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Neuroanatomical markers of social cognition in neglected adolescents

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ABSTRACT

Growing up in neglectful households can impact multiple aspects of social cognition. However, research on neglect's effects on social cognition processes and their neuroanatomical correlates during adolescence is scarce. Here, we aimed to comprehensively assess social cognition processes (recognition of basic and contextual emotions, theory of mind, the experience of envy and *Schadenfreude* and empathy for pain) and their structural brain correlates in adolescents with legal neglect records within family-based care. First, we compared neglected adolescents ($n = 27$) with control participants ($n = 25$) on context-sensitive social cognition tasks while controlling for physical and emotional abuse and executive and intellectual functioning. Additionally, we explored the grey matter correlates of these domains through voxel-based morphometry. Compared to controls, neglected adolescents exhibited lower performance in contextual emotional recognition and theory of mind, higher levels of envy and *Schadenfreude* and diminished empathy. Physical and emotional abuse and executive or intellectual functioning did not explain these effects. Moreover, social cognition scores correlated with brain volumes in regions subserving social cognition and emotional processing. Our results underscore the potential impact of neglect on different aspects of social cognition during adolescence, emphasizing the necessity for preventive and intervention strategies to address these deficits in this population.

1. Introduction

Social cognition, crucial for social interactions (Gallotti and Frith, 2013), undergoes developmental changes from childhood through adolescence (Kilford et al., 2016), shaped by the quality of social experiences and caregiving (Atzil et al., 2018). Neglectful caregiving can disrupt various social cognition domains, such as the recognition of basic emotions (Doretto and Scivoletto, 2018), theory of mind (ToM) (Pears and Fisher, 2005), and self-reported empathy (Zhang et al., 2023). However, key socio-cognitive domains, such as emotional recognition and empathy, have not been investigated using context-dependent experimental tasks in neglected samples. Additionally, the experience of social emotions like envy and *Schadenfreude* has been scarcely studied. Moreover, the structural brain correlates of these social cognitive processes in neglected adolescents remain poorly understood. To address these gaps, we conducted the first comprehensive assessment of social cognition processes (basic and contextual emotional recognition, ToM, the experience of envy and *Schadenfreude* and empathy for pain) in neglected adolescents using context-sensitive tasks. We also assessed the influence of physical and emotional abuse as well as

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executive and intellectual functioning on these social cognition domains and explored their brain structural correlates.

Neglect, the most prevalent form of child maltreatment (Gilbert et al., 2009), involves the failure of caregivers to meet the child's essential developmental needs (McLaughlin et al., 2017; Straus and Kantor, 2005). Neglect can impact the brain structure and function (Teicher and Samson, 2016) and cognitive, emotional, and social abilities (Haslam and Taylor, 2022; Hildyard and Wolfe, 2002). Despite its prevalence and impact, research in neglect remains understudied compared to other forms of adversity (Stoltenborgh et al., 2013) and has only recently gained increased attention (Widom, 2013). Particularly, existing research on social cognition has predominantly focused on children in institutional or foster care settings, often overlooking adolescents in family-based care. Given that adolescence is a critical period for developing social cognition and transitioning from familial to peer and romantic relationships (Kilford et al., 2016; Mills et al., 2014), it is crucial to study the socio-cognitive processes and their structural brain correlates in neglected adolescents.

Emotional recognition is crucial for social interaction (Frith and Frith, 2007). Neuroimaging findings have primarily linked this domain with the prefrontal cortex (Forbes and Grafman, 2010), amygdala (Dannlowski et al., 2013), and fusiform gyrus (Frank et al., 2019). Neglected adolescents exhibit impaired recognition of positive and negative facial emotional expressions (Marta et al., 2018). Similarly, neglected children (Pears and Fisher, 2005; Sullivan et al., 2010; Fries and Pollak, 2004) struggle to discriminate emotional expressions, particularly negative ones (Doretto and Scivoletto, 2018), and exhibit atypical neural responses during emotion processing (Tottenham et al., 2011; Maheu et al., 2010). Context has been recognized as a critical factor in emotion recognition (Barrett et al., 2011; Hassin et al., 2013), emphasizing the importance of integrating contextual cues such as body language (Aviezer et al., 2012; De Gelder et al., 2004), voice and visual signals (Davies-Thompson et al., 2019; de Gelder et al., 1999), and other contextual features into the experimental settings (Aviezer et al., 2011; Righart and De Gelder, 2008). However, most studies on neglected youths have relied on decontextualized assessments using isolated stimuli, which fail to capture the complexities of real-world emotional displays (Aviezer et al., 2012; Gonzalez-Gadea et al., 2014). Context-dependent tasks offer a more ecologically valid, sensitive and comprehensive assessment of social cognition by closely mimicking the spontaneity, dynamism and rapid changes of real-life interactions (Ibañez and Manes, 2012). These tasks also require the integration of multiple types of information (e.g., verbal, nonverbal, situational) and introduce additional processing demands not present when viewing static displays (McDonald et al., 2003). Such advantages make them particularly valuable for studying vulnerable adolescents (Gonzalez-Gadea et al., 2014; Santamaría-García et al., 2019). Thus, although previous findings suggest that early adversity can reshape human brain development, the impact of neglect on emotional recognition abilities of adolescents remains unclear. Furthermore, no studies have used context-dependent tasks to explore the neuroanatomical correlates of emotion recognition in this population.

Beyond recognizing emotions, ToM is crucial for social interaction (Frith and Frith, 1999). Neuroimaging evidence has identified the medial prefrontal cortex, temporoparietal junction and precuneus as core regions of the ToM network (Amodio and Frith, 2006; Schurz et al., 2014). The evidence linking maltreatment and neglect experiences to ToM is limited and inconclusive in both children (Benarous et al., 2015) and adolescents (Van Schie et al., 2017; Burack et al., 2006; Koizumi and Takagishi, 2014; Heleniak and McLaughlin, 2020). Studies in maltreated children and adolescents have revealed deficits in cognitive and affective ToM (Burack et al., 2006; Koizumi and Takagishi, 2014). Similarly, retrospective records of parental maltreatment experiences in adults, especially physical abuse, have been associated with diminished ToM performance (Germine et al., 2015). However, other studies revealed no impairments or atypical neural activity in mentalizing tasks in abused and neglected adolescents (Van Schie et al., 2017). Given the scarcity and ambiguity of behavioral and neuroanatomical evidence regarding ToM in neglected adolescents, further research is crucially needed.

Prosocial behaviors are essential in shaping social interactions and are related to social cognitive processes such as empathy and social emotions (Decety et al., 2016; Vaish, 2018). Social emotions are crucial in modulating behaviors based on their social appropriateness (Tangney et al., 2007). Unlike basic emotions, social emotions emerge from the interaction between basic emotions and higher-order cognitive processes (Panksepp, 2011). Examples of such emotions include envy and *Schadenfreude*, categorized as counter-empathic emotions (Cikara and Fiske, 2011, 2013; Ortony et al., 1988). The processing of these emotions is associated with brain areas responsible for pain and reward processing, including the anterior cingulate cortex (Takahashi et al., 2009), ventral striatum and inferior parietal lobe (Dvash et al., 2010; Baez et al., 2018a). Both emotions are triggered by social comparisons (Jankowski and Takahashi, 2014), a crucial mechanism for self-concept development during adolescence (Crone et al., 2022). Envy is an unpleasant emotion elicited by unfavorable upward social comparisons, while *Schadenfreude* is a pleasure response to others' misfortunes (Takahashi et al., 2009; Dvash et al., 2010). These complex emotions rely on higher cognitive and affective abilities such as mentalizing and empathy (Baez et al., 2018a; Jankowski and Takahashi, 2014; Franco-O'Byrne et al., 2021), and neglected adolescents, prone to cognitive deficits and counter-empathic tendencies (Hildyard and Wolfe, 2002; Todorov et al., 2023), may experience these emotions differently. Moreover, feelings of inferiority, which are common in this population (Maguire et al., 2015), can contribute to the emergence of these emotions (Smith and Kim, 2007). Critically, envy may inhibit prosocial attitudes during adolescence (Yu et al., 2018), whereas *Schadenfreude* is associated with competition and rivalry (Steinbeis and Singer, 2013).

Previous research has not explored envy and *Schadenfreude* in neglected adolescents through experimental tasks. However, retrospective studies in young adults with varied backgrounds of maltreatment and neglect have linked these early adversities to subsequent dispositional (Xiang et al., 2018) and malicious envy (Zhao et al., 2020). Furthermore, envy can promote the effects of maltreatment on internalized and externalized aggression (He and Xiang, 2021) and depression and anxiety (Li et al., 2022a) in adolescents. These youths also exhibit altered reward-related neural responses (Yang et al., 2021), which are crucially involved in envy and *Schadenfreude* (Takahashi et al., 2009; Dvash et al., 2010) and undergo significant development during adolescence (Somerville and Casey, 2010). Specifically, experiences of deprivation in adolescents, such as institutional rearing and emotional neglect, are associated with reduced ventral striatal engagement during reward anticipation and response (Hanson et al., 2015; Mehta et al., 2010). Given the enduring impact of maltreatment on envy in adulthood, mediated by social support (Xiang et al., 2018; Zhao et al., 2020) and the potential effects of envy and *Schadenfreude* on hindering prosocial attitudes (Yu et al., 2018) and promoting competition and rivalry (Steinbeis and Singer, 2013), aggression (He and Xiang, 2021), and depression and anxiety (Li et al., 2022a), studying these emotions and their neural correlates in neglected adolescents gains importance.

Positive parent-adolescent attachment and responsive parenting during adolescence are linked to increased empathy (Silke et al., 2018). Neuroimaging studies indicate that a core network comprising the anterior cingulate cortex, anterior insula and supplementary motor area is associated with empathy (Lamm et al., 2011; Fan et al., 2011). Childhood maltreatment, especially emotional neglect (Chen et al., 2023), is associated with reduced empathy (Yu et al., 2020) and disregard for others' feelings (Todorov et al., 2023). Notably, most studies on empathy in this population have relied on subjective self-report or caregiver-report questionnaires (Zhang et al., 2023), lacking ecological validity (Ickes, 2009). Additionally, no study has examined the structural neural underpinnings of empathy in neglected adolescents. To overcome these limitations, we employed a performance-based task featuring naturalistic stimuli to measure empathy for others' physical pain and explored its neuroanatomical correlates among neglected adolescents. This approach provides a more reliable assessment of individuals' empathetic skills, reducing biases and social desirability effects while offering better predictive and ecological validity than self-report or informant-report methods (Ickes, 2009). Moreover, our paradigm has proven to induce fast and automatic empathetic responses to others' pain (Escobar et al., 2014; Hesse et al., 2016) and activated a neural network associated with the direct experience of pain (Lamm et al., 2011; Akitsuki and Decety, 2009).

Against this background, we conducted the first comprehensive assessment of socio-cognitive processes in neglected adolescents, focusing on basic and contextual emotional recognition, ToM, the experience of social emotions (envy and *Schadenfreude*) and empathy for pain, along with their structural brain correlates. Given the heightened sensitivity of context-dependent emotion recognition tasks in capturing social cognition deficits (Gonzalez-Gadea et al., 2014; Baez et al., 2013; Baez and Ibanez, 2014), we expected that neglected adolescents would exhibit greater difficulty recognizing basic emotions within context-rich than decontextualized tasks. In addition, we expected diminished ToM performance in neglected adolescents compared to controls. Considering the impairments in self-reported empathy (Zhang et al., 2023; Moreno-Manso et al., 2018) and prosocial behaviors (Yu et al., 2020) and the counter-empathic nature of envy and *Schadenfreude* (Cikara and Fiske, 2011, 2013; Ortony et al., 1988), we anticipated increased envy and *Schadenfreude* ratings and reduced empathy for pain in neglected adolescents. Finally, we expected that scores in social cognition domains would be positively associated with grey matter (GM) volumes in key regions subserving each of these processes, namely: (a) emotion recognition [e.g., prefrontal cortex (Forbes and Grafman, 2010), amygdala (Dannlowski et al., 2013), and fusiform gyrus (Frank et al., 2019)], (b) ToM [e.g., medial prefrontal cortex (Amodio and Frith, 2006; Schurz et al., 2014), temporoparietal junction and precuneus (Schurz et al., 2014)], (c) empathy [e.g., cingulate cortex, anterior insula and supplementary motor area (Lamm et al., 2011; Fan et al., 2011)]. We also expected negative associations between envy and *Schadenfreude* ratings and GM volumes in social emotions-related areas [e.g., anterior cingulate cortex (Takahashi et al., 2009), ventral striatum (Dvash et al., 2010; Baez et al., 2018a), inferior parietal lobe (Baez et al., 2018a)].

2. Materials and methods

2.1. Participants

The study included 52 participants, comprising 27 neglected adolescents (NEG) and 25 controls (CN) with no history of neglect between ages 11 and 16 (*Mean* = 14.3, *SD* = 1.2; 23 males: 29 females). According to the Declaration of Helsinki, all participants and their caregivers provided written ascent and informed consent prior to study inclusion, respectively. The Ethics Committee of Icesi University approved the study. The NEG adolescents were recruited from a specialized institution operated by the Colombian Family Welfare Institute (*Instituto Colombiano de Bienestar Familiar*-ICBF), which is focused on safeguarding children and adolescents facing threats to their rights. Specifically, they were enrolled in the "Support and strengthening of the family" modality within the Support Intervention and Daycare programs (Instituto Colombiano de Bienestar, 2017). These adolescents were under state legal protection due to documented neglect experiences, which were determined through a comprehensive multidisciplinary assessment, including medical, educational, psychosocial, and psychological evaluations of the adolescents. This assessment also included home visits and psychosocial assessments to parents or caregivers. While they continued to live within their family environment or support network in compliance with Colombian law, both the adolescents and their families were legally required to participate in the institution's psychosocial and specialized psychological intervention programs.

NEG adolescents were not enrolled in ICBF programs for institutionalization, homelessness, or placement in foster homes. They were neither exposed to other forms of early-life adversity, such as sexual or severe physical abuse, malnutrition, extreme poverty, child labor, or armed conflict (e.g., forced migration, antipersonnel mines, explosive devices, war actions, and terrorist attacks).

Control participants were raised with their families in typical caregiving environments. They had no history of childhood adversity, as reported by the school's counselors and teachers, and a screening interview with the participants and their parents individually. CN adolescents were recruited from public schools of the same geographical region and similar socioeconomic levels to the NEG adolescents. We did not directly inquire about socioeconomic status, but all participants were recruited from the public school system, which typically serves students from low to middle-income backgrounds in Colombia (OECD, 2016). All participants were attending school at the time of the study. They all had normal weight and size and were affiliated with a health care system. No subject reported a history of psychiatric, neurological, or neurodevelopmental disorders, intellectual (IQ < 85) or physical disabilities, or MRI contraindication. Both groups were also matched by age, sex, and educational level (Table 1).

There were significant differences between groups in executive functioning and intellectual levels (Table 1), as measured by the INECO Frontal Screening (IFS) battery (Torralva et al., 2009) and the prorated scores from the Wechsler Abbreviated Scale of Intelligence for Children–4th ed (Grizzle, 2011). Therefore, all between-group analyses included these scores as covariates (see Data Analysis section and measures details in Supplementary Material 1).

The presence of neglectful conditions was ascertained using the

Table 1
Demographic, maltreatment, and cognitive data.

	NEG (n = 27)	CN (n = 25)	NEG vs. CN Statistics
Demographics			
Age (years)	14.11 (1.40)	14.40 (0.96)	$t_{(50)} = 0.98$; $p = 0.331$[a]
Education (years)	7.85 (1.30)	7.84 (1.40)	$t_{(50)} = -0.03$; $p = 0.975$[a]
Sex (F: M)	15:12	14:11	$X^2_{(1)} = 0.02$; $p = 0.974$[b]
Neglect and abuse measures			
MNBS total score	50.48 (2.08)	25.96 (4.76)	$t_{(50)} = -24.40$; $p<0.001$***[a]
CTQ physical abuse	7.59 (2.90)	6.20 (1.78)	$t_{(50)} = -3.49$; $p = 0.001$**[a]
CTQ emotional abuse	9.48 (4.31)	6.20 (1.94)	$t_{(50)} = -2.07$; $p = 0.044$*[a]
Executive functioning and intellectual level			
IFS total score	21.70 (2.04)	23.80 (2.36)	$t_{(50)} = 3.44$; $p = 0.001$**[a]
WISC-IV total score	95.41 (4.15)	97.60 (3.99)	$t_{(50)} = 1.94$; $p = 0.058$[a]

Results are presented as mean (*SD*), except for sex. [a] *p*-value calculated via independent *t*-test (*t*). [b] *p*-value calculated via chi-squared test (χ^2). Significance coding: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. NEG: Neglected adolescents; CN: Control adolescents; MNBS-A: Multidimensional Neglectful Behavior Scale-Form A; CTQ-SF: Childhood Trauma Questionnaire Short Form; IFS: INECO Frontal Screening Battery; WISC-IV: Weschler Abbreviated Intelligence Scale for Children 4th ed.

Multidimensional Neglectful Behavior Scale-Form A (MNBS-A) (Straus et al., 1995). Adolescents exposed to severe abuse conditions were excluded from the study using the psychosocial and legal reports. Nonetheless, given the frequent co-occurrence of neglect and abuse within Latin populations (Fry et al., 2021), potential abuse conditions, explored through the physical and emotional abuse subscales of the Childhood Trauma Questionnaire Short-Form (CTQ-SF) (Bernstein et al., 2003), were included as covariates in all between-group analyses (see Data Analysis section and measures details in Supplementary Material 2).

2.2. Materials

2.2.1. Social cognition assessment

2.2.1.1. Basic emotional recognition. We used the facial emotional recognition (FER) test of the Mini Social Cognition and Emotional Assessment (MiniSEA) (Bertoux et al., 2012). Participants viewed static pictures from the Pictures of Affect Series (Ekman, 1976) and were required to identify the depicted emotional category from a forced-choice list comprising six response options: sadness, anger, fear, disgust, surprise, happiness, and neutral (see details in Supplementary Material 3).

2.2.1.2. Contextual emotional recognition. We employed the Emotion Evaluation Test (Part 1) of The Awareness of Social Inference Test (TASIT) (McDonald et al., 2003), adapted for Latin American contexts (Gonzalez-Gadea et al., 2014; Baez et al., 2017; Fittipaldi et al., 2020), to measure the recognition of spontaneous emotional expressions. Participants watched ten short video clips portraying one of five basic emotions (sadness, anger, fear, disgust, and surprise) and were asked to identify the portrayed emotion from a forced-choice list (see details in Supplementary Material 3).

2.2.1.3. Theory of mind. We used a short version (Olderbak et al., 2015) of the Reading the Mind in the Eyes Test (RMET) (Baron-Cohen et al., 1997, 2001), focusing on the ability to infer emotional states from the eye region of faces (see details in Supplementary Material 3).

2.2.1.4. Social emotions. We used a well-characterized (Baez et al., 2016a, 2018a; Gómez-Carvajal et al., 2020; Santamaría-García et al., 2017) computerized task to elicit envy and *Schadenfreude*. Participants were presented with 48 situations divided into two experimental blocks: (a) envy block, where participants read 18 sentences describing fortunate events happening to one of the two characters (e.g., She/He managed to get accepted at the university because she/he is the daughter/son of the dean), and (b) *Schadenfreude* block, where participants read 18 unfortunate events (e.g., She/He was discovered as being corrupt, and she/he was denounced) involving one of the characters. After each scenario, participants rated their intensity of displeasure (envy) or pleasure (*Schadenfreude*) on a visual analog Likert scale, ranging from 1 (low intensity) to 9 (high intensity). For control purposes, each block included 6 neutral events [e.g., She/He brushed her/his teeth this morning (see details in Supplementary Material 3)].

2.2.1.5. Empathy for pain. We used the empathy for pain task (Baez et al., 2012, Baez et al., 2014a, 2015, 2016b), previously employed in vulnerable populations (Gonzalez-Gadea et al., 2014; Baez et al., 2018b). This task features 25 animated scenarios involving intentional harm (e.g., striking someone with a bat), accidental harm (e.g., accidently hitting someone with a bike) and neutral situations (e.g., one person receiving a flower from another). After each scenario, participants rated five questions assessing the multidimensional nature of empathy, including cognitive, affective, and moral dimensions, which interact and operate simultaneously to shape the experience of empathy (Decety and Jackson, 2004). Affective components of empathy are foundational, while cognitive components are more complex and may rely on other abilities (Decety and Jackson, 2004). Moral reasoning entails a complex integration of both affective and cognitive facets of empathy (Hesse et al., 2016; Decety and Cowell, 2014; Decety et al., 2012). The specific questions included: (Gallotti and Frith, 2013) cognitive aspects: (a) intentionality comprehension assesses if the participant correctly understands the action's intention ("Was the action done on purpose?"); (Kilford et al., 2016) affective aspects: (b) empathic concern, an other-oriented sensitivity to others' suffering and motivation to improve their welfare (Singer and Klimecki, 2014), is measured through the participant's capacity to emotionally resonate with the victim ("How sad do you feel for the victim?"); (c) degree of discomfort, a self-oriented emotional response to others' suffering (Singer and Klimecki, 2014), is assessed through the participant's personal distress or discomfort in response to the scenario ("How upset do you feel for the situation?"); and (Atzil et al., 2018) moral evaluation aspects: (d) judgment of the perpetrator's behavior addresses the moral judgement of the situation by asking the participant to assess the perpetrator's actions ("How bad is the person who did the action?") and (e) punishment, assesses the participant's sense of justice by inquiring about the deserved consequence ("How much penalty does the action deserve?"). Intentionality comprehension was answered with Yes/No, scoring 1 point for correct answers. The other questions were rated on a visual analog scale from −9 to 9 (see details in Supplementary Material 3).

2.2.2. Neuroimaging acquisition and preprocessing

A subsample of 26 NEG and 23 CN adolescents underwent structural MRI. The resulting samples remained demographically matched (Supplementary Table S1). Using a 3T Magnetom Skyra Intera scanner with a 32-channel/standard head coil, we acquired a whole-brain 3D T1-weighted spin echo volumes parallel to the plane connecting the anterior and posterior commissures and covering the whole brain tissue, with the following parameters: TR = 2200 ms; TE = 2.45 ms; flip angle = 8°; FOV = 192 mm; matrix size = 256 × 256; 160 axial slices; voxel size = 1 mm^3 isotropic.

MRI acquisition and preprocessing followed the Organization for Human Brain Mapping (OBHM) recommendations (Nichols et al., 2017). VBM preprocessing was performed in CAT12 Toolbox (https://neuro-jena.github.io/cat/), using SPM12 running on MATLAB (2023b). First, all images were visually inspected for artifacts and gross anatomical abnormalities. Given the specific requirements of our pediatric sample, we adapted the CAT12 pipeline following standard recommendations (https://neuro-jena.github.io/cat12-help/). This involved using customized tissue probability maps and DARTEL templates generated through the CerebroMatic Toolbox (Wilke et al., 2017). These templates were generated by entering variables such as age, sex, and scanner field strength of our dataset. Specifically, the CerebroMatic toolbox uses a "matched pairs (1:1)" approach to create brain templates that align precisely with our dataset's demographic characteristics and scanner technical details. This approach ensures that the templates are well suited for analyzing younger brains (Wilke et al., 2017), which vary significantly from adult brains (Brain Development Cooperative Group, 2012; Ziegler et al., 2012).

Following the generation of these matched templates, we proceeded with the standard preprocessing steps of the CAT12 pipeline, including tissue segmentation, spatial normalization and modulation. After preprocessing, the images were inspected for poor quality or incorrect preprocessing. Subsequently, total intracranial volume (TIV), comprising the sum of the GM, white matter, and cerebrospinal fluid, was extracted using the CAT12 estimation module. Finally, modulated normalized GM outputs were smoothed using a 6-mm full-width-at-half-maximum isotropic Gaussian kernel in the SPM12 smooth module. The kernel size was selected based on previous recommendations (https://neuro-jena.github.io/cat12-help/) and studies on children, adolescents (Li et al., 2022b; Ankeeta et al., 2021; Yu et al., 2012;

Cornwell et al., 2023) and adults (Ge et al., 2021; Guo et al., 2020). The smoothed outputs were then used in the second-level analysis to perform the correspondent statistics (see VBM analysis section).

2.3. Data analysis

2.3.1. Behavioral data analysis

Demographic, IQ, and EF data were compared among groups using independent *t*-test and Chi-squared test (X^2) as needed. Social cognition data were analyzed via ANCOVA, with physical and emotional abuse (CTQ scores) as covariates to control for abuse effects. Empathy for pain data was analyzed using mixed-effects ANCOVA, with group as a between-subject factor, condition (intentional, accidental, and neutral) as a within-subject factor, and the same abuse (CTQ scores) covariates. Bonferroni pairwise comparisons were used as *post-hoc* tests when required.

Subsequently, significant between-group differences in social cognition outcomes were replicated by covarying for EF (IFS total score) and IQ (WISC total score) in separate analyses. The first analyses included physical and emotional abuse (CTQ scores) and IFS total scores as covariates. The second one involved physical and emotional abuse (CTQ scores) and WISC total scores as covariates. All statistical tests were two-sided. Effect sizes were calculated through partial eta-squared (η_p^2) for main and interaction effects and Cohen's *d* for pairwise comparisons.

Additionally, we conducted separate multiple linear regression analyses to explore the relationship between neglect and abuse and social cognition outcomes in all participants. All regression models included neglect (MNBS total scores as a continuous variable) and physical and emotional abuse (CTQ scores) as predictors and the social cognition measures yielding significant differences between groups (TASIT, RMET, envy and *Schadenfreude* ratings, empathic concern and discomfort ratings in intentional and accidental situations and judgment of the perpetrator's behavior in intentional scenarios) as dependent variables. We report the R^2 and the standardized β coefficients as indicators of the model's goodness-of-fit and the strength of the associations between the predictors and outcome variables. Alpha was set at 0.05 for all analyses. All behavioral analyses were conducted on JASP package version 17.3.

2.3.2. VBM analysis

We conducted multiple regression analyses to explore the relationship between whole-brain GM volume and social cognition outcomes using the CAT12 regression module. These analyses were performed in each participant group separately. The models included as predictors only the social cognition measures that yielded significant differences between groups in our preliminary behavioral analyses, namely: (a) TASIT, (b) RMET, (c) envy ratings, (d) *Schadenfreude* ratings, (e) empathic concern in intentional situations, (f) empathic concern in accidental situations, (g) discomfort ratings in intentional situations, (h) discomfort ratings in accidental situations, and (i) judgment of the perpetrator's behavior in intentional situations. Thus, nine separate regression analyses were conducted for each group. All analyses included TIV as a covariate of no interest to control for differences in head size. Consistent with our directional hypotheses, we applied T contrasts to assess the predicted positive or negative associations [https://neuro-jena.github.io/cat12-help/#contrasts (Jenkinson et al., 2020)] between GM volume and each social cognition domain. Positive associations were tested for TASIT, RMET, empathic concern and discomfort ratings in intentional and accidental situations, and judgment of the perpetrator's behavior in intentional situations, using the contrast [0 1 0]. Negative associations were tested for envy and *Schadenfreude* ratings using the contrast [0–1 0]. In these contrasts, the zeros referred to the constant and TIV, respectively, while the one represented the specific social cognition measure under examination.

Due to our study's modest sample size and exploratory nature, statistical significance was set at $p < 0.001$, uncorrected for multiple comparisons, with an extent threshold of ≥30 voxels, consistent with previous VBM studies (Santamaría-García et al., 2017, 2019; de la Fuente et al., 2019; García-Cordero et al., 2016; Sedeno et al., 2017). This threshold avoids the detrimental effects of liberal primary thresholds on false positives. Neuroimaging simulation studies recommend using a $p < 0.001$ as a conservative lower limit and stricter thresholds or correction methods for highly powered studies (Woo et al., 2014). Other simulation studies suggest even more liberal uncorrected thresholds ($p < 0.005$ with 20-voxels extent) to achieve a balance between Type I and II error rates, potentially comparable to an FDR correction of $p = 0.05$ (Lieberman and Cunningham, 2009). Results were visualized using the xjView toolbox (https://www.alivelearn.net/xjview), and the brain regions were labeled according to the Automated Anatomical Labeling (AAL3) atlas (Rolls et al., 2020).

3. Results

3.1. Behavioral results

3.1.1. Comparisons between groups covarying for abuse measures

3.1.1.1. Basic and contextual emotional recognition. NEG adolescents scored significantly lower than CN in contextual emotional recognition [$F_{(1,48)} = 9.99$, $p = 0.003$, $\eta_p^2 = 0.17$] (Fig. 1A), but there were no differences between groups in basic emotional recognition [$F_{(1,48)} = 0.42$, $p = 0.521$, $\eta_p^2 = 0.01$].

3.1.1.2. Theory of mind. NEG adolescents performed significantly lower than CN in ToM [$F_{(1,48)} = 9.55$, $p = 0.003$, $\eta_p^2 = 0.17$] (Fig. 1B).

3.1.1.3. Social emotions. Compared to CN, NEG adolescents exhibited significantly higher envy [$F_{(1,48)} = 13.09$, $p < 0.001$, $\eta_p^2 = 0.21$] and *Schadenfreude* [$F_{(1,48)} = 11.45$, $p < 0.001$, $\eta_p^2 = 0.19$] ratings (Fig. 1C and D, respectively). However, the groups did not significantly differ in their neutral ratings [$F_{(1,48)} = 1.25$, $p = 0.268$, $\eta_p^2 = 0.03$].

3.1.1.4. Empathy for pain. Empathic concern outcomes revealed a significant group-by-condition interaction [$F_{(2,92)} = 6.84$, $p = 0.002$, $\eta_p^2 = 0.06$]. Bonferroni *post-hoc* comparisons showed that NEG adolescents reported significantly lower empathic concern in intentional ($p = 0.001$, $d = 1.28$) and accidental ($p < 0.001$, $d = 1.55$) situations than CN (Fig. 1E).

Degree of discomfort analysis yielded a significant group-by-condition interaction [$F_{(2,92)} = 4.88$, $p = 0.010$, $\eta_p^2 = 0.45$]. Bonferroni *post-hoc* comparisons indicated that NEG adolescents exhibited significantly lower discomfort ratings in intentional ($p < 0.001$, $d = 1.36$) and accidental ($p < 0.001$, $d = 1.40$) situations compared to CN (Fig. 1F).

Behavior of perpetrator outcomes revealed a significant group-by-condition interaction [$F_{(2,92)} = 4.93$, $p = 0.009$, $\eta_p^2 = 0.05$]. Bonferroni *post-hoc* comparisons revealed that NEG adolescents judged the perpetrators' behavior in intentional situations significantly less bad than CN ($p = 0.021$, $d = 1.04$) (Fig. 1G).

No main effects of condition and group or interaction effects were observed for intentionality comprehension (all *p*-values >0.28). Punishment ratings analysis revealed a main effect of condition [$F_{(2,90)} = 21.066$, $p < 0.001$, $\eta_p^2 = 0.21$]. As expected, Bonferroni *Post-hoc* comparisons revealed that, across groups, participants assigned significantly harsher punishments in intentional situations compared to accidental ($p_{\text{bonf}} < 0.001$, $d = 2.670$) and neutral ($p_{\text{bonf}} < 0.001$, $d = 4.332$) scenarios. They also gave significantly harsher punishments in accidental situations than neutral ones ($p_{\text{bonf}} < 0.001$, $d = 1.662$).

3.1.2. Comparisons between groups covarying for executive and intellectual functioning

All significant results remained consistent after covariation with EF

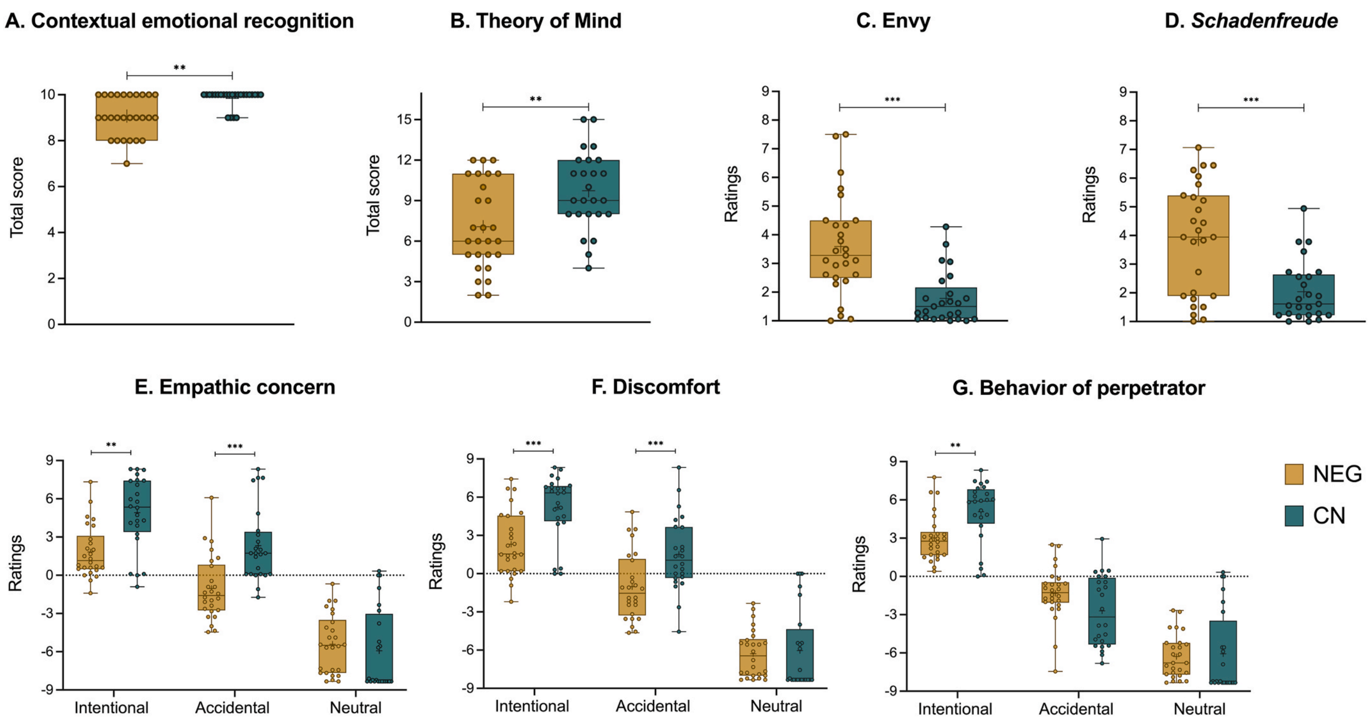

Fig. 1. Behavioral results. NEG adolescents exhibited lower performance in contextual emotional recognition and theory of mind, higher envy and *Schadenfreude* ratings, reduced empathic concern and discomfort in intentional and accidental situations, and a more lenient judgment of the perpetrator's behavior in intentional situations than CN. All results remained consistent after controlling for physical and emotional abuse and executive and intellectual functioning. NEG: Neglected adolescents; CN: Control adolescents. Significance coding: *$p < 0.05$; **$p < 0.01$; ***$p < 0.001$.

and IQ outcomes (Supplementary Material 4).

3.1.3. Associations between neglect, abuse and social cognition measures

All models were significant, and in all of them, neglect but not physical and emotional abuse was a significant predictor (Supplementary Material 5).

3.2. VBM results

3.2.1. Contextual emotional recognition

In the NEG group, contextual emotional recognition performance was positively associated with GM volumes in the cerebellum (left Crus I and Lobule III of the vermis), the left inferior temporal gyrus, and the right anterior cingulate cortex. In contrast, contextual emotional recognition performance in the CN adolescents positively correlated with GM volumes in the left superior frontal gyrus (Fig. 2 and Supplementary Table S2).

3.2.2. Theory of mind

ToM performance was positively associated with GM volumes in the left temporal (middle and inferior temporal gyri) and the right anterior cingulate cortex in the NEG group and the right frontal cortex (supplementary motor area and precentral gyrus) in the CN group (Fig. 2 and Supplementary Table S3).

3.2.3. Social emotions

Envy ratings were negatively associated with GM volumes in the right lingual gyrus in the NEG group. In the CN group, envy ratings were negatively related to GM volumes in the right occipital (middle occipital gyrus), right parietal (superior and inferior parietal gyri), and left temporal (superior temporal gyrus) areas (Fig. 2 and Supplementary Table S4). Additionally, *Schadenfreude* ratings were negatively related to GM volumes in the right cerebellum in the NEG group and the right inferior temporal gyrus in the CN group (Fig. 2 and Supplementary Table S5).

3.2.4. Empathy for pain

In the NEG group, empathic concern ratings in intentional situations were positively associated with GM volumes in bilateral frontal (right precentral gyrus, bilateral middle frontal gyrus, and left orbitofrontal gyrus), left parietal (left superior parietal gyrus), right temporal (parahippocampus) and right cerebellar (Crus I) regions, and left anterior cingulate cortex. In contrast, in the CN adolescents, these ratings were negatively associated with GM volumes in the right middle occipital gyrus (Fig. 2 and Supplementary Table S6). In the NEG adolescents, empathic concern ratings in accidental situations were positively associated with GM volumes in the left parietal (superior parietal gyrus), bilateral frontal (bilateral posterior orbitofrontal gyri and right precentral gyrus), right temporal (parahippocampus), and cerebellar regions (IV–V of vermis). Conversely, in the CN group, these ratings were positively associated with GM volumes in the right cuneus (Fig. 2 and Supplementary Table S7).

In the NEG group, discomfort ratings in intentional situations were positively associated with GM volumes in the left frontal (medial orbitofrontal and middle frontal gyrus), left parietal (superior parietal gyrus), and right temporal (temporal pole superior part) regions. No significant associations emerged in the CN group (Fig. 2 and Supplementary Table S8). In the NEG adolescents, discomfort ratings in accidental situations were positively associated with GM volumes in the left superior parietal gyrus, the right temporal pole, and bilateral orbitofrontal areas (right lateral and left posterior orbital gyri). Contrarily, in the CN group, these ratings were associated with bilateral temporal regions (right inferior and left middle temporal gyri and right parahippocampus) and the right anterior cingulate cortex (Fig. 2 and Supplementary Table S9).

The judgment of the perpetrator's behavior in intentional situations was positively associated with GM volumes in the left superior parietal gyrus and bilateral frontal regions (right precentral gyrus, left posterior

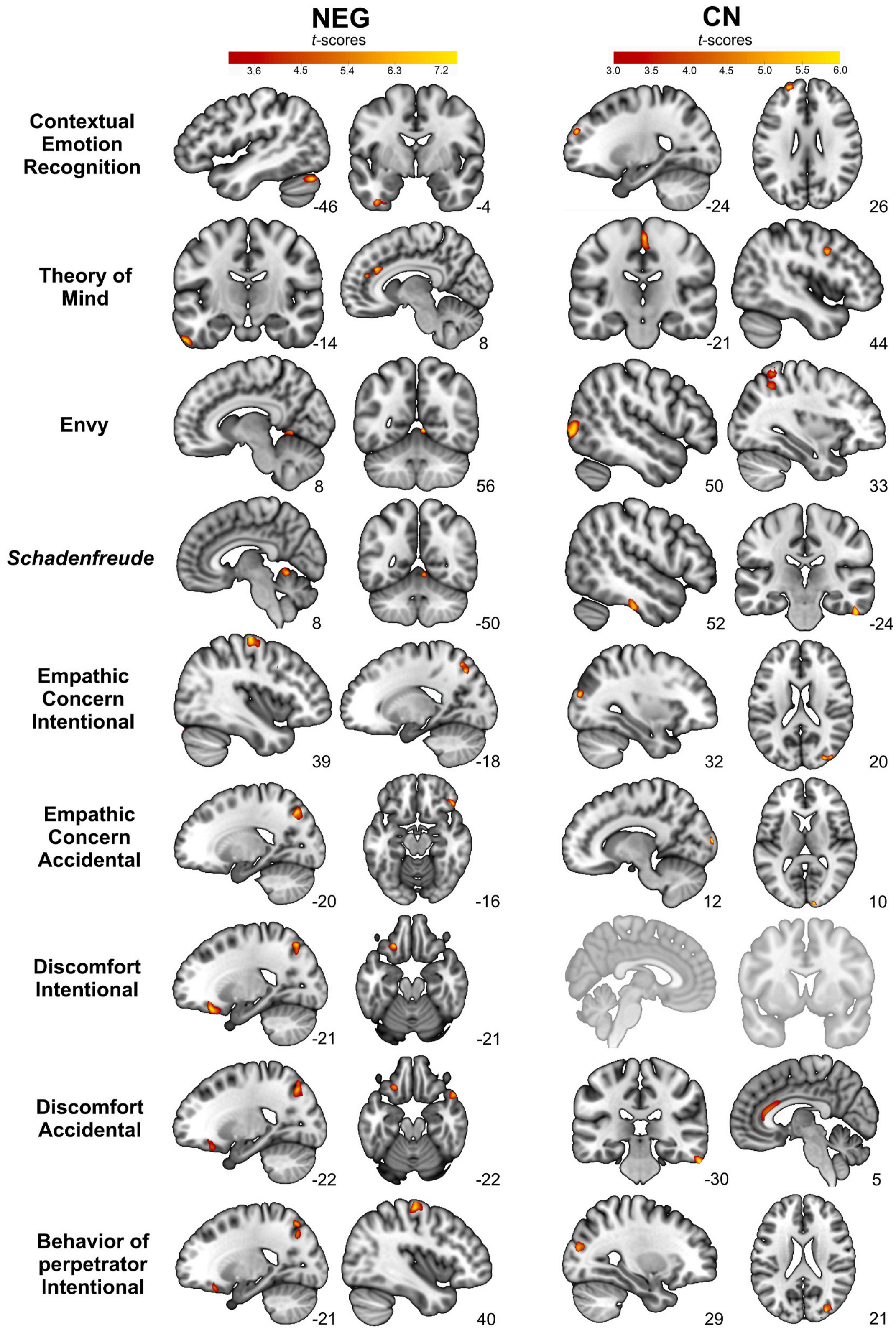

Fig. 2. Associations between grey matter volumes and social cognition domains. Each group was analyzed separately to identify brain regions associated with social cognition scores ($p < 0.001$, uncorrected, extent threshold = 30 voxels). In NEG adolescents, positive associations were observed between contextual emotional recognition and cerebellar, temporal, and anterior cingulate regions; ToM and temporal and anterior cingulate areas; empathic concern, discomfort, and judgment of perpetrator's behavior and parietal and frontal regions. Envy and *Schadenfreude* ratings negatively correlated with occipital and cerebellar volumes. In CN adolescents, positive associations emerged between contextual emotional recognition and ToM and frontal areas; empathic concern and judgment of perpetrator's behavior and occipital regions; and discomfort and temporal and anterior cingulate cortices. No significant associations emerged for discomfort ratings in intentional situations. Negative associations were found between envy and occipital, parietal and temporal cortices and *Schadenfreude* and inferior temporal cortex. Results are presented on MNI space using the AAL atlas and in neurological convention. Brain results were plotted using MRIcroGL. NEG: Neglected adolescents; CN: Control adolescents.

orbital gyrus, and left middle frontal gyrus) in the NEG group and the right middle occipital gyrus in the CN group (Fig. 2 and Supplementary Table S10).

4. Discussion

This study aimed to comprehensively assess social cognition processes (recognition of basic and contextual emotions, ToM, the experience of envy and *Schadenfreude* and empathy for pain) and their neuroanatomical correlates in adolescents with histories of neglect. Compared to CN, the NEG adolescents exhibited lower contextual emotional recognition and ToM performance, higher levels of envy and *Schadenfreude,* and diminished empathy. Physical and emotional abuse and executive or intellectual functioning did not explain these effects. Social cognition scores correlated with brain volumes in regions subserving social cognition and emotional processing. These results highlight the potential impacts of neglect on different aspects of social cognition during adolescence.

4.1. Behavioral results

NEG adolescents exhibited a lower contextual emotional recognition performance than CN. In contrast to previous studies, we adopted a more holistic approach employing a task introducing contextual cues such as prosody, facial expressions, and gestures (Gonzalez-Gadea et al., 2014; Baez et al., 2017; Fittipaldi et al., 2020). Our results confirm the heightened sensitivity of ecological tasks in revealing emotional-contextual processing deficits in vulnerable adolescents (Gonzalez-Gadea et al., 2014; Santamaría-García et al., 2019) and indicate that enduring neglectful parenting hinders emotional recognition and contextual cues processing, which are essential for everyday social interactions.

No significant group differences emerged in the decontextualized facial emotion recognition task. This finding contrasts with previous research indicating impairments in facial recognition of basic emotions among neglected populations (Pears and Fisher, 2005; Marta et al., 2018; Sullivan et al., 2010; Fries and Pollak, 2004; Pollak et al., 2000). Such discrepancy may stem from variations in sample characteristics, as prior studies primarily focused on children (Pears and Fisher, 2005; Sullivan et al., 2010; Fries and Pollak, 2004; Pollak et al., 2000) placed in foster care settings (Pears and Fisher, 2005; Fries and Pollak, 2004) and lacked control groups (Marta et al., 2018). Moreover, some of these studies used alternative forms of stimuli, such as line drawings of faces (Pears and Fisher, 2005) or vignettes (Pollak et al., 2000), instead of real facial expressions. Additionally, the aggregation of emotional recognition measures into composite scores in previous studies may obscure specific impairments in facial emotion recognition (Pears and Fisher, 2005; Sullivan et al., 2010). Thus, our findings suggest that the ability to recognize facial emotions remains conserved in NEG adolescents, possibly influenced by family-rearing contexts or increased extra-familial relationships. Alternatively, this ability might gradually normalize during adolescence. Future longitudinal studies should further explore this explanation.

Furthermore, NEG adolescents demonstrated lower ToM performance than CN, consistent with prior research on adverse experiences affecting ToM skills in childhood (Pears and Fisher, 2005; Benarous et al., 2015) and adolescence (Burack et al., 2006; Baez et al., 2018b). While the specific effects of different forms of maltreatment remain unclear (Benarous et al., 2015), emerging evidence suggests that neglect during critical developmental stages can indeed impair ToM abilities (Pears and Fisher, 2005; Benarous et al., 2015). Insufficient attachment security and parental sensitivity are necessary for ToM development (Fonagy et al., 1997; Symons and Clark, 2000). Considering the enduring effects of these adverse experiences on ToM into adulthood (Germine et al., 2015) and their potential contribution to externalizing psychopathology risk (Heleniak and McLaughlin, 2020), future longitudinal studies incorporating psychopathology measures are needed.

Regarding social emotions, NEG adolescents reported higher envy and *Schadenfreude* ratings than CN. This is the first study to tackle these specific social emotions in neglected adolescents. Our findings align with previous studies highlighting an increased dispositional and malicious envy (Xiang et al., 2018; Zhao et al., 2020) and reduced self-conscious social emotions (Docherty et al., 2018) in youths with maltreatment experiences. Moreover, given the counter-empathic nature of envy and *Schadenfreude* (Cikara and Fiske, 2011, 2013; Ortony et al., 1988), our findings converge with prior research demonstrating diminished empathy in neglected adolescents (Zhang et al., 2023; Moreno-Manso et al., 2018). Considering the potential effect of envy and *Schadenfreude* on hindering prosocial attitudes (Yu et al., 2018) and fostering aggression (He and Xiang, 2021), competition, and rivalry (Steinbeis and Singer, 2013), our results suggest that neglect may disrupt daily social exchanges and hinder the typical transition from familial to peer relationships during adolescence (Kilford et al., 2016). Future studies should explore the association between the experience of social emotions and social functioning in neglected adolescents.

Notably, neutral ratings were similar between groups, validating our task design and confirming that participants, regardless of their background, understood and engaged with the task effectively. Such baseline equivalence in neutral ratings and the lack of effect of executive or intellectual functioning on the emotional ratings suggests that the increased levels of envy and *Schadenfreude* in NEG adolescents are not associated with cognitive discrepancies but rather with the specific emotional impact of neglect.

In the affective dimension of empathy, NEG adolescents exhibited lower empathic concern and discomfort for intentional and accidental harms compared to CN. These components of empathy —empathic concern as other-focused sensitivity and discomfort as a self-focused response to another's suffering (Singer and Klimecki, 2014)—are crucial in motivating and inhibiting prosocial behaviors, respectively (Eisenberg, 2000). Neglect undermines empathic concern more than other dimensions of empathy (Zhang et al., 2023), thereby diminishing prosocial behaviors in youths (Chen et al., 2023). In addition, neglect may affect empathic distress differently than other forms of maltreatment, and empathy-accuracy tasks may better capture empathic distress responses than subjective report methods. In the moral dimension of empathy, NEG adolescents judged the perpetrator as less wrong in intentional painful situations than CN, resembling prior findings of moral sensitivity impairments in socially deprived adolescents (Escobar et al., 2014; Baez et al., 2018b). Converging evidence has also linked youths' maltreatment experiences (Wang et al., 2017) and weak attachment (Bao et al., 2015; Hyde et al., 2010) with moral disengagement in adolescents. Overall, the observed pattern of impaired affective and moral dimensions of empathy in NEG adolescents may underlie the increased aggression (Ran et al., 2023) and callous-unemotional traits (Todorov et al., 2023) consistently observed in this population. Future studies should explore the association between affective and moral empathy, aggression, and antisocial behavior in neglected adolescents.

Our results underscore the potential impact of neglect on various facets of social cognition during adolescence. Although we did not directly assess social functioning, our findings may suggest that such deficits likely contribute to common social challenges in neglected adolescents, such as poor relationship quality, friendship difficulties, deviant peer affiliations and increased aggression (Haslam and Taylor, 2022; Maguire et al., 2015; Logan-Greene and Semanchin Jones, 2015). Contextual emotion recognition and ToM deficits can impair effective communication and social understanding (Kennedy and Adolphs, 2012), while diminished empathy and increased envy and *Schadenfreude* may inhibit prosocial behaviors (Yu et al., 2018) and promote aggression (He and Xiang, 2021). For instance, perspective-taking and empathy skills mediate the relationship between childhood maltreatment and both prosocial behavior and moral disengagement (Chen et al., 2023; Yu et al., 2020; Fang et al., 2020). Future studies should include direct social functioning measures to confirm this proposed theoretical pathway.

Given these potential implications, assessment and interventional approaches targeting social cognition could benefit neglected adolescents. Integrating social cognition tasks into neuropsychological standard evaluations is crucial. Moreover, incorporating modules targeting social-cognitive skills into evidence-based interventions, such as trauma-focused cognitive behavioral therapy (Dorsey et al., 2017), could be advantageous. Other social behavioral interventions, such as didactic instruction, social modeling, skill practice and reinforcement, may be useful to improve social cognition and functioning in adolescents (Darling et al., 2021). Finally, meditation-based interventions (Valk et al., 2017), which enhance socio-cognitive abilities and induce structural changes in socio-cognitive brain networks in young adults, might also be considered.

4.2. Relationship between GM volumes and social cognition domains

Contextual emotional recognition scores in NEG adolescents positively correlated with GM volumes in regions involved in emotional processing (Sabatinelli et al., 2011; Pierce et al., 2022). The cerebellum is involved in recognizing emotional facial expressions and intonation (Keren-Happuch et al., 2014; Stoodley and Schmahmann, 2009) and discriminating emotional body expressions and gestures (Ferrari et al., 2022). The inferior temporal gyrus is consistently involved in perceiving emotional faces and scenes (Sabatinelli et al., 2011), while the anterior cingulate cortex contributes to emotional scene perception (Sabatinelli et al., 2011), context processing (Maren et al., 2013), and assessing the salience of emotional information (Bush et al., 2000). In the CN group, contextual emotional recognition scores were positively associated with GM volumes in the left superior frontal gyrus, involved in high-order processes in response to complex environmental changes (Ramnani and Owen, 2004) and social cognition processes (Wolf et al., 2010).

Furthermore, in NEG adolescents, ToM performance correlated positively with GM volumes in regions involved in mentalizing. The middle and inferior temporal gyri are consistently associated with mentalizing abilities in adolescents (Fehlbaum et al., 2022) and are particularly engaged in affective ToM tasks like the RMET (Schurz et al., 2014). The anterior cingulate cortex, a key hub for representing self and other mental states (Abu-Akel and Shamay-Tsoory, 2011), is also recruited in various ToM tasks (Molenberghs et al., 2016). In the CN group, ToM scores positively correlated with GM volumes in the right supplementary motor area and precentral gyrus. These regions are involved in affective mentalizing processes (Molenberghs et al., 2016; Arioli et al., 2021), suggesting embodied simulation mechanisms to understand other's mental and affective states (Gallese et al., 2004; Keysers and Gazzola, 2007).

Consistent with the visual and contextual nature of the task, higher envy ratings among NEG adolescents were associated with reduced GM volumes in the right lingual gyrus (Michl et al., 2014). Similarly, envy ratings in the CN group were negatively related to GM volumes in the right middle occipital gyrus. In addition, in the CN group, envy ratings correlated with the right superior and inferior parietal cortices and left superior temporal gyrus. The superior parietal cortex is implicated in processing displeasure in response to positive events experienced by envy targets (Cikara and Fiske, 2011), while the inferior parietal cortex is engaged in social status inference and comparisons (Chiao, 2010; Chiao et al., 2009), which are relevant to the experience of envy (Jankowski and Takahashi, 2014). *Schadenfreude* ratings in NEG adolescents were negatively related to GM volumes in the right cerebellum, involved in the experience of emotion (Pierce et al., 2022) and social cognition tasks (Van Overwalle et al., 2014). These results converge with previous studies linking *Schadenfreude* to mentalizing and perspective-taking abilities (Baez et al., 2018a; Shamay-Tsoory et al., 2007). In the CN group, *Schadenfreude* ratings were negatively associated with GM volumes in the right inferior temporal gyrus, engaged in processing other social emotions [e.g., gratitude (Zahn et al., 2014)] and social status signals (Chiao et al., 2009), and mentalizing and empathy processes relevant to the experience of *Schadenfreude* (Arioli et al., 2021).

Empathic concern ratings in NEG adolescents were positively associated with GM in regions involved in empathy or social cognition. The superior parietal and precentral gyri have been linked to prosocial behaviors in adolescents (Schreuders et al., 2019). These regions are also involved in observing painful stimuli (Benuzzi et al., 2008) and, imitating actions (Molenberghs et al., 2009) and empathic responses to painful and non-painful negative affective states (Timmers et al., 2018), respectively, suggesting putative simulation mechanisms (Gallese et al., 2004; Keysers and Gazzola, 2006). The orbitofrontal gyrus is a key component of the empathy network (Decety, 2011), serving as a specific neural marker for empathic care (Ashar et al., 2017). The cerebellum is engaged in processing the experience of pain and empathy for pain (Singer et al., 2004), while the parahippocampus is involved in processing compassion feelings (Moll et al., 2007) and exhibits increased cortical thickness following compassion training (Valk et al., 2017). Empathic concern in NEG adolescents was positively associated with GM in the right anterior cingulate cortex and right middle frontal gyrus, exclusively in intentional situations. The anterior cingulate cortex has been consistently involved in empathy for pain tasks and the direct experience of pain (Lamm et al., 2011; Fan et al., 2011). The middle frontal gyrus, encompassing the dorsolateral prefrontal cortex, modulates empathic affective responses to observed pain (Wang et al., 2014; Rêgo et al., 2015), likely through cognitive appraisal and emotion regulation mechanisms (Ochsner et al., 2012). In CN adolescents, empathic concern ratings positively correlated with GM volumes in the right middle occipital gyrus and right cuneus, consistent with the visual nature of our task and the involvement of the occipital cortex in the visual processing of emotional scenes (Sabatinelli et al., 2011) and painful stimuli (Baez et al., 2018a).

Discomfort ratings in the NEG group positively correlated with GM volumes in regions associated with affective empathy or empathy for pain, including in the bilateral orbitofrontal cortex (left posterior and medial, and right lateral) (Molenberghs et al., 2009; Decety, 2011; Wang et al., 2014; Rêgo et al., 2015; Rolls, 2023) and the superior temporal pole (Lamm et al., 2011). Furthermore, there was an association with the left superior parietal gyrus, consistently implicated in mentalizing (Schurz et al., 2014). In the CN group, discomfort ratings in accidental situations positively correlated with GM volumes in the middle and inferior temporal gyri, recruited in empathy for pain (Lamm et al., 2011) and emotional situations (Ding et al., 2020). There were also associations with other regions involved in processing pain-related stimuli directed at others, such as the parahippocampus (Wagner et al., 2020) and the anterior cingulate cortex (Lamm et al., 2011; Fan et al., 2011).

In the NEG adolescents, the judgment of the perpetrator's behavior in intentional situations was positively associated with GM volumes in the left superior parietal gyrus, right precentral gyrus, left posterior orbital gyrus, and left middle frontal gyrus. The superior parietal and middle frontal gyri contribute to the cognitive control and problem-solving skills essential for moral reasoning (Boccia et al., 2017; Fumagalli and Priori, 2012). The orbitofrontal gyrus is consistently engaged in various morality tasks (Eres et al., 2018), likely through encoding value-based representations (Rolls, 2023) and integrating internal signals with emotional and social cues (Adolfi et al., 2017). The precentral gyrus is involved in moral judgment tasks demanding higher emotional involvement and automatic emotional responses (Boccia et al., 2017). In the CN group, these ratings positively correlated with GM in the right middle occipital gyrus, aligning with the task's demands and its role in moral picture viewing in adolescents (Harenski et al., 2012).

4.3. Limitations and future directions

Some limitations of our study should be considered. First, our sample size was relatively small, although comparable to previous studies (Maheu et al., 2010; Van Schie et al., 2017; Baez et al., 2018b). Second, our use of self-reported maltreatment measures, inherently subjective and retrospective, is a common challenge in this research area. However, our sample selection was primarily based on legal protection for verified neglect, which involved comprehensive multidisciplinary assessments of adolescents and caregivers and interviews with parents and educators for the control group. Third, neglect can overlap with abuse and other forms of violence. We addressed this limitation by rigorously excluding adolescents exposed to severe physical and/or sexual abuse and other forms of violence and adjusting our analyses accordingly. Fourth, the cross-sectional design of our study precludes establishing a causal link between neglect and social cognition. Therefore, future longitudinal or comparative studies across age ranges and larger samples should corroborate our findings. Fifth, since our study did not include measures of social functioning, future studies should examine the interplay between social cognition and social functioning in neglected adolescents. Lastly, given our study's modest sample size and exploratory nature, VBM results were reported using uncorrected statistical thresholds ($p < 0.001$, uncorrected). Nonetheless, neuroimaging simulation studies recommend using a $p < 0.001$ as a conservative lower limit and stricter thresholds or correction methods for highly powered studies (Woo et al., 2014). Other simulation studies suggest even more liberal uncorrected thresholds ($p < 0.005$ with 20 voxels extent) for balancing Types I and II error rates that may be comparable to an FDR correction of $p = 0.05$ (Lieberman and Cunningham, 2009). Moreover, this approach aligns with previous VBM studies (Santamaría-García et al., 2017, 2019; de la Fuente et al., 2019; García-Cordero et al., 2016; Sedeno et al., 2017). Still, future highly powered studies employing stricter thresholds or multiple correction methods should confirm these results.

5. Conclusion

The present results showed that, compared to CN, NEG adolescents exhibited lower contextual emotional recognition and ToM performance, higher levels of envy and *Schadenfreude* and diminished empathy. Physical and emotional abuse and executive or intellectual functioning did not explain these effects. Social cognition scores correlated with brain volumes in regions subserving social cognition and emotional processing. These findings suggest that NEG exposure involves social cognition impairments, potentially resulting in difficulties in social interaction. Given the crucial role of social cognition in successful social functioning, these impairments should be considered in the assessment and treatment of neglect.

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Availability of data and materials

The data supporting this study's findings are available from the corresponding authors upon reasonable request.

Ethics approval and consent to participate

All participants and caregivers provided signed informed consent in accordance with the Declaration of Helsinki. The ethics committee of Icesi University approved this study.

Consent for publication

Not applicable.

CRediT authorship contribution statement

Catalina Trujillo-Llano: Writing – review & editing, Writing – original draft, Visualization, Investigation, Formal analysis. **Agustín Sainz-Ballesteros:** Writing – original draft, Formal analysis. **Fabián Suarez-Ardila:** Visualization, Formal analysis, Data curation. **María Luz Gonzalez-Gadea:** Writing – review & editing. **Agustín Ibáñez:** Writing – review & editing, Methodology, Conceptualization. **Eduar Herrera:** Writing – review & editing, Resources, Project administration, Methodology, Conceptualization. **Sandra Baez:** Writing – review & editing, Writing – original draft, Supervision, Formal analysis.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ynstr.2024.100642.

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