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EMPIRICAL ARTICLE

Transcendent thinking counteracts longitudinal effects of mid-adolescent exposure to community violence in the anterior cingulate cortex

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Abstract
Adolescence involves extensive brain maturation, characterized by social sensitivity and emotional lability, that co-occurs with increased independence. Mid-adolescence is also a hallmark developmental stage when youths become motivated to reflect on the broader personal, ethical, and systems-level implications of happenings, a process we term transcendent thinking. Here, we examine the confluence of these developmental processes to ask, from a transdisciplinary perspective, how might community violence exposure (CVE) impact brain development during mid-adolescence, and how might youths' dispositions for transcendent thinking be protective? Fifty-five low-SES urban youth with no history of delinquency (32 female; 27 Latinx, 28 East Asian) reported their CVE and underwent structural MRI first at age 14–18, and again 2 years later. At the study's start, participants also discussed their feelings about 40 minidocumentaries featuring other teens' compelling situations in a 2-h private interview that was transcribed and coded for transcendent thinking. Controlling for CVE and brain structure at the start: (1) New CVE during the 2-year inter-scan interval was associated with greater gray matter volume (GMV) reduction over that interval in the anterior cingulate cortex (ACC), a central network hub whose reduced volume has been associated with posttraumatic stress disorder, and across multiple additional cortical and subcortical regions; (2) participants' transcendent thinking in the interview independently predicted greater GMV increase during the 2-year inter-scan interval in the ACC. Findings highlight the continued vulnerability of mid-adolescents to community violence and the importance of supporting teens' dispositions to reflect on the complex personal and systems-level implications and affordances of their civic landscape.

KEYWORDS
adolescent brain development, environmental stressor, social cognition

INTRODUCTION

Community violence exposure (CVE) is a form of chronic social stress and a significant public health issue for many urban youths (Margolin & Gordis, 2000; Stein et al., 2003), especially for those living in lower SES communities (Buka et al., 2001). Exposure to community violence has been linked in childhood and adolescence with poorer cognitive outcomes (Butler et al., 2018; Sharkey, 2010), behavioral issues such as more aggression and juvenile justice involvement (Gorman-Smith & Tolan, 1998; Voisin, 2013), neurological effects (Butler et al., 2018; Romeo, 2017;

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Saxbe et al., 2018), and increased risk for psychiatric illnesses, such as depression and posttraumatic stress (Buka et al., 2001; Fowler et al., 2009; Margolin et al., 2009).

At the same time, adolescents are not passively impacted by the social happenings around them. Rather, adolescents' emerging capacities to engage in complex meaning-making about the social and civic worlds and self provide them with a source of resilience and personal agency that leverages and promotes social-cognitive development associated with identity, purpose, and well-being (Brittian & Lerner, 2013; Damon et al., 2003; Riveros et al., 2023). Such thinking, here termed *transcendent thinking* (Gotlieb et al., 2022a, 2024), enables adolescents to enrich their concrete, empathic, and context-specific interpretations of situations with abstract considerations that transcend the current situation to address broader personal, ethical, and systems-level issues, making meaning that empowers them to search for deep understanding and work for change (Immordino-Yang et al., 2024; Lee et al., 2021).

Potentially, given the importance of agency, social connectedness, and self-actualization for youths' development (for a review, see Immordino-Yang et al., 2024), adolescents' dispositions for transcendent thinking about the social world could mitigate the negative effects of CVE on their development. Community violence presents a source of immediate danger, and as such draws a person's attention to their immediate surroundings, a pattern associated with concrete construals and perspectives (Trope & Liberman, 2010). Transcendent thinking, by contrast, involves mentally generating bigger ideas and innovative possibility spaces that may help free a young person to make deeper meaning of the systems-level complexities of the situation, reflect on broader implications, and formulate ideas and narratives that tap into efficacious identities, civic engagement, and more complex social understanding (Gotlieb et al., 2022a; Immordino-Yang et al., 2012; Yang et al., 2018). As such, examining CVE and transcendent thinking together could provide insight into the relative contributions of these factors in youth development.

One way to examine the impacts of CVE and transcendent thinking on mid-adolescents' development is to examine their longitudinal effects on the developing brain, using a transdisciplinary approach. Adolescence is a period of extensive brain maturation (Foulkes & Blakemore, 2018; Galván, 2021); the hormonal changes associated with puberty launch a period of social sensitivity and emotional lability associated with neural plasticity, that is, with flexibility in how the brain grows and functions (Blakemore & Mills, 2014; Crone & Dahl, 2012). This plasticity represents a source both of vulnerability and of resilience (for a review, see Immordino-Yang et al., 2019). On the one hand, in the context of youth living in low-SES urban areas, this heightened sensitivity and plasticity may increase adolescents' susceptibility to social–relational stressors, such as exposure to violence or crime in the community, just at the age in which youth are gaining independence and spending more time outside the home. This heightened sensitivity and plasticity provides an opportunity to develop new psychological capacities, and even to adaptively rework brain development shaped by exposure to childhood trauma (Cisler & Herringa, 2021; Romeo & McEwen, 2006). The dispositions and capacities adolescents cultivate for transcendent reflection and meaning making may therefore be neurally protective. As youth leverage transcendent thinking to psychologically process what they have witnessed, they recruit neural networks in dynamic patterns that appear to strengthen neural connectivity and flexibility over time (Gotlieb et al., 2022b, 2024). This could be associated with brain structural changes such as increased gray matter volume (GMV) that could counter known decreases in GMV associated with exposure to CVE (Butler et al., 2018).

Given the complex dynamics of mid-adolescents' social and neurobiological development, here we utilize longitudinal structural neuroimaging data and psychosocial interview data with mid-adolescents from low-SES urban communities to ask, how is witnessing and/or learning about community violence associated with longitudinal change in these youths' brain structure? How might these youths' emerging dispositions to engage in transcendent, systems-level meaning-making about the broader social and civic implications of complex situations potentially counteract the neurological effects of CVE? We examine these questions in a coordinated way that integrates a method from developmental neuroscience, longitudinal structural neuroimaging, with one from human development psychology, quantification of results of qualitative analysis of open-ended interviews. Taking these methods together contributes to the study's ecological validity, honoring something about the meaning each participant is making and the affordances of this meaning-making for brain development, while also revealing a policy-relevant environmental condition that harms youth, community violence. The interpretation of findings is necessarily transdisciplinary, bringing an education-derived asset-based perspective to bear on a community issue, with the aim both of empowering youth and ameliorating the harmful circumstances they face.

In this context, our study examines how CVE and transcendent thinking relate to variability in intraindividual indices of neural *change over time*, no matter the starting structure of each participant's brain (see also Gotlieb et al., 2024). That is, we are asking the process question of how youths' brains grow over time, rather than the normative question of how youths' brains compare in absolute terms. This process-oriented approach allows us to interpret neural effects without assuming a deficit perspective in which some youths have inherently less 'fit' brains based on their experiences. By examining the longitudinal change in neural structure as it relates to CVE, and then reexamining while taking into consideration youths' psychological dispositions, we aim to capture both the growth-related impacts of CVE and potential downstream influences of adolescents' own psychosocial assets on their neural development. Such studies are important because they allow us to advocate for the improvement of community conditions, while also helping to identify youths' sources of resilience in order to inform the design of community programming, supports, and education for adolescents.

The effect of community violence exposure on the adolescent brain

Many studies have established the negative effects of exposure to violence in various contexts on the brain, from infancy to adulthood, including in the contexts of interpersonal relationships (Goetschius et al., 2020; Roos et al., 2017; Tsavoussis et al., 2014), war (Butler et al., 2017), video games/media (Hummer, 2015), and others. In particular, cross-sectional correlations between CVE and brain structure have been described, including among adolescents (Butler et al., 2018; Saxbe et al., 2018), as have effects of exposure to violence in infancy and childhood on later brain development (Goetschius et al., 2020; Mueller & Tronick, 2019). However, to our knowledge, no published studies have examined the impact of adolescents' exposure to community violence on concurrent longitudinal change in brain structure, that is, in the way individuals' brains change across the time period in which they experience the violence.

Our previous cross-sectional study of 65 youth, which included the 55 participants whose longitudinal data are analyzed here, found that cumulative lifetime CVE across childhood and early adolescence (measured at age 14–18, during the first study visit) inversely correlated with GMV in rostral anterior cingulate cortex (ACC; Butler et al., 2018). This finding held even controlling for socioeconomic status (SES), which often correlates with violence exposure, and which has been associated with differences in brain structure (Noble et al., 2015). ACC is a highly interconnected hub of the brain's salience network (Seeley et al., 2007), important for autonomic regulation, pain, and stress processing (Critchley, 2004; Posner et al., 2007), for motivational behavior (Hong & Stauffer, 2024; Parvizi et al., 2013), and for guiding attention (Bush et al., 2000). The ACC is also involved in detecting unexpected outcomes that enable learning in many domains (Carter et al., 1998), such as learning from errors during math problem-solving (Denervaud et al., 2020). The location of GMV reduction we found overlapped with the location of GMV reduction previously described among individuals diagnosed with post-traumatic stress disorder (Kühn & Gallinat, 2013) and in ground troops deployed to war (Butler et al., 2017), despite that our participants had not been diagnosed with clinical disorders and had reported no direct involvement in community violence either as perpetrator or victim. These findings complement psychological and clinical studies demonstrating the harmful effects of CVE on young people's social development and mental health (Margolin & Gordis, 2000; Romeo, 2017), and identify the ACC as a key neural region of interest.

Given the marked neural plasticity and social sensitivity associated with adolescence, the impact of CVE experienced during the mid-adolescent developmental period would be important to understand. Such questions are especially important given older teens' increasing independence and time spent outside the home and school, which could increase the likelihood of exposure, even among youths without direct involvement in such activities or situations. Due to the cross-sectional nature of previous studies, it remains unclear whether brain development across mid-adolescence reflects new CVE during this developmental period, beyond the effects of exposure when the participants were younger. It is also unclear whether the impact of CVE across mid-adolescence on neural growth differs based on levels of CVE earlier in life, and whether individuals' psychological dispositions could mitigate these effects.

Transcendent thinking and adolescent neural and psychosocial development

Adolescence has been described for at least a century as a sensitive period of psychosocial and cognitive development (Bruner, 1986; Dewey, 1933; Erikson, 1968; Fischer & Bidell, 2006; Steinberg & Morris, 2001) with important implications for young adulthood (Hill & Redding, 2021). By middle adolescence, youths typically develop capacities for "transcendent" thinking abilities to consider the abstract, systems-level implications of social situations that transcend their concrete and context-specific characteristics (Bruner, 1986; Fischer & Bidell, 2006; Gotlieb et al., 2022a; Immordino-Yang, 2016; Riveros et al., 2023). The proclivity to engage in transcendent thinking in mid-adolescence has been associated with real-world social and cognitive functioning (Gotlieb et al., 2022a), as well as with the development of personal values, identity, and life purpose (Damon, 2009; Malin et al., 2015; Riveros et al., 2023). Our previous research demonstrated that adolescents' tendencies to engage in transcendent thinking, irrespective of IQ score or family socio-economic status, longitudinally predicted the future development of network dynamics among key brain systems, which in turn predicted psychosocial achievements such as identity development and life and relationship satisfaction in young adulthood (Gotlieb et al., 2024).

In real time, our previous studies reveal that transcendent thinking and related forms of value-based, systems-level and narrative thinking recruit a complex pattern of unfolding neural activations and deactivations in networks and regions associated with executive control and social, cognitive, and affective processing, including autobiographical processing and processing of emotional experiences and accompanying physiological states (Gotlieb et al., 2022b; Immordino-Yang et al., 2009; Yang et al., 2018). Among the regions activated during emotionally engaged transcendent thinking is the ACC (Immordino-Yang et al., 2009, 2014; Saxbe et al., 2013). Given the neurological and psychosocial benefits across mid-adolescent development of transcendent thinking, we were interested here to examine whether such thinking could counteract the effect of CVE on GMV reduction in the ACC across mid-adolescence.

The current study

Here, we followed our previous cross-sectional sample forward 2 years to acquire a second round of structural neuroimaging data and to measure the new CVE they experienced in the interim (hereafter termed "mid-adolescent CVE"). We also examined the neural effects of participants' proclivity toward transcendent thinking. (We had previously quantified transcendent thinking based on participants' open-ended responses to 40 minidocumentaries during a private one-on-one interview during the first laboratory visit; see Gotlieb et al., 2022a). We hypothesized that mid-adolescent CVE would be associated with GMV reduction in the ACC in a whole-brain voxel-wise analysis, and that participants' disposition toward transcendent thinking would mitigate this reduction (i.e., through a positive main effect on GMV change and/or by moderating the effect of CVE on GMV reduction). Because we were interested specifically in identifying neurodevelopmental effects playing out in the mid-adolescent stage, our analyses control for CVE prior to the start of the study (across childhood and earlier adolescence), and for participants' GMV at the start of the study. Because previous studies have found relations between socioeconomic status (SES) and brain structure (Noble et al., 2015; Tooley et al., 2021), and because of the possibility that SES would be related to violence exposure, we collected and controlled for measures of participants' SES, including free/reduced school lunch (a measure of family financial income relative to needs) and parents' education level.

METHODS

Data for the current study were collected as part of a longitudinal project investigating psychosocial and neurobiological aspects of social emotional development in adolescence and young adulthood in two broad cultural groups, Latinx and East Asian. As such, participants also completed psychosocial activities, psychophysiological recordings, and other neuroimaging protocols unrelated to the present study (e.g., interviews about school; studies of heart-rate variability; diffusion tensor and functional neuroimaging; see https://osf.io/gqs34 for more information). All study activities were approved by the Institutional Review Board of the University of Southern California and were carried out in accordance with the relevant policies. All parents/legal guardians and participants gave written informed consent or assent as appropriate, and all participants were compensated for their time.

Participants

Sixty-five healthy, right-handed adolescents (age 14–18 years at recruitment, M_{age} = 15.8 years, SD = 1.1 years; 36 female/29 male) were recruited to participate in the initial lab visit from public high schools in low-SES neighborhoods with moderate to high levels of crime in Los Angeles. Enrollment criteria included no history of neurological or psychiatric disorders; physical or emotional abuse or neglect; use of psychotropic medication, recreational drugs, or alcohol; a medical condition that would preclude scanning. To ensure a culturally diverse sample, at least one of each participant's parents was born and raised to adulthood outside of the United States (participants' parents originated from 13 countries). Criteria also included full-time enrollment in school, passing all classes, fluent in the English language, and not under any disciplinary action. None were the direct victims or perpetrators of violent crimes.

Roughly 2 years later ($M_{time\ between\ visits}$ = 2.09 years, SD = 0.21 years), 62 of the 65 participants returned for the second laboratory visit (attrition resulted from participants moving out of the region). Six participants were not able to undergo MRI scanning at the second visit due to: dental braces (4 participants); metal pins in the leg (1 participant); or a technical problem with the scanner (1 participant). One participant's neuroimaging data were excluded from analysis due to a large imaging artifact of unknown origin. As a result, the current analysis includes 55 participants [32 female/23 male; aged 14–18 years at the first laboratory visit (M_{age} = 15.86 years, SD = 1.08 years); aged 16–20 years at the second visit (M_{age} = 17.95 years, SD = 1.07 years)]. Of this group, 27 participants identified as Latinx and 28 as East Asian (demographics for participants not included in the longitudinal analysis are as follows: 4 female/6 male; age range 14–16 years, $M_{age\ at\ first\ visit}$ = 15.27 years; 9 participants identified as Latinx/Afro-Latinx, 1 as East Asian).

Procedure

Interview

As described in Gotlieb et al. (2022a, 2022b), at the initial lab visit, participants reacted to 40 true, compelling stories about living, non-famous adolescents from around the world in a range of circumstances, during a 2-h private video-taped interview (the protocol was adapted from Immordino-Yang et al., 2009). The story corpus was previously piloted to be interesting and to elicit mixes of positively and negatively valenced emotions. The experimenter shared each story using a previously memorized script, and then played an accompanying documentary-style video of approximately 1 min in length depicting footage of the real-life protagonist (not an actor), using PowerPoint (Microsoft Office) displayed on a Lenovo laptop with a 17-inch screen. After showing each video, the experimenter asked, "how does this story make you feel?" The experimenter then looked down and transcribed as much as possible of the participant's verbatim responses by hand-written notes. Participants were told that notetaking was conducted in case the video camera failed. In actuality, these notes also served to standardize the experimenter's behavior, so that the participant could respond freely. Participants were encouraged to be as candid as possible.

Community Violence Exposure Questionnaire and interview

During both lab visits, participants reported their CVE using a modified 13-item version of the Survey of Children's

Exposure to Community Violence—self-report version (Margolin et al., 2009). The questionnaire includes a list of 13 events that involve either threatened or actual victimization (e.g., Item 9. Has anyone ever threatened to beat you up?) or witnessing and/or hearing about violence (e.g., Item 13. Have you ever witnessed or heard about someone being shot?). For each item, participants chose from four options, including "Never," "Once," "Twice," or "More than twice." After completing the questionnaire, each participant then underwent a private interview to confirm their answers and to determine whether the reported violence exposure occurred in the community (neighborhood or school), in the home, or in the media (e.g., on television). (Note: As described below, violence experienced in the home would disqualify the participant's data from analysis; violence witnessed in the media was not counted toward CVE.)

At the initial lab visit, participants were instructed to report any incidents of violence exposure they remembered experiencing (to measure childhood and early adolescent CVE prior to participation in the study). At the second lab visit, they were instructed to report new incidents over the 2-year period since the first lab visit (to measure mid-adolescent CVE).

MRI data acquisition

All neuroimaging was performed at the Dana and David Dornsife Cognitive Neuroimaging Center. At the first lab visit, data were acquired using a Siemens 3T MAGNETOM Trio system equipped with a 12-channel head coil. Structural images were acquired using a magnetization-prepared rapid acquisition gradient echo (MPRAGE) sequence with the following parameters: 1 mm isotropic voxel resolution over a 256 mm × 256 mm × 176 mm FOV; TI/TE/TR = 800/3.09/2530 ms; flip angle = 10°. At the second lab visit, data were acquired using a Siemens 3T MAGNETOM Prisma System equipped with a 20-channel head coil, using an MPRAGE sequence with the following parameters: 1 mm isotropic voxel resolution over a 256 mm × 256 mm × 256 mm FOV; TI/TE/TR = 850/32.05/2300 ms; flip angle = 8°. (Note: Because our analyses focus on the modulation effect of mid-adolescent CVE on intraindividual change in GMV between the two lab visits, effects cannot be confounded by effects related to the scanner upgrade. See also below.) As part of the center's standard protocol, all participants also underwent a T2-weighted scan for review by a radiographer; no incidental findings were reported.

Socioeconomic status (SES)

Participants reported whether they received free or reduced-price school meals (indicating low income/needs ratio for the family and therefore low-SES; Nicholson et al., 2014) and the highest level of education achieved by their parents, an additional factor associated with SES (Noble et al., 2015). Following work by Noble et al. (2015), parental education level was recoded as years of formal education, as follows: did not complete high school = 8 years; received a high school diploma or a General Education Development (GED) degree = 12 years; some college/received an Associate's degree or postsecondary vocational certificate = 14 years; received a Bachelor's degree = 16 years; received a Master's or a Doctoral degree = 18 years. Parental education data were missing from four Latino participants. Their parental years of education were imputed as the mean of Latino participants in their neighborhood (10 years of schooling).

Analysis

Transcendent construal coding

For our previous study, videotaped interviews had been transcribed and verified. Each participant response had then been blind coded and reliability coded for transcendent construals (see Gotlieb et al., 2024). In this work, transcendent construals were defined as utterances reflecting (i) systems-level analyses or moral judgments, or curiosities about how and why systems work as they do, for example,

> I also find it unfair that the people get undocumented. It's kind of weird how it's like a label how like just 'cause you are from some other place, um, you can't do certain things in another place. It's like a question. It's like something I've always wondered…;

(ii) discussions of broad implications, morals and moral emotions, perspectives, personal lessons or values derived from the story, for example,

> I think back to the idea that because children are the future […] we have to be able to inspire people who are growing and have the potential to improve the societies;
>
> it makes me happy for humanity;

or (iii) analyses of the protagonist's qualities of character, mind, or perspective, for example,

> "[she is] thinking, 'oh, you're not alone. You have others who are dependent on you'."

Importantly, it was not relevant whether the participant endorsed a value or lesson or agreed with the protagonist, for example,

> I wouldn't react that way. I'd just be really mad at the kid instead of, you know, selfless like that

> and trying to help him. Like I wouldn't be able to put myself in someone's shoes like that like he did.

Construals not considered transcendent pertain mainly to discussions of the protagonist's immediate situation, for example, "I'm glad it all worked out," or evaluating the protagonist's decisions or actions, for example, "I feel like they should have planned it more"; or to the empathic emotions of the participant, for example, "I feel really sad for her, and like, second-hand embarrassment." Unlike transcendent construals, these examples involve reactive, concrete, and context-dependent interpretations.

Participants received a score of 1 for each transcendent construal. Scores across all trials were summed to produce a total score for each participant.

Community violence exposure scoring

Participants' answers to the questionnaire were verified during a follow-up interview. Incidents that happened in the home or that involved family members would disqualify the participant (no such incidents were reported). Incidents witnessed in the media were not counted toward the violence exposure score.

For each item, participants received a score from 0 ("Never") to 3 ("More than twice"), giving a potential final score of between 0 and 39. Total scores were separately tallied for childhood/early adolescent CVE and mid-adolescent CVE.

MRI data processing

The MRI scanner at the Dana and David Dornsife Neuroimaging Center underwent an upgrade between the two data collections. It was confirmed that when data collected before and after the upgrade were processed independently, the scanner upgrade did not impact GMV estimation (see Habibi et al., 2018). Given this, we processed T1-weighted data from each time point independently.

Voxel-based morphometry

Images were processed using voxel-based morphometry analysis via the automatic Computational Anatomy Toolbox (CAT12 v.1600; http://www.neuro.uni-jena.de/cat/) and statistical parametric mapping (SPM12 v.7771; Welcome Trust Centre for Neuroimaging, http://www.fil.ion.ucl.ac.uk/spm), using default parameters running on MATLAB R2015b (Mathworks, Natick, MA, USA). Images were normalized to Montreal Neurological Institute (MNI) space and segmented into gray matter, white matter, and cerebrospinal fluid based on voxel signal intensity and a priori expectation of tissue type based on anatomical location, using default parameters. Modulation was applied in order to preserve the volume of a particular tissue within a voxel by multiplying voxel values in the segmented images by the Jacobian determinants derived from the spatial normalization step. To capture longitudinal change, a difference map contrasting modulated GMV from the two data collections (second lab visit minus initial lab visit) was calculated for each participant. Difference maps were smoothed with an 8-mm full-width at half-maximum kernel.

To estimate total intracranial volume (TIV) for each participant, and to construct a gray matter mask that identifies voxels to be included in statistical analysis, midpoint average images were created using the pairwise registration of data from the initial and second scans from the same participant. Midpoint average maps were used to calculate TIV for each participant, and to generate a group-level gray matter mask using an absolute gray matter probability threshold of 0.2.

Statistical analysis

Whole-brain analysis

Whole-brain voxel-wise statistical analysis was performed on spatially normalized and smoothed gray matter difference maps using SPM12. Covariates of no interest included in the whole-brain analysis were participants' childhood/early adolescent CVE; age at the start of the study in days; sex; midpoint average TIV; and time interval between the two study visits in days. Results were examined within the midpoint average gray matter mask. To control for type-I error at $\alpha < .05$ corrected for multiple comparisons, results were subjected to a voxel-level cluster-forming threshold of $p < .005$ and a corresponding non-isotropic smoothness-corrected cluster size threshold (implemented in CAT12; Hayasaka et al., 2004).

Regions of interest (ROI) analysis

For each significant cluster revealed by the whole-brain voxel-wise analysis (13 clusters total), the MarsBar toolbox (Brett et al., 2002) was used to calculate the mean GMV at the initial data collection and the mean change in GMV between the two data collections. An ACC ROI was created by imposing an anatomically defined ACC mask on the whole-brain results and identifying significant voxels within the mask boundary. (The ACC mask was defined by combining all cingulate masks from the Automated Anatomical Labeling Atlas (Tzourio-Mazoyer et al., 2002) and setting the posterior boundary at $y = -24$; see Figure 1, turquoise outline). Voxels in the ACC ROI were averaged together to calculate the mean GMV at the initial data collection and the mean change in GMV between the two data collections.

The effect of mid-adolescent CVE on GMV change was examined for each significant cluster and for the ACC ROI controlling for GMV within the cluster/ROI at initial data collection, in addition to the covariates of no interest included in the whole brain analysis (listed above).

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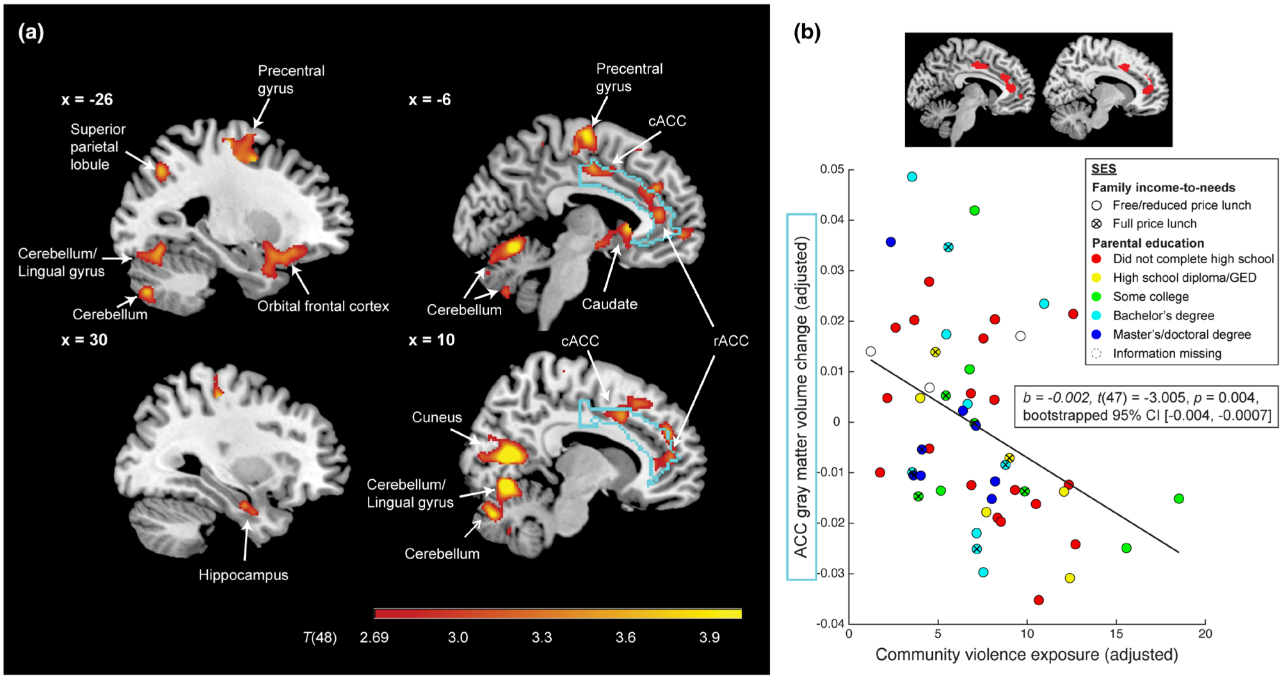

FIGURE 1 Effects of mid-adolescent community violence exposure on mid-adolescent longitudinal change in gray matter volume. (a) Results from a whole-brain analysis reveal brain regions whose gray matter volume (GMV) change between the two data collections was negatively correlated with mid-adolescent community violence exposure (CVE), controlling for childhood/early adolescent exposure (also controlled are: age at the initial data collection; sex; time interval between the two data collections; and midpoint average TIV). Results are subjected to a cluster-forming threshold of $p < .005$ and an expected-voxels-per-cluster threshold (estimated accounting for non-isotropic smoothness), which together control type I error rate at $\alpha < .05$. The anterior cingulate cortex (ACC) is outlined in turquoise. (b) Scatter plot illustrating the negative effect of mid-adolescent CVE on GMV change in significant voxels within the ACC, depicted in the inset. GMV change and mid-adolescent CVE are adjusted for GMV at the initial data collection, as well as for the controls listed in (a). Each dot represents one participant. For illustration purposes, data points are labeled by family income-to-needs ratio as indexed by school lunch status and parental education level (measures of socioeconomic status, SES). cACC, caudal anterior cingulate cortex; rACC, rostral anterior cingulate cortex.

Another model was then run to additionally control for participants' SES (school lunch status and years of parental education).

To examine whether transcendent thinking counteracts the effect of CVE on ACC gray matter development during the mid-adolescent period, an additional linear regression model was run, with GMV change in the ACC ROI as the dependent variable and mid-adolescent CVE and transcendent construal scores as the predictors, controlling for ACC ROI GMV at the initial data collection, and the covariates of no interest included in the whole-brain analysis (listed above). Interaction models were run to test whether the effect of mid-adolescent CVE on ACC ROI GMV change would be moderated by childhood/early adolescent CVE, or by transcendent construal scores; these models controlled for ACC ROI GMV at the initial data collection, and the covariates of no interest included in the whole-brain analysis (listed above).

All ROI statistical analyses were carried out using RStudio (Version 2023.06.0+421, Posit Software, PBC) and R (Version 4.3.1). All reported statistical tests are two-tailed.

Bootstrapping analysis

To confirm the robustness of findings, percentile bootstrapped confidence intervals for the effects of interest were calculated using the Bootstrap Functions ("boot") package (Version 1.3-28.1; Canty & Ripley, 2022) implemented in RStudio (Version 2023.06.0+421, Posit Software, PBC, Version 4.3.1) with 10,000 bootstrapped samples.

RESULTS

Participants' childhood/early adolescent CVE scores ranged from 0 to 34 (M = 11.2, SD = 9.1). Participants' mid-adolescent CVE scores ranged from 0 to 20 (M = 7.3, SD = 5.3). Transcendent construal scores ranged from 3 to 64 (M = 26.4, SD = 14.3). Forty-two participants reported receiving free or reduced-price lunch at school; 13 paid full price for lunch. Parents' education ranged from 8 to 18 years (M_{educ} = 12.4 years, SD = 3.8).

CVE scores at the two data collections were correlated ($r[53] = .68$, $p < .001$). Mid-adolescent CVE was higher in lower SES participants (lunch status: $t[31.9] = -3.05$, $p = .005$; parental education: $r[53] = -.47$, $p < .001$). Transcendent construal scores and mid-adolescent CVE scores were not correlated ($r[53] = -.08$, $p = .55$). Transcendent construal scores did not differ by SES (lunch status: $t[17.4] = -.33$, $p = .74$; parental education: $r[53] = -.06$, $p < .67$).

Mid-adolescent CVE is negatively associated with GMV change across the 2-year interval

Controlling for childhood/early adolescent CVE, GMV at the initial data collection, and additional covariates of no interest: Mid-adolescent CVE was associated with greater GMV reduction in cortical and subcortical regions, including the ACC (see Table 1 and Figure 1). Analysis of each significant cluster revealed that the effect holds additionally controlling for SES (all p's < .05). No positive relationships between CVE and mid-adolescent GMV change were found at the whole-brain level. Childhood/early adolescent CVE did not significantly moderate the effect of mid-adolescent CVE on GMV change in any cluster or in the ACC ROI (all p's > .27).

Transcendent thinking is positively associated with GMV change in the ACC, independent of the negative effect of mid-adolescent CVE

Participants' transcendent construal scores were positively associated with GMV change in the ACC ROI, controlling for mid-adolescent CVE, childhood/early adolescent CVE, GMV at the initial data collection, and additional covariates of no interest; see Figure 2. No interaction between transcendent construal scores and mid-adolescent CVE was found (p = .64).

Findings are robust to bootstrapping

None of the effects reported had bootstrapped 95% confidence intervals that crossed zero, confirming the robustness of the effects.

DISCUSSION

Community violence exposure is a source of social stress for many urban youth, despite not being involved. Building from our previous finding that CVE in childhood and early adolescence is associated with lower GMV in the ACC; here we report that, as hypothesized, new CVE across 2 years of mid-adolescence was associated with accelerated GMV reduction in a range of regions across the brain. Among these was the ACC, a centrally connected network hub of the brain involved in many psychological functions due to its central role in physiological regulation (Critchley, 2004); cognition, emotion, and attention (Allman et al., 2001; Bush et al., 2000; Posner et al., 2007); social emotion (Immordino-Yang et al., 2009, 2014; Saxbe et al., 2013); learning and motivation (Holroyd & Yeung, 2012; Hong & Stauffer, 2024; Parvizi et al., 2013). Analyses controlled for CVE participants had experienced in childhood and early adolescence, prior to the initial visit to the laboratory, and controlled for participants' structural brain development at the start of the study. The findings suggest that CVE in mid-adolescence influences structural brain development, even accounting for effects associated with youths' earlier experiences. One might have expected an attenuated effect that would be consistent with habituation, but we did not find this. The results highlight young people's continued vulnerability across the late teen years to community violence, in a developmental time when increased freedom and independence is normative, as youths typically spend more time outside home and school, in the community.

Mid-adolescence has long been described by developmental scientists as a special period of social, emotional, and cognitive growth, and more recently, as a period of marked neurological maturation tied to social sensitivity (Blakemore & Mills, 2014; Crone & Dahl, 2012; Foulkes & Blakemore, 2018; Galván, 2021). Here, we find that a hallmark psychological developmental achievement of this age group (Bruner, 1986; Dewey, 1933; Fischer & Bidell, 2006), the disposition to mentally grapple with complex ethical, identity-relevant, and systems-level meaning-making about the social world through transcendent thinking, may counter the effect of CVE on brain development. In our study, youths' propensities to engage with the broader complexities of compelling true social situations faced by other youth around the world were associated with relative increases in GMV across the 2-year interval between brain scans in the ACC, independent of exposure to community violence during this time period. Taken together, these independent effects suggest both that CVE continues to be harmful for mid-adolescent youths, and that transcendent thinking serves as an important developmental asset in this age group. The implication for policy is that it is important to keep youths safe and to work toward ameliorating the issues that lead to community violence and crime, while also supporting youths to think in complex, nuanced ways about the issues they and their communities face, such as through civically oriented approaches to education (Lee et al., 2021; Nathan et al., 2024), as we discuss below.

The regions of the brain that showed a significant negative effect of CVE on GMV across the 2-year interval included those involved in learning, memory formation and retrieval (e.g., the hippocampus; Bird & Burgess, 2008), attention (e.g., the superior parietal lobule; Behrmann et al., 2004), somatosensation and motor control (e.g., the pre and post-central gyri, the cerebellum), physiological regulation and stress, social processing, social emotion, and other forms of complex cognition and emotion (e.g., the orbital frontal cortex, the medial prefrontal cortex; Critchley, 2005; Damasio & Damasio, 2022). These findings together suggest that CVE has a generalized negative effect on brain development in mid-adolescence, extending previous cross-sectional findings (Butler et al., 2018; Saxbe et al., 2018).

Among the ACC sectors associated with CVE in our study was the rostral ACC, a part of the salience network (Seeley, 2019; Seeley et al., 2007) whose cortical structure has been related to traumatic experience and exposure to

TABLE 1 Significant whole-brain and ROI (significant cluster) results demonstrating the negative effect of mid-adolescent CVE on gray matter volume change between the two data collections.

(A) Whole brain results						(B) ROI results
	Peak coordinates					Bootstrapped 99% CI of mid-adolescent CVE effect
Cluster size	*x*	*y*	*z*	*z*-Score	Brain region	
5159	10	−68	−9	4.55	R lingual gyrus	−0.0033, −0.0013
	8	−63	12	4.46	R cuneus	
	−2	−63	−12	4.26	L cerebellum	
	18	−56	−15	4.19	R cerebellum	
3953	−22	−3	50	4.00	L superior frontal gyrus	−0.0049, −0.0005
	−8	−10	66	3.78	L precentral gyrus	
	30	−26	54	3.39	R precentral gyrus	
	−15	−33	66	3.51	L postcentral gyrus	
	30	−26	54	3.39	R postcentral gyrus	
1570	−27	21	−18	3.31	L orbital frontal cortex	−0.0057, −0.0006
	−21	12	−15	3.26	L orbital frontal cortex	
1350	12	14	39	3.38	R caudal anterior cingulate cortex	−0.0051, −0.0003
	−4	−6	44	3.34	L caudal anterior cingulate cortex	
1271	3	50	10	3.58	R superior medial frontal gyrus	−0.0066, −0.0003
	14	48	10	3.11	R rostral anterior cingulate gyrus	
1257	−14	−75	38	3.87	L cuneus/precuneus	−0.0044, −0.0005
	−46	−50	30	2.90	L supramarginal gyrus	
	−28	−64	40	3.58	L superior parietal lobule	
	−38	−62	39	3.42	L angular gyrus	
1119	−20	21	2	3.63	L head of caudate nucleus	−0.0029, −0.0005
	−2	−6	−15	3.59	L hypothalamus	
	−6	18	2	3.54	L head of caudate nucleus	
863	−22	−70	−16	3.60	L lingual gyrus/cerebellum	−0.0046, −0.0008
641	−10	38	30	3.53	L medial superior frontal gyrus	−0.0044, −0.0004
	−8	39	10	3.30	L rostral anterior cingulate cortex	
444	−22	−76	−42	3.76	L cerebellum	−0.0054, −0.0007
372	−3	−69	−42	3.20	L cerebellum vermis	−0.0052, −0.0008
288	−40	−27	−16	3.11	L inferior temporal gyrus	−0.0038, −0.0003
159	27	−3	−28	3.73	R hippocampus	−0.0032, −0.0004

Note: (A) Whole-brain voxel-wise analysis results, controlling for childhood and early adolescent community violence exposure, average total intracranial volume between the two waves, age, gender, and time between waves. All reported clusters exceed a voxel level cluster-forming threshold of $p < .005$ and a corresponding non-isotropic smoothness corrected cluster size threshold, which together controlled for type-I error at $\alpha < .05$ corrected for multiple comparisons. Montreal Neurological Institute (MNI) coordinates for the location of maximum effect within each cluster are reported. Select local maxima are included to show the spatial extent of the cluster as needed. (B) ROI analysis results showing the bootstrapped 99% confidence intervals for the average cluster-level effect. Models controlled for each cluster's average gray matter volume at initial data collection, in addition to the covariates included in the whole brain model.

Abbreviations: L, peaks located in the left hemisphere; R, peaks located in the right hemisphere.

violence (Butler et al., 2017), and whose functioning is implicated in mental health, such as in posttraumatic stress disorder (Kühn & Gallinat, 2013), obsessive compulsive disorder (Kühn et al., 2013), addiction (Goldstein & Volkow, 2002), and anxiety disorders (Pannekoek et al., 2013), including in adolescence (Romeo, 2017; Suffren et al., 2019).

The ACC is also notable for its involvement in error monitoring—the ubiquitous process by which individuals rapidly recognize surprising or unexpected events, such as realizing their attention has lapsed when reading or noticing a mistake when solving a math problem, in order to adaptively shift strategies and learn (Carter et al., 1998; Ullsperger et al., 2014). The functioning of this region during error monitoring is known to be sensitive to the social context in the immediate sense and over time. For example, ACC involvement in learning from one's own and others' mistakes differs during competitively versus collaboratively framed tasks (Koban et al., 2010), and depending on the style of schooling one has experienced (Denervaud et al., 2020). A recent study showed, for example, that

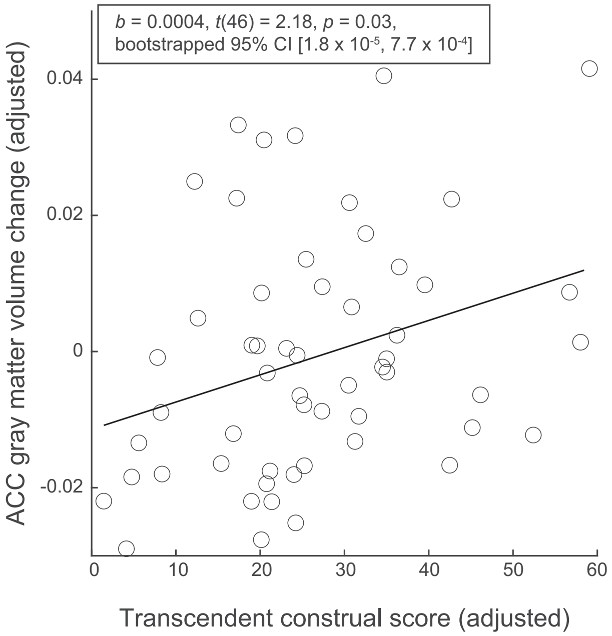

FIGURE 2 Scatter plot illustrating the independent effect of transcendent thinking on longitudinal gray matter volume (GMV) change in regions of the anterior cingulate cortex (ACC) showing significant associations with mid-adolescent community violence exposure (CVE; see Figure 1, panel b inset for a depiction of included voxels). GMV and transcendent thinking scores are adjusted for mid-adolescent CVE; childhood/early adolescent CVE; GMV and age at the initial data collection; sex; time interval between data collections; and midpoint average TIV. Each dot represents one participant.

this region's shifting connectivity to other regions of the brain in response to errors versus correct answers during a math task differs between Montessori and traditionally schooled Swiss 8- to 12-year-old students (Denervaud et al., 2020). The Montessori method emphasizes exploration and peer-to-peer learning, while the traditional approach emphasizes direct teaching, with students working independently and demonstrating their knowledge on formal tests (Lillard, 2023). While Montessori schooled students showed greater functional connectivity between the ACC and frontal regions of the brain following errors, the traditionally schooled students showed greater connectivity between the ACC and the hippocampus following correct answers (Denervaud et al., 2020). These findings suggest that children's schooling influenced how the ACC contributed to their learning process. Although the current study did not examine participants' processes of error monitoring, the implication of GMV reduction in the ACC following CVE is that CVE may impact the neurological substrate for learning. Future work should address this possibility, as well as the possibility that schooling that supports transcendent thinking may counter this effect. There is a growing focus on such approaches to schooling for adolescents, which are associated with a range of psychosocial and academic benefits, especially for youth from underprivileged environments (Daniel et al., 2019; Hantzopoulos, 2016; Lee et al., 2021; Nasir et al., 2021).

The cellular-level mechanisms responsible for longitudinal changes in GMV across development are not well understood. However, they likely involve interactions among a multitude of physiological processes that are differentially invoked depending on a person's characteristics, processing and context. Although the specialization and maturation of networks through adolescent development involves pruning associated with increased processing efficiency, and hence a normative GMV reduction (Gogtay et al., 2004), some research suggests that through this developmental stage, the protracted nature of the loss of GMV, that is, the attenuation of GMV reduction or possibly also GMV increase, is associated with beneficial outcomes, such as identity development (Becht et al., 2018) and higher intelligence as measured by IQ (Shaw et al., 2006). While pruning increases efficiency and enables a person to react in an automatic way and quickly, such as would be adaptive in a physically dangerous situation, such processing can also be a liability, ramping up anxiety and reactivity at the potential expense of slower, more complex thinking (Immordino-Yang et al., 2009, 2019). Transcendent thinking, with its calm reflective focus (Immordino-Yang et al., 2009; Yang et al., 2018), is slower and more deliberative, enabling more nuanced perspectives and narratives that transcend the directly observable happenings of the here-and-now (Riveros et al., 2023). It may be these properties of transcendent thinking that counteract GMV reduction, as well as the psychological liabilities associated with the reduction, such as anxiety and posttraumatic stress. Future work is needed to explore these issues in a range of developmental contexts, and to relate these neural developmental processes to mental health outcomes later in life.

It is interesting to note that though lower SES was associated with increased CVE, SES itself, as measured both financially and in terms of parental education, did not explain the effects we describe on brain development in our sample. Research on structural brain development has typically reported effects of SES, including reported associations with cortical surface area and network maturational trajectories (Noble et al., 2015; Tooley et al., 2019). However, SES is a proxy for many aspects of social experience, and fails to capture variation in individual and community sociocultural assets. Our study, although modest in size, identifies variation in two factors more proximal to the person that appear to be influencing brain development. While CVE is harmful and was higher in youth from low-SES families in our sample, variation existed among even the lowest SES participants. At the same time, transcendent thinking was beneficial in our study, representing an asset that did not differ with SES.

Relatedly, we hope our study will contribute to a roadmap of hypotheses for larger scale studies (e.g., the ABCD study; Jernigan et al., 2018). Those studies are able to reliably map variability in neural structure, and therefore to speak to normative questions about the range of brain states that exist in the population, and the ways that these brain states correlate with past experiences and current and future development on average. As such, studies with very large samples can map experience-dependent deficits and can provide important indicators of negative environmental impacts on youth. Their results hold implications for policies to mitigate environmental harms, because they mainly locate the source of variability "outside" the person, such as in community violence or other stressors. However, it is difficult for such studies to understand the more nuanced sources of individual variability also present in the data (Foulkes & Blakemore, 2018), and potential factors within the person associated with resilience that can be targeted for developmental support.

Here, to complement large-scale studies, we focus on a mixed method, transdisciplinary approach that allows us to examine effects of environment in tandem with a developmentally advantageous disposition of mind "inside" the person—transcendent thinking. Because all participants in our study engaged in transcendent thinking at least some, it must be that all the participants are capable of such thinking. Our study is able to examine, then, how the degree to which youths spontaneously invoke such thinking positively impacts their development, even in the face of a stressor such as community violence. Although such in-depth qualitative and quantitative analysis limits the study to a modest sample size, it provides potential insights into sources of variability and resilience that are hidden within large-scale normative studies, and gives insights into possible psychological mechanisms involved in resilience.

It is possible that the effects of mid-adolescent CVE we observed on structural brain development may be confounded with social factors that covary with violence exposure in this age group. This represents an unavoidable limitation of our study. While we cannot definitively rule out this possibility, to begin to address this limitation we ran post hoc tests to examine whether mid-adolescent CVE may have covaried with any of the other measures of social–emotional experience and functioning we collected in the broader project, such as satisfaction with self, friendships, and family relationships, quality of home life experiences, satisfaction with school, experiences of bullying as perpetrator or victim, emotional functioning and empathy, perspective taking, social problem-solving and others. No significant relationships were found, adding confidence that CVE likely causes the neurological effect. Future studies should replicate our findings.

To increase confidence in the ecological validity of our transcendent thinking measure, we note that we previously analyzed participants' transcendent thinking in a separate interview pertaining to youths' reasoning about societal challenges (see Gotlieb et al., 2022a). Among the challenges participants were asked to reflect upon was community violence. While we thought it more appropriate to utilize the transcendent thinking scores from the longer interview about minidocumentaries in the current neural analysis, because that interview provided all participants equal opportunity to think transcendently about the same set of social happenings, we note that participants' transcendent thinking scores in the two interviews were significantly correlated (Gotlieb et al., 2022a). That finding suggests that participants' transcendent thinking extends to their thinking about the violence they have witnessed and other civic issues, and may potentially be helpful to youths in making meaning of what they have witnessed, possibly leading to neurological resilience.

The findings support the need for educational programming that could potentially bolster resilience through transcendent thinking, and contribute to the evidence base for civically oriented, community-based educational methods (Daniel et al., 2019; Lee et al., 2021). These approaches encourage students to grapple with complex ideas and dynamic systems thinking through problem- and project-focused pedagogical approaches and civically framed curriculum (Immordino-Yang et al., 2024). Out-of-school informal learning can also be helpful; for example, one study of an intergenerational story-telling program for adolescents and seniors from the same communities found increases in adolescents' transcendent thinking over time, that in turn predicted increases in life purpose and other psychosocial benefits (Riveros et al., 2023). Future studies are needed to examine the effects of such educational programming on brain development (Immordino-Yang et al., 2019).

In sum, our study identifies two sources of variability in mid-adolescent brain development: one negative, exposure to community violence, and one positive, the disposition to think transcendently about the social world and self. Our findings highlight the continued vulnerability of mid-adolescent youth to community violence. They also underscore the important role young people play in their own brain development through the meaning they make of the social world.

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CONFLICT OF INTEREST STATEMENT

All authors declare no financial or other conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in The Open Science Framework at https://osf.io/wmc4v/.

PARTICIPANT CONSENT STATEMENT

All parents/legal guardians and participants gave written informed consent or assent as appropriate, and all participants were compensated for their time.

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