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PAPER

The neural correlates of emotion processing in juvenile offenders

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Abstract

Individuals with severe antisocial behaviour often demonstrate abnormalities or difficulties in emotion processing. Antisocial behaviour typically onsets before adulthood and is reflected in antisocial individuals at the biological level. We therefore conducted a brain-based study of emotion processing in juvenile offenders. Male adolescent offenders and age-matched non-offenders passively viewed emotional images whilst their brain activity was recorded using electroencephalography. The early posterior negativity (EPN) and the late positive potential (LPP) components were used as indices of emotion processing. For both juvenile offenders and non-offenders, the EPN differentiated unpleasant images from other image types, suggesting that early perceptual processing was not impaired in the offender group. In line with normal emotion processing, the LPP was significantly enhanced following unpleasant images for non-offenders. However, for juvenile offenders, the LPP did not differ across image categories, indicative of deficient emotional processing. The findings indicated that this brain-based hypo-reactivity occurred during a late stage of cognitive processing and was not a consequence of atypical early visual attention or perception. This study is the first to show attenuated emotion processing in juvenile offenders at the neural level. Overall, these results have the potential to inform interventions for juvenile offending.

Research highlights

- A neural correlate of emotion processing reveals that juvenile male offenders demonstrate deficiencies in emotion processing, compared with their non-offending peers.
- Electrophysiological data indicate that juvenile offenders are hypo-reactive to the emotional content of visual events, as they fail to distinguish between unpleasant stimuli and pleasant or neutral stimuli.
- Hypo-reactivity to emotional information in juvenile offenders reflected impaired evaluative processing, and not impaired early visual processing.
- Failures in emotion processing at the neural level were observed despite equivalent behavioural ratings across offender and non-offender participants.
- It is suggested that interventions for juvenile offending should focus on the emotional mechanisms underlying young people's behaviour.

Introduction

Antisocial and criminal behaviour represent serious public health problems, in terms of financial expenditure and negative social impact. Estimates suggest that the societal cost of raising a child with antisocial behaviour is ten-fold the cost of raising a child without conduct problems (Junghöfer, Bradley, Elbert & Lang, 2001; Moffitt, Caspi, Rutter & Silva, 2001; Schupp, Markus, Weike & Hamm, 2003b; Scott, Knapp, Henderson & Maughan, 2001). Given that antisocial behaviour typically onsets during childhood or adolescence (Loeber & Stouthamer-Loeber, 1998), studies of juvenile offending can help reveal the mechanisms underlying antisocial behaviour. Understanding the biological basis of delinquent behaviour should aid the development of interventions that can be implemented in childhood, before antisocial behaviour becomes severe and entrenched (Sterzer & Stadler, 2009). A growing evidence base

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suggests that antisocial behaviour is underpinned by emotion processing deficits. Specifically, physiological and neurological measures indicate that antisocial adults are hypo-reactive to emotionally arousing stimuli (Kiehl, Hare, McDonald & Brink, 1999; Patrick, Bradley & Lang, 1993). The current study was therefore designed to examine the neural correlates of emotion processing in a community sample of juvenile offenders (JOs).

Influential models of antisocial behaviour propose that antisocial individuals are characterized by under-arousal and reduced capacity to learn from punishment. As a result, they are thought to be predisposed to engage in delinquent behaviour because they do not fear the consequences of such behaviour (Raine, 1993). An alternative interpretation is that these individuals engage in sensation-seeking behaviours to achieve normal levels of arousal (Zuckerman, 1979). To investigate the link between deficient emotion processing and antisocial behaviour, researchers have tended to employ physiological measures. In adult criminal psychopaths, fear-conditioning is impaired or absent (Birbaumer, Veit, Lotze, Erb, Hermann, Grodd & Flor, 2005; Patrick, 1994), as are electrodermal responses to distress cues (Blair, 1999). Unlike control participants, adult psychopaths' startle responses are not enhanced in response to unpleasant stimuli (Levenston, Patrick, Bradley & Lang, 2000; Patrick *et al.*, 1993). At the neural level, electroencephalography (EEG) research reveals that adult psychopaths are less aroused when processing affective words (Kiehl *et al.*, 1999; Williamson, Harpur & Hare, 1991). Brain imaging research highlights abnormalities in the orbitofrontal cortex and limbic system (Kiehl, Smith, Hare, Mendrek, Forster, Brink & Liddle, 2001; Veit, Flor, Erb, Hermann, Lotze, Grodd & Birbaumer, 2002), as well as reduced grey matter in pre-frontal regions (Raine, Lencz, Bihrle, LaCasse & Colletti, 2000; Yang, Raine, Lencz, Bihrle, LaCasse & Colletti, 2005).

While the psychophysiological basis of emotion processing abnormalities in antisocial adults is well established, there is less evidence concerning emotion processing in JOs. Behaviourally, children with antisocial behaviour are impaired in recognizing sad and fearful faces (Fairchild, van Goozen, Calder, Stollery & Goodyer, 2009). Physiologically, children diagnosed with conduct disorder display reduced autonomic activity (Lahey, McBurnett, Loeber & Hart, 1995; van Goozen, Matthys, Cohen-Kettenis, Gispen-de Wied, Wiegant & van Engeland, 1998), as do adolescents later convicted of crime (Raine, Venables & Williams, 1990). Antisocial children and adolescents show impairments in fear conditioning (Fairchild, van Goozen, Stollery & Goodyer, 2008), show reduced startle reflexes to aversive images (Fairchild, Stobbe, van Goozen, Calder & Goodyer, 2010; Fairchild *et al.*, 2008; van Goozen, Snoek, Matthys, van Rossum & van Engeland, 2004), and reduced skin conductance responses to unpleasant stimuli (Syngelaki, Fairchild, Moore, Savage & van Goozen, 2013b). Further, the magnitude of startle and skin-conductance responses evoked by emotional stimuli is inversely related to severity of antisocial behaviour in JOs (Syngelaki, Fairchild, Moore, Savage & van Goozen, 2013a; Syngelaki *et al.*, 2013b). Therefore, there is quite strong evidence of a link between emotion processing and delinquency arising before adulthood.

Notwithstanding the value of peripheral physiological measures, recent efforts have focused on understanding the brain basis of emotion processing deficits in children and adolescents with antisocial behaviour. A number of functional magnetic resonance imaging studies have examined emotion processing in male youth with conduct problems (e.g. Jones, Laurens, Herba, Barker & Viding, 2009; Marsh, Finger, Mitchell, Reid, Sims, Kosson, Towbin, Leibenluft, Pine & Blair, 2008; Passamonti, Fairchild, Goodyer, Hurford, Hagan, Rowe & Calder, 2010; Sebastian, McCrory, Cecil, Lockwood, De Brito, Fontaine & Viding, 2012; Sterzer, Stadler, Krebs, Kleinschmidt & Poustka, 2005). These studies revealed hypo-activation of at least one neural region typically implicated in emotion processing: the amygdala, anterior cingulate cortex or anterior insula. Collectively, these findings suggest that the neural systems subserving emotion processing are affected in antisocial youth (for a review see Blair, 2013). Importantly, Sterzer and Stadler (2009) note that neural hypo-activation may occur at the perceptual level (early visual attention) or at a later stage of processing. The temporal resolution of functional neuroimaging means that it cannot distinguish between early visual effects and higher-order cognitive effects. EEG is ideal for examining rapidly unfolding neural correlates of affective processing, and can separate early attention from later cognitive processes. One of the earliest neural indices of emotion processing is the early posterior negativity (EPN), which onsets approximately 150 msec after stimulus onset, and is sensitive to the emotional content of visual images (Junghöfer *et al.*, 2001; Schupp *et al.*, 2003b; Schupp, Öhman, Junghöfer, Weike, Stockburger & Hamm, 2004c). Another well-validated and reliable index of emotion processing is the late positive potential (LPP). The LPP effect extends to several thousand milliseconds post-stimulus onset, and is consistently larger (more positive) in response to emotionally arousing stimuli compared to neutral stimuli (Bradley, Hamby, Löw & Lang, 2007; Cuthbert, Schupp, Bradley, Birbaumer & Lang, 2000; Naumann, Bartussek, Diedrich & Laufer, 1992). Together, these two components can usefully disentangle emotion-driven effects on early perceptual processing versus late evaluative processing. The EPN is sensitive to the emotional content of images, and is argued to reflect early perceptual processing (Schupp *et al*., 2004c). Therefore, any evidence of impaired EPN reactivity would be indicative of a deficit at the early perceptual level. The EPN is observed bilaterally in temporo-occipital scalp areas, where amplitudes are larger (more negative) for arousing, compared with neutral, stimuli (Junghöfer, Sabatinelli, Bradley, Schupp, Elbert & Lang, 2006; Schupp, Cuthbert, Bradley, Hillman, Hamm & Lang, 2004a; Schupp, Junghöfer, Weike & Hamm, 2003a, 2004b; Schupp *et al*., 2003b). This scalp distribution suggests that the EPN is generated in the visual cortex and is reflective of early visual processing.

The LPP reflects sustained processing of arousing stimuli, unaffected by early attention and perception (Codispoti, Ferrari & Bradley, 2007). Therefore, evidence of impaired LPP reactivity would suggest that emotional hypo-reactivity occurs during high-order cognitive processing, such as an evaluative response to, or further reflective processing of, the stimulus content. A number of authors argue that the LPP does not index low-level cognitive processes, such as the mere evaluative categorization of stimuli (Cuthbert *et al*., 2000; Lang, Bradley, Fitzsimmons, Cuthbert, Scott, Moulder & Nangia, 1998; Schupp *et al*., 2004b). This assertion is consistent with the neural generators of the LPP, which comprise emotional and motivational brain circuits including the amygdala, insula and cingulate cortex (Liu, Huang, McGinnis-Deweese, Keil & Ding, 2012). Although studies have examined the LPP in community samples of children (Dennis & Hajcak, 2009; Hajcak & Dennis, 2009; Kujawa, Klein & Hajcak, 2012), EEG has never to our knowledge been used to examine emotion processing in juveniles with antisocial behaviour.

The current study is the first electrophysiological investigation of emotion processing in JOs. We recruited adolescent males from inner-city communities who had recently engaged in criminal activities (based on self-report), and a comparison group drawn from the same locality. To measure emotion processing, EEG was recorded while participants passively viewed pleasant, unpleasant and neutral images from the International Affective Picture System (IAPS; Lang, Bradley & Cuthbert, 2008). We exclusively recruited males because antisocial behaviour is more common in males, presents differently between males and females, and because gender differences occur in IAPS image processing (Bradley, Codispoti, Sabatinelli & Lang, 2001; McManis, Bradley, Berg, Cuthbert & Lang, 2001; Moffitt *et al*., 2001). We focused on a community sample because community samples of delinquent adolescents are under-represented in the research arena (but see Sebastian *et al*., 2012; Syngelaki, Fairchild, Moore, Savage, and van Goozen, 2013b). Further, the community sample ensured that our offending and control samples were drawn from the same geographic and social region. Finally, studying offenders in special units may be biased because convicted offenders are ‘unsuccessful’ offenders, who may not represent law-breaking behaviour in the community (Ishikawa, Raine, Lencz, Bihrle & Lacasse, 2001). We hypothesized that JOs would show emotional hypo-reactivity (as measured by the LPP) in comparison to their non-offending peers.

Materials and methods

Participants

One hundred and twenty-two male adolescents (aged 13–17 years) were recruited from an inner-city, South-East London region characterized by high levels of socioeconomic disadvantage. Socioeconomic status was determined using a tool from the Office for National Statistics (UK), which estimates proportions of households living in poverty (below 60% median income). Poverty estimates are derived using survey, census and administrative data to produce accurate data for small geographic areas. As shown in Table 1, the sample was marked by high levels of poverty. Notably, the JO and non-offender groups did not differ in socioeconomic status.

To be eligible for inclusion in the JO group, participants had to report that they had committed at least one of the following criminal offences within the last six months: stolen a car, stolen a bike, stolen an item worth more than £50 from a store, broken into a house and stolen something, taken part in a gang fight, carried a weapon, or been arrested by the police. These participants also scored in the top half of the sample in terms of

Table 1 *Demographic and behavioural characteristics for the non-offender and offender groups. Means are shown and standard deviations are in parentheses. * = p<.01*

	Non-Offenders	Offenders	*p*-value
Age	15.44 (1.16)	15.61 (0.82)	.545
Households in poverty (%)	34.45 (7.41)	32.26 (9.39)	.651
Delinquency (SRYB)	1.298 (0.13)	2.226 (0.42)	< .001*
SDQ			
Pro-social behaviour	7.08 (2.00)	7.17 (2.12)	.889
Hyperactivity	4.25 (2.35)	5.29 (3.01)	.188
Emotional symptoms	2.54 (2.15)	2.71 (1.73)	.769
Conduct problems	2.00 (1.56)	3.67 (2.14)	.003*
Peer problems	2.42 (1.56)	2.58 (1.79)	.733

Table 2 *Mean amplitudes (μV) for each group and each component reported in the ERP analyses. Standard deviations are shown in parentheses*

			Unpleasant	Neutral	Pleasant
EPN	Left	Non-Offenders	10.75 (5.74)	11.46 (6.13)	10.98 (5.41)
		Offenders	7.75 (3.52)	8.35 (3.68)	8.11 (3.53)
	Right	Non-Offenders	11.01 (6.32)	11.68 (6.43)	11.27 (5.92)
		Offenders	8.73 (3.93)	9.26 (3.83)	9.07 (3.62)
Early LPP	Fz	Non-Offenders	−3.67 (2.44)	−3.37 (2.47)	−3.89 (1.85)
		Offenders	−2.15 (2.53)	−2.28 (1.57)	−2.31 (2.12)
	Cz	Non-Offenders	−1.15 (2.24)	−1.27 (2.07)	−1.38 (2.13)
		Offenders	−0.38 (2.39)	−0.56 (1.86)	−0.59 (2.04)
	Pz	Non-Offenders	2.18 (1.91)	1.49 (2.33)	1.75 (1.85)
		Offenders	1.65 (1.12)	0.93 (1.29)	0.85 (1.79)
Middle LPP	Fz	Non-Offenders	1.00 (1.79)	0.40 (1.65)	0.51 (1.42)
		Offenders	1.59 (1.91)	1.04 (1.23)	1.16 (1.97)
	Cz	Non-Offenders	0.83 (1.94)	0.73 (1.81)	0.63 (1.73)
		Offenders	0.97 (1.91)	0.91 (1.50)	0.74 (1.56)
	Pz	Non-Offenders	−0.07 (1.91)	0.10 (1.43)	−0.16 (1.72)
		Offenders	−0.54 (1.27)	−0.37 (1.33)	−0.73 (1.75)
Late LPP	Fz	Non-Offenders	2.34 (2.17)	1.3 (1.88)	1.68 (1.80)
		Offenders	1.89 (2.11)	1.55 (1.90)	1.62 (1.85)
	Cz	Non-Offenders	2.17 (2.08)	1.45 (2.06)	1.41 (2.09)
		Offenders	1.21 (1.72)	1.37 (1.83)	1.22 (1.61)
	Pz	Non-Offenders	−0.13 (1.57)	−0.07 (1.34)	−0.32 (1.65)
		Offenders	−0.38 (1.57)	−0.13 (1.73)	−0.58 (2.00)

their self-reported delinquent behaviour (as measured by the Self-Report of Youth Behaviour, see below). For the non-offender group, participants had never committed any of the offences indicated above, and had not been excluded from school within the past six months. Participants in the non-offender group additionally scored in the bottom half of the sample in terms of self-reported delinquent behaviour.

From the original participant pool, 35 participants satisfied the JO criteria, and 40 satisfied the non-offender criteria. Of these participants, 11 were excluded due to poor EEG data quality. Given that ERP amplitudes are correlated with age, we carefully matched the two groups, excluding participants that could not be age-matched. This resulted in two groups of 24 participants.

Written, informed consent was provided by participants, and was obtained from parents or legal guardians for participants under 16 years. Participants had normal or corrected-to-normal vision, and none reported being diagnosed with a developmental disability. Participants were compensated with £30 (as a shopping voucher). The study was approved by the Research Ethics Committee at University College London (ID: 3064/001).

Stimuli and measures

Passive image viewing task

The task consisted of three blocks of 69 images from the IAPS. Twenty-three images reflected pleasant events (e.g. families), 23 reflected unpleasant events (e.g. violence) and 23 were neutral (e.g. household objects).[1] Only developmentally appropriate stimuli were used. Based on normative adult data, the pleasant images (Mean valence = 7.56, SD = 0.48) were higher in valence than the neutral (Mean valence = 5.09, SD = 0.62; $p < .001$) and unpleasant images (Mean valence = 2.47, SD = 0.38, $p < .001$), and the neutral images were higher in valence than unpleasant images ($p < .001$). Further, the pleasant (Mean arousal = 5.34, SD = 1.23) and unpleasant images (Mean arousal = 5.35, SD = 0.83) were rated as more arousing than neutral images (Mean arousal = 3.87, SD = 0.89; $p < .001$). Arousal did not differ between the pleasant and unpleasant images ($p = .967$). Although normative values reflect adult responses, developmental research confirms that children similarly distinguish pleasant, unpleasant and neutral images (McManis *et al.*, 2001). If IAPS images are not matched for perceptual complexity, artifactual LPP differences can emerge (Bradley *et al.*, 2007; Ito & Cacioppo, 2000). We therefore attempted to match images to ensure that differences obtained were

[1]Pleasant images were the following IAPS images: 1441, 1920, 2080, 2154, 2303, 2306, 4007, 4250, 4622, 5210, 5700, 5760, 5780, 5825, 5833, 8080, 8190, 8300, 8370, 8380, 8420, 8490, 8510. Neutral images were the following IAPS images: 1560, 1670, 2032, 2038, 2122, 2271, 2309, 2411, 2487, 2575, 2749, 2880, 5740, 7021, 7036, 7092, 7461, 7476, 7496, 7632, 9210, 9331, 9411. Unpleasant images were the following IAPS images: 2095, 2205, 2345, 2375, 2800, 3180, 3301, 3350, 3500, 3530, 3550, 6313, 9000, 9001, 9050, 9183, 9325, 9421, 9520, 9560, 9901, 9910, 9925.

driven by stimulus meaning and not visual features of the task. The visual complexity of each image was categorized as either simple (figure–ground composition) or complex (scenes with no main focus). Forty-eight percent of the unpleasant images, 52% of the neutral images, and 35% of the pleasant images were simple compositions. Furthermore, an attempt was made to match the groups of images for the number that featured people (78, 70, and 61%, respectively) and animals (10, 13, 10%, respectively).

Each image was presented once per block in a randomized order, such that each image was seen three times over the experiment. Images were presented in colour on a Dell E2009W monitor and the task was programmed using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA). Images (10 cm × 12 cm) appeared on a black background. Images appeared for 1000 msec, with a variable inter-stimulus interval ranging between 2300 and 2700 msec.

Strengths and Difficulties Questionnaire

Participants completed the Strengths and Difficulties Questionnaire (Goodman, 1997). This measure is suitable for use in community samples and provides subscores for pro-social behaviour, hyperactivity, emotional symptoms, conduct problems and peer problems.

Self-Report of Youth Behaviour

Antisocial behaviour was assessed using this short tool, which measures the prevalence and frequency of delinquent behaviours including vandalism, theft and fraud (Olweus, 1989). This measure asks about both criminal (e.g. theft) and non-criminal (e.g. being rude to a teacher) behaviours. Based on the guidance from Jessor and Jessor (1977), total scores were derived. Total scores consider whether behaviours have ever been committed, as well as their frequency in the last six months. Higher total scores indicate more frequent delinquent behaviour. This tool was used to determine recent criminal activity, and therefore, group allocations.

Experimental procedure

Participants passively viewed the images whilst EEG was recorded. Participants were asked to think about how the images made them feel. Following completion of the three blocks, participants rated the valence of each image using a 9-point scale. Images of sad, neutral and happy faces were positioned above the beginning, middle and end points of the scale respectively.

EEG acquisition and preprocessing

EEG was recorded using the 129-channel HGSN Electrical Geodesics system, sampling at 250 Hz. An anti-aliasing low-pass filter of 70 Hz was applied during data acquisition. Offline, the data were band-pass filtered between 0.1 and 30 Hz and recomputed to an average reference. The continuous EEG was segmented into epochs between –200 and 2000 msec relative to the onset of each image. Spline interpolation was carried out on individual channels if required (JO mean interpolated channels = 2.70%, range: 0.78–7.81%; non-offender mean interpolated channels = 2.25%, range: 0.78–5.47%). Independent component analysis was run using FASTER to remove stereotyped artifacts (Nolan, Whelan & Reilly, 2010). Epochs were excluded from analysis if they met any of the following artifact rejection criteria: voltage deviations exceeded 100 μV relative to baseline or peak to peak moving amplitude exceeded 100 μV in a 200 msec moving window.

To investigate the EPN, we calculated mean amplitudes using the same electrodes and time window that Schupp *et al*. (2004c) used to reveal an emotion-sensitive early processing effect (also see Junghöfer *et al*., 2001; Schupp *et al*., 2003b). Specifically, mean amplitudes in the window 240–280 msec after image onset were computed for left and right temporal-occipital areas.[2]

Following previous IAPS research (e.g. Cuthbert *et al*., 2000; Schupp, Cuthbert, Bradley, Cacioppo, Ito & Lang, 2000), mean LPP amplitudes were calculated at midline scalp locations. To make use of the high spatial density offered by the electrode nets, we created clusters of electrodes surrounding the traditional Fz, Cz and Pz scalp locations.[3] Difference topographies confirmed that our observed effects were strongest at midline electrodes. As per Hajcak and Dennis (2009), mean LPP amplitudes were calculated during three time windows: 500–1000 msec, 1000–1500 msec and 1500–2000 msec.

Data analysis

The offender and non-offender groups were contrasted across each self-report measure using independent-sample *t*-tests. To investigate brain-based differences in emotion processing, mean amplitudes for the EPN, and

[2]Left cluster: electrodes 56, 63, 64, 65, 66, 68, 69, 70, 73, 74. Right cluster: 82, 83, 84, 88, 89, 90, 94, 95, 99, 107. All electrode numbers taken from the EGI Channel Map.

[3]Fz cluster: electrodes 4, 11, 16, 19. Cz cluster: electrodes 7, 31, 55, 80, 106, 129. Pz cluster: electrodes 61, 62, 72, 78. All electrode numbers taken from the EGI Channel Map.

for each time window of the LPP were entered into an ANOVA with Site (Fz vs. Cz vs. Pz) and image valence (pleasant vs. neutral vs. unpleasant) as within-subjects factors and group (offender vs. non-offender) as a between-subjects factor. Similarly to the ERP data, mean valence ratings were compared using an image valence × group ANOVA. Wherever appropriate, post-hoc contrasts were corrected using the Sidak procedure.

Results

Sample characteristics

As shown in Table 1, JOs and non-offenders were matched for age and socioeconomic status. JOs had engaged in the following criminal activities in the previous six months: 32% had stolen a bike, 4% had stolen a car, 16% had stolen an item worth more than £50 from a store, 8% had broken into a house and stolen something, 40% had participated in a gang fight, 28% had used a weapon and 64% had been arrested by the police. The groups differed markedly in their overall levels of self-reported antisocial behaviour, as measured by the SRYB and the conduct problems subscale of the SDQ (see Table 1). Notably, levels of delinquency were also relatively high in the non-offender group (despite the fact that those participants had not engaged in criminal activity). This is likely because all participants were recruited from high-risk communities, and confirms that the non-offender participants provide a useful control sample for the current study. The two groups did not differ with respect to pro-social behaviour, hyperactivity, emotional problems or peer problems.

Valence ratings

Ratings of pleasantness differed across the picture categories ($F(2, 96) = 233.857$, $p < .001$, $\eta^2_p = .836$). Post-hoc contrasts confirmed that pleasant images (Mean rating = 6.87, $SD = 0.99$) were rated higher than neutral images (Mean rating = 4.94, $SD = 0.51$; $p < .001$) and unpleasant images (Mean rating = 2.93, $SD = 0.89$; $p < .001$), and neutral images were rated higher than unpleasant images ($p < .001$). Valence ratings did not interact with group ($F < 1$).

ERP results: EPN

Similarly to previous research, mean EPN amplitudes differed according to the emotional content of the images ($F(2, 92) = 9.404$, $p = .007$, $\eta^2_p = .103$). Post-hoc contrasts indicated that the EPN was significantly more negative for unpleasant images compared with neutral images ($p = .006$). A main effect of hemisphere also revealed that amplitudes were significantly enhanced in the right hemisphere ($F(1, 46) = 5.039$, $p = .030$, $\eta^2_p = .099$). No effects involving group were statistically significant, suggesting that emotional processing did not differ between JOs and non-offenders at an early stage of processing. The ERPs used for this analysis are shown in Figure 1. The same results held when peak (as opposed to mean) EPN amplitudes were analysed (main effect of valence: $F(2, 92) = 4.583$, $p = .013$, $\eta^2_p = .091$; valence × group interaction: $F < 1$).

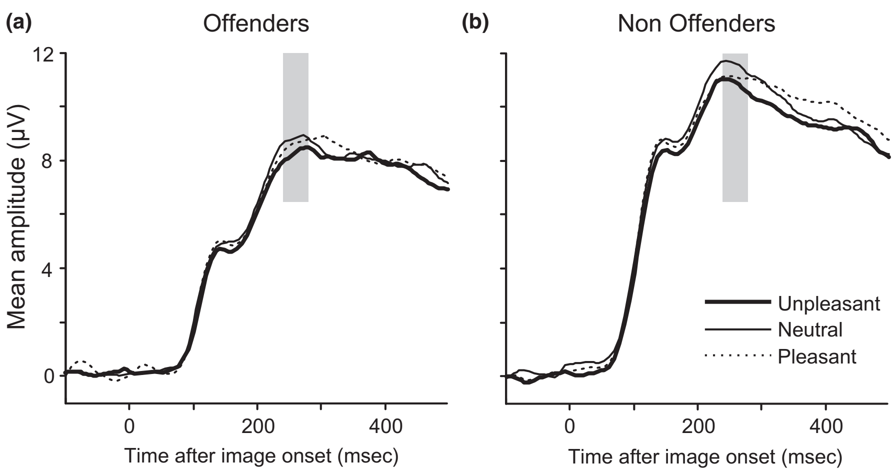

Figure 1 *The EPN (measured in the window 240–280 msec) did not differ between JO and non-offender groups. Mean amplitudes are also shown in Table 2.*

ERP results: LPP

500–1000 msec

Mean amplitude in the 500–1000 msec window differed according to site ($F(2, 92) = 94.472$, $p < .001$, $\eta^2_p = .673$). Post-hoc contrasts indicated that amplitudes were more positive around Pz than Cz ($p < .001$) or Fz ($p < .001$), and more negative around Fz than Cz ($p < .001$). A main effect of image valence ($F(2, 92) = 3.626$, $p = .030$, $\eta^2_p = .073$) emerged. Follow-up contrasts indicated that the LPP was more positive following unpleasant images compared with neutral and pleasant ($p = .009$) images. The LPP evoked by neutral and pleasant images did not differ ($p = .892$), presumably because the age-appropriate selection of images meant that highly arousing pleasant images (erotic images) were not included (see De Cesarei & Codispoti, 2006). No interactions involving group were significant.

1000–1500 msec

In the 1000–1500 msec window, the only effect to reach statistical significance was the main effect of site ($F(2, 92) = 12.884$, $p < .001$, $\eta^2_p = .219$). Post-hoc contrasts indicated that activity at the Pz cluster was more negative than at the Fz ($p = .002$) or Cz ($p < .001$) clusters, but did not differ between the Fz and Cz clusters ($p = .854$).

1500–2000 msec

In the 1500–2000 msec window, mean amplitudes differed according to site ($F(2, 92) = 24.867$, $p < .001$, $\eta^2_p = .351$) and image valence ($F(2, 92) = 4.884$, $p = .010$, $\eta^2_p = .096$). Post-hoc pairwise comparisons indicated that amplitudes were more positive at Cz than at Pz ($p < .001$), and in response to unpleasant images versus pleasant images ($p = .018$). Importantly, an interaction between image valence and group emerged ($F(2, 92) = 3.148$, $p = .048$, $\eta^2_p = .064$). Specifically, the LPP was more positive for unpleasant images versus neutral images ($p = .011$) and pleasant images ($p = .009$) for non-offenders only. For JOs, the LPP evoked by unpleasant images did not differ from neutral images ($p = .999$) or pleasant images ($p = .736$), and neutral images did not differ from pleasant images ($p = .487$). These data are shown in Figure 2, and suggest that the non-offenders were sensitive to the valence of the stimuli, showing enhanced LPP responses to unpleasant images relative to neutral, while JOs were hypo-reactive to unpleasant stimuli.

The difference topographies shown in Figure 2 suggest that, for non-offenders, the valence effect observed in fronto-centro-parietal electrodes at 1500–2000 msec was accompanied by a phase-reversal of that effect in centro-posterior scalp electrodes. In order to test whether posterior scalp activity differed as a function of valence and group, we calculated mean amplitudes in a posterior electrode cluster[4] and employed an ANOVA with valence as a within-subjects factor and group as a between-subjects factor. This analysis confirmed the phase reversal of the valence effect ($F(2, 92) = 15.337$, $p < .001$, $\eta^2_p = .250$). The interaction between group and valence approached significance, suggesting that, as expected, the effect of valence was strongest for non-offenders ($F(2, 92) = 2.657$, $p = .076$, $\eta^2_p = .055$).

ERP results: additional analysis

Visual inspection of the ERPs and topographies suggested that emotion-driven differences could exist between the groups at other time windows or scalp locations than those in our data analysis plan. For example, the Cz cluster shown in Figure 2 suggests a possible valence effect 300–400 msec after stimulus presentation in the non-offender group but not in JOs.[5] We therefore calculated mean amplitudes in this temporal window, and entered these data into an ANOVA with valence as a within-subjects variable and group as a between-subjects variable. However, in that analysis, no main or interaction effects were statistically significant, suggesting that visual processing did not differ between non-offenders and JOs during this early time window (valence main effect: $F(2, 92) = 2.338$, $p = .102$, $\eta^2_p = .048$; group main effect: $F(1, 46) = 2.679$, $p = .109$, $\eta^2_p = .055$; interaction effect: $F(2, 92) = 1.498$, $p = .229$, $\eta^2_p = .032$). The results did not change if peak, rather than mean, amplitudes were analysed (valence main effect: $F(2, 92) = 1.332$, $p = .269$, $\eta^2_p = .028$); group main effect: $F(1, 46) = 3.191$, $p = .081$, $\eta^2_p = .065$); interaction effect: $F < 1$).

Discussion

The current study revealed that JOs are hypo-reactive to unpleasant emotional images at the neural level. In contrast to their peers, adolescent males who had recently committed crimes showed no LPP differentiation between unpleasant images and other images in the period 1500–2000 msec after stimulus onset. These data

[4]Posterior cluster: electrodes 69, 70, 74, 75, 82, 83, 85, 89. All electrode numbers taken from the EGI Channel Map.

[5]We thank an anonymous reviewer for this suggestion.

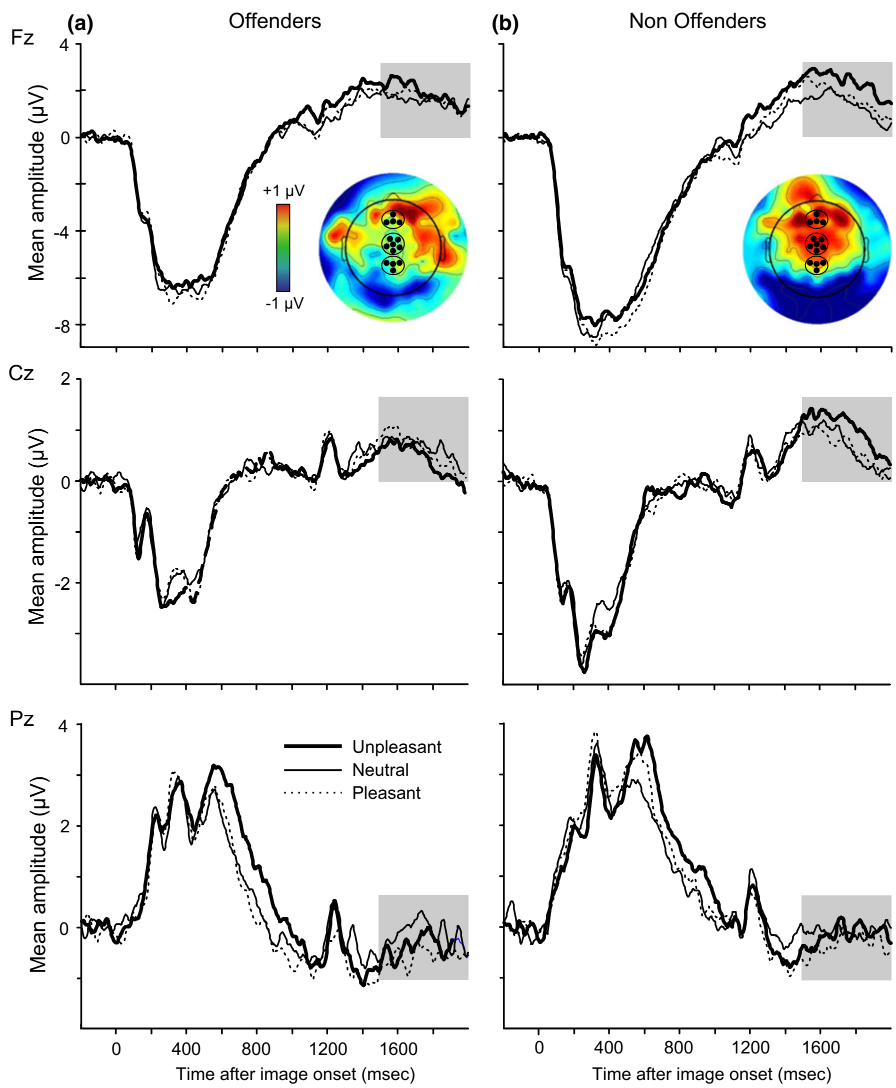

Figure 2 *LPP results: ERPs and difference topographies (unpleasant images minus other images) for the JO and non-offender groups. JOs showed emotional hypo-reactivity to the unpleasant images. Difference topographies are shown for the window 1500–2000 msec after stimulus onset. Black circles on the topographies indicate the scalp electrodes used for ERP analyses. Mean amplitudes are also shown in Table 2.*

support the notion that young people with a history of antisocial behaviour show reduced emotional responsiveness (e.g. Fairchild, van Goozen, Stollery, and Goodyer, 2008; Syngelaki *et al.*, 2013a, 2013b; van Goozen *et al.*, 2004). The data also suggest that, at least in the context of the current paradigm, the locus of the emotion processing deficit is at a late stage of information processing and not during early visual perception or attention (because the EPN and early LPP did not differ between the groups). Past work strongly suggests that the LPP represents the activation of an evaluative system (Codispoti, Ferrari & Bradley, 2006; Pastor, Bradley, Löw, Versace, Moltó & Lang, 2008). Furthermore, the effect we observed occurred 1500–2000 msec after stimulus onset, which is substantially later than initial visual processing and stimulus categorization. Notably, the observed effects did not appear to be driven by group differences in age or socioeconomic status, or by differences in stimulus complexity across image categories, as there were none.

The current study adds to a compelling evidence base showing that offending is linked to emotional hypo-reactivity, measured at the level of the brain and peripheral physiology (Passamonti *et al.*, 2010; Syngelaki *et al.*, 2013a, 2013b). However, less is known about the causal mechanisms giving rise to hypo-reactivity. Reduced emotional reactivity might encourage young people to engage in criminal activity to achieve normal levels of autonomic arousal, or because they do not fear the consequences of antisocial behaviour (Raine, 1993; Zuckerman, 1979). Alternatively, emotion processing might be impaired as a consequence of engaging in criminal activity: through criminal interactions, JOs are exposed to highly adverse and dangerous situations, which may 're-calibrate' emotional responding to a higher threshold. A further possibility is that the observed neural differences reflect social-environmental risk factors (e.g. early adversity, maltreatment) that are themselves linked to antisocial behaviour, the manifestation of genetic influences and/or their interaction (Afifi, McMillan, Asmundson, Pietrzak & Sareen, 2011; Foley, Eaves, Wormley, Silberg, Maes, Kuhn & Riley, 2004; Moffitt, 1990; Raine, 2002; van Goozen & Fairchild, 2008). Although the current study cannot separate these possibilities, there is evidence to suggest that abnormal brain functioning precedes antisocial behaviour. For example, reduced P300 amplitudes at age 11 are associated with high levels of antisocial behaviour at age 23 (Gao, Raine, Venables & Mednick, 2013). It is important to note, however, that unlike the current study, Gao *et al.* (2013) did not examine emotion processing. Instead, these authors measured the P300 event-related component in a simple visual attention task, which is unable to speak to emotion processing in antisocial youth.

JOs do not represent a distinct psychiatric population. Despite this, JOs' symptomatology is typically similar to psychiatric disorders such as psychopathy or disruptive behaviour disorders (see Syngelaki *et al.*, 2013a). It is therefore useful to study JOs to shed light on early developmental and neural mechanisms underlying psychiatric disorders in adolescence and adulthood. Despite the fact that the JOs typically reported engaging in non-violent crimes, our data parallel previous work demonstrating impaired emotion processing in adult psychopaths and young people with disruptive behaviour disorders (Blair, Jones, Clark & Smith, 1997; Fairchild *et al.*, 2010; Fairchild, van Goozen, Stollery, and Goodyer, 2008; Herpertz, Werth, Lukas, Qunaibi, Schuerkens, Kunert, Freese, Flesch, Mueller-Isberner, Osterheider & Sass, 2001; Levenston *et al.*, 2000; Patrick, Bradley, and Lang, 1993; van Goozen *et al.*, 2004). Similarly to our findings, Levenston *et al.* (2000) used the startle reflex response to demonstrate abnormal emotional processing in adult psychopaths at a late stage of cognitive processing.

Even though JOs demonstrated attenuated emotional reactivity, they did not process unpleasant images as if they were affectively neutral or simply failed to process the content of the images. During the EPN and the early time window of the LPP (500–1000 msec), neural activity was modulated by emotion in both groups of participants. In other words, these data suggest that JOs process emotion to some degree. By contrast, JOs appeared to be muted in their reflective evaluation of emotional stimuli. It is not unusual for muted emotional reactivity to be restricted to certain parts of a response, as shown in adult psychopaths using electromyography (Patrick, Bradley, and Lang, 1993). By extensively examining the LPP across successive time windows, and showing that offenders and non-offenders did not differ in the early time windows, we confirm that the obtained effects reflect real group differences, and not differences in ERP latency (see Kiehl, Hare, McDonald, and Brink, 1999), or in following task instructions to attend to the images.

It is useful to further consider the functional significance of the various LPP time windows employed here. Importantly, why was the LPP modulated by valence in JOs in the earliest time window, but not in the latest? An answer may be found in the relationship between the LPP and the well-studied P300 component. Specifically, the LPP's early phase has a similar latency and topographical distribution to the P300 ERP component (Hajcak & Dennis, 2009). Given that the P300 reflects increased transient attention towards target stimuli, the early LPP window likely reflects a similar cognitive mechanism (see arguments by Hajcak & Dennis, 2009). Hence, our finding of intact LPP modulation at 500–1000 msec for both groups could be interpreted as an initial increase in transient attention towards unpleasant material. Unlike the P300, the LPP is a sustained response. The LPP persists for the duration of, and continues after, stimulus presentation (Cuthbert *et al.*, 2000; Hajcak & Olvet, 2008). Hajcak and Dennis (2009) therefore argue that the late time window of the LPP reflects sustained attentional increases, or devotion of cognitive resources, to emotional information. This is consistent with other suggestions that the LPP indexes an evaluative mechanism, and not a simple categorization mechanism (Lang, Bradley & Cuthbert, 1997). Our finding that LPP differences were absent during the late time window for JOs may therefore be attributed to a failure of sustained attention to emotional information. In other words, JOs appear to be less aroused by unpleasant images, suggesting that they do not engage in the late, evaluative stages of emotional processing.

Participants' subjective valence ratings were equivalent across the two groups and paralleled adult normative ratings (Lang *et al.*, 2008). Hence, even though unpleasant images were not physiologically evaluated in the same way for JOs versus non-offenders (as indicated by the late LPP), the offenders were able to accurately categorize the images. Equivalent subjective ratings across the groups are likely driven by the Jos' knowledge of what the correct classifications should be. In fact, previous work with adult psychopaths and non-psychopaths confirms that equivalent subjective ratings are often obtained, despite unequal physiology across the groups (Patrick, Bradley, and Lang, 1993; Rothemund, Ziegler, Hermann, Gruesser, Foell, Patrick & Flor, 2012). These differences may arise for a variety of reasons including differences in the underlying processes that the measures index and/or social desirability.

This study has some limitations that require acknowledgement. First, JOs represent a heterogeneous group, rather than a distinct psychiatric population. Second, the results might not hold for female offenders. Finally, we relied upon self-reports of delinquent behaviour. This constitutes both a strength and a limitation because, on the one hand, self-reports are not necessarily accurate reflections of delinquent behaviour. On the other hand, self-reports allowed us to access a wider range of young offenders, as we were not restricted to young offenders who had been convicted of crimes. While a parallel study of young offenders using officially recorded criminal convictions would be invaluable, such records do not directly reflect objective criminal or antisocial activity, are subject to a number of biases and thereby have their own measurement limitations.

To conclude, the current study is the first to examine emotion processing in JOs at the neural level. We demonstrate that JOs are hypo-reactive to unpleasant images, despite categorizing those images in the same way as their non-offending peers, suggesting a strong link between antisocial behaviour and muted emotion processing. We confirm that hypo-reactivity occurred during a late stage of cognitive processing, and not during early attention or perception. The findings of the current study, when combined with past research, are relevant to efforts to develop and implement treatments for juvenile antisocial behaviour. If JOs experience attenuated neural and physiological responses when processing cues signalling danger or threat, and if they are not aroused by aversive situations, their antisocial behaviour is likely to be enhanced or sustained. Future treatment programmes might therefore do well to focus on the emotional mechanisms underlying young people's behaviour.

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