Cortical structure in relation to empathy and psychopathy in 800 incarcerated men

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Abstract

Background. Reduced affective empathy is a hallmark of psychopathy, which incurs major interpersonal and societal costs. Advancing our neuroscientific understanding of this reduction and other psychopathic traits is crucial for improving their treatment.

Methods. In 804 incarcerated adult men, we administered the Perspective Taking (IRI-PT) and Empathic Concern (IRI-EC) subscales of the Interpersonal Reactivity Index, Hare Psychopathy Checklist-Revised (PCL-R; two factors), and T1-weighted MRI to quantify cortical thickness (CT) and surface area (SA). We also included the male sample of the Human Connectome Project (HCP; N = 501) to replicate patterns of macroscale structural organization.

Results. Factor 1 (Interpersonal/Affective) uniquely negatively related to IRI-EC, while Factor 2 (Lifestyle/Antisocial) uniquely negatively related to IRI-PT. Cortical structure did not relate to either IRI subscale, although there was effect-size differentiation by microstructural class and/or functional network. CT related to Factor 1 (mostly positively), SA related to both factors (only positively), and both cortical indices demonstrated out-of-sample predictive utility for Factor 1. The high-psychopathy group (N = 178) scored uniquely lower on IRI-EC while having increased SA (but not CT). Regionally, these SA increases localized primarily in the paralimbic class and somatomotor network, with meta-analytic task-based activations corroborating affective-sensory importance. High psychopathy also showed "compressed" global and/or network-level organization of both cortical indices, and this organization in the total sample replicated in HCP. All findings accounted for age, IQ, and/or total intracranial volume.

Conclusions. Psychopathy had negative relationships with affective empathy and positive relationships with paralimbic/somatomotor SA, highlighting the role of affect and sensation.

Brain structure | Empathy | Psychopathy | Multivariate prediction | Structural gradients | Antisocial population

Introduction

Empathy allows us to understand another person ("cognitive empathy") as well as to share their emotion and care for them ("affective/compassionate empathy") (Decety & Jackson, 2004; Zaki & Ochsner, 2012; Baron-Cohen et al., 2013; Decety, 2015a; Decety & Holvoet, 2021; Schurz et al., 2021). This distinction is important for studying psychopathy, where affective empathy is reduced most notably (Bird & Viding, 2014; Keysers & Gazzola, 2014; Decety et al., 2016; Lockwood, 2016; Burghart & Mier, 2022; Campos et al., 2022). Psychopathy is a constellation of interpersonal/affective traits (e.g. lack of attachment and remorse, beyond lack of empathy) and lifestyle/antisocial traits (e.g. impulsivity, parasitic lifestyle, criminal versatility), as operationalized by Factors 1 and 2, respectively, of the Hare Psychopathy Checklist-Revised (PCL-R; Hare, 1991; 2003; Hare & Neumann, 2008). Based on the PCL-R, the prevalence of psychopathy approximates 1.2% in the general population; it is higher in incarcerated samples (up to 25%) and in males/men compared to females/women (Beryl et al., 2014; De Brito et al., 2021a; Sanz-García et al., 2021). Because psychopathy incurs interpersonal and societal costs that reach hundreds of billions of USD per annum through violence, crime, and recidivism, we need a better neuroscientific understanding of this empathic reduction and other psychopathic traits to improve their treatment (Kiehl & Hoffman, 2011; Reidy et al., 2015; Viding & McCrory, 2019) and advance the broader antisocial literature (Tully et al., 2023).

Dispositional empathy, which is often measured with the Interpersonal Reactivity Index (IRI; Davis, 1983; de Lima & de Lima Osório, 2021; Briganti et al., 2024), has garnered substantial interest in psychology and neuroscience, although less so from a brain-structural perspective (with a meta-analysis still missing; for study examples, see Eres et al., 2015; Valk et al., 2017; Wu et al., 2023) than from a brain-functional one (for a cognitive, affective, and multidimensional paradigm, see e.g. Saxe & Kanwischer, 2003; Singer et al., 2004; Kanske et al., 2015; for meta-analyses, see e.g. Lamm et al., 2011; Diveica et al., 2021; Schurz et al., 2021). Across meta-analyses, cognitive empathy is associated with the medial prefrontal cortex, temporoparietal junction, and precuneus; affective empathy is associated with the insula, midcingulate cortex, and inferior frontal gyrus (while subcortical structures are further involved in the compassionate component; e.g. Singer & Klimecki, 2014). Cognitive empathy thus maps more closely onto the default-mode network while affective empathy onto the somatomotor and ventral-attention networks (Yeo et al., 2011; Shurz et al., 2021). Identifying such neurobiological mechanisms of empathy has been necessary for shedding light on reduced empathy in the psychopathic brain (Penagos-Corzo et al., 2022).

A growing body of literature on criminal male psychopathy suggests atypical functional processing in relation to empathy (Decety et al., 2013a; 2013b; Meffert et al., 2013; Decety et al., 2014; 2015b; Deming et al., 2020) that adds to general differences in brain function, including at the network level (e.g. Kiehl et al., 2001; Yoder et al., 2015; Hosking et al., 2017; Espinoza et al., 2018; Tillem et al., 2019; Nummenmaa et al., 2021; for meta-analyses, see Poeppl et al., 2019; Deming & Koenigs, 2020; Dugré & Potvin, 2021). These differences occur alongside structural differences, with most studies focusing on gray-matter volume (GMV) (Ly et al., 2012; Ermer et al., 2012; 2013; Baskin-Sommers et al., 2016; Korponay et al., 2017; Miskovich et al., 2018; for a meta-analysis across mixed community and incarcerated samples, see De Brito et al., 2021b), although the high heterogeneity of these differences is to be acknowledged, as their replicability is low (Deming et al., 2024). One conceptual attempt to explain psychopathy from a structural perspective concerns

paralimbic regions (Kiehl, 2006; for subsequent reviews, see Anderson & Kiehl, 2012; Pujol et al., 2019; Johanson et al., 2020). Having little laminar differentiation, these regions form a ring at the base of the cortex to cover some of the affective-empathy hubs (i.e. portions of the insula and cingulate cortex; Mesulam, 2000; Chanes & Barrett, 2016; García-Cabezas et al., 2019). Integrating microstructural (Mesulam, 2000) alongside macrofunctional (Yeo et al., 2011) information may thus offer additional insights into psychopathy and deficits in empathy.

The two PCL-R factors may differentially relate not only to empathy (Campos et al., 2022) but also GMV (De Brito et al., 2021b). Since cortical thickness (CT) and surface area (SA) contribute to GMV through largely independent genetic (Grasby et al., 2020) and developmental (Bethlehem et al., 2022) processes, they may also differentially relate to specific psychopathic traits. Furthermore, SA has been shown to be more sensitive than CT to broadly construed antisocial behavior in community (Carlisi et al., 2020) and mixed (Gao et al., 2024) samples. Acknowledging this cortical distinction is even more pressing given that SA has not yet been investigated in relation to psychopathy, to the best of our knowledge. This investigation could further benefit from a multivariate framework to enhance discovery and future replicability (Sui et al., 2020; Pauli & Lockwood, 2023; Makowski et al., 2024).

Finally, it remains unknown whether structural differences in psychopathy could extend from single regions to macroscale organization based on cortex-wide patterns of covariance (Paquola et al., 2019; Valk et al., 2020; Royer et al., 2023) – an opportunity to deepen our understanding beyond more traditional univariate and multivariate frameworks. There is meta-analytic evidence for CT "gradients" to differ across major psychiatric conditions in a transdiagnostic fashion (Opel et al., 2020; Hettwer et al., 2022; Park et al., 2022) that dovetails with differences along the primary axis of functional variability in autism (Hong et al., 2019), schizophrenia (Dong et al., 2023), or depression (Xia et al., 2022).

Here, we investigated CT and SA in relation to dispositional empathy and clinical psychopathy in 804 incarcerated adult men. We addressed five broad questions: Q1: How does psychopathy relate to empathy, given the multidimensionality of both constructs? Q2: How does cortical structure relate to empathy and psychopathic traits? Q3: Does cortical structure predict empathy and psychopathic traits in out-of-sample individuals? Q4: How does cortical structure differ by psychopathy group (i.e. high vs low psychopathy)? Q5: How does structural covariance differ by psychopathy group?

Methods and Materials

Participants

Out of 912 adult men (gender was self-reported) from correctional facilities in the southwest and midwest of the United States, we included N = 804 who sequentially met the following criteria: (1) passed MRI quality control ($N_{excluded}$ = 105; see below); (2) had available data on empathy, psychopathy, age, and IQ ($N_{excluded}$ = 1); and (3) had an IQ of at least 70 ($N_{excluded}$ = 2) (for participant characteristics, see *Table **1***). All participants gave written informed consent, and all research protocols were approved by the Institutional Review Board of the University of New Mexico or the Ethical and Independent Review Services for data collection post June 2015.

To replicate our findings on structural gradients, we included the male sample of the Human Connectome Project (HCP) Young Adult S1200 release with available structural-MRI and IQ data (N = 501; Van Essen et al., 2012; Glasser et al., 2013; Van Essen et al., 2013) (for participant characteristics, see *Supplementary Table **S1***). Note that this sample did not have our measures of empathy and psychopathy available.

Table 1. Participant characteristics

	Total	**Low psychopathy**	**High psychopathy**	Cohen's D, P
N	804	289	178	–
Age	33.78 ± 8.23	34.20 ± 8.51	33.69 ± 8.19	-0.06, 0.521
Range	[18.75, 62.83]	[18.75, 60.56]	[19.47, 62.83]	–
IQ	97.88 ± 13.14	98.56 ± 13.26	100.03 ± 12.68	0.11, 0.277
Range	[71, 137]	[72, 134]	[72, 137]	–
PCL-R	22.85 ± 7.06	15.15 ± 3.83	32.04 ± 1.96	5.19, 7e-74
Range	[3.20, 38]	[3.20, 20]	[30, 38]	–
PCL-R F1	7.90 ± 3.61	4.74 ± 2.58	12.14 ± 1.86	3.17, 2e-70
Range	[0, 16]	[0, 12]	[8, 16]	–
PCL-R F2	12.79 ± 4.01	8.97 ± 3.26	16.85 ± 1.89	2.80, 5e-68
Range	[1.10, 20]	[1.10, 17]	[11, 20]	–
Race (W)	534	225	100	3e-07
Substance use	21.63 ± 21	19.44 ± 19.81	22.34 ± 19.44	0.15, 0.022
Range	[0, 158]	[0, 107]	[0, 111]	–
Adj. substance use	7.01 ± 3.64	6.40 ± 3.74	7.43 ± 3.55	0.28, 0.008
Range	[0, 18.89]	[0, 15.19]	[0, 18.89]	–
TIV	1.58e+06 ± 1.5e+05	1.60e+06 ± 1.4e+05	1.58e+06 ± 1.6e+05	-0.13, 0.293
Range	[9.6e+05, 2.0e+06]	[1.1e+06, 2.0e+06]	[1.1e+06, 1.9e+06]	–
Euler no.	11.88 ± 4.95	12.20 ± 4.99	12.31 ± 5	0.02, 0.753
Range	[0, 24]	[3, 24]	[3, 23]	–

Note. Given are means and standard deviations (or frequencies for race) as well as Cohen's Ds for the high-psychopathy (PCL-R $\geq$ 30) vs low-psychopathy (PCL-R $\leq$ 20) groups, with P-values derived from Wilcoxon's rank-sum test (or Pearson's χ^2 test for race). IQ = full-scale IQ estimate based on the WAIS-III or WASI-II Vocabulary and Matrix Reasoning subtests (Wechsler, 1997; 2011); PCL-R = PCL-R total score; PCL-R F1 = Interpersonal/Affective factor score; PCL-R F2 = Lifestyle/Antisocial factor score (N = 778); Race (W) = White (vs non-White; N = 789); Substance use = total years of substance use based on the ASI

(McLellan et al., 1992; N = 748); Adj. substance use = age-corrected and square-root-transformed (to correct for opportunity to use and skewness) total years of substance use based on the ASI (N = 748); TIV = estimated total intracranial volume [mm^3]; Euler no. = total number of topological defects in the cortical surface prior to fixing in the FreeSurfer pipeline (to be treated as a measure of structural-data quality).

MRI

On the grounds of the correctional facilities, we acquired high-resolution T1-weighted MRI scans with the Mind Research Network's mobile scanner (i.e. 1.5-T Siemens MAGNETOM Avanto scanner with a 12-channel, multi-echo MPRAGE pulse sequence). The scanning parameters were as follows: repetition time = 2,530 ms; echo times = 1.64 ms, 3.50 ms, 5.36 ms, and 7.22 ms; inversion time = 1,100 ms; flip angle = 7°; slice thickness = 1.3 mm; matrix size = 256 × 256, yielding 128 sagittal slices with an in-plane resolution of 1.0 mm × 1.0 mm.

Each of the 912 scans underwent the standard "recon-all" pipeline in FreeSurfer version 7.4.1 (Fischl, 2012; https://surfer.nmr.mgh.harvard.edu/). The output was parcellated by resampling the "HCP-MMP1.0" template (Glasser et al., 2016) in the "fsaverage" space to the native space via FreeSurfer's surface-based registration to delineate 360 regions. For quality control, we applied thresholding by the Euler number (Rosen et al., 2018), defined as the total number of "holes" or topological defects in the cortical surface prior to fixing in the recon-all pipeline (Bethlehem et al., 2022). Specifically, we excluded participants whose Euler number was greater than 3 median absolute deviations (MADs) above the median (N = 105 out of 912, i.e. ~12%). However, since the Euler number has no universally accepted threshold – nor is there a "gold standard" for quality control in general (Bedford et al., 2023) – we ran two sensitivity analyses for some of the main structural findings in the total sample (i.e. findings at $P_{FDR} < 0.05$; Benjamini & Hochberg, 1995) to probe their consistency. First, we used a much more conservative threshold (i.e. > 2 MADs above the median, excluding N = 154, i.e. ~17%; note that this threshold in Bethlehem et al. [2022] excluded ~9-10% of scans per dataset, while we already surpassed this percentage at > 3 MADs). Secondly, we controlled for the Euler number as a covariate instead (Bedford et al., 2023; Warrier et al., 2023). Both sensitivity analyses were supplemented with tests of spatial correspondence with the main findings using Spearman's correlation and spin permutation (Alexander-Bloch et al., 2018).

Structural-MRI data in HCP were acquired and underwent the minimal-preprocessing pipeline as described in Glasser et al. (2013). FreeSurfer output was parcellated in FreeSurfer version 6.0.0 using the same templates and code as above.

Empathy

Dispositional cognitive and affective empathy were measured with the Perspective Taking (IRI-PT) and Empathic Concern (IRI-EC) subscales, respectively, of the Interpersonal Reactivity Index (IRI; Davis, 1983). The remaining Fantasy and Personal Distress subscales were not included, as they are less frequently used to denote cognitive and affective empathy (van Langen et al., 2014), and are also less related to psychopathy (Burghart & Mier, 2022). For a meta-analysis in support of this four-factorial structure, see Raimondi et al. (2023). IRI-PT assesses the "tendency to spontaneously adopt the psychological point of view of others" while IRI-EC the "feelings of sympathy and concern for unfortunate others" (Davis, 1983, pp. 113–114). Each subscale includes

seven items scored on a five-point scale ranging from "Does not describe me well" (zero points) to "Describes me very well" (four points) (for all items, see *Supplementary Table **S2***). Possible scores thus range from 0 to 28 points per subscale, with higher scores indicating higher empathy. Internal consistency was acceptable for both IRI-PT (unidimensional McDonald's ω_t = 0.766) and IRI-EC (unidimensional McDonald's ω_t = 0.799), as confirmed using the "psych" package in R version 4.4.0 (R Core Team, Vienna, Austria).

In addition, aiming to improve reliability for structural sensitivity analyses (Gell et al., 2024), we calculated IRI-PT and IRI-EC scores using positively scored items only, since the reverse ones tend to show smaller factor loadings (Raimondi et al., 2023). Internal consistency became good for IRI-PT (unidimensional McDonald's ω_t = 0.802) and remained acceptable for IRI-EC (unidimensional McDonald's ω_t = 0.759).

Psychopathy

Clinical psychopathic traits were measured with the Hare Psychopathy Checklist-Revised (PCL-R; Hare, 1991; 2003). The PCL-R is an expert-rated, semi-structured interview with 20 items that correspond to two factors with two facets each: Interpersonal/Affective (F1) and Lifestyle/Antisocial (F2) (for all items, see *Supplementary Table **S3***). Each item is scored zero, one, or two points, indicating no evidence, some evidence, and pervasive evidence, respectively. The total score is a sum across the 20 items, thus ranging from 0 to 40 points, with a higher score indicating higher psychopathic traits. In the North-American population, a "diagnostic" cut-off is typically used at 30 points (Hare, 2003). For items omitted due to insufficient information, we used a prorating formula to estimate the total and factor scores with possible decimals. PCL-R total and F1 scores were available for the total sample (i.e. N = 804, where N = 582 and N = 798 had complete item-level data, respectively), while PCL-R F2 score was available for N = 778 (where N = 617 had complete item-level data). Internal consistency was good for the PCL-R (bidimensional McDonald's ω_t = 0.836) and acceptable for both PCL-R F1 (unidimensional McDonald's ω_t = 0.772) and PCL-R F2 (unidimensional McDonald's ω_t = 0.703).

Following the PCL-R guideline (Hare, 2003) and previous work in incarcerated adult males/men (Decety et al., 2013a; 2013b; 2014; 2015; Philippi et al., 2015; Wolf et al., 2015; Yoder et al., 2015; Korponay et al., 2017; Drayton et al., 2018), we identified the "high-psychopathy" group as those scoring 30 or above, and the "low-psychopathy" group as those scoring 20 or below, on the PCL-R.

Results

Empathy and psychopathy

In 804 incarcerated adult men, we first tested for relationships between empathy and psychopathy (Q1). In particular, five continuous variables of interest – IRI-PT, IRI-EC, PCL-R, PCL-R F1, and PCL-R F2 – were tested for relationships with empathy as the dependent variable, controlling for age and IQ. PCL-R F1 had a negative relationship with IRI-EC, while both PCL-R and PCL-R F2 had a negative relationship with both IRI subscales (*Fig.* ***1A-B*** and *Supplementary Table* ***S4***). In categorical analyses, the high-psychopathy group compared to the low-psychopathy group scored lower on both IRI subscales, with a larger effect size for IRI-EC, controlling for age and IQ (*Fig.* ***1C***). These relationships somewhat clarified when additionally controlling for the other IRI subscale (*Supplementary Fig.* ***S1*** and *Supplementary Table* ***S5***). Both PCL-R and PCL-R F1 uniquely negatively related to IRI-EC, while PCL-R F2 uniquely negatively related to IRI-PT. Further, the group difference on IRI-PT disappeared, while the group difference on IRI-EC remained, and this did not change when additionally controlling for race and substance use (i.e. two variables on which the groups differed; *Table* ***1***).

These findings suggest robust negative relationships of psychopathy with affective empathy.

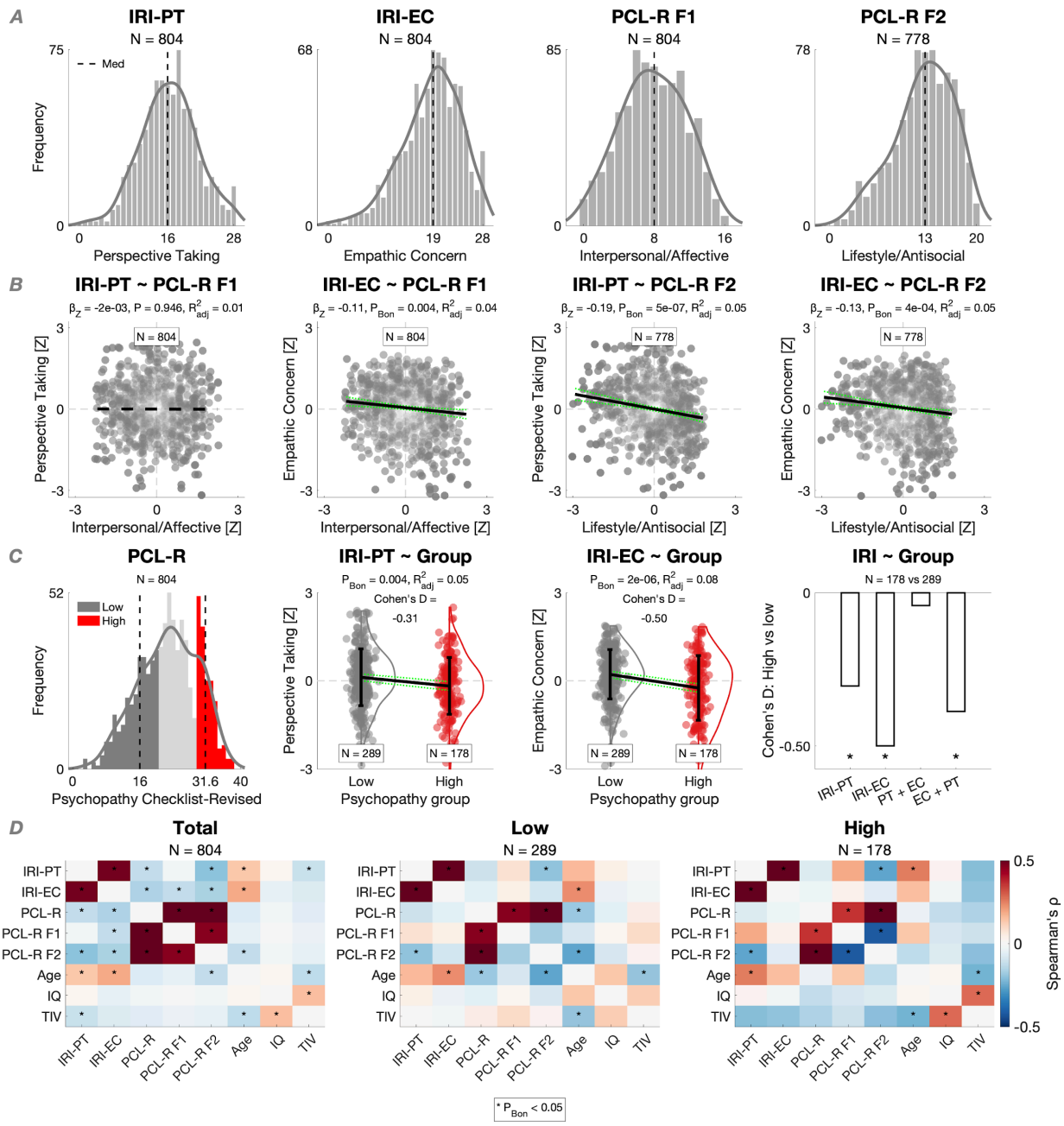

Figure 1. Psychopathy in relation to empathy. (A) Distribution of four continuous variables of interest. (B) Negative relationships of PCL-R F1 and PCL-R F2 with IRI-PT and IRI-EC, controlling for age and IQ in a robust linear regression, with Bonferroni correction across the two IRI subscales. (C) From left to right: Distribution of the PCL-R total score, depicting the low-psychopathy group (PCL-R ≤ 20; dark gray) and the high-psychopathy group (PCL-R ≥ 30; red); lower scores on IRI-PT and IRI-EC in high psychopathy, controlling for age and IQ, with Bonferroni correction across the two IRI subscales; lower score in high psychopathy on IRI-EC but not IRI-PT when additionally controlling for the other IRI subscale. (D) Sample-specific Spearman's correlation matrices, with Bonferroni correction across the 28 tests.

Cortical structure, empathy, and psychopathic traits

Next, we tested for relationships of CT and SA with empathy and psychopathic traits (Q2). Controlling for age, IQ, and total intracranial volume (TIV) across 360 parcels (Glasser et al., 2016),

SA was not related to either IRI subscale (*Fig.* ***2A***). In contrast, SA in 51 parcels had a positive relationship with PCL-R (*Supplementary Fig.* ***S2*** and *Supplementary Table* ***S6***), SA in 103 parcels had a positive relationship with PCL-R F1 (*Supplementary Table* ***S7***), and SA in three of the same parcels in the right auditory cortex had a positive relationship with PCL-R F2 (*Supplementary Table* ***S8***). In terms of microstructural classes (Mesulam, 2000) and functional networks (Yeo et al., 2011), betas for IRI-PT localized primarily in the heteromodal class and default-mode network (in absolute terms), with there being differentiation by both class and network (*Fig.* ***2B***). Betas for IRI-EC localized primarily in the paralimbic class and ventral-attention network, with differentiation by class. Betas for PCL-R and its both factors localized primarily in the paralimbic class and somatomotor network, with differentiation by network for all three variables and also by class for PCL-R and PCL-R F2. Similarly, CT was not related to either IRI subscale – nor to PCL-R or PCL-R F2 (*Supplementary Fig.* ***S3A***). However, CT in 16 parcels had a positive relationship and six parcels had a negative relationship with PCL-R F1, localizing primarily in the heteromodal class and frontoparietal network, with differentiation by both class and network (*Supplementary Fig.* ***S3A-B*** and *Supplementary Table* ***S9***).

We then ran sensitivity analyses for the IRI (which showed no relationships) and the PCL-R factors (which showed more relationships than PCL-R). The null CT and SA findings for the IRI did not change when leveraging their psychometrically modified versions (*Supplementary Fig.* ***S4***), while the positive CT and SA findings for PCL-R F1 (but less so for PCL-R F2) remained highly consistent when taking two alternative approaches to structural-data quality control (Spearman's ρ for all spatial correlations ≥ 0.93; *Supplementary Fig.* ***S5***). Furthermore, addressing Q3, relationships of both CT and SA with PCL-R F1 (but not PCL-R F2) were corroborated in a predictive framework with cross-validation (*Supplementary Methods*), explaining ~6% and ~8% of the out-of-sample variance, respectively (*Fig.* ***3*** and *Supplementary Fig.* ***S6***).

Most importantly, these findings suggest positive relationships of SA with the interpersonal/affective traits of psychopathy, highlighting the somatomotor network and showcasing predictive utility.

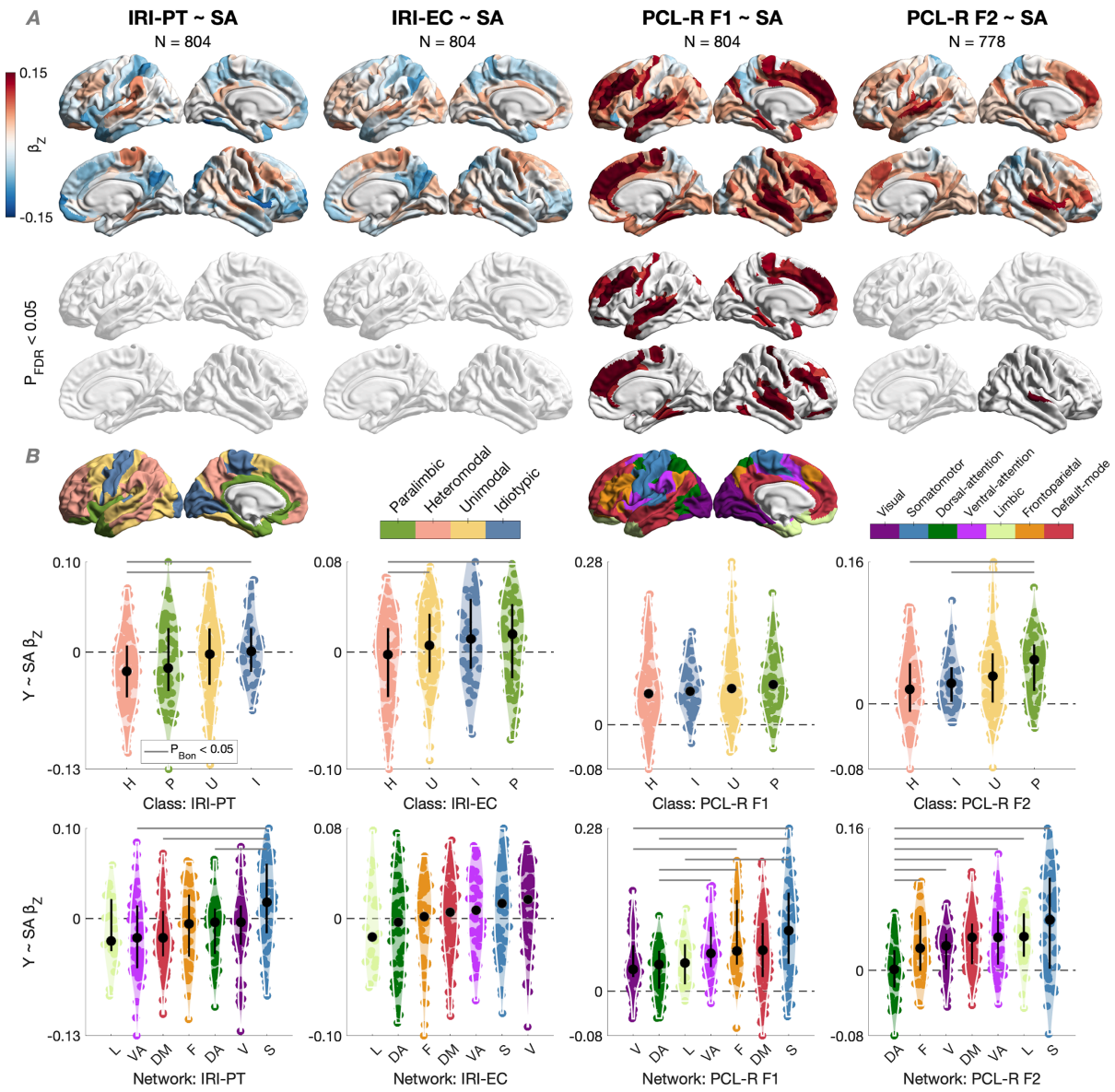

Figure 2. SA in relation to empathy and psychopathic traits. (A) Relationships of SA (positive, if any) with four continuous variables of interest, controlling for age, IQ, and TIV in a robust linear regression with FDR correction. (B) Standardized betas by microstructural class and functional network, median-ordered and tested for distribution differences using Wilcoxon's rank-sum test with Bonferroni correction within class (six comparisons) or network (21 comparisons).

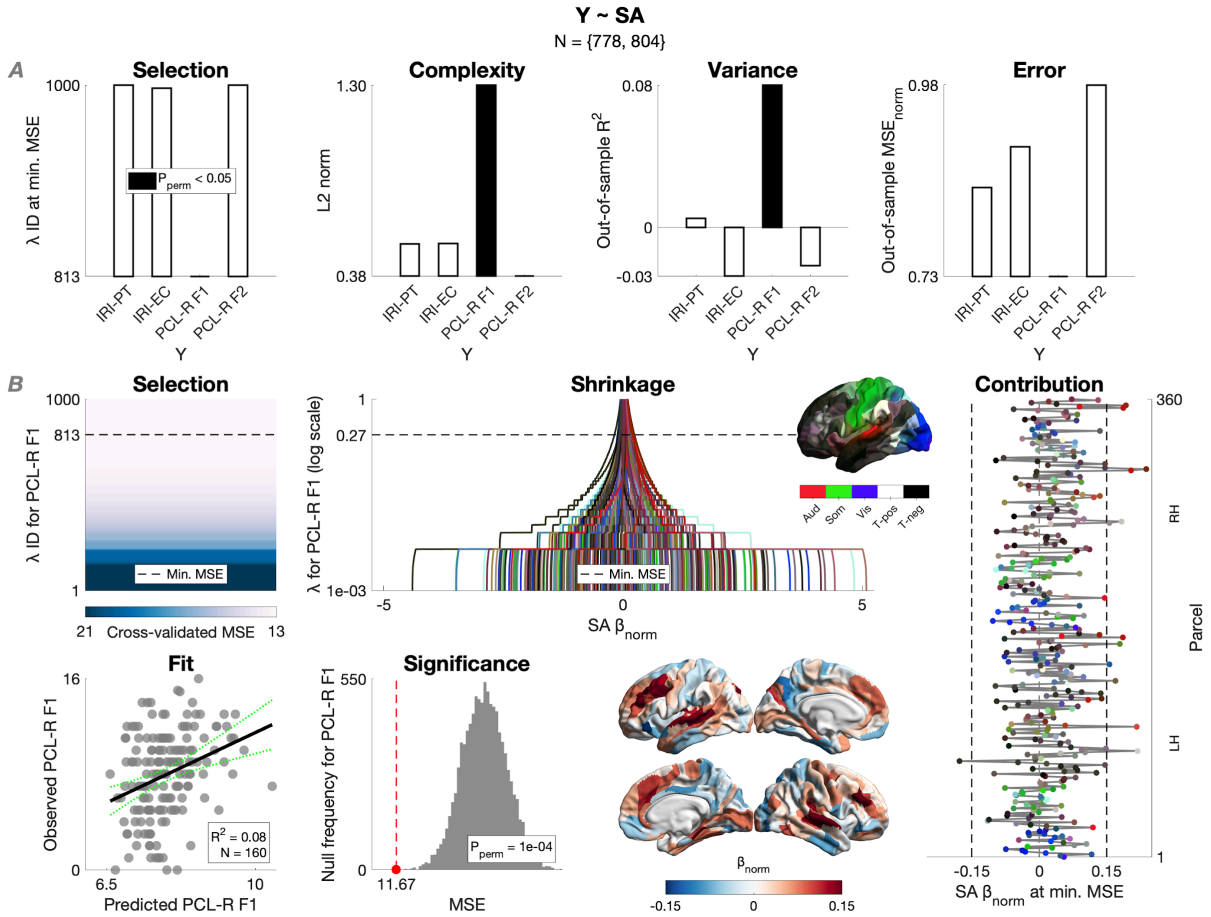

Figure 3. Multivariate prediction of empathy and psychopathic traits from SA. (A) For four continuous variables of interest, we inform on: model selection using cross-validated ridge regression (i.e. lambda corresponding to the minimum cross-validated MSE at which the model was selected); model complexity (i.e. Euclidean norm of the final beta vector); variance explained (i.e. out-of-sample coefficient of determination); and prediction error (i.e. out-of-sample MSE divided by the maximum possible score and thus normalized). Only PCL-R F1 was able to be predicted. SA was corrected for age, IQ, and TIV separately in the training (N = 644) and test (N = 160) sets. (B) For PCL-R F1, we inform on model selection, beta shrinkage, final beta vector, predicted-observed fit, and significance based on permutation for out-of-sample MSE (N_{perm} = 10,000).

Cortical structure by psychopathy group

Next, we tested for global and regional differences in cortical structure by psychopathy group (Q4). Controlling for age, IQ, and TIV, the high-psychopathy group compared to the low-psychopathy group had increased total SA; regionally, there was an increase in 65 parcels (*Fig. **4A*** and *Supplementary Table **S10***). Similarly to the dimensional PCL-R analyses, these differences localized primarily in the paralimbic class and somatomotor network, with differentiation by both class and network. Further, the cluster of FDR-corrected SA increases in high psychopathy overlapped up to four times more with affective-empathy clusters compared to their cognitive counterparts based on meta-analytic task-based activations across ~200 studies with N > 4,200 (Schurz et al., 2021). This affective-first ranking was observed for the "baseline", partly overlapping clusters ("Cognitive" and "Affective"), clusters with a higher meta-analytic loading compared to their counterpart ("Cog > Aff" and "Aff > Cog"), and clusters covering parcels that were not covered by

their baseline counterpart ("Cog: Unique" and "Aff: Unique") (*Supplementary Methods*, *Fig.* ***4B***, and *Supplementary Fig.* ***S7***). What is more, the paralimbic class and somatomotor network – in which the psychopathic differences concentrated – both mapped affective empathy better. We then explored the broader psychological relevance of these SA increases using another meta-analytic resource, Neurosynth (Yarkoni et al., 2011). Across 24 wide-ranging terms (Margulies et al., 2016; Paquola et al., 2019; Valk et al., 2022), the overlap was highest for affective-sensory terms (e.g. "pain", "affective", "auditory") and lowest for visual terms (e.g. "visuospatial"). Repeating the regional analysis whilst additionally controlling for race and substance use yielded highly similar results (Spearman's ρ = 0.87, denoting spatial correlation with the map from *Fig.* ***4A***; *Supplementary Fig.* ***S8***). In contrast, global and regional analyses for CT by psychopathy group, controlling for age and IQ, revealed no difference (*Supplementary Fig.* ***S9***).

Adding to the dimensional analyses of the PCL-R, these findings suggest increased SA in high psychopathy, highlighting the paralimbic class and somatomotor network, and thus stressing the importance of affect and sensation.

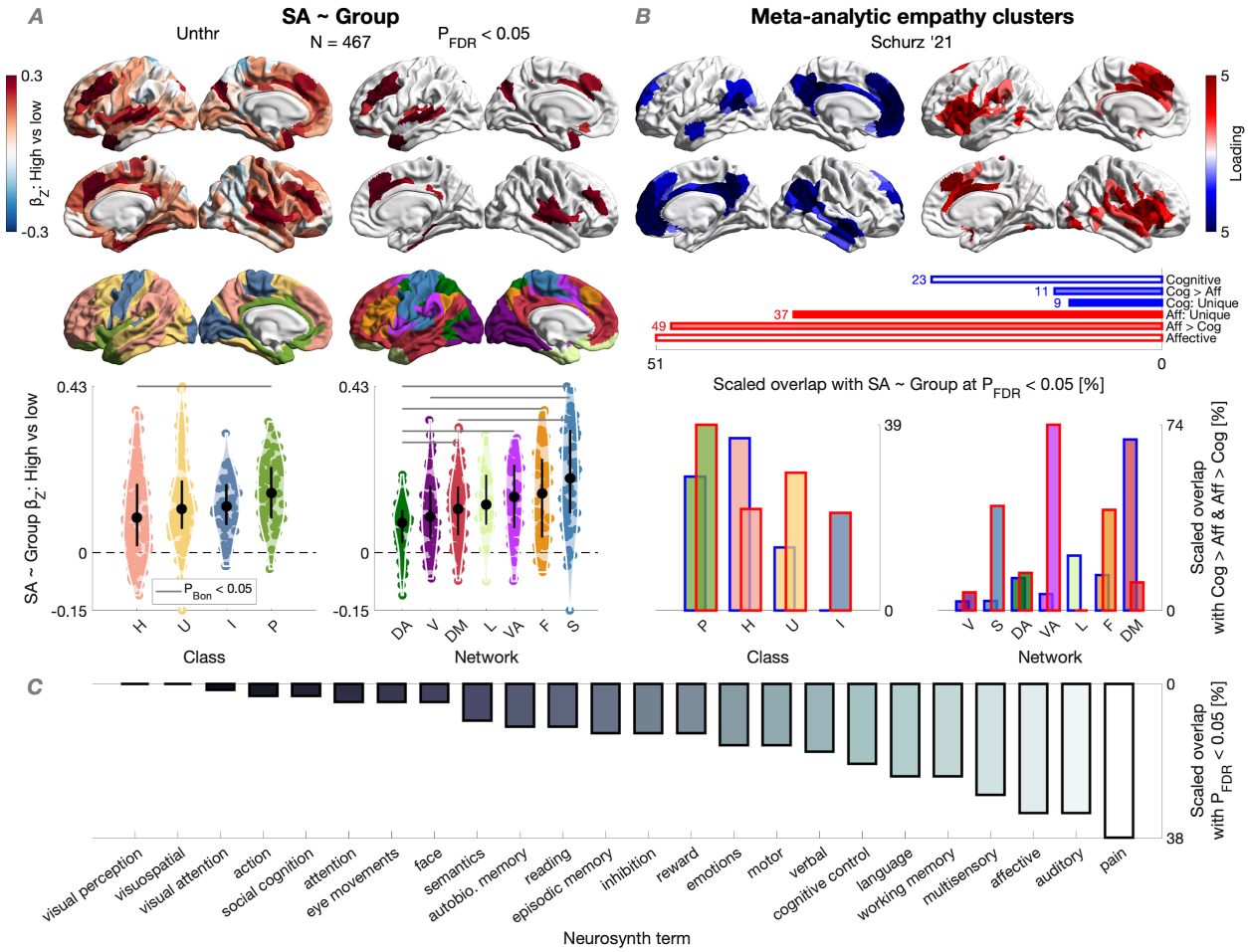

Figure 4. SA by psychopathy group. (A) Differences in SA by psychopathy group, controlling for age, IQ, and TIV in a robust linear regression with FDR correction; 65 parcels survived. Standardized betas for the high-psychopathy (N = 178) vs low-psychopathy (N = 289) groups were further median-ordered by class and network, and tested for distribution differences using Wilcoxon's rank-sum test with Bonferroni correction within class (six comparisons) or network (21

comparisons). Total SA was increased in high psychopathy as well, controlling for the same covariates (β_z = 0.25 [95% CI: 0.14, 0.36], P = 9e-06, adj. R^2 = 0.67, Cohen's D = 0.39, N = 467). (B) Meta-analytic clusters of cognitive and affective empathy across ~200 studies with N > 4,200. The cluster of FDR-corrected SA increases in high psychopathy overlapped up to four times more with the affective-empathy clusters compared to their cognitive counterparts. Scaling was done by dividing the number of overlapping parcels by the number of significant parcels to indicate what proportion of the latter fell into the empathy cluster. In turn, the non-overlapping affective-empathy cluster compared to its cognitive counterpart covered more of the paralimbic and somatomotor parcels (where scaling was done by dividing the number of overlapping parcels by the number of class/network parcels). (C) Overlap between the FDR-corrected cluster and Neurosynth clusters (where scaling was done as for the empathy clusters).

Structural covariance by psychopathy group

Finally, we investigated structural covariance by psychopathy group (Q5). First, we investigated macroscale structural organization or "gradients" that represent low-dimensional axes of brain variability (e.g. Margulies et al., 2016; Huntenburg et al., 2018; Fornito et al., 2019) (*Supplementary Methods*). To replicate our gradients in a normative population, this is where we included the male sample of the Human Connectome Project (HCP; N = 501; Van Essen et al., 2012). Taking the non-linear approach of diffusion-map embedding to decompose the high dimensionality of cortical structure in the total sample (correcting for age and IQ with CT, and additionally for TIV with SA), we observed that the primary gradient of CT traversed an anterior-posterior axis, which was similar for SA (*Fig.* ***5B*** and *Supplementary Fig.* ***S10***). Both gradients were correlated positively with gradients in HCP following spin permutation (especially for CT), thus confirming their replicability (*Fig.* ***5A***). We then tested for psychopathic differences in gradients aligned to those in the total sample to ensure that they were directly comparable (*Fig.* ***5B-C***; for raw gradients, see *Supplementary Fig.* ***S11***, with gradients in the high-psychopathy group traversing different axes). Notably, the primary gradient of CT was "compressed" in the high-psychopathy group compared to the low-psychopathy group, such that both gradient ends were less extreme and thus pulled toward the center. Such global compression was not observed for SA. However, aggregating gradient loadings by class and network revealed median compression in the limbic network for both cortical indices and further compression in the paralimbic and unimodal classes as well as in the visual and dorsal-attention networks for CT (*Fig.* ***6***). Secondly, at the edge level (*Supplementary Methods*), there was no difference by psychopathy group (*Supplementary Fig.* ***S12***).

These findings suggest that canonical macroscale organization of cortical structure is compressed in high psychopathy.

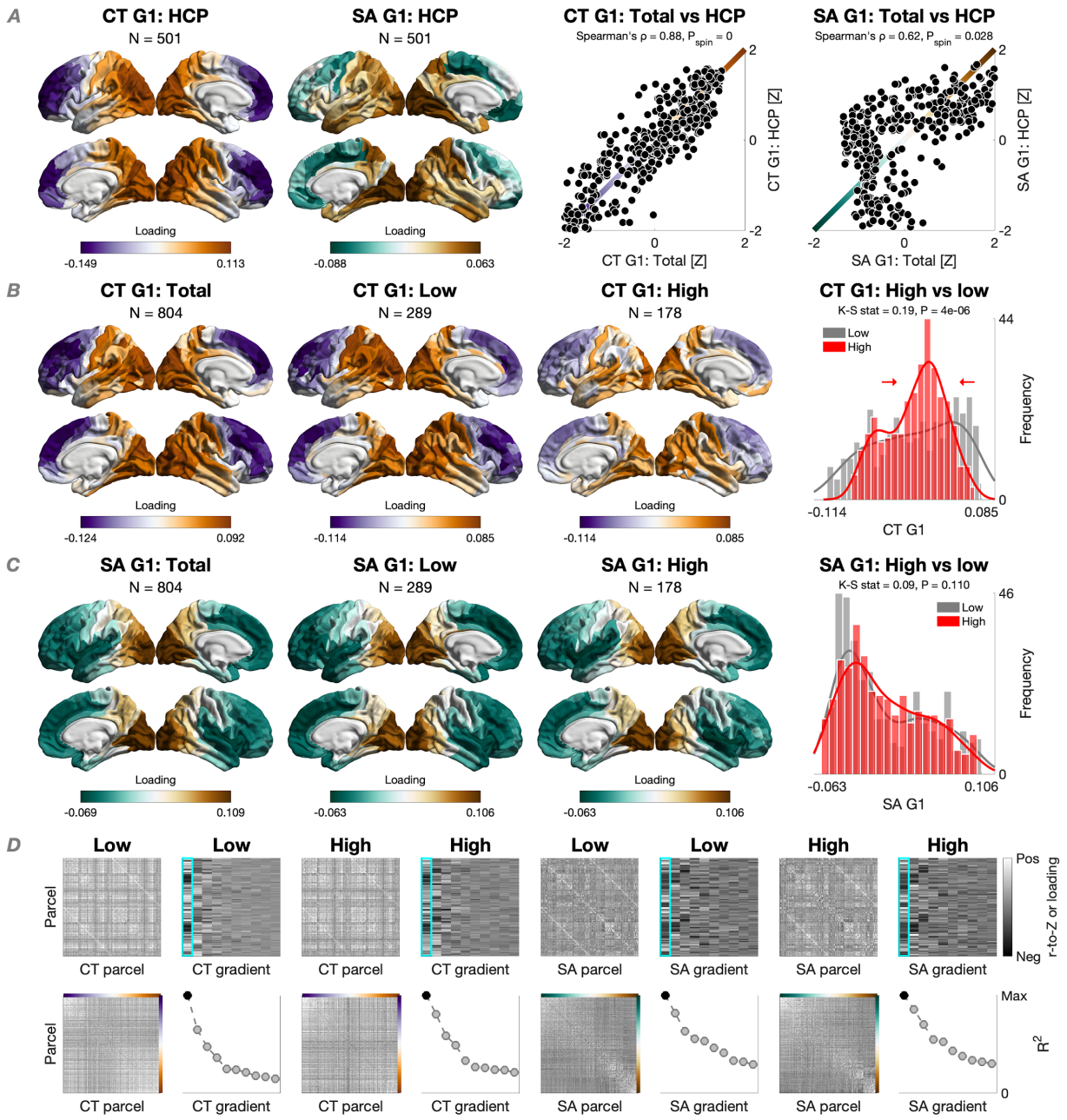

Figure 5. Macroscale structural organization by psychopathy group: Global analysis. (A) Primary gradients of CT and SA in HCP (N = 501) and their positive correlations with gradients in the total sample (N = 804) following spin permutation (N_{perm} = 1,000). In both datasets, CT was corrected for age and IQ, while SA was additionally corrected for TIV. (B) Primary gradients of CT in the total sample, the low-psychopathy group, and the high-psychopathy group, corrected for age and IQ. The CT gradient was compressed in the high-psychopathy group compared to the low-psychopathy group using Kolmogorov-Smirnov's test. (C) Primary gradients of SA in the three samples, corrected for age, IQ, and TIV. The high-psychopathy group did not differ compared to the low-psychopathy group using Kolmogorov-Smirnov's test. (D) Consider the two-by-two left-hand tiles: Sample-specific covariance matrix (top left), array of the first 10 gradients (top right), covariance matrix ordered by the primary gradient (bottom left), and the first 10 gradients ordered by the proportion of variance explained (i.e. scaled eigenvalues; bottom right). All matrices were set to the range [-0.5, 0.5]; all arrays were set to the minimum-maximum range.

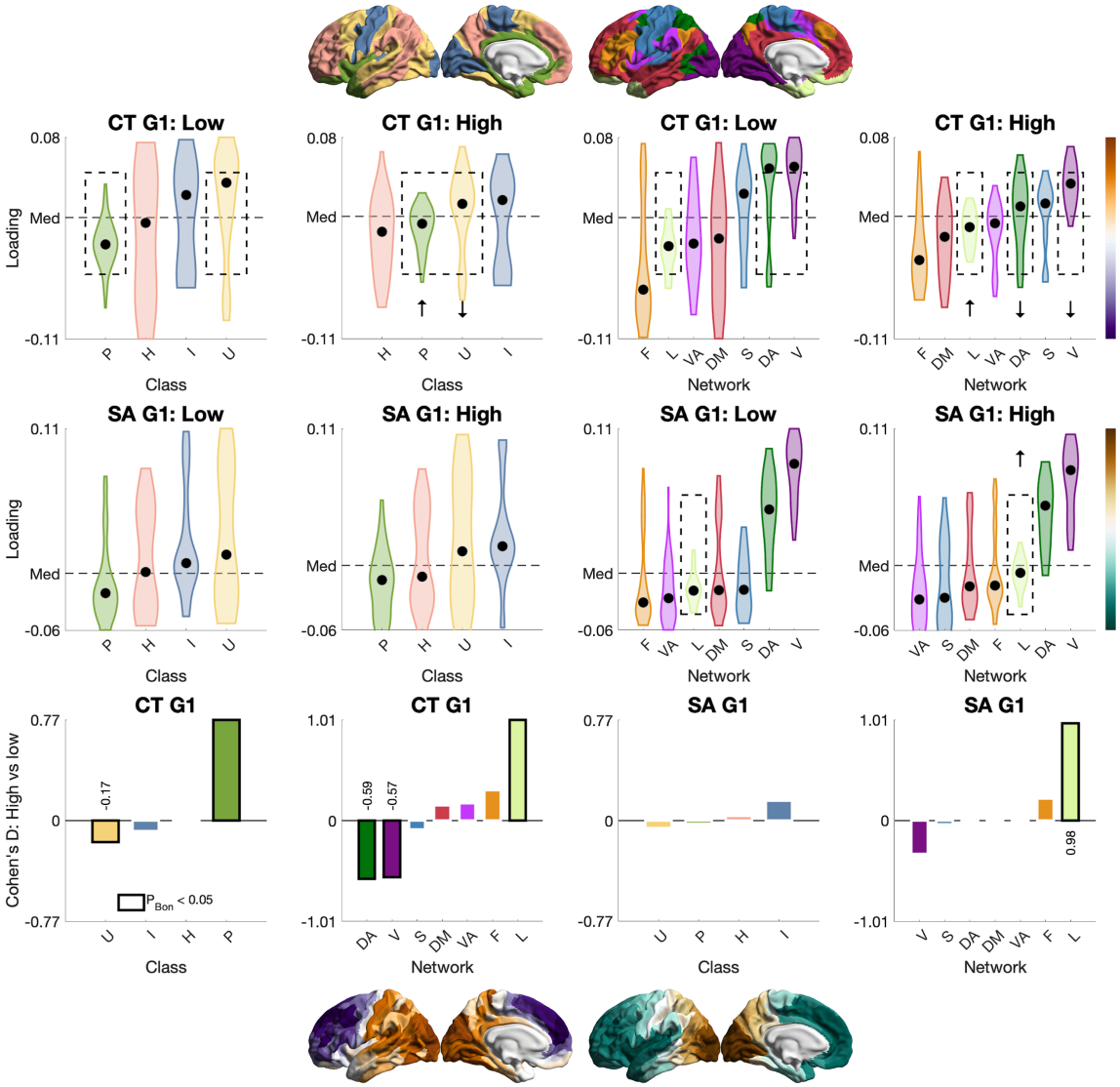

Figure 6. Macroscale structural organization by psychopathy group: Local analysis. Top two rows: CT and SA gradients by class and network in the low-psychopathy (N = 289) and high-psychopathy (N = 178) groups, median-ordered. Bottom row: Using Wilcoxon's rank-sum test with Bonferroni correction within class (four tests) or network (seven tests), the CT gradient was compressed in the high-psychopathy group compared to the low-psychopathy group (i.e. the median loading was pulled toward the center) in the paralimbic and unimodal classes as well as in the visual, dorsal-attention, and limbic networks. The SA gradient recapitulated the compression in the limbic network.

Discussion

In 804 incarcerated adult men, we investigated cortical thickness (CT) and surface area (SA) in relation to dispositional empathy and clinical psychopathy. Addressing five broad questions with a combination of univariate, multivariate, meta-analytic, and covariance-based methods for continuous and/or categorical analysis, we provide novel insights into behavior and brain structure in a large antisocial population.

As expected, psychopathy had negative relationships with empathy, controlling for age and IQ (Q1). PCL-R F1 (Interpersonal/Affective) had a negative relationship with IRI-EC (Empathic Concern) but not IRI-PT (Perspective Taking), while PCL-R F2 (Lifestyle/Antisocial) had a negative relationship with both IRI subscales. Controlling for the other subscale revealed a unique contribution of PCL-R F1 to IRI-EC and of PCL-R F2 to IRI-PT. The high-psychopathy group scored lower on both IRI subscales, but only the difference on IRI-EC survived controlling for the other subscale (as well as for race and substance use). This is in line with meta-analytic evidence that psychopathy entails a larger reduction in affective than cognitive empathy, whether as measured by the IRI (Burghart & Mier, 2022) or across tasks (Campos et al., 2022) (for a similar conclusion based on self-report data, see e.g. Seara-Cardoso et al., 2020). Psychopathic reduction in cognitive empathy – meta-analytically replicable also based on performance data (Wilson et al., 2011; Dawel et al., 2012; Song et al., 2023) – may thus be partly dependent on the reduction in affective empathy. However, the use of a self-report questionnaire such as the IRI cannot be conclusive, keeping in mind the affective/compassionate distinction between sharing and caring (Decety & Cowell, 2014; Singer & Klimecki, 2014; Weisz & Cikara, 2021), and the questionable correspondence between self-report questionnaires and performance tests of empathy (Murphy & Lilienfeld, 2019).

SA had positive relationships with psychopathic traits, controlling for age, IQ, and TIV (Q2). Such a relationship was present for 51 out of 360 parcels (Glasser et al., 2016) for PCL-R, as many as 103 parcels for PCL-R F1, and three parcels for PCL-R F2; they localized primarily in the paralimbic class (Mesulam, 2000) and somatomotor network (Yeo, 2011). We did not observe any relationship between SA and the IRI, which may raise questions about the reliability of the latter (Gell et al., 2024), at least in structural forensic neuroimaging. However, we did observe subscale-specific differentiation by class and/or network, thus motivating future work into brain relationships with empathy as a function of microstructural and macrofunctional properties. Regarding CT, we observed more circumscribed relationships with PCL-R F1 compared to SA but not with any other behavioral variable, controlling for age and IQ. This suggests that the observed relationship of SA with the interpersonal/affective traits of psychopathy is particularly robust, especially since we were able to corroborate it in a predictive framework, where SA explained more out-of-sample variance than CT did (Q3). To the best of our knowledge, this is the first demonstration of a relationship between SA and psychopathic traits.

The high-psychopathy group had increased SA both globally and regionally, controlling for the same covariates (Q4). These SA increases spanned 65 parcels, also localizing primarily in the paralimbic class and somatomotor network. The paralimbic class has been hypothesized to be uniquely relevant to psychopathy under the "paralimbic-dysfunction" model (Kiehl, 2006). Adding to the volumetric literature (Anderson & Kiehl, 2012; Johanson et al., 2020; De Brito et al., 2021b), these findings support this model based on SA. What further supports the importance of affect and sensation in high psychopathy is that the SA increases overlapped up to four times more with

meta-analytic clusters of affective empathy compared to their cognitive counterparts based on ~200 studies (Schurz et al., 2021). In addition, across 24 wide-ranging meta-analyses from Neurosynth (Yarkoni et al., 2011), the overlap was highest for affective-sensory terms, such as "pain". Beyond general sensory processing, these SA increases could underlie the greater psychopathic reduction in affective than cognitive empathy that transcends the IRI (Campos et al., 2022). In contrast, we observed no group difference in CT either globally or regionally, in line with predominantly null findings in the literature that typically includes N < 100 per study (Deming et al., 2024). While these findings agree with a greater sensitivity of SA than CT to broadly construed antisocial behavior, they differ in direction – reductions rather than increases in SA have been reported among antisocial individuals, although drawn largely (Gao et al., 2024) or exclusively (Carlisi et al., 2020) from community rather than incarcerated samples. Because SA closely tracks gray-matter volume (GMV; phenotypically and genetically; Warrier et al., 2023), it will be essential for future work to reconcile the SA increases we observed in high psychopathy with the reductions commonly reported for GMV (although, again, across mixed samples [De Brito et al., 2021b] and not always; Korponay et al., 2017).

Finally, the macroscale organization of both CT and SA was "compressed" globally and/or locally in the high-psychopathy group, controlling for the same covariates (Q5). The primary gradient in the total sample traversed an anterior-posterior axis for CT (as reported across the sexes; Valk et al., 2020) and a similar axis for SA (which is also anterior-posterior according to genetic organization; Makowski et al., 2022), with these axes replicating in a normative male sample of the Human Connectome Project. When testing for psychopathic differences along these axes, we observed a globally compressed (i.e. pulled toward the center) gradient of CT but not SA. At the class and network level, the high-psychopathy group further showed localized compression not only in CT but also SA, with the CT/SA differences converging in the limbic network. CT gradients have been reported to differ across major psychiatric conditions (Opel et al., 2020; Hettwer et al., 2022; Park et al., 2022), as has been the primary functional gradient in terms of compression (Hong et al., 2019; Xia et al., 2022; Dong et al., 2023). We provide the first evidence that high psychopathy exhibits similar macroscale differences in the cerebral cortex.

There are limitations to our study. For instance, a performance test of empathy could have yielded additional insights. These findings may also not generalize to community (Korponay & Koenigs, 2021) or female samples, with there being sex/gender differences not only in psychopathy but also empathy (Christov-Moore et al., 2014; Greenberg et al., 2018; Baron-Cohen et al., 2022). While this could be the largest structural study on psychopathy to date (at least as measured by the PCL-R; De Brito et al., 2021b; Deming et al., 2022; 2024), it is possible that some analyses were still underpowered due to sample size, effect size, or both (Marek et al., 2022; Cecchetti & Handjaras, 2022; Makowski et al., 2024). Further, since we limited our analyses to CT and SA, the role that other cortical indices, as well as subcortical structures, could play in the reduced empathy of individuals with high psychopathy remains to be elucidated.

In conclusion, psychopathy had negative relationships with affective empathy and positive relationships with paralimbic/somatomotor SA, highlighting the role of affect and sensation. Future work should aim to replicate and build upon these findings in the general and incarcerated populations to improve treatment of psychopathic traits in the long run.

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Some of the generated data and code will be shared upon publication online (https://github.com/MARadecki/EmpathyPsychopathy). Regarding the source data, please contact K.A.K. Human Connectome Project data are available pending access approval online (https://www.humanconnectome.org/). The following resources are further available online: meta-analytic empathy data (Schurz et al., 2021; https://osf.io/pav27/); Neurosynth data (Yarkoni et al., 2011; https://neurosynth.org/); volumetric and surface-based template data as part of neuromaps (Markello et al., 2022; https://github.com/netneurolab/neuromaps); code for volume-to-surface mapping as part of the Connectome Workbench (Marcus et al., 2011; https://www.humanconnectome.org/software/connectome-workbench; code for cortical parcellation as part of the ENIGMA Toolbox (Larivière et al., 2021; https://enigma-toolbox.readthedocs.io/); code for gradient mapping as part of BrainSpace (Vos de Wael et al., 2020; https://brainspace.readthedocs.io/).

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