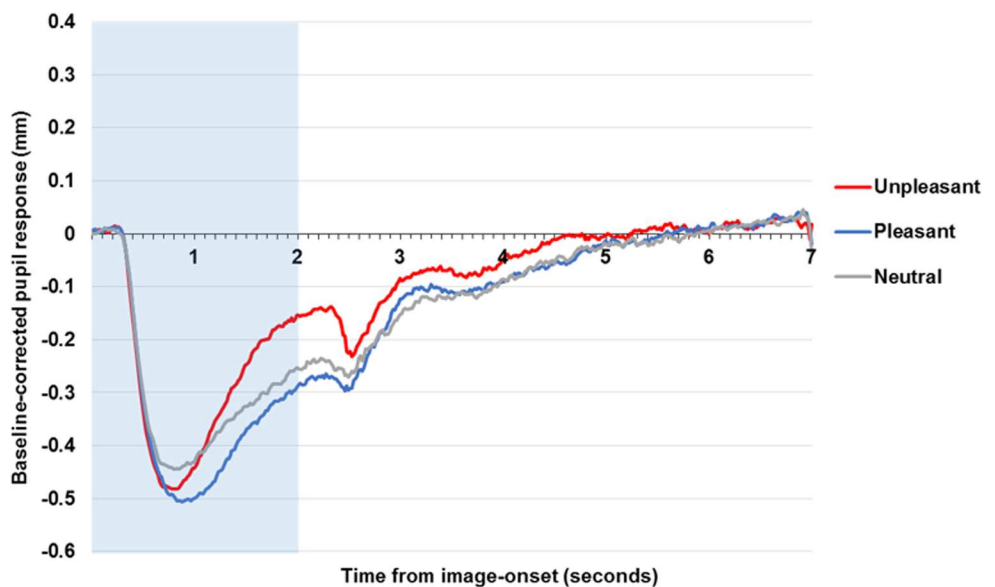


Fig 1. Pupil response to affective and neutral images across the community sample. Figure displays baseline-corrected pupil size to affective images. The shaded area indicates stimuli presentation.

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It is evident that pupil diameter was modulated by image valence with unpleasant images leading to the greatest pupil size by image offset. There was a main effect of condition, $F(2, 192) = 23.18, p < .001, \eta^2_p = .19$, with greater pupil size to unpleasant images compared to both pleasant, $t(96) = 6.82, p < .001, d = 0.70$, and neutral images $t(96) = 3.58, p = .001, d = 0.36$. Surprisingly, neutral images led to greater pupil diameter compared to pleasant images, $t(96) = -3.21, p = .002, d = 0.33$.

Static faces

As can be seen in Fig 2, pupil response to the static facial expression parallels the pupil response pattern to the affective images. The static images led to a degree of emotional modulation, $F(4.48, 421.32) = 4.16, p = .001, \eta^2_p = .04$. In comparison to the neutral face, the pupil was more dilated to images of faces that were fearful, $t(94) = 2.86, p = .005, d = 0.29$, disgusted, $t(94) = 3.08, p = .003, d = 0.32$, and angry, $t(94) = 2.20, p = .03, d = 0.23$, with a similar trend for sad faces $t(94) = 1.82, p = .07, d = 0.19$. However, happy and neutral faces produced no significant differences, $t(94) = 0.02, p = .98, d = 0.002$.

Dynamic faces

The dynamic facial expressions (Fig 3) led to a small initial constriction, albeit with a similar latency, reaching a nadir of approximately -0.18 mm at 0.7 s, before the pupil increased in size steadily to approximately 0.08 mm above baseline pupil diameter by 1.8 s. The increase in pupil diameter slows at 1.8 s and emotional modulation occurs at this point, which is 0.4–0.5 s after the target emotion begins on the face. Following the video-clip, the pupil constricts below baseline diameter and then appears to recover to slightly exceed baseline pupil diameter at the end of the trial, although Fig 3 does not show the full recovery period for the dynamic faces.

The dynamic faces produced a main effect of facial condition on pupil size, $F(4.29, 390.30) = 2.51, p = .03, \eta^2_p = .03$. Compared to the neutral faces, planned comparisons showed greater pupil dilation to disgusted, $t(91) = 2.16, p = .03, d = 0.23$, angry, $t(91) = 2.15, p = .03, d = 0.22$,

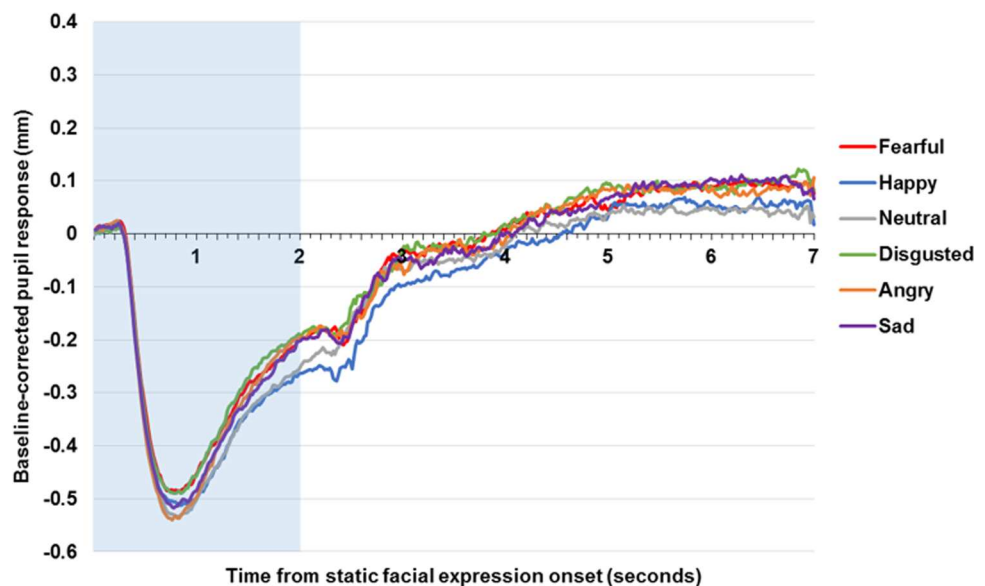


Fig 2. Pupil response to static affective and neutral facial expression across the community sample. Figure displays baseline-corrected pupil size to static facial expressions. The shaded area indicates stimuli presentation.

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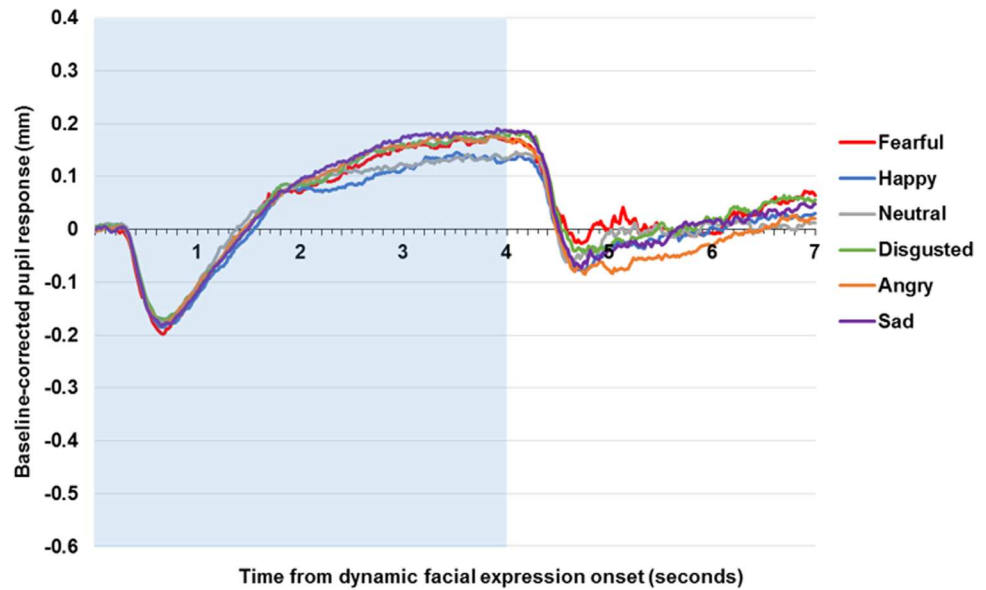


Fig 3. Pupil response to dynamic affective and neutral facial expression across the community sample. Figure displays baseline-corrected pupil size to dynamic facial expressions. The shaded area indicates stimuli presentation.

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and sad faces, $t(91) = 2.70, p = .01, d = 0.28$, but no statistical differences to fear, $t(91) = 1.36, p = .18, d = 0.14$, or happy, $t(91) = 0.11, p = .91, d = 0.01$, faces.

Affective sounds

Fig 4 demonstrates pupil reactivity across sound-clip presentation. The pupil begins to dilate with a latency of around 0.3 s, reaching a peak between 2–4 s, before pupil recovery that has not quite returned to baseline levels at 7 s, although Fig 4 does not display the full recovery period. Sound-clip valence affected pupil diameter across early, $F(2, 192) = 8.09, p < .001, \eta^2_p = .08$, middle, $F(2, 190) = 26.56, p < .001, \eta^2_p = .22$, and late, $F(2, 190) = 22.47, p < .001, \eta^2_p = .19$, analysis windows. Planned comparisons identified greater pupil size in response to unpleasant sound-clips compared and neutral sound-clips (early, $t[96] = 3.49, p = .001, d = 0.36$; middle, $t[96] = 6.12, p < .001, d = 0.62$; late, $t[96] = 5.84, p < .001, d = 0.60$). No difference in pupil diameter emerged between pleasant and neutral sound-clips (early, $t[96] = -0.25, p = .80, d = 0.03$; middle, $t[96] = 0.33, p = .74, d = 0.03$; late, $t[96] = 1.840, p = .07, d = 0.19$).

Effects of gender

Across all tasks, there was no main effect of participant gender on pupil diameter ($ps > .08$ see S1 Table) nor did any interaction surpass adjusted significance ($\alpha = .01$).

Subjective valence and arousal

Previous research has suggested that pupil response is driven by arousal rather than the valence of the stimuli [63]. To assess the degree to which arousal led to the observed changes in pupil diameter, we explored whether pupil diameter was related to the normative valence and/or the normative arousal ratings (scored on a 9-point scale with higher scores representing positive valence and high arousal respectively; data taken from [119, 125]). For the affective images, regression analyses for both the valence ratings and for the arousal ratings showed that neither

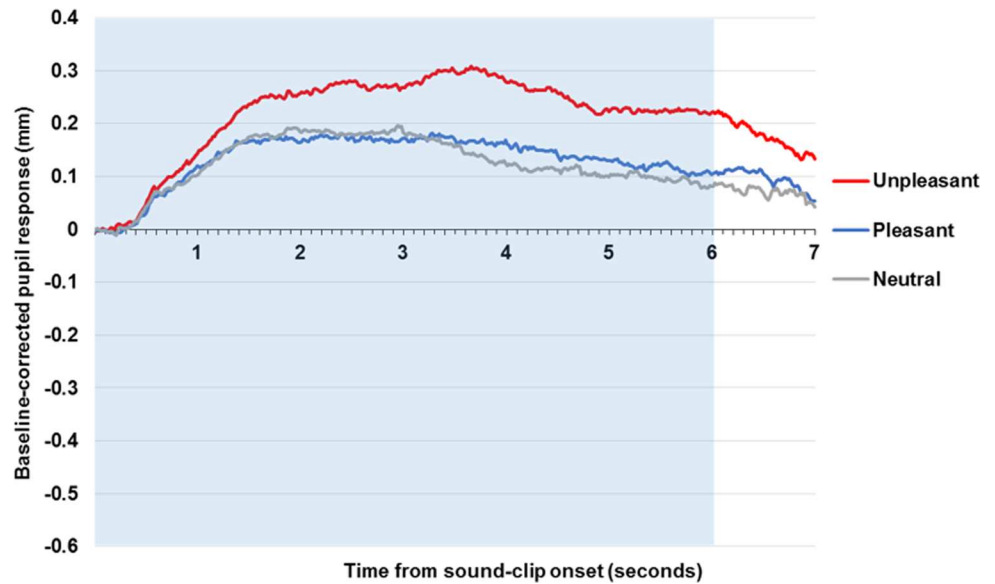


Fig 4. Pupil response to affective and neutral sound-clips across the community sample. Figure displays baseline-corrected pupil size to affective sound-clips. The shaded area indicates stimuli presentation.

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the linear nor quadratic component was significant ($ps > .26$). For the affective sounds, valence produced a strong quadratic component ($p = .02$ for the early component, $ps < .01$ for middle and late components) while arousal produced a strong linear component (all time epochs: $p < .001$). Following this, both subjective arousal and the quadratic subjective valence term (subjective valence centred and squared) were entered into regression analyses to assess unique predictive contributions towards pupil diameter to sound-clips. Across each time-window, only subjective arousal predicted pupil diameter ($ps < .006$) with the quadratic subjective valence term not predictive ($ps > .51$).

Effects of psychopathy

Table 2 displays the relationship between participant's score on the Tri-PM subscales and their pupil diameter emotional indexes across each task (the difference between pupil diameter in response to affective versus neutral stimuli).

Our first hypothesis was that the emotional modulation of the pupil, here represented as the emotional index, would be weaker in those scoring highly on Boldness and Meanness specifically. Pearson's zero-order correlations revealed that Boldness, Meanness and Disinhibition were all unrelated to emotional index to either unpleasant or pleasant images, and a multiple linear regression demonstrated that the three Tri-PM subscales failed to predict any emotional index either collectively or uniquely (this was the case without correction for multiple-tests). This lack of a significant relationship between the Tri-PM scales and the emotional index was found across all tasks (see Table 2).

Hierarchical regression analyses examined whether participant gender moderated the relationship between Tri-PM subscales and emotional index for each task. At the first step, Tri-PM total score and participant gender failed to predict the emotional indexes across any stimuli, apart from female participants showing greater modulation of pupil size to unpleasant sound-clips during the late time-window. Importantly, no interaction between participant gender and Tri-PM total score in the second step was significant. These variables did not

Table 2. Summary of zero-order correlations and multiple regression analysis between the subscales of the Triarchic Psychopathy Measure and emotional indexes for baseline-corrected pupil diameter in response to affective images, static and dynamic faces, as well as sound-clips.

			Boldness		Meanness		Disinhibition		R ²
			r	β	R	β	r	β	
Affective images		Unpleasant	-.02	-.02	-.03	.02	-.07	-.08	.01
		Pleasant	.02	-.01	.05	.07	-.001	-.04	.003
Static facial expressions		Fearful	.03	.01	.00	.13	-.17	-.24	.04
		Happy	.07	.02	.11	.13	.01	-.06	.02
		Disgusted	-.04	-.10	.05	.16	-.05	-.12	.02
		Angry	-.01	.01	-.06	-.05	-.05	-.02	.003
		Sad	.03	.03	-.00	-.001	-.03	-.03	.002
Dynamic facial expressions		Fearful	-.01	.02	-.05	-.03	-.07	-.06	.01
		Happy	.10	.10	.05	.02	-.01	-.04	.01
		Disgusted	.03	.05	-.02	-.04	-.01	.002	.002
		Angry	-.05	-.10	.07	.13	.03	-.03	.01
		Sad	.06	.06	.03	.003	.01	.003	.004
Affective sound-clips	Early	Unpleasant	.09	.09	.02	.02	-.05	-.07	.01
		Pleasant	.02	.08	-.10	-.16	-.02	.05	.02
	Middle	Unpleasant	.01	-.003	-.003	.06	-.09	-.12	.01
		Pleasant	-.02	.05	-.14	-.14	-.09	-.03	.02
	Late	Unpleasant	.06	.06	.02	.04	-.05	-.08	.01
		Pleasant	.02	.12	-.19	-.25	-.11	.01	.05

*p < .05.

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significantly improve the predictive model across any of the four tasks, indicating that Boldness, Meanness and Disinhibition were unrelated to pupil diameter to emotional stimuli regardless of participant gender. Details are available in [S2 Table](#).

A further hypothesis was that psychopathy, specifically Disinhibition, might be related to an overall hypo-responsivity that was not related to the affective content of the stimulus. To test this we correlated the three scales of the Tri-PM with baseline corrected pupil diameter to the neutral stimuli alone in our four experiments. No correlation approached significance (-.06 > rs < .12, ps > .24).

Discussion

In line with previous studies [63], we found that the pupil was larger when presented with a stimulus with affective content in comparison to an emotionally neutral stimulus, although this was specific to negative stimuli. We hypothesised that the interpersonal/affective components of psychopathy would be associated with an insensitivity to the affective content of the stimuli and would therefore show less emotional modulation of the pupil. No such evidence was found. We also hypothesised that the lifestyle/antisocial aspect of psychopathy would be related to a general hypo-arousal to all stimuli (including the neutral ones). Again, we found no evidence to support this hypothesis.

Psychopathic traits and pupil activity

We found that interpersonal/affective psychopathic traits were unrelated to emotional responses to images, static facial expressions, dynamic facial expressions and sound-clips as measured by changes in pupil diameter. This contrasts with research that found changes in

emotional responses using SCRs [14, 45]. It might be typically argued that this discrepancy is a result of sample gender as both SCRs studies [14, 45] recruited male participants only, whereas the present sample consisted of both male and female participants; indeed, previous studies that have recruited female participants [60, 61] have also failed to demonstrate an association between interpersonal/affective psychopathy traits and hypo-arousal to emotional stimuli. Previous research has reported that psychopathy is more prevalent in males [43, 130] and there are reported gender differences in the conceptualisation of psychopathy [131], which may account for specific-gender effects. Yet, this explanation seems ultimately unlikely for the present data as we found no interaction between participant gender and Tri-PM scores in predicting emotional modulation of pupil diameter.

Moreover, as described in the introduction, the presence and nature of psychopathic impairments to the simple presentation of emotionally arousing stimuli has been inconsistent. These conflicting findings may reflect that psychopathic individuals are not wholly deficient in their initial autonomic response to emotion, but rather it is how they use this early information to activate appropriate defensive and appetitive motivational systems [65] that is abnormal. In support, several studies have found psychopathy to be associated with normal emotional modulation of electrodermal responses to emotion (or reduced overall SCR), but this is followed by abnormal affective potentiation of the startle response [16–19, 60], thought to reflect the underlying action disposition of the individual [132]. Therefore, it could be argued that psychopathic individuals can show normal initial autonomic response to affective cues, but rather that these cues fail to activate defensive or appetitive mobilisation.

Emotion and pupil size across the tasks

The present data indicated that unpleasant stimuli led to greater emotional response (i.e. larger pupil dilation) than pleasant and neutral stimuli across all stimuli. This is consistent with previous psychophysiological studies showing that unpleasant affect causes elevated autonomic responses compared to pleasant affect, unless erotic stimuli are employed [96–100]. Indeed, there is evidence that the amygdala, which is central to the generation of pupil reactivity to emotion [133–136], demonstrates preferential responsivity to negative compared to positive affect [101, 137–143], and as the amygdala has been proposed as an encoder of the representation of value [144] this could suggest that pleasant affect fails to hold the same motivational value as negative affect. However, we urge caution in using the present data to support such a notion in relation to the affective images and sound-clips as we did not match the negative and positive images/sounds in terms of subjective arousal. The differences may simply reflect the greater arousal ratings of the unpleasant stimuli in comparison to the pleasant stimuli. Consistent with this, previous studies that have identified elevated pupil size to both negative and positive images [63, 78, 145] and sound-clips [72] have employed stimuli matched for subjective arousal ratings. Indeed, the present data showed that pupil diameter to the sound-clips was predicted by subjective arousal ratings uniquely over subjective valence.

However, we did not observe a linear relationship between subjective arousal and pupil diameter during the images. This may suggest that emotional arousal to images, as indexed by pupil diameter [63], and subjective arousal may not be equivalent. Weinberg and Hajcak (2010) [96] used electromyography to highlight several discrepancies between self-reported arousal and physiological responses to emotion, arguing that physiological reactivity is determined not only by perceived arousal to an affective stimulus, but also by the motivational significance of that stimulus. They found that erotic images led to brain potentials disproportionately larger than those elicited by affiliative (e.g. cuddly animals, smiling faces) and exciting images (e.g. exciting sports) despite similar subjective arousal. They suggest that

exciting and affiliative images do not convey survival-relevant information and, therefore, fail to trigger motivational systems. The present study employed solely affiliative images for the pleasant category, which may explain the failure to observe an autonomic advantage to the pleasant compared to the neutral images. Furthermore, it has been found that substantial increases in SCR only occur in response to the most arousing images [100] suggesting that there is a threshold for motivation activation, which the current pleasant images may not have surpassed.

Alternatively, the failure to find a linear relationship between subjective arousal and pupil response may reflect the influence of the pupil light reflex on pupil diameter. The magnitude of the pupil light reflex primarily reflects visual stimulus factors with increased constriction to greater brightness or luminance contrast [122]. Hence, measuring pupil diameter immediately following the light reflex is likely to dilute any relationship between subjective arousal towards a stimulus and subsequent pupil diameter. Indeed, previous studies that have identified a positive relationship between subjective arousal and pupil response to images have presented images for longer durations where the influence of the light reflex on pupil diameter will be diminished [63, 146]. Further research will be needed to elucidate the precise relationship between perceived arousal and pupil response to affective images.

We also observed comparable pupil diameter between positive and neutral affect for both static and dynamic facial stimuli, despite our expectation that happy faces would induce greater emotional arousal than neutral expressions. This finding may be due to the amygdala, which has been found to be central to the generation of pupil reactivity to emotion [147], not being as responsive to happy faces as negative expressions [102]. Indeed, research indicates that happy faces are less reliant on the amygdala as patients with bilateral amygdala lesions show deficits in recognising negative faces, but no deficits in the recognition of happy faces [137, 140, 141]. The amygdala may be less central to the processing of happy faces as they do not hold motivational relevance to the individual [144] in comparison to fearful or angry faces that may signal immediate danger. An additional explanation is that neutral faces can be evaluated as negative due to an implicit social expectation for a positive facial expression [148, 149]. This is particularly pertinent in response to dynamic faces where a lack of movement conveys negative emotion [150]. It could be speculated that this perceived negativity could have contributed to physiological arousal that led to comparable pupil diameter between pleasant and neutral facial affect.

Participant gender largely showed little effect on pupil diameter to emotional and neutral stimuli across tasks. This fits with previous research that finds comparable SCR between genders in response to affective stimuli [151–153].

Limitations and future directions

The present study used a community sample of mainly undergraduate students. Therefore the overall levels of psychopathy were low. The affective deficits of psychopaths are typically thought of as difficult to detect [154] may not manifest at lower levels of psychopathy. Several community studies that have found psychopathy is associated with autonomic hypo-responsivity to emotion [15, 45, 55, 59] have specifically recruited individuals who show high psychopathic traits to maximise the effects of psychopathy [45, 55]. This suggests that researchers may need to explore the more extreme end of the psychopathy spectrum to identify psychopathic affective deficits within normal populations. Indeed, Coid and Yang (42) reported that, within a large British community sample, psychopathy was a dimensional construct until a threshold where there was a dramatic increase in social and behavioural difficulties, and it could be argued that the same threshold might exist for affective deficits.

Supporting Information

S1 Table. Table displaying the results of mixed model ANOVAs exploring the role of gender on pupil diameter in response to affective and neutral stimuli across each task. (DOCX)

S2 Table. Table displaying the results of hierarchical regressions exploring gender as a moderating variable between Tri-PM subscales and pupil diameter emotional indexes across each task. Gender was dummy coded (males = 0, females = 1). (DOCX)

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Investigation: DTB.

Methodology: DTB NSG RJS.

Project administration: RJS.

Resources: RJS NSG.

Software: DTB.

Supervision: RJS NSG.

Validation: DTB RJS.

Visualization: DTB.

Writing – original draft: DTB RJS.

Writing – review & editing: DTB NSG RJS.

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