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Bennett, Carmel; Blissett, Jacqueline; Carroll, Douglas; Ginty, Annie T.

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Author: Carmel Bennett Jackie Blissett Douglas Carroll Annie T. Ginty

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Rated and measured impulsivity in children is associated with diminished cardiac reactions to acute psychological stress.

Carmel Bennett[1], Jackie Blissett[1], Douglas Carroll[2], Annie T. Ginty*[2]

[1] School of Psychology, University of Birmingham, Birmingham, UK
[2] School of Sport, Exercise, and Rehabilitation Sciences, University of Birmingham, Birmingham, UK

Running head: Impulsivity and cardiac stress reactivity

*Corresponding author at: School of Sport, Exercise, and Rehabilitation Sciences, University of Birmingham, Birmingham, B15 2TT, United Kingdom
Telephone: ++44 121 414 8748
Fax: ++44 121 414 4121
Email: a.t.ginty@bham.ac.uk

Abstract

This study examined the association between impulsivity and heart rate reactions to a brief psychological stress in pre-adolescent children. Impulsivity was assessed by two response inhibition tasks and maternal self-report. Heart rate was measured at rest and in response to a mental arithmetic challenge. Children high in impulsivity showed blunted cardiac stress reactions. This result resonates with previous findings that blunted stress reactivity is characteristic of a range of problematic behaviours often associated with impulsivity.

Keywords: Acute psychological stress; Heart rate; Impulsivity

1. Introduction

Impulsivity is a stable disposition, characterised by lack of foresight, problems with delaying gratification and inhibiting inappropriate responses (Patton, Stanford, & Barratt, 1995). It is a feature of patients with Attention Deficit Hyperactivity Disorder (ADHD; Nigg, 2011) and conduct disorder (Allen, Briskman, Humayun, Dadds, & Scott, 2013), and is associated with a range of adverse behavioral outcomes: substance abuse (Perry et al., 2005; Reynolds, 2006), gambling (Madden et al., 2009), problematic eating and overweight/obesity in adults and in children (Galanti, Gluck, & Geliebter, 2007; Thamotharan, Lange, Zale, Huffhines, & Fields, 2013). Diminished cardiovascular and/or cortisol reactions to acute psychological stress have been associated with the same problematic behaviours (Carroll, Phillips, & Der, 2008; Ginty, Phillips, Higgs, Heaney, & Carroll, 2012; Koo-Loeb, Pedersen, & Girdler, 1998; ; Lovallo, Dickensheets, Myers, Thomas, & Nixon, 2000; Paris, Franco, Sodano, Frye, & Wulfert, 2010; von Polier et al., 2013) and are characteristic of patients with ADHD (Pesonen et al., 2011) and conduct disorder (Ortis & Raine, 2004). The question arises as to whether impulsivity, particularly in the absence of a diagnosis of ADHD or conduct disorder, is also associated with blunted stress reactivity.

Few studies have examined this issue in non-clinical populations and the results are mixed. Whereas two studies found that high impulsivity is related to low cardiac reactivity (Allen et al., 2009; Munoz & Anastassiou-Hadjicharalambous, 2011), another reported an association in the opposite direction (Diller, Patros, & Prentice, 2011), with a further finding no clear association between impulsivity and cardiac stress reactivity (Mathias & Stanford, 2003). In addition, impulsivity has been related to blunted electrodermal activity during stress (Stankovich, Fairchild, Aitken, & Clark, 2013) and diminished secretory alpha- amalyse reactivity (Spinrad et al., 2009), both considered to be measures of sympathetic nervous system activation. However, very few of the studies have used behavioral measures of impulsivity, relying largely on questionnaire devices and most have been conducted on convenience samples of undergraduate students.

We revisited the issue of impulsivity and cardiac reactions to acute stress, but studied pre-adolescent children and employed both behavioural and maternal report measures of children's impulsivity. On the balance of the evidence to date, it was hypothesised that higher levels of impulsivity would be related to diminished cardiac reactivity.

2. Methods

2.1 Participants

Fifty children (28 female) aged 7-11 years and their parents were recruited through the University's Infant and Child Laboratory Database and from local schools. The mean (standard deviation; SD) of the children's age was 8.22 (1.12) years and the mean age of their parents was 38.44 (5.41). The mean age and sex adjusted BMI for the children, based on height and weight measurements in the laboratory, was .35 (1.07). Exclusion criteria were no current or recent major illness, no diagnosed developmental disability, or impulsivity-related disorder. The study was approved by the University of Birmingham Ethics Review Board; informed parental written consent and verbal assent from the children were obtained in all cases. Parents were present in the next room at all times and could view what was happening through a video link.

2.2 Impulsivity tasks

The Circle Drawing Task (Bachorowski & Newman, 1990) measured each child's ability to inhibit an ongoing motor response. Children had to trace the outline of a large printed circle (50.80 cm ø), with their index finger from a set point. There were two conditions. First, children traced the circle's outline; second, they traced the outline as slowly as possible. Circle difference score (CDS) was the duration of the circle drawing time during the neutral condition subtracted from the time during the inhibition condition. A Go-NoGo task was used to assess the extent to which children were able to inhibit prepotent responses. The target stimulus (sun) required a key-press, whereas the non-target (flower) required the inhibition of the key-press. A fixation cross was presented at the centre of the screen for 500ms at the beginning of each trial followed by the 500ms presentation of the target or non-target. There were 100 trials; the ratio of target to non-target was 3:1. Failures to inhibit a response to the non-target (errors of commission) were used as an index of impulsivity. Finally, parents' reports of their children's impulsivity were assessed using the seven items (e.g., Fails to finish things he/she starts) that comprise Conner's

Global Index: Restless-Impulsive (Conners, Sitarenios, Parker, & Epstein, 1998). Items were scored on a 0 to 3 Likert Scale with higher scores indicating greater impulsivity.

2.3 Stress testing

The study took place in the University's Infant and Child Laboratory. Children's heart rates (HR) were measured in 5s intervals using a wireless HR monitor (Polar RS 400). The stress task consisted of mental arithmetic with age-appropriate, challenging problems. Each problem consisted of three parts displayed on a laptop on three separate slides (e.g., slide 1: 4*3; slide 2: +8; slide 3: -12; answer = 8). Children were instructed to look at all slides before giving their answer and completed a practice problem before starting. The first two slides were displayed for 2.5 seconds and the third for 4 seconds. The key HR measurement periods were baseline, which was the average HR during the minute before stress task onset, and stress, which was the average HR during the seven minutes of the stress task. Reactivity was calculated as stress HR minus baseline HR. Children rated perceived stress using a 100mm visual analogue scale (VAS) with the anchors "not stressed at all" and "extremely stressed" immediately before and after the stress task. Self-perceived task stressfulness was calculated as the VAS stress score immediately after the stress task minus the VAS stress score prior to the stress task.

2.4 Statistical analysis

Stress task impact on HR was determined using repeated measures (baseline, average task) ANOVA. Similarly, stress task impact on self-perceived stressfulness was determined using repeated measures (prior to the task, immediately after the task) ANOVA. The associations between measures of impulsivity and HR reactivity were analyzed using bivariate correlations, followed by linear regression, with adjustment for age and gender. Associations between self-perceived task stressfulness, measures of impulsivity, and HR reactivity were analyzed using bivariate correlations. P values ≤ .05 were considered indicative of statistical significance. All correlations were analyzed using a two-tailed approach. Occasional minor variations in degrees of freedom reflected missing data for some variables. It was hypothesized that higher levels of impulsivity on each of the three measures: CDS, errors of commission, and parent rated impulsivity would be associated with diminished heart rate reactivity to the acute psychological stress task; separate regressions were carried out for each impulsivity measure. Based on previous research in the area it was hypothesized that these associations would have a medium effect size (Allen et al., 2009; Munoz et al., 2011).

3. Results

HR during stress was significantly higher than HR during baseline, F (1,45) = 31.31, $p \leq .001$, $_{p}\eta^2 = .410$ and self-perceived stress levels immediately following the stress task were significantly higher than self-perceived stress levels prior to the stress task, F (1,44) = 97.16, $p \leq .001$, $_{p}\eta^2 = .688$. Mean scores and SDs for HR and self-perceived stress levels during baseline and stress and impulsivity measures are presented in Table 1. HR reactivity correlated positively with CDS, r (44) = .37, *p* = .012, and negatively with commission errors, r (41) = -.30, *p* = .050, and parent rated impulsivity, r (41) = -.31, *p* = .046. These associations are illustrated in Figure 1. Commission errors correlated significantly with parental rated impulsivity, r (42) = .50, *p* = .001; there were no associations between CDS and the other impulsivity measures. Regression analyses adjusting for age and gender confirmed the above outcomes for reactivity and: CDS, β = .362, t = 2.53, *p* = .015, $\Delta R^2 = .131$; errors of commission, β = -.329, t = 2.38, *p* = .022, $\Delta R^2 = .108$; and parent rated impulsivity, β = -.316, t = 2.10, *p* = .042, $\Delta R^2 = .122$. The only other association to emerge from the regression analyses was a positive relationship between age and errors of commission, β = -.391, t = 2.83, *p* = .007. Finally, since the parent rated impulsivity was somewhat skewed, we log transformed the data and repeated the correlation and regression analyses. The outcomes, for the relationship between parent rated impulsivity and HR reactivity, r (41) = -.34, *p* = .033, and β = -.354, t = 2.30, *p* = .027, were virtually identical to those described above. There were no significant associations between self-perceived task stressfulness (M = 40.42, SD = 27.51) in response to the task and measures of impulsivity (*p*s > .383) or HR reactivity (*p* = .216).

[Insert Figure 1 about here]

4. Discussion

The present study examined the relationship between cardiac reactions to acute psychological stress and impulsivity in pre-adolescent children with no clinical diagnoses. Lower cardiac reactivity was associated with higher levels of impulsivity, measured both behaviourally and through maternal-self report. These results resonate with the findings and effect sizes of two previous studies which also report a negative association between impulsivity and cardiac reactivity (Allen et al., 2009; Munoz et al., 2011) and two additional studies reporting that indices of decreased sympathetic nervous system activation, electrodermal and alpha-amalyse activity, during stress are characteristic of higher impulsivity (Spinrad et al., 2009; Stankovich et al., 2013). There is evidence that the sympathetic nervous system contributes substantially to cardiac stress reactions (Winzer, Ring, Carroll, Willemsen, Drayson, & Kendall, 1999).

Diminished arousal and heightened impulsivity have been regarded as a risk factor and/or marker of a number of adverse behavioral and clinical outcomes, such as substance abuse, addiction, ADHD, and conduct disorder (Raine, 1993; von Polier, Vloet, Herpertz-Dahlmann, 2012). Previous studies have shown associations between low stress reactivity and a number of these behavioural outcomes (Ginty et al., 2012; Koo-Loeb et al., 1998; Lovallo et al., 2000; Ortis & Raine, 2004 Paris et al., 2010; Pesonen et al., 2011; Popma et al., 2006; Van Goozen, Matthys, Cohen-Kettenis, Buitelaar, & van Engeland, 2000). Children of parents with substance abuse addictions, who themselves do not have an addiction, display lower stress responses (Moss, Vanyukov, & Martin, 1995; Sorocco, Lovallo, Vincent, & Collins, 2006). Additionally, lower cortisol responses to a stress task have been associated with poorer treatment outcomes for addictive and delinquent behaviours (Van de Wiel, Van Goozen, Matthys, Snoek, Van Engeland, 2004; al' Absi, Hatsukami, & Davis, 2005). The participants in the current study did not have any clinical disorders or addictions. It could be that those who were higher in impulsivity and lower in cardiovascular responses may be at the most risk for developing such disorders during adolescence or adulthood. The strong link between impulsivity and diminished arousal even in the absence of disorder could be driven by neural dysregulation.

It has been argued that blunted cardiovascular and/or cortisol reactions to acute stress may be peripheral markers of an under-recruitment of brain systems during situations, such as acute stress exposure, requiring motivated action (Carroll, Lovallo, & Phillips, 2009; Lovallo, 2011). This proposition is supported by a recent fMRI study showing that individuals with blunted cardiac stress reactions exhibited a hypoactivation of the anterior cingulate cortex (ACC) in response to a standard stress condition compared to a non-stress control condition (Ginty et al., 2013). Both lesion and fMRI studies have implicated the ACC in response inhibition and impulsivity (Bari & Robbins, 2013). Additionally, dysfunction of the ACC has been associated with ADHD (Bush et al., 1999; Durston et al., 2003) and delinquent behaviors (Yang & Raine, 2009). The link between impulsivity and diminished arousal could also be explained by a pre-existing dopamine and/or serotonin deficiency. Dopaminergic system dysfunction is associated with decreased function in the anterior cingulate gyrus (Volkow, Wang, Fowler, Tomasi, & Telang, 2011) and with a number of addictive and impulsive behaviors (Comings & Blum, 2000; Blum et al., 2000; Goldstein & Volkow, 2002; Hommer, Bjork, & Gilman, 2011; Volkow et al., 1996). Experimental studies have shown that decreasing serotonin levels in healthy adults results in increases in impulsive behavior (Crockett, Clark, Lieberman, Tabibnia, & Robbins, 2010; Worbe, Savulich, Voon, Fernandez-Egea, & Robbins, in press). Additionally, lower levels of serotonin, measured from cerebrospinal fluid, have been associated with diminished cardiovascular stress reactions to an acute psychological stress task (Williams et al., 2001). However, it should be noted the research investigating the relationship between serotonin transport genes and cardiovascular stress reactivity has produced mixed results (Agorastos et al., 2014; Leyton et al., 1999; Mueller, Strahler, Armbrustel, Lesch, Brocke, & Kirschbaum, 2012; Williams et al., 2008). Finally, both blunted stress reactivity and impulsivity appear to have common antecedents, notably early life adversity (Lovallo, 2013).

The present study is not without limitations. First, the sample size can be regarded as small. However, it is of the same magnitude or larger than comparable studies in the field. Second, alpha levels indicate that the associations were just significant. However, according to current guidelines (Cohen, 1992) the effect sizes are medium to large. Third, there were no measures of stress task performance. It could be participants who were higher in impulsivity did not have as much investment in the task. However, self-perceived stress in response to the task was not related to impulsivity or HR reactivity, suggesting that participants found the task equally stressful regardless of impulsivity. Finally, only HR reactivity was measured and a fuller haemodynamic picture may have proved instructive. Nevertheless, it is HR rather than blood pressure reactivity that was more strongly associated with impulsivity in previous studies (Allen et al., 2009).

In conclusion, children with high, but not clinically elevated levels of impulsivity exhibited blunted cardiac reactions to acute psychological stress. This result adds to the notion that blunted stress reactivity is a marker of a central dysfunction that may predispose individuals to a host of problematic behaviours associated with impaired inhibition. Future research should examine the neural underpinnings of the relationship between impulsivity and diminished stress reactivity in the absence of a diagnosed clinical disorder.

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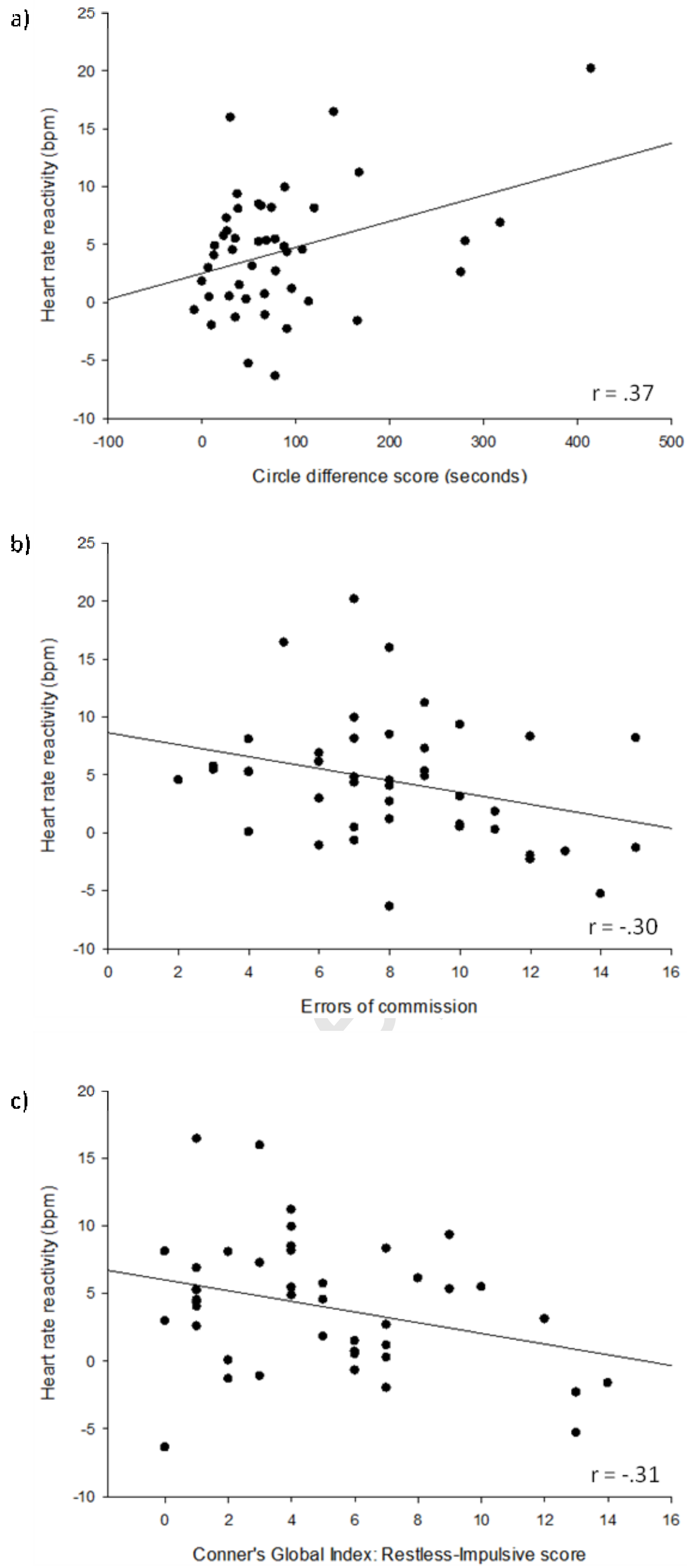
Table 1. Mean (SD) heart rate responses at baseline and during stress and mean (SD) impulsivity scores.

	Mean (SD)
Heart rate (bpm)	
Baseline	87.70 (10.10)
Stress	94.07 (9.06)
VAS Stress rating (mm)	
Before task	10.67 (13.66)
Immediately post task	51.09 (29.26)
Circle Difference Score (seconds)	79.33 (84.01)
Commission Errors in Go-NoGo task	8.26 (3.12)
Parent rated restlessness-impulsivity	4.91 (3.82)

Figure Caption

Figure 1. The association between heart rate reactivity and a) circle difference score, b) errors of commission, and c) Conner's Global Index: Restless-Impulsive score.


a)
Heart rate reactivity (bpm)
25
20
15
10
5
0
-5
-10
r = .37
-100
0
100
200
300
400
500
Circle difference score (seconds)
b)
Heart rate reactivity (bpm)
r = -.30
0
2
4
6
8
10
12
14
16
Errors of commission
c)
Heart rate reactivity (bpm)
20
r = -.31
Conner's Global Index: Restless-Impulsive score