International Journal of Psychophysiology 170 (2021) 168–177

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Heart-wired to be cold? Exploring cardiac markers of callous-unemotional traits in incarcerated offenders☆

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ARTICLE INFO

Keywords:
HRV
HR
Physiological markers
Callous-unemotional traits
Offenders
Juveniles

ABSTRACT

Elevated callous-unemotional (CU) traits have been repeatedly identified in a subgroup of offenders that displays severe antisocial behavior; establishing physiological markers may help improve early identification and treatment efforts. This study examines to what extent baseline-resting heart rate (HR) and heart rate variability (HRV) can be used as markers of CU in incarcerated juvenile and adult offenders. CU traits were assessed using the Inventory of Callous-Unemotional traits. Results of the multiple hierarchical regression tests indicated that there was a small yet significant positive association between baseline HR and CU and negative association between HRV and CU in juvenile offenders with medium model effect sizes ($R^2 = 0.115$ for HR-CU; $R^2 = 0.126$ for HRV-CU). The cardiac markers were unrelated to CU in adult offenders. These findings are important because they demonstrate that impaired cardiac autonomic activity is related to CU traits in juveniles, suggesting that socioemotional processing difficulties should be considered in understanding these deficits. Future research should be conducted in large samples, under reactive and static conditions, while including cardiac covariates, to get more clarity on the interplay between biological systems and behavioral expression.

1. Introduction

There is great heterogeneity among offenders in terms of the types and severity of crimes committed (Frick et al., 2014b). The group of delinquents with the most persistent and severe antisocial behavior throughout life has repeatedly been found to show elevated callous-unemotional (CU) traits, which consists of limited guilt, remorse and empathy, shallow emotionality, and coldhearted use of others (Frick et al., 2014b; Frick and White, 2008; Hawes and Dadds, 2005). In order to improve the identification of those with poor prognosis and intervene successfully in this group, it might be useful to explore physiological correlates of CU traits (Beauchaine and Thayer, 2015; Fanti, 2018; Insel et al., 2010). Heart rate (HR) and, to some extent, heart rate variability (HRV) have been studied as physiological correlates in relation to CU. HR and HRV are important markers to study as they are considered to reflect the functioning of the Autonomic Nervous System (ANS), the system that is predominantly responsible for the regulation of physiological arousal levels in response to environmental demands, and thereby, plays a key role in socioemotional regulation (Appelhans and Luecken, 2006; Beauchaine and Thayer, 2015). The present study examined the association between CU traits, HR and HRV in a sample of incarcerated juveniles and adults.

1.1. Towards a better understanding of CU traits

In the last decades, CU traits have become important in research on aggression and antisocial behavior. This is because the presence of CU traits designate a particularly aggressive subgroup of individuals who display severe antisocial behavior (e.g., Frick and White, 2008). CU traits are related to a more stable pattern of antisocial behavior over time, earlier onset of delinquency, and these traits have also been found to predict future offending in the form of, for example, future arrests (Frick et al., 2014a; Frick and White, 2008). Moreover, some evidence suggests that this subgroup is less responsive to treatment efforts (e.g.,

☆ Our thanks to Helena Oldenhof for her assistance. We also thank the Jo Kolk and the Madeleine Julie Vervoor Foundation, who supported this international collaboration by providing travel grants.

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https://doi.org/10.1016/j.ijpsycho.2021.10.006
Received 24 July 2020; Received in revised form 2 September 2021; Accepted 9 October 2021
Available online 16 October 2021
0167-8760/

Hawes and Dadds, 2005). Understanding more about CU traits seems imperative to offset severe criminal trajectories. Theories that explain the development and manifestation of severe behavioral problems (e.g., Blair, 2001; Raine, 1993), have relied heavily on studies that have examined the physiology behind forms of antisocial behavior. One such prominent theory is the Low Arousal Theory, which proposes that those with extremely low baseline HR may seek stimulation in excessive forms due to a chronic, unpleasant state of physiological under-arousal, which results in antisocial behavior (Quay, 1965). In line with this theory, several studies have found low HR at rest to be a robust correlate of antisocial behavior (i.e., Portnoy and Farrington, 2015). Etiological models of CU traits have also proposed that low arousal and physiological functioning are one part of the wide array of (behavioral, temperamental, neural, and physiological) risk factors that could give rise to CU traits. Essential to the existing etiological models are also the neurophysiological mechanisms showing socioemotional processing impairments, which are believed to give rise to the socioemotional difficulties associated with CU traits (Wagner and Waller, 2020).

1.2. Socioemotional difficulties associated with CU traits

Individuals with high CU traits appear to struggle in areas that are essential for successful socioemotional functioning in the human world. Overall, their emotional responsiveness is reduced in different settings (Frick et al., 2014a). Even though they are able to establish social relationships, albeit with more "deviant others," these relationships are considered of a poorer quality because they are perceived as less intimate and more transient (Haas et al., 2018; Matlasz et al., 2020; Munoz et al., 2008). Those high on CU traits recognize their own social difficulties, as they rate themselves as having poorer social competence; they also appear to be right as evidenced by the higher dislike ratings that they receive from peers (e.g., Haas et al., 2015). More distinctively, individuals high on CU traits do recognize their behavior as having negative consequences for others; they just do not feel bad about it (Frick et al., 2014a; Haas et al., 2015). Overall, empathy deficits are considered to be one of the most pronounced aspects of the CU construct (Frick, 2009). Studies have repeatedly demonstrated CU traits being associated with deficits in affective empathy, that is, the ability to feel negative emotions due to the damage done to others (Frick et al., 2014b). This impaired affective empathy may partly explain why those with high CU traits are less successful in functioning socially (Haas et al., 2015). In sum, CU traits designate a subgroup of individuals with severe socioemotional, and antisocial impairments.

1.3. Cardiac markers and the socioemotional difficulties of CU traits

To be able to "feel what others feel" and function successfully in the social human world several emotional and cognitive processes need to be regulated quickly based on what is happening in the environment (Lischke et al., 2018). The parasympathetic nervous system (PNS) is a branch of the ANS that drives these fast emotional and behavioral adaptation processes by adjusting a person's arousal level (Appelhans and Luecken, 2006; Wagner and Waller, 2020). Vagally mediated heart rate variability (HRV) has been proposed as a cardiac marker that captures the functioning of the PNS, and that therefore gives insight into a person's emotional and behavioral functioning (e.g., Lischke et al., 2018; Porges, 2007). In a resting position, higher HRV is indicative of successful self-regulation and cognitive control, which allows for flexible and quick responding to environmental needs (Appelhans and Luecken, 2006; Beauchaine and Thayer, 2015). Heart rate (HR) has been proposed as another marker of the ANS, which reflects the functioning of the PNS as well as the other – sympathetic (SNS) – branch of the ANS. The PNS and SNS antagonistically control one's baseline arousal levels, that is, the PNS inhibits arousal and is thereby responsible for lowering heart rate. The SNS, on the other hand, is responsible for "fight or flight" tendencies by increasing arousal, which results in a higher heart rate. Therefore, HR at rest gives insights into a person's baseline arousal level (Kavish et al., 2017).

Studies have demonstrated that those with higher HRV are more successful socioemotionally, such as, in establishing relationships of mutual understanding and engaging in cooperative behaviors (e.g., Beffara et al., 2016; Kok and Fredrickson, 2010; Lischke et al., 2018). Moreover, empathetic like traits and states, such as feeling compassionate towards others, are also more pronounced in those with higher HRV (e.g., Lischke et al., 2018; Stellar et al., 2015). In sum, the flexibility of the PNS (i.e., higher HRV) supports positive socioemotional functioning, such as the ability to understand and be compassionate. As CU traits are characterized by impaired socioemotional functioning – including deficits in empathy, and a lack of remorse and guilt – it has been suggested they are associated with an inflexible PNS resulting in lower HRV at rest (Wagner and Waller, 2020). Reduced PNS-functioning also means that the break on the "fight or flight" activity of the SNS is impaired (Oldenhof et al., 2019), which may result in a higher prevailing heart period (i.e., higher HR) at rest. Therefore, CU traits may be positively associated with heart rate at rest.

1.4. Impaired PNS functioning and the display of CU: The Neurovisceral Integration Model

To better understand how impaired PNS-functioning, as indexed by reduced HRV, may influence the display of CU traits, it is important to understand the biological structures that influence PNS-functioning. The Neurovisceral Integration Model (NIM) posits that certain executive brain areas (e.g., the prefrontal cortex), maintain inhibitory control over certain sub-cortical brain (e.g., the amygdala), which collectively regulate ANS activity (Thayer and Lane, 2000; Williams et al., 2015). The same brain areas that influence ANS-functioning are in control over the socioemotional processes that are of interest to the display of CU traits (Wagner and Waller, 2020). Therefore, HRV is not solely an indicator of heart functioning – or even of PNS-functioning – but also as an index of how well the brain-heart interactive system functions to carry out socioemotional processes (Thayer and Lane, 2000; Wagner and Waller, 2020; Williams et al., 2015).

Based on the NIM, reduced PNS-functioning reflects the diminished control of executive brain structures that are essential to successful socioemotional regulation and functioning (Wagner and Waller, 2020; Williams et al., 2015). When there is less top-down control, a person may have less resources available to adapt to the alternating socioemotional demands of the environment (Wagner and Waller, 2020). In line with the NIM, CU traits have been associated with decreased top-down control over brain areas that are essential for ANS-activity. For example, hyporeactivity has been observed in brain areas of those with high CU traits when processing social cues (e.g., Lozier et al., 2014), imagining others' feelings (e.g., Sethi et al., 2018), and witnessing people experience pain (e.g., Lockwood et al., 2013) – all essential for the development of empathy (Wagner and Waller, 2020). Reduced activity in these brain areas, can result in less top-down control over ANS-activity, as evidenced by impaired control of the PNS over cardiac markers (i.e., reduced HRV, increased HR). As a result, reduced HRV can been seen as an indicator of impaired top-down-control of brain-heart mechanisms (Williams et al., 2015), which can underlie the socioemotional difficulties associated with CU traits (Wagner and Waller, 2020).

1.5. Previous research on relationship between HRV, HR, and CU traits

Interestingly, few studies have examined the association between cardiac markers and CU traits directly, in particular the relationship between HRV and CU traits remains understudied as demonstrated by a recent review (i.e., Wagner and Waller, 2020). Of the studies that have been conducted, some have indeed found reduced HRV at rest to be related to elevated CU levels in community samples of children (e.g., Mills-Koonce et al., 2015; Thomson and Centifanti, 2018); also in a clinical sample of male adolescents with disruptive behavior disorder, HRV at rest was found to be significantly lower in those with high CU traits (De Wied et al., 2012). However, the opposite pattern has also been observed. For example, some other studies with community samples found greater autonomic control (i.e., higher HRV) to be associated with higher levels of CU in children (Gao et al., 2017) and affective psychopathy in adults (Thomson et al., 2019b); also in a small clinical sample of adult detainees Hansen et al. (2007) found higher HRV to be positively correlated with the affective dimension of psychopathy (i.e., CU traits are considered to tap into this; Dotterer et al., 2019). More recently, in a large European sample of adolescents with conduct disorder (Oldenhof et al., 2019; Prätzlich et al., 2019), no relationship was found between CU and HRV.

The findings on the relationship between baseline HR and CU traits are similarly contradicting, with some finding lower arousal at rest (i.e., lower HR at rest) to be associated with higher levels of CU in community samples (Fanti et al., 2017; Gao et al., 2017; Kavish et al., 2017; Kavish et al., 2019b), whereas others have found no association in community (Kavish et al., 2019a; Raine et al., 2014) and clinical or detained samples across age groups (De Wied et al., 2012; MacDougall et al., 2019).

In sum, it remains unclear to what extent basal HRV and HR can be used as physiological indicators of CU. Some of the conflicting findings may be explained by the lower average and less varied levels of CU traits found in community samples (Kavish et al., 2019a). However, as demonstrated, the few studies that have been conducted on clinical or detained samples with higher levels of CU traits also report discrepant findings. In addition, the assessments used to measure CU-traits also differed between studies. Most used (short) subscales of rater-based (e.g., Hansen et al., 2007) or self-report instruments (e.g., Anastassiou-Hadjicharalambous & Warden, 2008), whereas some others measured CU-traits more extensively (e.g., Kavish et al., 2017; Kavish et al., 2019a). It has been suggested that especially the short subscales of self-report instruments measuring CU-traits have been hampered by low internal consistency (Kimonis et al., 2016), which could have given rise to disparate findings. Another factor that may have played a role in conflicting findings is the age of participants. Already in 2001 it was demonstrated in an overview study how developmental stage can have an influence on – and even turn the direction of – psychophysiological relationships (Beauchaine, 2001).

A final design factor that may have influenced the disparate findings is that most studies that did find a relationship between cardiac activity and CU traits, in clinical, forensic, and community samples, only did so in bivariate models (Anastassiou-Hadjicharalambous and Warden, 2008; De Wied et al., 2012; Fanti et al., 2017; Gao et al., 2017; Hansen et al., 2007; Kavish et al., 2017; Prätzlich et al., 2019; Thomson et al., 2019b). Only few studies, examined – and controlled for – the potentially confounding role of (demographic) factors (Kavish et al., 2019b; Prätzlich et al., 2019). For example, the role of gender was rarely examined, even though some studies have found that it moderates the relationship between cardiac markers and CU traits (e.g., only a relationship in males was found; Kavish et al., 2017). In conclusion, differences in study design and sample characteristics could have resulted in discrepant findings. Future research is needed that explores the role of demographic and lifestyle factors on the relationship between cardiac markers and CU traits.

1.6. The added value of the investigation of biomarkers for CU traits

Despite the importance of CU traits in the negative trajectory of criminal pathways, much remains unclear about the physiological correlates of CU. Overall, the conceptualization of CU traits has relied upon the assessment of emotional and behavioral symptoms, similarly to other mental health issues. Studying the relationship between cardiac markers and CU traits can help isolate neurophysiological processes of CU traits (e.g., brain-HRV-CU mechanisms), which can help inform etiological models (e.g., Wagner and Waller, 2020). As stated, researching cardiac markers – in particular HRV (i.e., PNS functioning) – is seen as important as they give insight into top-down regulatory processes that play a key role in the socioemotional impairments associated with CU-traits (Wagner and Waller, 2020). Especially in "real-life" context, such as prison, the assessment of cardiac markers is seen as an affordable, easily accessible method that can provide insight into (neuro)physiological underpinnings of CU traits in a more ecologically valid, and potentially generalizable way (Wagner and Waller, 2020).

Ultimately, it is believed that research on the relation between PNS functioning and CU traits, could help inform the development of treatment interventions that aim to target mechanisms that underlie CU-traits (Wagner and Waller, 2020). In general, studying the core biological mechanisms that are disrupted in different forms of psychopathology has been encouraged (see the Research Domain Criteria) with the goal of improving diagnostic systems and treatment (Beauchaine and Thayer, 2015; Insel et al., 2010). Although the search for "biomarkers" of mental health problems is still in its infancy, the addition of physiological data to behavioral assessments has already been helpful in some cases. For example, adding physiological data to behavioral assessments enabled the identification of subtypes of antisocial behavior (e.g., Fanti, 2018) and improved the risk assessments of incarcerated juveniles (de Ruigh et al., 2021).

1.7. The present study

As summarized above, cardiac markers – in particular HRV – are seen as valuable indices to assess, as they give insight into pathways that underlie the socioemotional difficulties of CU traits (Wagner and Waller, 2020). There are conflicting results surrounding HR and HRV as physiological markers of CU and thus, it is unclear to what extent impaired PNS functioning is associated with CU traits. More research is needed that accounts for the influence of potential covariates, including demographic (e.g., age) and lifestyle factors (e.g., smoking) that may influence the relationship between cardiac markers and CU traits (Portnoy and Farrington, 2015; Prätzlich et al., 2019). Therefore, the aim of the current study was to investigate the association between physiological markers (HR, HRV) and CU in a large sample of detainees, while considering cardiac covariates, and using a validated measure to assess CU traits (Cardinale and Marsh, 2020). We hypothesized that CU traits may be associated with impaired PNS functioning (i.e., lower HRV at rest) due to core socioemotional impairments (i.e., lack of affective empathy, feelings of guilt/remorse) that characterize these traits, in line with neuroimaging research (Wagner and Waller, 2020). As reduced PNS-functioning may also HR at rest, we hypothesized CU traits may be positively associated with baseline HR. To our knowledge, this is the first study focusing on HR, HRV and CU in a large detained sample including offenders of all age groups (juvenile and adults), which is rarely the case in psychophysiology studies of psychopathy (Lorber, 2004). To account for the influence of developmental stage (e.g., Beauchaine, 2001), juvenile and adult offenders were examined separately, which is imperative as it may explain some aforementioned inconsistencies in the literature. Study findings will help to shed light on the usability of HR and HRV as physiological correlates of CU traits in the detained population. Given the importance of CU traits for the course of antisocial behavior in offenders, a clearer and more complete picture on how HR and HRV are related to CU is needed, as it may ultimately help illuminate developmental pathways, improve diagnostic systems, and aid the development of more effective treatment (Beauchaine and Thayer, 2015; Fanti, 2018; Insel et al., 2010).

2. Methods and materials

2.1. Participants

Participants in the current study were male detainees who were part of a longitudinal study to assess the effectiveness of a dog training program offered at correctional facilities in the Netherlands (Schenk et al., 2018). For the present study, baseline (pre-intervention) data were used of 190 of the 207 male participants. The 17 excluded participants (8%) did not consent to the ECG ($n = 4$), did not attend the baseline assessment due to sanction, which required him to stay in isolation ($n = 1$), were excluded due to technical issues (e.g., broken electrode; program failure to record stimuli times correctly; $n = 10$), or did not complete the CU assessment ($n = 2$).

For offenders who are between 18 and 23-years-old, Dutch law dictates that the judge decides whether an offender is placed in a juvenile or adult facility based on an offenders' psychosocial maturity, as assessed by a forensic behavioral expert. This type of age categorization is also supported by research that demonstrates how psychosocial development can continue beyond adolescence until around the mid-20s (e.g., Monahan et al., 2013). For the current study, we followed this assessment and assigned 18–23-years-old offenders to the juvenile or adult group depending on the decision of the court. As a result, of the 190 participants, 82 were juvenile offenders, whereas the 108 other participants were adult offenders.

The correctional facilities of the present study have a standard level of security in the Netherlands, which means that incarcerated people stay in closed – and secured – facilities, which are isolated from society. Inside the facilities they follow a strictly regulated program. At set times visitors, who have undergone a security check, can be received. The "standard" security level distinguishes itself from lower levels of security, where incarcerated people go on regular leave (usually towards the end of their sentence), and higher levels of security where there is very little freedom and more security for those who are of high risk to fleeting or society (e.g., terrorists). Baseline data were obtained between 2017 and 2019. Table 1 includes participants' background characteristics in terms of age, incarceration time, type of offense committed, ethnical and educational background, and the presence (or absence) of psychiatric diagnoses, obtained from case files.

Table 1
Participants' demographic information.

	Juveniles		Adults	
	N	Mean (range; sd)	*N*	Mean (range; sd)
Age	78	19.2 (14.9–25.5; 2.1)	103	38.7 (18.5–73.2; 12.1)
Incarceration in years	47	0.7 (0.0–2.4; 0.7)	87	0.1 (1.7–14.6; 2.3)
	N	%	*N*	%
Type of offense[a]				
(Attempted) homicide	6	7.7	18	17.5
Violent behavior	24	30.8	39	37.9
Theft or fraud	3	3.8	12	11.7
Sexual offenses	9	11.5	10	9.7
Drug related crime	–	–	7	6.8
Other & unknown	36	46.2	17	16.5
Offense category[b]				
Single	10	12.8	41	44.7
Mix	33	42.3	46	39.8
Unknown	35	44.9	16	15.5
Ethnical background				
Western immigrant or native Dutch	33	42.3	62.0	60.2
Non-Western immigrant	42	53.8	33.0	32.0
Unknown	3	3.8	8	7.8
Educational background				
None or primary education	4	5.1	7	6.8
Secondary education	32	41.0	38	36.9
Tertiary education: lower track	22	28.2	37	35.9
Tertiary education: higher track	1	1.3	9	8.7
Other or unknown	19	24.4	12	11.7
Psychiatric diagnosis				
Yes	38	48.7	53.0	51.5
No	7	9.0	16.0	15.5
Unknown	33	42.3	34.0	33.0

Note. sd = standard deviation.
[a] Type of offense = Categorization based on conviction for most severe crime.
[b] Offense category = offense category – single = individual is currently serving sentence based on a single offense, offense category – mix = individual is currently serving sentence based on multiple offenses.

2.2. Procedure

Ethical approval for this study was obtained before the start of data collection from the Ethical Committee of the Faculty of Social and Behavioral Sciences of the University of Amsterdam (No. 2015-CDE-6363). Participation in the study was voluntary. Research participants were informed on the purpose and content of the study prior to signing the informed consent form. The assessments took place in a private room at the residing correctional facilities, in the presence of one or two trained research assistants. The baseline assessment, consisting of a battery of questionnaires and tests, was performed prior to the start of the intervention and lasted for approximately 60–90 min. Upon completion of the assessment, participants received a small stipend for their contribution in the form of a gift for a maximum of 5 Euros (e.g., shower gel, candy, shop credit for prison store).

2.3. Measures

2.3.1. Callous-Unemotional traits (CU)

CU-traits were assessed using the Dutch version of the Inventory of Callous-Unemotional traits (ICU; Frick, 2004). This self-report scale consists of 24-items, to be answered on a 4-point Likert scale ranging from 0 (*not at all true*) to 3 (*definitely true*), loading onto a general *callous-unemotional* trait factor to provide a total score of CU traits. In line with the recommendation of Ray et al. (2016), only the ICU total score was used for the current study. This total score includes items on all CU dimensions (i.e., callousness, uncaring, unemotional); Frick, 2004). Higher total scores indicate a greater level of CU traits. Psychometric properties of the ICU include good construct and convergent validity, adequate internal consistency, and good test-retest stability in community and institutionalized samples (Feilhauer et al., 2012; Pihet et al., 2015). In the current sample, Cronbach's α for CU was 0.766 for the adult group, and 0.828 for the youth group, indicating good overall internal consistency.

2.3.2. ANS functioning

Cardiac activity data were recorded during the entire assessment via a customized portable amplifier (University of Amsterdam, 2014) with a 1GΩ input resistance and a bandwidth of 0.1 Hz (6 dB/oct) to 250 Hz (24 dB/oct) containing a National Instruments NI-USB6210 A/D converter to digitize the analogue data at a rate of 1000 samples per second (S/s). We used disposable pre-gelled Ag/AgCl 3 M Red Dot electrodes. For the electrocardiogram (ECG), two electrodes were placed just below the left- and right clavicle; a third electrode was placed just below the left rib cage in LEAD-II configuration. The program Vsrrp98 was used to record and analyze the data (Vsrrp98 v11, University of Amsterdam, 1998–2018). For the present study, resting HR and (parasympathetically mediated) HRV were determined based on the cardiac activity recorded across the entire duration of a three-minutes long aquatic film clip. The film clip of underwater sea-life was chosen as previous research identified it as being successful at achieving cardiovascular baseline levels (Piferi et al., 2000). Participants watched the film clip at the beginning of the assessment, after they had become accustomed to the research setting and filled in some questionnaires.

HR in beats per minute was extracted from the inter beat intervals (i.e., time (ms) in between the R-spikes of successive cardiac cycles) during the three-minutes aquatic video clip. HRV – the variation in time (ms) between the R-spikes of successive cardiac cycles – was also calculated based on inter beat intervals (IBI). IBI's were subtracted from the ECG recordings, using Vsrrp98 software, and data files containing IBI were subsequently imported into the Kubios HRV Premium program (version 3.2; Tarvainen et al., 2019). Artifacts (i.e., missed, extra, and misaligned beats, ectopic beats) were visually detected in the IBIs and a correction filter was applied to remove the artifacts as they can distort accurate HR and HRV measurements (Shaffer and Ginsberg, 2017). The filter compared each IBI against a local mean; beats were identified as artifacts if a specific threshold was exceeded. Next, Root Mean Square of Successive Differences (RMSSD) and High Frequency (HF) HRV (0.15–0.4 Hz) were extracted. RMSSD is a recommended time domain measure and HF HRV a recommended frequency-based power spectral measure of parasympathetic nervous system (PNS) activity (Thayer et al., 2010). RMSSD (ms) and HF HRV (ms^2) values were imported into Statistic Package of Social Sciences (SPSS) and log-transformed before the analyses were conducted; the right skewed distribution became close to normal. RMSSD and HF HRV values correlated highly in the current samples (0.978, $p < .001$) therefore, only HF HRV values are reported.

2.3.3. Cardiac covariates

At the start of the assessment, participants answered questions about their health (e.g., average physical activity), average caffeine intake, drug and medication use (i.e., smoking, prescribed medications), as these factors have been found to co-vary with cardiac activity (see e.g., Alvares et al., 2016; Antelmi et al., 2004; Hill et al., 2015; Hu et al., 2017; Koenig, 2014). Finally, respiration frequency was also examined as a potential covariate. There is much debate on the influence of the inhalation-to-exhalation pace on HRV and on whether this respiration rate should be controlled for in HRV measurements (Grossman et al., 1991; Shaffer and Ginsberg, 2017).

2.3.4. Lifestyle covariates

2.3.4.1. Physical activity. Participants' level of physical activity was assessed by asking them how many hours (on average) per week they engaged in sports.

2.3.4.2. Smoking. Smoking behavior was assessed by asking participants how many cigarettes they had smoked the hour prior to the assessment. For the analysis, a dichotomous variable was created (0 = *smoked*; 1 = *not smoked*).

2.3.4.3. Caffeine intake. Caffeine intake was assessed by asking participants how many caffeine-containing drinks they consumed in the past 24 h.

2.3.4.4. Medication use. Participants were asked if and what kind of medication they took. For the analysis, a dichotomous variable was created (0 = *not medicated*; 1 = *medicated*).

2.3.4.5. Drug use. Participants were asked whether they had used drugs (e.g., marijuana, stimulants, opiates, hallucinogens) in the past 24-h, a dichotomous variable was created based on this information (0 = *no drugs used*; 1 = *drugs used*).

2.3.4.6. Respiration frequency. High-frequency (HF) peak values of the ECG measurement, as a measure of respiration frequency, were derived from the autoregressive analysis in Kubios (Thayer et al., 2002).

2.3.5. Demographic covariates

2.3.5.1. Ethnicity. As part of the battery of questionnaires, participants were asked where they – and their parents – were born. For the analysis, a dichotomous variable was created (0 = *participant and participant's parents are born in the Netherlands or another Western country* and 1 = *participant and/or participant's parents are non-Western immigrants*).

2.3.5.2. Age. Participants were asked to report their date of birth. Age was calculated based on the participants' date of birth and the date of the assessment.

2.4. Data analysis

First, outliers (i.e., values more than 1.5 interquartile ranges above the 75% upper quartile) were removed based on box plot analyses, resulting in the removal of 9 outliers overall (e.g., Sun et al., 2020). For descriptive purposes, means and standard deviations were calculated for all continuous variables of the final sample of juvenile ($N = 78$) and adult ($N = 103$) offenders. In addition, juvenile and adult participants were compared on relevant variables by conducting one way ANOVA's and Chi Square Tests. We then investigated the relationship between HR, HRV, CU, and potential correlates of cardiac activity (i.e., ethnicity, age, level of physical activity, smoking habits, caffeine, medication) by examining Pearson's and Spearman's bivariate correlations.

To examine the association between HR, HRV, and CU, multiple hierarchical regression tests were conducted with CU as outcome variable. To account for the influence of developmental stage (e.g., Beauchaine, 2001), juvenile and adult offenders were examined separately. Assumptions for the regression analyses (i.e., linearity, homoscedasticity, independence, and normality) were checked before conducting the tests. The lifestyle and demographic factors that significantly correlated with HR or HRV (bivariate correlations, see Table 3) were added in step 1 of the respective regression models, to control for their potential influence. Step 2 included HR or the log transformed HF HRV (i.e., LnHF HRV) as predictor of CU to assess to what extent HR or HRV predicted the specific CU outcome, while accounting for cardiac covariates. All of the above analyses were performed using the IBM SPSS statistical software program, version 25.

Table 2
Mean and sd of variables.

	Juveniles ($N = 78$)		Adults ($N = 103$)		F
	Mean (range)	SD	Mean (range)	SD	
LnRMSSD	1.7 (1.0–2.3)	0.2	1.4 (0.5–2.2)	0.4	41.429***
LnHF-HRV	6.7 (4.0–9.1)	1.0	5.2 (1.0–9.2)	1.7	48.395***
HF-HRV	37.0 (10.9–76.9)	14.6	26.5 (3.3–76.8)	17.0	19.112***
HR	71.9 (43.9–105.5)	11.8	73.5 (44.1–115.5)	11.7	1.707
Physical activity	5.0 (0.0–21.0)	3.6	4.8 (0.0–42.0)	6.6	0.071
Caffeine	3.4 (0.0–30.0)	4.7	5.4 (0.0–20.0)	4.0	10.097**
Respiration freq	0.25 (0.15–0.38)	0.07	0.25 (0.15–0.39)	0.07	0.012
CU	28.1 (10.0–48.0)	8.3	23.6 (11.0–38.0)	6.2	17.614***
	%	*n*	%	*n*	X^2
Smoking					18.380***
Yes	35.9	28	68.0	70	
No	64.1	50	32.0	33	
Medication use					30.195***
Yes	30.8	24	67.0	69	
No	69.2	54	25.2	26	
Unknown	–	–	7.8	8	
Drug use[a]					7.529**
Yes	20.5	16	6.8	7	
No	79.5	62	93.2	96	

Note. LnRMSSD = log-transformed root mean squared differences, LnHF-HRV = log-transformed high frequency heart rate variability, Hz = Hertz, HR = mean heart rate, CU = callous-unemotional traits, Respiration freq = respiration frequency.

[a] Drug use = drug-using participants only reported marijuana use in the past 24-h.

3. Results

Descriptive statistics can be found in Table 2. Pearson and Spearman (when one of the variables was dichotomous) correlations are presented in Table 3 and below. For juveniles, the following lifestyle and demographic factors were associated with HR, physical activity ($r = -0.248$, $p = .028$) and drug use (-0.288, $p = .011$). For HRV: ethnicity ($r = 0.294$, $p = .010$), caffeine ($r = 0.233$, $p = .040$), and drug use ($r = 0.212$, $p = .063$) were cardiac covariates. For adults, HR was only correlated with the demographic factors of age ($r = 0.234$*, $p = .017$) and ethnicity ($r = -0.271$, $p = .035$). In addition to age ($r = -0.541$, $p < .001$) and ethnicity ($r = 0.406$, $p < .001$), HRV was also correlated with medication use ($r = -0.206$, $p = .045$). As expected, HRV and HR were inversely correlated in juveniles ($r = .\text{-}632$, $p < .001$) and adults ($r = -0.710$, $p < .001$). Finally, HR and CU were not significantly correlated for juveniles ($r = 0.158$, $p = .167$) and adults ($r = -0.055$, $p = .580$), whereas HRV and CU were also not significantly correlated for juveniles ($r = -0.118$, $p = .305$) and adults ($r = 0.017$, $p = .865$).

3.1. HR

The results of the regression analyses demonstrated that HR at rest was positively associated with CU in juvenile offenders ($\beta = 0.231$, $p = .05$; partial $r = 0.222$, $p = .05$). There was no association between baseline HR and CU in adult offenders. Model results are reported in Table 4, which include the standardized regression coefficients for the independent variables at step one and two.

3.2. HRV

The results of the regression analyses demonstrated that LnHF-HRV was negatively associated with CU in juvenile offenders ($\beta = -0.247$, $p = .049$; partial $r = -0.300$, $p = .010$). Baseline LnHF-HRV was not associated with CU in adult offenders. Model results are presented in Table 5, including the standardized regression coefficients for the independent variables at step one and two.

4. Discussion

The purpose of the current study was to examine the association between baseline HR, HRV, and CU in incarcerated juvenile and adult males, to gain insight into underlying socioemotional regulation difficulties. Thereby, contributing to the knowledge on biological mechanisms associated with CU traits. The aspiration is that this knowledge will eventually help isolate neurophysiological processes of CU traits, which can help inform etiological models and aid the development of interventions that target underlying CU-mechanisms (Wagner and Waller, 2020). Results demonstrated that impaired autonomic cardiac activity as associated with CU in juveniles. There was a small yet significant positive relationship in juvenile offenders between HR and CU, and a negative relationship between HRV and CU. Interestingly, no relationship between cardiac markers and CU was found in incarcerated adults. These findings suggest that for incarcerated juveniles, socioemotional CU trait deficits (e.g., low empathy, low prosociality, and remorseless behaviors) are associated with an inflexible PNS, as evidence by reduced HRV, which is indicative of impairments in the ability to quickly adjust emotional and behavioral processes that are necessary to function successfully in a social world (e.g., Appelhans and Luecken, 2006; Lischke et al., 2018). As suggested by the NIM, there is impaired “top-down” vagal control, which interferes with successful emotional and behavioral regulation (Porges, 2007; Thayer and Lane, 2000; Williams et al., 2015). Put differently, the negative association between HRV and CU traits demonstrates that those juveniles with high CU traits appear to have less resources available at baseline to navigate social and emotional demands of the environment (Wagner and Waller, 2020). The prevailing higher HR at rest – in relation to CU traits – is likely due to the lower PNS activity, as this is marked by higher HR.

CU traits play an important role in the course of antisocial behavior, and little research has been conducted on the relationship between CU traits and cardiac markers in incarcerated people. These findings illustrate the importance of considering physiological correlates of CU traits in the juvenile population in prison and confirm previous research that illustrated socioemotional difficulties of those with higher CU levels (Frick and White, 2008). Importantly, our findings highlight the importance of considering juvenile versus adult offenders, as the association between CU traits and both resting HR and HRV may differ between these groups.

The results in incarcerated juveniles, demonstrating that socioemotional impairments of CU traits are associated with reduced HRV and heightened HR, are in line with some previous research. For example, elevated CU traits have previously been associated with reduced HRV at rest in male adolescents with disruptive behavioral problems (De Wied et al., 2012; Mills-Koonce et al., 2015; Thomson and Centifanti, 2018; Wagner and Waller, 2020). In addition, Lischke et al. (2018) found that better socioemotional functioning – as indicated by higher levels of empathy – was associated with higher HRV at rest in a sample of male students; others have found similar associations (e.g., Miller et al., 2009; Stellar et al., 2015). On the other hand, no relationship between cardiac markers and CU related constructs (e.g., Prätzlich et al., 2019), or even opposite activity patterns (e.g., Gao et al., 2017) have also been found, perhaps due to diverging design choices.

In the incarcerated adult offenders of this study, no relationship was

Table 3
Correlation matrix of HRV, HR, lifestyle and demographic factors - juvenile offenders (N = 78) below diagonal, adult offenders (N = 103) above diagonal.

	1	2	3	4	5	6	7	8	9	10	11
1. HRV	–	−0.710**	0.052	−0.541**	0.406**	−0.120	−0.001	0.057	−0.206*	0.066	0.017
2. HR	−0.632**	–	−0.086	0.234*	−0.217*	0.125	−0.050	−0.102	0.194	−0.008	−0.055
3. Resp	0.177	−0.030	–	0.018	0.127	−0.106	0.010	−0.186	0.003	−0.092	0.106
4. Age	−0.002	−0.064	−0.051	–	−0.334**	0.017	0.282**	−0.168	0.139	−0.211*	−0.131
5. Eth	0.294*	−0.086	−0.049	−0.217	–	−0.182	0.041	0.149	−0.316**	0.026	0.099
6. Caf	0.233*	−0.148	0.056	0.188	−0.109	–	−0.170	−0.098	0.083	−0.079	−0.056
7. Smok	0.027	−0.179	−0.142	0.015	−0.025	−0.290**	–	−0.077	0.083	−0.079	−0.075
8. PA	0.111	−0.248*	0.003	0.171	0.196	−0.091	0.154	–	−0.084	0.088	−0.108
9. Meds	−0.052	0.127	0.067	0.236*	−0.083	0.168	−0.196	−0.228*	–	−0.098	−0.019
10. Drugs	0.212^	−0.288*	0.019	−0.031	0.080	0.271*	−0.149	0.185	−0.132	–	0.188
11. CU	−0.118	0.158	−0.151	0.027	0.060	0.051	−0.122	0.084	−0.099	0.246*	–

Note. Pearson Correlations. Spearman correlations are reported when one of the variables is dichotomous. HRV = log-transformed high frequency heart rate variability, HR = mean heart rate (beats per minute), Resp (Hz) = respiration (Hertz), Eth = ethnicity (Western versus Non-Western), Caf = caffeine, Smok = smoking, PA = physical activity, Meds = medication, CU = callous-unemotional traits, Emp = empathy.

^ $p < .10$.

* $p < .05$.

** $p < .01$.

Table 4
Summary per step of multiple hierarchical regression juveniles and adults - HR.

Model	Juveniles (N = 80) - CU					Adults (N = 98) - CU			
	β	R^2	ΔR^2	F		β	R^2	ΔR^2	F
Step 1		0.069	–	2.868	Step 1		0.026	–	2.578
Physical activity	0.046				Age	−0.162			
Drugs	**0.254***								
Step 2		0.115	0.046^	**3.304***	Step 2		0.026	0.000	1.278
Physical activity	0.101				Age	−0.160			
Drugs	**0.314***				HR	−0.007			
HR	**0.231***								

Note. CU = callous-unemotional traits, HR = heart rate, 2 outliers were removed for the youth analyses, 10 outliers were removed for the adult analyses; physical activity = *amount of hours per week*; drugs = *no drugs used* (0), *drugs used* (1).

Table 5
Summary per step of multiple hierarchical regression juveniles and adults– HRV.

Model	Juveniles (N = 78) - CU			F		Adults (N = 103) - CU			F
	β	R^2	ΔR^2			β	R^2	ΔR^2	
Step 1		0.076	–	1.939	Step 1		0.020	–	0.556
Ethnicity	0.075				Age	−0.115			
Caffeine	0.022				Ethnicity	0.057			
Drugs	**0.256***				Medication	0.017			
Step 2		0.126	**0.050***	**2.516***	Step 2		0.027	0.007	0.559
Ethnicity	0.148				Age	−0.161			
Caffeine	0.079				Ethnicity	0.084			
Drugs	**0.298***				Medication	0.012			
LnHF-HRV	**−0.247***				LnHF-HRV	−0.104			

Note. CU = callous-unemotional traits, LnHF-HRV = log-transformed high frequency heart rate variability, 4 outliers were removed for the youth analyses, 5 outliers were removed for the adult analyses; ethnicity = participant and participant's parents born in the Netherlands or another Western country (0), participant and/or participant's parents are non-Western immigrants (1); caffeine = amount of caffeine-containing drinks consumed in the past 24 h; drugs = no drugs used (0), drugs used (1).

* $p < .05$.

found between CU and cardiac markers at rest. In general, research on the relationship between PNS-functioning and psychopathy in adults is lacking (Thomson, 2019, p.87). In a small sample of incarcerated males, higher HRV at rest was associated with the affective psychopathy facet. A positive relationship between HRV at rest and affective psychopathy was also found in a sample of women (Thomson et al., 2019b). However, when controlling for age, gender, and race, a negative relationship between HR and cold-heartedness in adults in the community dissappeared (Kavish et al., 2019b). In the current study, there was no relationship between cardiac markers and CU traits with or without the consideration of confounding factors. It is unclear to what extent the current null results differ from previous adult research due to diverging design choices (e.g., use of different assessment methods to measure CU, sample make-up) – or because the relationship between cardiac markers and CU traits is perhaps only present in juveniles. To our knowledge, no studies have directly compared the association between CU-type constructs and cardiac markers in juvenile and adult participants and longitudinal research designs investigating this topic are also scarce. Interestingly, some studies that compared juveniles and adults in other types of psychophysiological relationships, also found stronger evidence for such an association in youth. For example, Gold and Assmus (2015) reported a relationship between psychological constructs and cardiac markers in younger adult prisoners, but failed to find such a relationship in older adult detainees. Another longitudinal study on the relationship between HR at rest and delinquency, found a relationship in mid-adolescence but not in adulthood (Hammerton et al., 2018). Finally, in a recent review study on the relationship between antisocial behavior and HR, it was suggested that most evidence from previous research was found in juvenile samples (Portnoy and Farrington, 2015). Together, these results demonstrate the importance of conducting longitudinal research, and to more generally consider the role of age, in psychophysiological relationships (Beauchaine, 2001; Gold and Assmus, 2015; Wagner and Waller, 2020).

Recently, Caldwell and colleagues (2019) suggested that physiological impairments may only be present at high levels of CU based on an examination of the brain correlates of CU dimensions in incarcerated adolescents. In the subgroup that was characterized by high CU traits, they found the strongest structural impairments in brain regions related to cardiac control. For exploratory purposes, we therefore compared the CU levels for juveniles and adults in the current study. Results of the one-way ANOVA test (F = 17.614, p < .000) indicated that CU levels of the incarcerated juveniles (M = 28.1) were significantly higher than that of their adult counterparts (M = 23.6). If physiological impairments are only present at higher levels of CU, this may explain why a relationship was found between cardiac markers and CU in the incarcerated adolescents and not in the adults. On the other hand, differences in CU levels between juveniles and adults could also be explained by the use of the ICU, which was originally developed for assessment in youth (Feilhauer et al., 2012; Pihet et al., 2015). Even though some evidence exists supporting the ICU's use in younger adults (e.g., Byrd et al., 2013; Kimonis et al., 2013) and studies find adolescent and adult psychopathy to be similar (Kyranides et al., 2017; Lynam and Gudonis, 2005), the applicability of the ICU for the adult population is unknown and caution is warranted in interpreting the adult findings.

Current findings in juvenile and adult participants could be interpreted as being in contrast with the Low Arousal Theory as a positive relationship was found between HR and CU in juveniles, and no relationship was found in adults. Even though this theory aims to explain the relationship between physiological arousal and antisocial behavior, it has been suggested that this theory can also be applied to psychopathy as well, as this construct is also characterized by extreme risk-taking, stimulation-seeking, and under-arousal (Thomson, 2019). However, psychopathy is a more dimensional construct with affective and behavioral features; Low Arousal Theory may be more applicable to the behavioral facets (Thomson, 2019). In general, the conclusions that can be drawn about current HR-CU findings are limited – compared to the HRV-CU findings – because HR at rest lacks "system-specific specificity" (p.179, Wagner and Waller, 2020). This is because baseline HR is influenced by both the PNS and the SNS; therefore it cannot be related to core neurological regulatory mechanisms (Wagner and Waller, 2020).

There are several strengths associated with the current study. One strength is the inclusion of one of the largest samples of a study on the relationship between CU-HRV, and CU-HR, in detainees. Another strength is that the role of potential cardiac covariates was explored, and that influential demographic and lifestyle factors were included in the analyses. Over the years, there has been a push to integrate autonomic activity measures more routinely in criminological research to help advance the development of integrative, biopsychosocial theories on the etiology of psychopathy (e.g., Choy et al., 2015). Some prominent theories that have been used to explain the relationship between HR and antisocial behavior constructs (i.e., Fearlessness theory; Stimulation-seeking theory; Quay, 1965; Raine, 2002) have been criticized more recently for lacking supporting evidence (e.g., Gillespie et al., 2018). Overall, reliable theory development seems to have been hindered by contradicting results; this may have been a consequence of diverging design choices. For example, a recent meta-analysis found that 80% of previous research on the relationship between HR and antisocial behavior has not examined the influence of potential cardiac covariates (Portnoy and Farrington, 2015), even though this can influence the relationship between cardiac markers and antisocial constructs. For example, low HR at rest is considered to be "the best replicated biological marker" of antisocial behavior (Portnoy and Farrington, 2015), however, HR and antisocial behavior were no longer related after accounting for age and smoking in a large sample of a recent study (Prätzlich et al., 2019). Also in the research reviewed for the current study, most studies did not consider or account for the role cardiac covariates might play in the relationship between CU constructs and cardiac markers (e.g., Gao et al., 2017; Mills-Koonce et al., 2015; Thayer et al., 2009; Thomson et al., 2019b). Finally, and as mentioned, studies have not reported such associations stratified by juvenile and adult offenders, making this a particularly important strength of the current investigation.

4.1. Limitations

Caution is warranted in extrapolating current study findings without considering its limitations. One limitation is that baseline HR and HRV were determined during only one three-minute-long film clip. Yet, even though multiple five minute recordings of cardiac activity are preferred to diminish the (potential) influence of measurement context, HF-HRV can be estimated based on three-minutes ECG's in a spontaneous breathing setting (Bertsch et al., 2012; Task Force of The European Society of Cardiology and The North American Society of Pacing and Electrophysiology, 1996). Vulnerable populations such as incarcerated offenders in highly secured settings are difficult to access; therefore, tradeoffs between what is feasible and ideal are unavoidable (e.g., Wakai et al., 2009).

Another general limitation is that when conducting research on detainees, it is difficult to control for comorbid psychopathology, such as trauma, that could influence the relationship between CU and HRV. One previous study found that incarcerated adolescents with adverse early life experience and CU traits had a unique physiological arousal profile, compared to those juveniles high on CU but without childhood trauma (Gostisha et al., 2014). Therefore, the potential influence of traumatic stress on the CU-HRV relationship should receive attention in future studies.

4.2. Future research

Overall, there is a need to replicate the current results in future research, preferably in an even larger sample. Due to aforementioned conflicting evidence, uncertainty may remain and more evidence is needed before more definitive conclusions can be drawn (Thomson et al., 2019a). To continue the investigation of (potential) physiological mechanisms underlying CU in the future, it is also important that the research conducted is more robust by accounting for cardiac and demographic covariates – to reduce the risk of finding spurious relationships. Furthermore, there has been a push for future studies to include ANS measures of both the parasympathetic as well as the sympathetic branch (e.g., pre-ejection period, electrodermal responding) under static and reactive conditions in order to get a better understanding of the association between ANS functioning and CU traits (e.g., Thomson, 2019). Impaired ANS functioning may be more prominent in reactive states. Therefore, examining the parasympathetic and sympathetic branches separately is important for understanding complex psychophysiological interactions (Prätzlich et al., 2019; Thomson, 2019). As CU-traits are characterized by socioemotional impairments, such as lack of empathy and social connectedness, it would be interesting to study ANS-reactivity in response to situations that aim to elicit behaviors of social affiliation, to enhance understanding of how physiological deficits relate to CU traits (Wagner and Waller, 2020). In addition, examining ANS-activity in relation to potentially different CU facets – if reliably measured – may also be an interesting endeavor for future research. The current study also underscores the need for future research to be conducted across age groups, and in community and clinical/forensic populations, because findings cannot simply be generalized across contexts. Already in 2001, Beauchaine demonstrated how the relationship between personality traits/behavior and HRV must be viewed in a developmental context, relative to normative and non-normative samples.

4.3. Conclusion

Only a handful of studies have been conducted on the relationship between CU and cardiac markers (particularly HRV) at rest, and even fewer have considered the impact of covariates. To our knowledge, our study is the first to investigate the association between CU traits and both basal HR and HRV in a relatively large – high risk – sample of detainees stratified by juvenile and adult offenders while controlling for important cardiac and demographic covariates. In conclusion, a small positive relationship was found between HR and CU, and a small negative relationship was found between HRV and CU in incarcerated juveniles; such associations were not evident in incarcerated adults. Therefore, our findings provide initial evidence that inflexible PNS-functioning (reduced HRV; e.g., Appelhans and Luecken, 2006; Lischke et al., 2018) is associated with impaired socioemotional functioning in incarcerated juveniles, as evidenced by higher CU traits. As long as robust psychophysiological research is limited, theory development will be hindered. Future research on markers of CU needs to be conducted in large samples, across populations and ANS states (reactive versus passive), while including cardiac covariates. Only then can research eventually provide more clarity on the interplay of biological systems and behavioral expression in this high-risk population.

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